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Critical Technical Review and Evaluation of Site-Specific Studies Techniques for the MMS Marine Minerals Program

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LIST OF ABBREVIATIONS AND ACRONYMS

ABC	Abundance Biomass Comparison
ADCP	Acoustic Doppler Current Profiler
ANOVA	Analysis of Variance
BACI	Before-After, Control-Impact
BHM	Breaking Wave Height Modulation
CDA	Canonical Discriminant Analysis
cm	centimeter
CTD	conductivity-temperature-depth
EFH	Essential Fish Habitat
ESA	Endangered Species Act
FVCOM	Finite Volume Coastal Ocean Model
GPS	global positioning systems
HYCOM	Hybrid Coordinate Ocean Model
IOOS	Integrated ocean observing systems
IRI	Index of Relative Importance
LST	Longshore sand transport
m	meter
mm	millimeter
µm	micron
MDS	multi-dimensional scaling
MMP	Marine Minerals Program
MMS	Minerals Management Service
NDBC	National Data Buoy Center
NEON	National Ecological Observatory Network
NEPA	National Environmental Policy Act
NOAA	National Oceanic and Atmospheric Administration
OCS	outer continental shelf
POM	Princeton Ocean Model
RCOOS	Regional Coastal Ocean Observing Systems
RFP	request for proposal
ROMS	Regional Ocean Model System
ROV	remotely operated video
SMS	Surface Water Modeling System
SPI	sediment profile imagery
STWAVE	STeady state irregular WAVE model
SWAN	Simulating WAves Nearshore
USACE	U.S. Army Corps of Engineers
USGS	U.S. Geological Survey
VIMS	Virginia Institute of Marine Sciences
WABED	Wave-Action Balance Equation Diffraction
WIS	Wave Information System

1.0 INTRODUCTION

1.1 Study Objectives

The Minerals Management Service (MMS) Marine Minerals Program (MMP) is charged with environmentally responsible management of Federal Outer Continental Shelf (OCS) sand and gravel resources. MMS has a long history of conducting scientific assessments and studies that improve their understanding of the likely effects of offshore dredging and support decision making about how to best manage these resources. The primary purpose of MMS-funded site-specific environmental studies has been to address concerns raised by the potential for adverse environmental impacts on marine life as a consequence of dredging sand on the OCS. Biological studies have mostly concentrated on potential dredging effects on sessile benthic invertebrates (i.e., benthos) and have applied grab or core sampling to define general community structures often in relation to sediment characteristics in impacted and non-impacted areas. Fewer studies have documented mobile invertebrates or fishes, and these have mostly applied trawl sampling to document the fauna present on and near shoals. Fish feeding habits were investigated in some studies. Physical studies have focused on wave climate, wave transformation, and sediment transport used to assess the impact to local substrate and associated benthic communities, in addition to coastal processes and potential impacts to shoreline change. MMS has funded generic studies on a wide range of topics on specific issues, such as protection of archaeological resources and modeling of turbidity plumes.

The general methods of data collection and analysis in the site-specific studies have not significantly changed in the nearly ten years that MMS has been conducting them. The main change has been the addition of a fisheries component to address the information needs for the essential fish habitat (EFH) consultation required with the National Oceanic and Atmospheric Administration (NOAA) under the Magnuson-Stevens Fishery Management and Conservation Act. Over time, the demand for OCS sand has increased significantly, and some borrow sites have been repeatedly accessed. Therefore, MMS identified the need to have an expert team review study objectives and protocols and determine if changes are needed. There are always calls for more data to improve the ability to identify potential impacts and propose actions to prevent or minimize any adverse impacts. More quantitative and comprehensive studies are very expensive, and funding is becoming more difficult to predict and obtain. Studies need to be designed to provide the most critical scientific data appropriate for evaluation of the likely impacts of dredging at a specific site and lead to actions needed to avoid or minimize such impacts. The site-specific studies provide the data on which MMS develops stipulations to lessees. They also provide the baseline data on which long-term, cumulative impacts may be identified during post-dredging monitoring. How MMS should consider cumulative impacts at sites subject to repeated use is a particularly important, yet complicated, issue to be addressed.

With this background, MMS requested a scientific review team to review and evaluate the appropriateness of the MMS marine minerals site-specific studies conducted to date and determine if the current study designs and methods should be modified to yield information that may be more scientifically appropriate or provide a greater cost/benefit relative to the assessment of environmental impacts of offshore dredging operations on the biological and physical environments. To meet these objectives, Research Planning, Inc. (RPI) formed the following team:

Jacqueline Michel, Ph.D. – Program Manager
Robert Nairn, Ph.D., P.E. – Numerical Modeling and Coastal Sediment Transport
Robert Randall, Ph.D., P.E. – Offshore Dredging Technology
Charles H. Peterson, Ph.D. – Benthic Ecology
Steve W. Ross, Ph.D. – Fisheries Biology
Robert Weisberg, Ph.D. – Physical Oceanography

The team performed the following tasks:

Task 1. Review of MMS MMP site-specific studies methodologies
Task 2. Technical review meeting to present the results of the scientific review to MMS
Task 3. Preparation of the draft and final technical report
Task 4. Preparation of the draft and final technical summaries

1.2 Requirements for MMS Studies at OCS Sand and Gravel Borrow Sites

MMS conducts studies at potential sand and gravel borrow sites to address three main requirements: 1) to comply with environmental regulations; 2) to support their responsibility to manage these public resources in an environmentally sound manner; and 3) to identify long-term, cumulative impacts that are then used in making management decisions.

1.2.1 Regulatory Requirements

The MMP has been conducting site-specific studies to support their assessment of the potential impacts associated with dredging, as part of their compliance with various Federal regulations such as the National Environmental Policy Act (NEPA), Endangered Species Act (ESA), EFH under the Magnuson-Stevens Fishery Management and Conservation Act, and Marine Mammal Protection Act. The current practice is to conduct baseline studies over a two-year period to account for some inter-annual variability. Because of the EFH issues, MMS started including more fish studies in the last few years.

In general, both invertebrate and fish studies have followed standardized (within but not between studies), accepted sampling protocols. Studies are variable in the quality of results and statistical treatments, with some areas being reasonably well characterized, while others not. The mobile fauna (predominantly fishes) have been particularly hard to document on meaningful spatial and temporal scales. While these studies have provided useful data on individual sites, their contribution to the understanding of interdisciplinary ecological processes has been limited. Lacking data on such processes prevents adequate modeling of biological effects under varying environmental conditions (Peterson, 1993). In addition, studies applying experimental manipulations or hypothesis testing were generally lacking (see review in Brooks et al., 2006). Regional process-oriented studies and/or studies involving experimental manipulations or well-designed before-after assessments of impacts, coupled with some level of site-specific surveys, may improve impact evaluation.

1.2.2 Monitoring for Environmentally Sound Management Responsibility

One of MMS's responsibilities is the environmentally sound management of the OCS sand and gravel resources. Dredging of offshore borrow sites has both short- and long-term impacts, as summarized in Research Planning, Inc. et al. (2001). From a purely physical perspective, the only change of consequence is the potential impact of dredging on shoreline change. MMS studies on predicting shoreline change under different removal scenarios have improved over time. All other physical impacts caused by dredging are important only if they result in a biological impact, either directly or indirectly. Studies investigating the recovery of benthic communities following dredging (Blake et al., 1996; Newell et al., 1998; Van Dolah et al., 1992; 1998) have indicated that communities of similar total abundance and diversity can be expected to re-colonize dredge sites within several years. However, there is uncertainty whether the new benthic communities will fill the same trophic function and provide the same energy transfer to higher trophic levels, as did the original communities. Brooks et al. (2006) indicated that there were too few studies to make good generalizations about benthic community recovery. Also, there is little known about the direct and indirect impacts to fish. For fish and other mobile fauna, observational sampling alone (e.g., trawling) can result in misleading results. Short-term increases in fishes (due to enhanced feeding opportunities provided by bottom disturbance exposing prey) can be followed by abandonment of the area, but the latter is hard to document without direct observations, movement data, or behavior information.

1.2.3 Predicting Potential Long-term Impacts

Clearly, the demand for sand to use in shoreline restoration is increasing, and the availability of sand from within state waters is decreasing. Many of the OCS sand resources are isolated from the sediment budget of the littoral system by large distances and muddy areas, indicating that these sand resources are not renewable. Natural processes will not replace sediments removed during dredging, and repeated dredging over time is likely to alter the topography and the surface sedimentology of the sites, with high potential for long-term impacts. Cumulative impacts on the sediments are inevitable in that the sand features become progressively depleted, and subsequent cumulative biological impacts may also arise. At some point, the physical changes to a shoal feature could be relatively sudden; if the height of the shoal feature was reduced enough to disrupt the process that maintains the shape of the shoals, it could deflate or unravel, losing its form with time (Hayes and Nairn, 2004). A central biological question common to these assessments is: Do these sand structures function in a unique way (ecologically) and/or do they support unique fauna compared with surrounding habitats? Answering this question involves measuring relevant biological and physical parameters. The degree of uniqueness of sand shoal sites may dictate different management strategies and biological and physical monitoring.

2.0 REVIEW OF PAST STUDIES

Table 1 includes the list of studies reviewed. The physical and biological methods used in these studies are summarized and evaluated in the following sections. In the following discussions, the studies in Table 1 are referred to as the Document number listed in this table.

TABLE 1. List of MMS Marine Minerals Program studies (Documents) that were reviewed.

1. Design of a Monitoring Protocol/Plan for Environmentally Sound Management and Development of Federal Offshore Sand Borrow Areas Along the United States East and Gulf of Mexico Coasts. OCS Study 2001-089
2. Biological Characterization/Numerical Wave Model Analysis within Identified Borrow Sites Offshore the Northeast Coast of Florida – SEA NE FL Cruise Plan, Model Grid, Benthic Sorting
3. Biological Characterization/Numerical Wave Model Analysis within Identified Borrow Sites Offshore the West Coast of Florida/Physical Implications of Sand Dredging on the Topography of the West Florida Shelf - SEA West FL Cruise Plan, Model Grid, Benthic Sorting, other documents
4. Utilization of Benthic Communities by Fish Populations on Ridge and Shoal Features (Ship Shoal) – USGS Study Proposal
5. Numerical modeling evaluation of the cumulative physical effects of offshore sand dredging for beach nourishment – MMS 2001-098
6. Wave-Bottom Interaction and Bottom Boundary Layer Dynamics in Evaluating Sand Mining at Sabine Bank for Coastal Restoration, Southwest Louisiana – Stone Sabine Bank Technical Proposal
7. Investigation of Finfish Assemblages and Benthic Communities within Potential Borrow Areas Inside Federal Waters Offshore SE Texas and Southwest Louisiana – USGS Work Plan, Benthic Polychaete Assemblage Plan, Cruise Report
8. Ship Shoal, Louisiana: Sand, Shrimp, and Seatrout Investigation – Condrey Study Plan
9. Environmental Investigation of the Long-Term Use of Ship Shoal Sand Resources for Large-Scale Beach and Coastal Restoration in Louisiana (Cooperative Agreement with Louisiana State University) – Stone Proposal and First Report
10. Field Testing of a Physical/ Biological Monitoring Methodology for Offshore Dredging and Mining Operations – VIMS March 2006 Report, RPI Team Comments, and VIMS Response to RPI Comments
11. Comparisons Between Marine Communities Residing on Sand Shoals and Uniform-Bottom Substrate in the Mid-Atlantic Bight - OCS Study MMS 2005-042
12. Environmental Surveys of Potential Borrow Areas Offshore Northern New Jersey and Southern New York and the Environmental Implications of Sand Removal for Coastal and Beach Restoration. OCS Study MMS 2004-044
13. Environmental Surveys of Potential Borrow Areas on the East Florida Shelf and the Environmental Implications of Sand Removal for Coastal and Beach Restoration. OCS Study MMS 2004-037
14. Collection of Environmental Data within Sand Resource Areas Offshore North Carolina and the Environmental Implications of Sand Removal for Coastal and Beach Restoration. OCS Study MMS 2000-056
15. Surveys of Sand Resource Areas Offshore Maryland/Delaware and the Environmental Implications of Sand Removal for Beach Restoration Projects. OCS Study MMS 2000-055
16. Wave Climate and Bottom Boundary Layer Dynamics with Implications for Offshore Sand Mining and Barrier Island Replenishment, South-Central Louisiana. OCS Study 2000-053
17. Environmental Surveys of OCS Sand Resources Offshore New Jersey. OCS Study MMS 2000-052
18. Environmental Survey of Identified Sand Resource Areas Offshore Alabama. OCS Study MMS 99-0051
19. Use of Federal Sand Resources for Beach and Coastal Restoration in New Jersey, Maryland, Delaware and Virginia. OCS Study MMS 99-0036
20. Environmental Studies Relative to Potential Sand Mining in the Vicinity of the City of Virginia Beach, Virginia. OCS Study MMS 97-0025
21. Wave Climate Modeling and Evaluation Relative to Sand Mining on Ship Shoal, Offshore LA, for Coastal and Barrier Islands Restoration. OCS Study MMS 96-0059
22. Environmental Investigation of the Long-Term Use of Trinity and Tiger Shoals as Sand Resources for Large-Scale Beach and Coastal Restoration in Louisiana – Tiger - Trinity Proposal

2.1 Physical Methods Summary

A review of all the physical studies associated with the document review list (Table 1) was completed. A summary of this review is included in Appendix A. In general, the body of work completed to date represents a wide area of a given state or states and presents a very comprehensive assessment of baseline conditions. It is noted that the objectives of each investigation varied and were mostly, but not always, listed at the beginning of the report. A series of reports by Applied Coastal Research and Continental Shelf Associates had the following objectives related to physical processes:

- Evaluate impacts to waves and currents as a result of dredging.
- Evaluate sediment transport impacts at site and at shore.

A review and summary of the different approaches applied to the various categories is presented in the following sub-sections. Key data gaps in the site-specific studies are discussed in Section 2.4. The categories included in Appendix A, listed below, form the building blocks for addressing the above-noted objectives:

- Wave climate
- Wave transformation
- Hydrodynamics and circulation
- Sedimentology/geomorphology of the dredged area
- Dredged area evolution (substrate change inside and beyond pit)
- Turbidity/plume (if applicable)
- Longshore sand transport changes/shoreline impacts
- Dredging techniques discussion

2.1.1 Wave Climate

It is essential to define the offshore wave climate in any assessment of physical or biological impacts of dredging as waves are one of the primary driving forces for change at the site and potentially inshore of the dredge site. Document 1 provides protocols for the definition of the offshore wave climate and recommends the use of a combination of wave hindcast databases (mostly the U.S. Army Corps of Engineers [USACE] Wave Information System [WIS]) and other measurements (from NOAA's National Data Buoy Center [NDBC] network of buoys or other sources). However, there are seldom enough data at specific locations to adequately describe the long-term wave climate. Systematic measurements, acquired over long durations from which wave climatologies can be assessed at several key locations compatible with the Marine Minerals Program, are needed. At the very least and wherever possible, measurements of waves should be used to validate the hindcast data. In general, this is the approach that has been taken by most of the studies. One shortcoming of the WIS data that are widely available is that they only provide summary parameter data and do not include full 2D spectral information. This should be and has been addressed by some of the study documents through development of site-specific hindcasts or creation of theoretical spectra using measured data as a guide. The spectral information is required as a boundary condition for the nearshore wave transformation model. In some of the studies, the variations in the offshore wave climate along the wave transformation model boundary could have been considered, had this information been available (e.g., there is only one central wave input point each for the western Long Island and northern New Jersey STWAVE grids shown in Figure 4-3 of Document 12).

There is a high cost of collecting wave data. Using ADCP or wave buoys, the cost of collecting wave data at one location for the period of a year is in the range of $75,000 to $125,000. Clearly, it would be cost-prohibitive to collect data for one or more years at all proposed dredge sites on the OCS. However, by making use of emergent Regional Coastal Ocean Observing Systems (RCOOS) under the concept of Integrated Ocean Observing Systems (IOOS), there is an opportunity to acquire these needed wave data on a cost-sharing basis. Wave, current, and other data are required by academic, governmental, and commercial sectors, and cost-sharing on these data collection initiatives will significantly reduce costs to specific organizations and avoid duplication of effort. The IOOS initiatives are discussed in more detail in Section 3.2.2 of this report.

2.1.2 Wave Transformation

As discussed in Document 1, wave transformation is essential to define how the waves change as they move from deepwater over the dredged area (before and after dredging) and how in turn they propagate towards shore inshore of the dredged area (before and after dredging). There are many different numerical models of wave transformation available to the coastal engineering and science community. Some of the studies (15, 21) follow the recommendation of Document 1 to complete a Model Selection phase to choose the most appropriate model. Document 1 discusses the capabilities and limitations of the various models to provide guidance on model selection. While there is no universal model appropriate for all conditions, the STWAVE model (Steady state irregular WAVE model) has become a clear model of choice (used in studies 2, 3, 6, 12, 13, 14, 16, 21). The USACE continues to upgrade this model and have completed or are working on upgraded versions that are full-plane (eliminates the need to align grids with principal direction of wave approach), have improvements to bottom interaction, incorporate true diffraction near surface-piercing structures, include glancing reflection off structures, and have third-generation source terms for wave growth and interaction. Nevertheless, STWAVE will remain a stationary model, and where non-stationary conditions must be considered, models such as SWAN (Simulating WAves Nearshore) must be applied. Non-stationary models are only really suitable where large model domains must be considered and where the spatial and temporal variation of the wind field across the domain is important for wave growth. Non-stationary models are very demanding or expensive in a computational sense. Another recent development by the USACE is the spectral wave model WABED (Wave-Action Balance Equation Diffraction)–see Lin et al. (2006). WABED is a spectral model that theoretically considers diffraction and to a limited extent, reflection. WABED is linked to M2D in Surface Water Modeling System (SMS) and was applied in the study described in Document 2. Given these different wave models and their respective limitations, either on the basis of model physics or computational demands, there exists a need for intercomparison studies wherein all models are gauged against in situ data under a range of environmental conditions to determine quantitative metrics of performance. This type of comparison is currently being performed (without the benefit of measured wave data) for the Holly Beach Dredge Pit under an existing MMS study due to be completed this year with a report titled “An Examination of the

Physical and Biological Implications of Using Buried Channel Deposits and Other Non-Topographic Offshore Features as Beach Nourishment Material."

2.1.3 Circulation

The coastal ocean circulation is generally referred to as "Hydrodynamics," and because hydrodynamics has a broader connotation (including the waves), it is best to distinguish the circulation portion from the overall hydrodynamics (circulation and waves). The studies reviewed treat circulation at various levels, but none entirely adequately. In general, most studies only included a review of existing measurements or models that often were not directly associated with the anticipated dredge areas. Document 1 providing protocols for monitoring/modeling of impacts is silent on circulation modeling and, in hindsight, this is a shortcoming that should be addressed. Some of the more recent studies have included towed Acoustic Doppler Current Profiler (ADCP) measurements over the shoal (Documents 18, 20) or the application of 2D hydrodynamic models (Documents 2, 3, 22). A 3D model was applied only in one study (Document 15), and in this case the 600-meter (m) grid spacing was insufficient to resolve near-field flow changes in the vicinity of a dredged area. In order to develop an improved understanding of the near-field impacts of dredging on currents and the possibly important biophysical interactions during recolonization, 3D circulation and sediment transport models would be appropriate to apply.

The state of the art of 3D circulation modeling is rapidly advancing, just like the state of the art of wave and wave transformation modeling. Along with existing modeling frameworks, such as Princeton Ocean Model (POM), Regional Ocean Model System (ROMS), Finite Volume Coastal Ocean Model (FVCOM), and Hybrid Coordinate Ocean Model (HYCOM), are the use of these models by the Regional Coastal Ocean Observing Systems (RCOOS) that are emergent nationally. An opportunity, therefore, exists for the MMP to gain leverage from the emergent RCOOS. Two points are particularly noteworthy. First, the RCOOS are developing long-time series of water velocity, temperature, and salinity at various locations of interest to the MMP. These measurements can help to define circulation climatologies as well as the seasonally modulated synoptic scale variability. Second, these time series can also be used for quantitative comparisons against model simulations, thereby providing quantifiable metrics on model performance. Given levels of veracity attributable to any of the 3D coastal ocean circulation models, these models can then be used to address matters of MMP importance, such as mechanisms and pathways for larval delivery and fish recruitment or for sediment resuspension and transport. It is emphasized that the third (vertical) dimension is of critical importance to such matters since the transport pathways and mechanisms in a shallow coastal ocean environment are largely influenced by the surface and bottom Ekman layers. Hence inferences drawn from 2D models may not be adequate to describe and understand the 3D transports, even in very shallow water. Similarly, the flow-field modifications at a particular site are typically 3D modifications. Rather than initiating separate regional-scale circulation model studies as part of the MMP site-specific studies, an attempt should first be made at assessing ongoing circulation measurement and modeling activities and leveraging these for MMP purposes.

Whereas the regional-scale circulation studies may find information in RCOOS regional-scale studies, there may still be the need for site-specific studies on the scales of the actual features to be exploited. For instance, regional-scale models with grid spacing of order several kilometers do not necessarily resolve the feature scales that may be of order tens of meters. To consider the flow-field modifications that may result in habitat alteration or in sediment infilling, it may be useful to perform very high resolution measurements and model experiments of the actual geometries envisaged by sand and gravel mining projects. So long as the aspect ratios are small enough, it should be sufficient to employ hydrostatic models, and this could be pursued in a generic sense as contrasted with doing such studies at each site.

2.1.4 Sedimentology/Geomorphology of the Dredged Area

Most of the statewide or multiple-state studies provided a comprehensive review of the geology, sedimentology, and geomorphology based on a compilation of many data sets (grab samples with sediment grain size, cores, and geophysical studies) and interpretations. While this valuable baseline data may need to be updated from time to time with new information, the conditions will not be changing significantly with time (with the exception of at or near dredged areas) and this area of study may require less of the overall focus of site-specific studies in the future.

2.1.5 Dredged Area Evolution (substrate change inside and beyond pit)

None of the documents reviewed included geomorphic modeling of dredged areas, whether shoals or pits in buried channels. MMS has three such investigations currently under way for dredged pits offshore of Louisiana and shoals offshore of Maryland/Delaware. To date this has been addressed through very simplistic methods for predicting sediment transport at one location just outside the dredged area, providing some indication of pit infilling rates (Documents 2, 3, 6, 12, 13, 14, 16, 18 – note that only interim work product has been reviewed from the studies associated with Documents 2 and 3) and through a consideration of historic bathymetric changes at the site (Documents 12, 13, 14, 18). The recommended protocols of Document 1 only recommend monitoring of bathymetric change after dredging through surveys, and this should be updated to include the application of morphologic models.

The morphologic modeling is required to provide: 1) *predicted* morphologic change in order to evaluate impacts as part of an environmental assessment versus the bathymetric change surveys which only provide documentation of change after it has occurred; and 2) a complete temporal perspective of changes versus the snapshots provided by the bathymetric change monitoring. As an example, it is essential to predict the total time to infill for dredged pits in muddy settings along the Gulf coast in order to quantify the duration of impacts to benthic communities and higher trophic levels.

2.1.6 Turbidity/Plume (if applicable)

From previous reviews of the impacts of dredging summarized in Documents 1 and 19, the key concern with turbidity plumes at OCS borrow sites is not with suspended sediment, but instead, the impact of the sedimentation associated with the plume on burial of benthic communities. Sedimentation impacts are more of a concern where there is hard-bottom and particularly live-bottom conditions near the dredge site. In most cases this impact is not discussed at all, and in those studies where it is discussed it is mentioned in a very general manner without any quantification of the impact (see Documents 12, 13, 14, 18, 19). Understandably, it is difficult to evaluate this impact without knowing the specifics of the dredging program, such as amount of sediment to be removed, area of dredged zone, current speeds during dredging, and type of equipment. In 2003 a study was completed for MMS to develop a Plume Model for Trailing Suction Hopper Dredges (Baird & Associates, 2004). This model could provide the basis for some generic recommendations on buffer requirements to avoid unacceptable levels of sedimentation.

2.1.7 Longshore Sand Transport (LST) and Cross-Shore Changes/Shoreline Impacts

The potential of shoreline impacts (through changes to wave transformation and LST gradients) is a critical issue to consider in the evaluation of dredging impacts. If the sand dredged to mitigate shoreline change (erosion) itself causes erosion at the same location or elsewhere, the mitigation efforts are defeated. The Protocols Document 1 recommends the application of GENESIS to evaluate the influence of changes to longshore sand transport gradients caused by changes to wave transformation patterns on shoreline change. The various recent studies by Applied Coastal Research (Documents 12, 13, 14) rely on the approach of Kelly et al. (2004) that evaluates whether the predicted LST under the post-dredge conditions remains within an envelope of 0.5 times the standard deviation of average annual sand transport (for a 20-year period) moving along the shore, in which case the change is deemed to be insignificant. In other words, it is considered to be within the year-to-year changes of LST.

Of all the studies reviewed, the Kelly et al. (2004) approach is the most rigorous. However, a concern with this approach is that it neglects the fact that the long-term gradient in LST will be permanently altered. It is important that this method or others be evaluated to determine whether the somewhat arbitrary selection of 0.5 times the standard deviation is indeed acceptable. This could be evaluated theoretically using the GENESIS model proposed in Document 1, but it would be best to have field verification for at least one location where significant dredging has occurred. Other approaches used to evaluate the significance of changes to wave patterns on shoreline change include Document 15 and 18. Document 18 considers whether the predicted change is within the error of LST predictors; the problem here is that the error would be expected to be consistent for predictions at different locations and, therefore, does not negate the fact that LST gradients are predicted to change. Document 15 implements an approach to quantify the change in maximum wave height gradient along the area of interest (it is referred to as the Breaking Wave Height Modulation - BHM). This does not directly quantify the implication of changes to wave climate on shoreline change and, therefore, does not provide a direct measure of what might be acceptable in terms of change. Documents 12, 13, 14, and 18 all are commended for comparing the predicted gradients in LST to measured shoreline change, if only in a qualitative sense. The next step is to complete this validation (or calibration as required) quantitatively using a model such as GENESIS to compare actual predictions and observations of shoreline change. This approach has been successful in other published GENESIS applications throughout the United States, and it would provide the basis for evaluating whether modification to shoreline change (and not just LST gradient) caused by dredging is indeed within an acceptable range.

None of the reviewed documents considered the potential for cross-shore impacts. These potential impacts to the nearshore sediment budget can occur in two general ways: 1) where sand that may be making its way towards the shore is intercepted by a dredged area, preventing supply from reaching the shore, at least until the pit area is full and bypassing sand again; and 2) where sand from the nearshore profile moves offshore to fill the dredged pit, depleting the nearshore sediment budget, this process is sometime referred to as "drawdown." Generally these processes are believed to be insignificant given the distance of borrow pits from shore on the OCS (more than 3 miles offshore). A review of the literature on this on this topic is provided in Nairn et al. (2007).

The shoreline evolution models that have been used in the various project studies have also generally omitted the effects of inlets and other morphological features that may be important. For the purpose of advancing our predictive skill on how a project might alter the ambient shoreline, there is the need to better understand how the shoreline is maintained in the absence of any modification

The current standard of practice to evaluate potential impacts of offshore anthropogenic influences (such as dredged pits or offshore structures) is to apply a 2D or 3D model of wave transformation, hydrodynamics, and morphologic change. Measured to this standard, all the previous completed studies fell short. However, it must be recognized that the tools available to make more detailed morphologic assessments for applied engineering and science problems have only recently become more widely applied (i.e., in the last 2 to 3 years), whereas the completed studies reviewed were mostly completed between 1997 and 2001. Nevertheless, the understanding of potential shoreline change through the application of more detailed morphologic models together with measurements of waves and shoreline change is identified as an information gap in Section 2.4.1.

2.1.8 Dredging Techniques Discussion

This topic was mostly addressed in generic terms without specific reference to the site-specific conditions at the sites. Of the reports reviewed, Document 19 provided the most comprehensive coverage of dredging techniques including shapes of furrows left by dredges. The difficulty with this topic is the lack of *a priori* knowledge of the specifics of future dredging programs (type of equipment, area of dredging, and depth of cut). This type of information generally becomes available closer to the time of dredging. Nevertheless, it would seem prudent to have more discussion on the types of projects that are likely to occur (pits versus dredging on shoals) and recommendations for these cases, given the consideration of both possible physical and biological impacts. Documents 12 and 14 suggested that dredging the leading edge of shoals was the preferred approach, but there is no direct evidence yet to suggest this is better than other options (MMS has an ongoing study to investigate the impacts of different dredging approaches on shoals). The primary impact of dredging on biological processes relates to the removal of the benthic community, changes to the substrate in this area, and possible water quality impacts where pits are involved. The site-specific studies provide an opportunity to recommend specific approaches to dredging to mitigate the impacts. Only one of the documents (7) provided recommendations on environmental windows to aid the recovery of benthic communities.

2.2 Biological Methods Summary

A review of the biological studies (included in 17 of the 22) associated with the document review list (Table 1) was completed. Three studies involved only physical studies (Documents 5, 6, 21), one was an overall environmental review (Document 19), and the purpose of Document 1 was to propose biological and physical monitoring protocols to assess long-term impacts from shoal sand mining. A review and summary of the different approaches applied to the various categories below is presented in Appendix B and discussed in the following sub-sections. The following categories (included in Appendix B) provide the basis for evaluations of the various studies:

- Benthic communities and/or fish
- Sampling methods
- Target fauna
- Sampling design
- Taxonomic discrimination level
- Sample analysis methods
- Community analysis methods
- Correlation with other parameters

2.2.1 Sampling Methods

Benthos

Sampling for benthic invertebrates most often employed a grab sampler, typically a Smith-McIntyre grab covering 0.1 m^2 in surface area (Documents 2, 3, 12, 14, 16, 18, 20). In some cases, a Young-modified Van Veen grab was employed, covering 0.04 m^2 in surface area (Documents 10, 15). In studies where meiofauna were sampled as well as macrofauna, box cores of varying sizes were deployed, from which 2.6-5 centimeter (cm) diameter cores were extracted for the macrofauna (Document 4). Sieves of 0.5 millimeter (mm) mesh were deployed to separate the macrofauna from the sediments, although some studies used additional sieving at larger mesh sizes up to 2 mm. Meiofaunal sampling was accomplished by use of syringe or other types of subcores of varying diameters, typically taken to 10 cm depth, then separating contents over nested sieves of 500, 63, and 45 micron (µm) (Documents 2, 3, 22).

These sampling methods conform to standard practices in benthic ecology, although they have some limitations. The box coring methods provide more reliable quantitative estimates of density of the smallest, surface-dwelling benthic invertebrates because they can be retrieved to the ship with less physical winnowing of contents. Furthermore, the natural sediment surface is better preserved and more readily subsampled from a box core, and the surface is where the smallest invertebrates, including both the meiofauna and the newly recruited macrofauna live. Frequently, surface sedimentological parameters were also assessed by subsampling surface sediments from grabs or box cores; these too provide more reliable estimates of fine sediments if taken from box cores. Nevertheless, box coring is typically more expensive, so a price is paid in replication achieved with the budget available. Use of core subsamples for macrofauna with diameters as small as 5 cm constrains the size of benthic organisms that can be sampled and is thus not effective where abundances of larger bivalve mollusks, possibly including ones of commercial importance, like surf clams, may be important.

In a few studies (Documents 10, 12, 14, 16, 20, 22), the sediment profile imagery (SPI) camera sediment profiler was also deployed to infer the depth of the surface oxygenated layer, abundance of visible macrofaunal traces, and successional state of the macrobenthic community. These efforts provided unsatisfactory results in large part because the shelf sediments possess lower densities of large macrofauna and deeper, more diffuse oxygenated layers than the calmer shallow waters in which this approach was developed. Video sleds or epibenthic camera sleds, suspended at about 0.2 m off the bottom, were frequently used to survey wide areas of the seafloor (Documents 2, 3, 10, 11) to detect surface evidence of large epibiota or even some infauna, as well as to detect demersal fishes. The larger epibiota are not adequately sampled by grab or core sampling of the seafloor on the shelf because of their large body size and typically sparse populations. Consequently, use of this sampling tool can be justified, especially if water clarity allows good imaging, and useful data on demersal fishes and other information can be gathered simultaneously. The potential for wide areal coverage is appealing. In some cases, the surface epibiota may be of special value as structural recruitment habitat for demersal fishes, providing motivation for such surveys.

Fish

Most studies used some variation of otter trawls for benthic sampling, with a few other gears being represented (e.g., gill net, mongoose trawl, beam trawl, epibenthic sled, and angling). Trawls (all types) ranged in width from 2.4 to 7.6 m, and most tows lasted 10 minutes (5-30 minute range). Most studies used global positioning systems (GPS) to log sample track distance. Unlike the fixed size samples obtained with grabs for which sampling area is known (see Benthos above), trawl area of coverage is less certain. Nevertheless, some studies assumed that trawls covered known areas (usually without adequate documentation) and used these areas to calculate species/faunal densities. Various plankton nets were used for sampling larval fishes in a few studies. Most plankton samples were surface and/or near surface and no discrete depth sampling was undertaken. Some common methodological issues involved lack of gear standardization, lack of adequate replication in time or space, lack of appropriate collection of environmental data, and lack of data association with habitat maps. Lack of data association with habitats may represent the issue that needs most attention in future surveys.

Bioacoustics were applied in two studies (Documents 11, 22). Acoustic surveys were conducted on and off shoals to compare overall biomass of nekton using the different areas. One study ran transects day and night (Document 11), while the other surveyed during day or at dawn/dusk (Document 22). These methods are becoming more sophisticated and accurate and have the advantage of covering large areas rapidly. However, all data collected usually represent a conglomerate of species that cannot be identified from sonar data alone. Some species that sit on the bottom (flatfishes, lizardfish) or bury in the sediments (eels, lizardfish, rays) would not be “seen” with this method.

2.2.2 Target Fauna

Benthos

Macrobenthos, defined as those bottom invertebrates retained on a 0.5-mm mesh, were sampled in all studies treating benthic biology. This is appropriate because these invertebrates are sessile (thus reflecting spatial patterns of impacts), well known taxonomically, and well enough studied to allow comparisons with other analogous data and often some inferences about community status and even stress. Some studies also assessed meiofauna. Inclusion of meiofauna, although more difficult to process, is well justified in cases where shrimp resources are known or suspected to be of high value because penaeid shrimps consume meiofauna as a key component of their diet. Some studies also reported mysid densities from sediment samples. This taxon is considered bentho-pelagic in habits because of its behavior of association with the sediments during day and movement into the water column at night. Unfortunately, because mysids are not sessile invertebrates buried in the sediments, just temporally associated with the bottom, quantitative sampling for mysids should involve use of specialized gear, namely an epibenthic dredge sampling the bottom 1 m of the water column (Barnett, 1987). These crustaceans provide an important food source for many fishes and, where some of the mysid consumers may be considered valuable, targeted mysid sampling with an epibenthic dredge may be important to conduct.

Fish

All 17 studies included sampling for or analysis of fishes. Generally, particular species, taxonomic groups (families), or functional groups were not targeted (an exception being Document 8). Instead, whatever fishes were captured by the gear used in the study became, in effect, the target organisms. In some instances specific target species (e.g., spotted seatrout, red snapper, Atlantic croaker) were identified for specific analyses (growth, diet). While including all captured species in analysis is appropriate and recommended, the limitation here in characterizing the whole fish community revolves around sampling method limitations. Use of only trawls during daylight would somewhat limit the potential species pool. Broader sampling methods should be encouraged.

2.2.3 Sampling Design

Benthos

All studies completed to date and included in our review assess impacts of mining sand resources contained in sand shoals, so comments here reflect the designs used for this situation. When sand resources are located in buried channels, covered by a fine-grained cap, different sampling designs may be required.

The large-scale spatial design of benthic sampling was similar in intent for all studies that sampled the benthos. Sampling was done, or intended to be done, on and at some distance off the sand shoal(s) designated for potential dredging. The motivation for distributing samples between shoals and off-shoal locations nearby is to be able to assess the degree to which benthic biological resources of sand shoals are unique or serve special roles, generally as food for commercially or recreationally valuable fish or crustaceans. That goal can be achieved only if the shoal community is compared to the off-shoal community. Some studies intentionally targeted not only shoals designated for possible dredging but also shoals not targeted for dredging (Documents 12, 13, 14, 17, 18); this design can well serve to provide baseline information in a form that can allow sampling of undredged shoals in the future to provide a control for natural temporal variability, such as that driven by climate change. Absent such a control for natural temporal variability, future differences between baseline conditions and post-dredging conditions on dredged shoals could be misinterpreted as solely a consequence of the disturbance, when rapidly changing broad environmental conditions could play an important role.

Sampling effort is typically unbalanced in these studies, with the bulk of sampling targeted for shoals and smaller numbers of samples collected from off-shoal sites (e.g., Documents 2, 12, 14, 18, 20). Such a strategy can be justified by financial limitations that render development of knowledge of shoal resources and communities the main goal of the baseline monitoring. However, subsequent formal statistical testing becomes less powerful and less capable of resolving differences with unbalanced sampling effort. On the whole, however, this consideration is probably less important than the desire to sample as many potential target shoals as possible and to characterize pre-disturbance conditions on them most effectively. Uncertainty over which shoal(s) would be dredged also imposes a need to sample shoals more widely so as to ultimately be successful in providing the baseline information on pre-dredging state for the feature(s) that is (are) disturbed.

The more specific sampling designs employed to compare the benthic resources and communities of shoals to those of the surrounding seafloor differed among studies. Most used randomly (or haphazardly if no true randomization scheme existed) placed samples within each targeted shoal feature and on the surrounding seafloor. Occasionally, off-shoal sampling was concentrated along one axis (Document 10), motivated by choosing seafloor habitat of a particular type, in a particular location, or simply where the limited off-shoal sampling effort could provide more precise estimates of the abundance of benthic resources. That practice is somewhat concerning because it fails to yield information about the complete perimeter of surrounding seafloor habitat. An alternative to random sampling of the shoal surface and nearby seafloor habitat is to conduct sampling along distance gradients from the shoal outwards. Studies (Document 9) that used this design typically applied perpendicular sampling (transect) lines so as to cover the surrounding seafloor habitat in each direction. Use of such a gradient design has merit in circumstances where the spatial extent of impacts is uncertain so the spatial isolation required to achieve a true control, unaffected by the treatment, is unknown. This may apply to sand dredging on shoals and help justify use of a gradient design, although it applies more strongly to dredging of buried sand resources because the surface muds that must first be removed may be mobilized and deposited at some substantial distance away from the mining site. Gradient designs allow regression types of approaches to data analysis in lieu of categorical analyses like ANOVAs, with some ensuing benefits in understanding of patterns even beyond dealing with the question of distance of impacts away from the mining site.

Another approach to sampling involves use of stratification within each of these types of areas to be compared. Stratification can be simply to control spatially based error variance so as to achieve tighter estimates of means. Spatial stratification also plays a useful role when the location of the dredging activity is uncertain because the stratified sampling will allow segregation of areas into those dredged and those remaining undisturbed with separate stratum-specific estimates of benthic resource abundances for each type of area. However, there is a further important justification for stratifying the sampling done on sand shoals. Stratification can be done by habitat type on two spatial scales. On an intermediate spatial scale of tens of meters, strata can be, and have been in some studies, identified and sampled separately as leading edge, trailing edge, and interior of sand shoals (Document 7). Such sampling nicely contemplates the geomorphologic structural heterogeneity, likely sedimentological differences, and differences in physical transport processes as a function of position on the shoals, thereby facilitating interdisciplinary linkage to the physical process measurements and understanding. On a finer spatial scale of meters, stratification could profitably be defined by the crests versus troughs of the wave-like features of surface topography in the interior of the sand shoals. The crests are characterized by substantially coarser sediments, higher bottom shear stresses, more dynamic sediment movements, and benthic communities that differ from what is found in the troughs in response to these physical forcing differences. Finally, the interiors on the sand shoals are energetic enough to have ripple features on a centimeter scale, important but probably on too fine a spatial scale to justify any stratification of sampling.

The temporal design of benthic sampling of sand shoals and the nearby seafloor has been done as frequently as seasonally (Document 4) and as infrequently as semiannually (usually spring and fall: Documents 12, 13, 14, 15, 17, 18, 20). For studies designed as experiments testing the impacts of sand dredging, "before-sampling" has varied from 1 to 6 month(s) prior to dredging (Documents 9, 10) and "after-sampling" has begun either 4 or 6 months post dredging (Documents 9, 10). A model design suggests that after-sampling occur every 2 years for 7 years (Document 1).

Two critical issues must contribute to deciding the timing, temporal frequency, and duration of sampling. First, for baseline monitoring, sampling must be frequent enough to depict patterns in benthic resources of value in and of themselves (like sea scallop populations) or as prey for valuable consumer species. Any benthic invertebrate of value commercially will live long enough that sampling the benthos more frequently than annually is unnecessarily redundant. Prey species of benthic invertebrates may have far shorter life spans, but macrofaunal prey sampling need be no more frequent than semiannually (with spring and fall dates appropriate) and, for meiofaunal prey sampling, no more frequent than quarterly. To use the baseline sampling as before-sampling in a BACI (Before-After, Control-Impact) test of how much effect dredging has on the benthic resources and communities and how quickly recovery occurs, timing of sampling must hold season constant, occur on short enough time scales after dredging to document recovery dynamics in the short term, and extend as long as necessary to detect ultimate convergence, if it will occur, or stabilization of the community in a different state, if that is the ultimate outcome (Peterson and Bishop, 2005). BACI testing at minimum requires one sampling before the dredging and preferably several years of observation at the same season. Absent before-sampling, the only means of inference about dredging impacts comes from spatial contrasts between the disturbed sand shoal(s) and other sand shoals that remain undisturbed as controls. If there are no undisturbed sand shoals sampled as controls, then temporal contrasts of the sand shoal before and after dredging provide the only means of inferring impacts and recovery. This approach confounds any impacts with natural temporal dynamics, of which seasonality of the benthos will be the major source, requiring at minimum that season be held constant in such contrasts. In cases where dredging creates depressions that act as depositional basins, initially sand substrata may be replaced by finer sediments for perhaps a longer period of time. Such cases may require several years of monitoring to be able to observe and document convergence and thus recovery of benthic communities. Thus duration of sampling may need to be dictated empirically by observed recovery dynamics.

Fish

Much of the above discussion of sampling design issues (placement of samples, randomization, replication, stratification) also applies to fish-related sampling designs. It seems clear, however, that better sampling designs would also result from more detailed and explicit habitat maps, data on currents, and basic water chemistry. Having such maps and data from the beginning would allow appropriate sampling scales to be determined and would facilitate designation of strata as well as control and impact areas.

Most sampling designs incorporated a strategy to compare shoal catches to non-shoal catches or dredged areas to non-dredged areas. Sampling replication was generally low (limited by funding and logistics), and most sampling was during daylight only. The issue of unbalanced sampling design was less apparent than for the Benthos (see above). Although gear biases and efficiencies were not determined, some studies (e.g., Documents 10, 11) converted trawl catch data to densities (numbers per unit area). In general, such conversions are inappropriate. Statistical power of analyses was not assessed.

Examination of fish diets in impact (shoal) compared with non-impact (off shoal) areas was a major component of most studies. Fish samples analyzed for diets were sub-sampled from the overall catches. In several studies, diet analyses were supplemented by stable isotope analyses (Documents 4, 10, 22). Both methods yield different views of trophic structure, with stomach data yielding a short-term snapshot and isotopes integrating a longer-term general view of carbon sources and trophic levels. While isotope data can be very useful, the rational for expecting differences over such small spatial scales between sampling spots was not well defended. In fact, a likely result is that disturbances from dredging would not be so severe as to change the overall basis of the food web to the extent that would be expressed in isotope data. On the other hand, changes in feeding behavior are more likely to be detected through diet analysis. Samples for diet analysis should include representatives of all functional feeding types (benthic grazers, plankton pickers, top predators) and should include enough temporal sampling (admittedly somewhat subjective) to characterize feeding variability. Stable isotope analyses should still be considered but with a better explanation of rational and expected outcomes. Such methods should consider mixing models (see Document 22). Also, in addition to muscle tissue, stable isotopes from other organs (liver) which have different (shorter) turn-over rates will allow some estimation of duration of residency on feeding grounds. Pooling of isotope samples (Document 22) is not recommended as this prevents any measure of variability.

2.2.4 Taxonomic Discrimination Level

Benthos

The level of taxonomic identification of benthos used in past studies of sand shoals ranges from species to phylum. Occasionally, species-level identifications were made only for taxonomic groups of particular interest, such as harpacticoid copepods among the meiofauna on which penaeid shrimps feed (Documents 9, 22) and polychaetous annelids where they dominated the macrofauna (Document 7). One study discriminated among macrobenthos by functional rather than by taxonomic group (Document 4), which could have great merit in determining mechanistic explanations for impacts and recovery dynamics. Clearly, if a benthic invertebrate resource existed which is valued at a species level (like surf clams), then species-level identification would be required to assess the uniqueness of sand shoals in general or any specific sand shoal as habitat for that resource. The likelihood that a benthic prey resource would have special value at the species level is small, and knowable in advance, so identifications at higher trophic levels (probably phylum) will almost always suffice. Previous research on benthic macroinfauna has demonstrated that family-level taxonomic discrimination is at least as effective as discrimination at the species level in detecting patterns of community composition and thus impact and recovery metrics (Warwick, 1988). Even more recent research has shown that phyletic distinctions are sufficient to detect patterns of macrofaunal community change that can discriminate between two major classes of pollutant, organic loading and toxics (Lenihan et al., 2003). Thus identifications at the level of phylum for the macrobenthic and, where sampled because of the importance of shrimp, for the meiofaunal, community are likely sufficient, augmented to species-level information on any benthic organism of high value (like a surf clam or sea scallop species).

Fish

Captured fishes were identified to species levels in all studies. For diet analyses of captured fishes, gut contents were nearly always identified to the lowest possible taxa. This level of detail is both appropriate and logistically feasible.

2.2.5 Sample Analysis Methods

Benthos

After sorting to the desired taxonomic level, the metrics computed for each macrobenthic group were density (Documents 2, 3, 12, 13, 14, 17, 18, 22), biomass (Document 10), or both (Documents 7, 15, 20). For meiofaunal taxa, density (Documents 2, 3, 22) or density and biomass (Document 20) were computed. The most appropriate treatment of the samples would involve both density measures by taxon or functional group to allow community composition analyses and biomass to allow value of benthic prey to be expressed in units related to energetics. Any individual benthic species of high value, like a sea scallop, should be counted to provide density estimates by size class, so that population-level impacts can be assessed. In such cases, size-at-age data may also be useful to address any sublethal impacts of dredging on individual growth rates.

Fish

In most cases very simple, basic analyses were performed on catch data (tables of species, counts, sizes, diversity). It was unclear in some studies exactly what data were recorded (e.g., Document 14). These descriptive data (not really analyses) provide very general characterization of fauna present and its size structure. A critique of the use of diversity indices and suggestions for better analyses follows in section 2.2.6 and 2.2.7. Comparative statistics should be used more (e.g., Kolmogorov-Smirnov comparisons of size frequencies between samples and areas, plots of species accumulation curves to assess sampling adequacy, and statistical comparisons of these curves between areas). Data on efficiency and bias of trawls were missing and such data should be considered and may be necessary if densities are calculated. Fish stomach contents were identified and measures of gut fullness, prey abundance, and prey ranking (Index of Relative Importance, IRI) were made. Stable isotope analysis (C, N, S) of fish flesh, and in some cases the lower trophic levels, were made on dominant species in three studies (Documents 4, 10, 22). While isotope analyses can be useful, exactly how they would benefit the current projects was unclear (see also section 2.2.3). Use of mixing models and analyses of tissues with faster turn over than muscle are two suggestions that might improve these types of trophic data

2.2.6 Community Analysis Methods

Benthos

Benthic data on community composition have been used in past monitoring studies of sand shoals for two different types of community-level analyses. First, this information on abundance by taxon (at species level up to phylum) has been widely used (Documents 2, 3, 7, 12, 13, 14, 15, 17, 18, 22) to construct various indices of species diversity: S (species or taxonomic richness), D or H' (information theoretic species diversity), and E or J'' (indices of evenness of species representation). The notion that such indices provide indicators of stress on natural communities or indicators of successional stage after disturbance was prevalent in ecology approximately three decades ago. About 30 years ago, this usage of such diversity indices went out of favor with the realization from many studies that not only was the conceptual and theoretical basis for this application weak, but also the empirical evidence failed to provide compelling and consistent support for their value as indicators of community health (Hurlbert, 1971). Consequently, their continued use in monitoring studies, including benthic monitoring, to infer impacts of dredging on marine benthic communities is questionable at best and misleading at worst. Little or no effort should be expended on these outmoded indices in future monitoring of baselines on sand shoals or on seafloor communities associated with buried sand resources.

The second widespread community-level analysis conducted in many of the baseline monitoring, impact assessment, and science process studies associated with the extraction of sand resources, is a type of multivariate similarity analysis or ordination. Older forms of these analyses, which were employed in some of the sand shoal studies (Documents 12, 13, 14, 15, 17, 18), are cluster analyses that group samples together in patterns based upon similarity in community composition. These clustering techniques and the associated Canonical Discriminant Analyses (CDAs) have been replaced by more powerful analytic ordination analyses, such as and especially the non-metric multi-dimensional scaling (MDS) approach of Clarke (1993). Several sand shoal baseline monitoring and impact studies employed the PRIMER software that runs these MDS analyses (Documents 3, 7, 9, 15, 22).

Additional community-level analyses were applied in individual studies, with little success. One applied the seldom-used ABC (Abundance Biomass Comparison) method to infer disturbance levels (Document 7). Another (Document 10) developed its own index of biotic integrity by analogy to the index produced by decades of monitoring of the Chesapeake Bay macrobenthos, but without benefit of a perspective of empirical evidence from shelf systems.

Fish

These analyses (when present) consisted mostly of older methods (Shannon-Weiner diversity, H') to attempt to quantify numbers of species and individual species abundances (see Benthos discussion above for relevant points). Cluster analysis to group similar samples was applied in four studies. At least one study (Document 11) used the more powerful PRIMER analysis (multi-dimensional scaling) for grouping samples, which is a recommended technique. In general, most studies had inadequate sampling (too few replicates or sample locations) to support community-level analyses.

2.2.7 Correlation with Other Parameters

Benthos

Two types of important connections can conceivably be drawn between the benthos and other monitoring components: one set of relationships with the physical forcing and a second set of relationships with the fish or crustacean consumers. Some past monitoring studies on sand shoals and the adjacent seafloor have made modest attempts to make these connections, although this area of developing the functional inter-relationships among ecosystem components deserves much more in-depth attention in future studies. Previous studies of sand shoals have made efforts to relate the sediment grain size distribution to the benthic community composition (Documents 3, 9, 12, 13, 14, 15, 17, 18, 20). Unfortunately, these analyses have not been as successful as possible in large part because the analytic methods did not employ the most powerful tools, such as those available in the PRIMER software package. This package not only delivers the non-metric multi-dimensional scaling program that allows multivariate points to be plotted in two dimensions to display relationships among groups, but in addition, it includes software for powerful analyses of which groups contribute most to observed dissimilarity and how well independent forcing functions explain the patterns of community segregation. In no case was any other physical parameter compared to benthic biological data. It seems reasonable, based on first principles for example, that suspension feeders (one prominent functional group) may be more abundant where current flows and mixing are greater, whereas deposit feeders may be predicted to be more abundant in lower-energy conditions.

The relationship between the benthos and consumers of the benthos is also an important connection to make because, with the exception of situations where a benthic species is valuable as a fishery target, the value of the benthos lies in how it feeds organisms of importance on higher trophic levels. Some previous monitoring studies on sand shoals made attempts at this set of connections but much work remains to be done. Two studies (Document 4, 10) attempted to use analyses of C and N stable isotopes to compare the benthos to the demersal fishes as a means of testing whether prey communities and fish feeding on those prey differed between shoal and adjacent seafloor habitats. This stable isotope work was not well justified by first principles in that it is unclear why either the source of initially fixed carbon (indicated by C isotopic ratio) or the trophic level on which the consumers feed (indicated by N isotopic ratio) would be expected to change between habitats or after dredging disturbance. Several studies did (Document 3, 4, 15, 22) or are doing (Document 9) extractions of gut contents of fish, crabs, or shrimps to allow contrasts with the benthic sampling data by habitat so as to determine if the benthic prey that dominate the diets of valuable consumer species are especially segregated into the sand shoal habitat. These analyses would have benefited from more careful characterization of the benthic invertebrate prey community in the guts and then MDS re-analyses of the benthic sampling data performed on only the subset of benthos that serves as important prey. That procedure would carry greater potential for identifying such shoal-specific use of benthic resources, if that actually exists.

Fish

Correlation of fish data with other parameters was rare. One study (Document 2) discussed the possible impact of red tide on fish communities. Because detailed habitat maps were lacking, catches could not easily be associated with physical features (see relevant point in Benthos above). Although some basic environmental data were collected, these were generally not correlated with nekton catches. As discussed elsewhere, better habitat maps (including physical/chemical oceanography data) and fish sampling by habitat would have been helpful.

2.3 Biophysical Considerations

None of the documents reviewed made a significant attempt to develop an improved understanding of the site-specific relationships between physical and biological processes associated with dredging impacts and recovery. Many of the studies (Documents 1, 7, 9, 11, 12, 13, 14, 15, 18, 19, 22) mentioned in general terms, and sometimes in specific terms, that there were relationships, particularly between benthic communities and sediment characteristics. However, none of the studies made any recommendations about how these relationships might be used to avoid, minimize, or mitigate the impacts of dredging.

Focused model studies might include research that can better illuminate important physical-biological relationships that could then aid in managing sand dredging operations in the future. The unanswered questions include asking how bottom topography on several spatial scales relates to sedimentological differences and how they influence or even determine the distribution and abundance of benthic biological resources. Expanded biophysical understanding would improve ability to mitigate dredging on sand shoals and dredging sand deposits in buried channels.

2.4 Key Data Gaps in Past Site-Specific Studies

Based on the review of the site-specific studies conducted to date, the following key data gaps have been identified and are described in more detail below:

- Shoreline impact assessment approach
- Prediction of the morphologic development of the dredged area
- Development of biophysical mapping of habitats
- Benthic recovery mechanisms
- Use of habitat (spatial/temporal use by larger mobile fauna)
- Understanding relationships between physical and biological processes
- Site-specific recommendations on mitigation measures
- True assessment of cumulative impacts

2.4.1 Shoreline Impact Assessment Approach

As described in Section 2.1.7, none of the site-specific studies directly evaluated the impact to shoreline evolution of dredging on the OCS. This would require: linking a 1) wave transformation model to a 2) longshore/cross-shore sand transport model and 3) a shoreline change/morphodynamic model. Several of the studies completed the first two modeling steps, but none took the third step to conclusively determine the significance (or lack thereof) of impacts to shoreline change. Modeling of shoreline change due to changes to wave transformation caused by dredging is a practical step to take as recently demonstrated by Benedet et al. (2007). This type of analysis may not be required for every site-specific study, but in the absence of any evaluation of this type, possible shoreline impacts of dredging cannot conclusively be eliminated as a possibility.

Calibration and validation of a shoreline change modeling assessment would be a challenging task. Ideally it would be best to first demonstrate the capability of a model to predict shoreline/nearshore morphologic changes at the area of interest prior to implementation of a dredging project. Data required for this assessment would at the least include: offshore wave data for the period of assessment; nearshore wave data (at one or more locations between the dredged area and the shore); nearshore bathymetry surveys (preferably several snapshots in time before and after dredging); and shoreline/profile change measurements (more frequently that the full bathymetry measurements, and at least quarterly). Given the far-reaching scope of such an investigation, and given the fact such an investigation would also benefit local coastal managers, it may be best to perform such an investigation in partnership with state and county agencies in order to share the costs and benefits.

2.4.2 Prediction of the Morphologic Development of the Dredged Area

The morphologic evolution of the dredged area is central to evaluating the spatial and temporal extent of both physical and biological effects of dredging. None of the studies applied a linked hydrodynamic and morphologic model to define how and how fast the dredged area would evolve in terms of possible pit migration, pit infilling, and side slope changes. This type of modeling is becoming more commonly applied within the coastal engineering community as described by Van Rijn et al. (2005) for pits in sandy settings and Nairn et al. (2005; 2006) for muddy capped pits to access buried channels.

None of the site-specific studies reviewed had to address the dredging of sand resources that are located in buried channels. This type of dredging activity poses somewhat different questions. For example, the surface layers of finer sediments must be removed and either disposed or potentially stored nearby for return to the excavation pit. This procedure carries more risk of causing sedimentation on the seafloor than mining of surface sands from shoals. In addition, any disposal or bottom storage of those fine sediments can itself have biological impacts that require assessment in a site-specific study and inclusion in management plans. Because these sand resources are buried, creation of an excavation pit is inevitable. Large depressions will serve as deposition basins but also will be influenced by physical processes that intensify current flows around their interior margins, so a different set of physical, sedimentological, and biological issues arises when sand mining targets these buried resources. The impacts of dredging sand from buried channels are investigated in a recent MMS report by Nairn et al. (2007); this study also provides examples of the validation of various different analysis approaches for morphologic evolution of dredged pits from analytical procedures to 2D and 3D models.

2.4.3 Development of Biophysical Mapping of Habitats

Developing habitat maps has not been a requirement for any of the previous studies. However, they are extremely valuable for designating strata for sampling schemes, correlation of results, understanding interdisciplinary physical-biological coupling, and development of specific recommendations for mitigation measures. Habitat maps would also be very useful in planning the dredging operations. Including development of biophysical habitat maps is one of the important recommendations for future studies.

2.4.4 Benthic Recovery Mechanisms

Impacts of dredging on benthic communities include two separate processes. There is direct mortality that occurs as the benthic invertebrates are extracted along with the sand resources during dredging. The second component of impact involves the time frame and successional processes of recovery. Site-specific research done to date on sand shoals does not fully assess how alternative dredging schemes might differentially affect these two components of benthic biological impact and thus provide the conceptual basis that would allow mitigation. To illustrate this issue better, we present here two alternative hypotheses that could be tested in a focused model study. The degree of initial injury to benthic resources from surface dredging is simply proportional to the surface area of the dredging footprint. That includes the specific area dredged plus any area of slumping at the margin. Thus, if slumping were minimal, the smallest footprint and impact would arise from dredging a single deep pit. The first hypothesis would then be that use of fewer, deeper pits would minimize benthic biological impacts. However, recovery time may be greatly elongated for deeper pits for several reasons. First, limited water exchange could induce hypoxia/anoxia at the bottom of a deeper pit and thus prevent any benthic macrofaunal recovery until sedimentation ultimately reduced the pit depth sufficiently. Second, one large pit may be recolonized mostly by larvae, whereas taking the same volume of sand from several smaller excavations creates more perimeter edge, from which recovery may be facilitated by colonists that immigrate in as adults through post-project slumping or limited movement. So the second hypothesis is that extracting sand from several shallow pits would minimize benthic impacts because recovery rates would be much more rapid. No data exist to test these alternative recovery hypotheses and thereby determine whether dredging a few large pits or several smaller pits minimizes the time-integrated benthic biological impacts.

Consideration of benthic recovery has usually been focused on the non-mobile sediment associated invertebrates. Recovery of mobile macrofauna (fishes, crabs) is more difficult to assess, but should be considered. The key to assessing how this group responds to disturbance is to understand how they use the benthic habitat under normal conditions. Assessment of trophic structure would be most useful here, especially how much habitat it takes to support a given number of animals.

2.4.5 Use of Habitat (Spatial/temporal use by larger mobile fauna)

Assessment of potential impacts and appropriate mitigation measures requires a firm understanding of the spatial and temporal use of the shoal habitat. However, the degree of biological segregation by topographic feature on sand shoals is unknown, and hence the consequences of targeting or preserving different kinds of features is uncertain. These features include: at coarse scale, the leading and trailing edges, sides, and tops of shoals; at intermediate scale, the crests and troughs of wave structures; and at fine scales, the ripple tops and bottoms. We do not yet have a good understanding of how benthic organisms are differentially distributed among these geological features or how fish use varies among the features. For the fishes, crabs, and shrimps, the studies did not adequately sample bottom nekton by specific feature. Behavioral observations on how fishes, crabs, and shrimps make use of the specific habitats that they occupy were lacking, as were correlations with environmental parameters. Furthermore, if demersal fishes, crabs, or shrimps target specific features of sand shoals for feeding, we do not yet have a good impression of the energetic importance of particular benthic prey associated with that feature or, alternatively, if substitute prey on other types of bottom habitat are sufficient to meet energetic demands. This issue relates to the above section (2.4.4) as well.

2.4.6 Understanding Relationships between Physical and Biological Processes

If better basic understanding existed of how benthic biological processes are coupled to physical and geological forcings, then impacts of dredging for sand resources could be better anticipated, modeled, and mitigated. For the case of mining buried sand resources in buried channels, the recovery of the benthos will depend on how long it takes for deposition processes to fill the pit(s) that are created by dredging, whether the infilling rate will vary with area and/or depth of the pit, and how hypoxia of water at the bottom of such pits may depend on pit area and depth. The ability of the benthos to initiate recovery will be dependent on the answers to those questions, and thus will depend on pit sizes, depths, and local environmental conditions. Because these buried sand resources occur in environments characterized already by relatively fine seafloor sediments, the infilling of pits by fine sediments is likely to produce a sedimentology similar to that of the natural seafloor before removal of the overlying finer sediment cover. Thus, the benthic community that ultimately returns is expected, based on the known importance of animal-sediment relationships, to resemble closely the one initially present before any dredging. The unanswered biophysical questions for this situation are currently under review in an ongoing MMS study to be completed in 2007.

For the case of dredging sands from shoals, a wider suite of physical/geological processes is relevant to predicting and mitigating benthic biological impacts. As a topographic high above the surrounding seafloor, the shoals modify the local and surrounding circulation patterns and exposure to wave shear stresses. Underwater microclimates are created with areas of different residual flow direction and speed, and different sediment mobility related to exposure to shear stresses. The existing microclimates, and associated substrate conditions, may provide relatively unique habitat, as discovered at two locations to varying degrees in MMS studies described in Documents 4 and 8. If these shoals are significantly reduced in size or modified in form, the unique habitats, if they exist, may be permanently lost. There are two ongoing MMS studies to: 1) evaluate the potential impacts of dredging on the morphologic integrity of shoals; and 2) evaluate the physical and biological impacts of dredging shoals. These studies should provide a better understanding of the relationship between oceanographic conditions, sedimentology, and benthic and fish community composition to assist in the evaluation of potential impacts of dredging on shoals. Furthermore, we do not yet know how closely important demersal fishes, crabs, and shrimps are tied to prey of sandy bottoms versus prey characteristic of muddier bottoms. That linkage needs to be better established to anticipate and mitigate impacts of dredging so much sand from shoals as to remove the heterogeneity of oceanographic and substrate conditions on and near shoals. Other relationships between the physical bottom shear stress, flow speed, sedimentology, and benthic biology that need better characterization are described above in the Key Data Gaps section, where we describe the broad-, intermediate-, and fine-scale topographic features of sand shoals and how our understanding of the biological significance of those features is incomplete.

2.4.7 Site-Specific Recommendations on Mitigation Measures

MMS uses the site-specific studies to identify dredging strategies that would reduce both short-term and long-term impacts. For example, dredging could be done in different spatial patterns that are hypothesized to speed the short-term recovery of benthic communities. Dredging in strips could preserve islands of relatively intact benthic invertebrates, which may then facilitate recolonization of the dredged areas. Although this mitigation approach has been suggested by others in general terms (Documents 7, 15, 18), the hypothesis that it would improve recolonization has not yet been adequately tested, and no guidance into the optimal spacing between strips has been proposed and confirmed.

While intuitively appealing, observed higher recolonization of dredged areas may occur simply from slumping of sediments and transport of invertebrates from undredged margins with no net enhancement of biological recovery of the area. Furthermore, spreading the dredging thinly over several sand shoals clearly results in more surface area disruption than focusing on deeper mining of a single shoal. The surface of the seafloor is where the benthic biological resources live and where demersal fishes, shrimps, and crabs forage, so minimizing surface area disturbed is likely to minimize biological impacts in the short term. On the other hand, recovery rates of benthic invertebrates, including prey for demersal fishes, shrimps, and crabs, may be slower where dredging penetrates more deeply, so it is necessary to evaluate how to balance short- and long-term impacts in a focused study. In addition to ridges and shoals, buried channels are another potential geomorphic target feature for OCS dredging. Creation of pits to remove sand from buried channels results in a somewhat different set of impacts and mitigation methods. Distinctive issues include anoxia/hypoxia and change of substrate in the pits, pit margin erosion and impact of the disposal mound of stripped material. There are many important questions of physical/biological coupling that require consideration. Examples include:

- How do local, undisturbed current patterns impact the distributions of fishes or their major food items?
- If current anomalies (vortices, null areas, etc.) form around pits or shoals, do these impact fish distributions (shelter) or behaviors (feeding)?
- Does bathymetry or sediment composition affect fish distribution or behavior patterns?
- Does variability in water chemistry (temperature, salinity) have a larger impact on distributions than changes in sediment or current patterns?

2.4.8 True Assessment of Cumulative Impacts

Because most sand shoals in the OCS are not renewable resources and elevated topographic features, each dredging event on one of them further diminishes its profile, modifies local bathymetry by deepening the water column, changes local flow, erosion, and deposition processes around the sand shoal, and changes the shoal so that it has progressively less influence on modifying waves by bottom friction. Consequently, this set of progressive changes fits the definition of a cumulative impact, at least on physical processes. If several nearby shoals all become mined, then the cumulative effects of physics and geology would be even greater. If no biological resource of value is tightly associated with the shoals or any of their constituent features (crests, troughs, leading edge, trailing edge, ripples), then no cumulative biological impacts would be anticipated. Based on the preliminary findings of an ongoing MMS study of the physical and biological impacts of dredged pits, it would appear that the dredging of pits in muddy seafloor areas to access sand in buried channels will only have temporary impacts until such time the pits are infilled, thus cumulative impacts will not be a concern. However, in areas where pits are created that do not rapidly infill, or do not infill at all, the possibility of cumulative impacts of a permanent change to the seafloor topography and related circulation patterns and water quality (such as dissolved oxygen levels) must be considered. Nevertheless, the past practice of using superficial assessments of cumulative impacts in environmental impact assessments for sand mining may not be justifiable in the context of the growing and changing physical and biological consequences of repeated sand mining from both sand shoals and buried channels. Consequently, producing sufficient basic scientific understanding of physical and biological processes to be able to make more confident predictions of cumulative impacts seems to represent one goal of the MMS program.

3.0 RECOMMENDATIONS FOR FUTURE STUDIES

The recommendations for future studies fall into two categories: general guidelines that would improve the study products and suggestions for the types of studies to be conducted in the future. Each category is described in more detail in the following sections.

3.1 General Guidelines for Studies of OCS Borrow Sites

3.1.1 Improve the Scope of Work

Many of the hypotheses in past studies were not focused sharply enough, and the studies would have provided much higher, more general returns if they had actually tested implications of broader concepts. Before a request for proposal (RFP) goes out, it should go through more technical review just as the proposals themselves should (below). Alternatively, a more diverse review board should construct the study plan for RFPs from the beginning. A peer panel might help focus this better and help tie studies together better. Ideally a technical review panel should be assembled ad hoc after proposals have been received so that potential conflicts of interest can be identified with knowledge of the Principal Investigators and their affiliations. The panel should be comprised of experts with the relevant expertise (physical oceanography, sediment dynamics, ocean engineering, biology of shelf benthos, and fishes). These experts should have inshore shelf experience and show evidence of interdisciplinary collaboration in their own backgrounds. A mixture of academic, industry, and government scientists may provide a diversity to stimulate healthy debate.

The scope of work in the RFP should propose key study questions whose answers will lead to an ability to minimize negative impacts of dredging, determine allowable actions, and improve predictions of impacts. Example questions might include: Do sand shoals harbor unique benthic resources and demersal fishes and crustaceans temporally or spatially? If so, how does that fauna use the shoals? Do shoals accumulate or support fauna differently than surrounding habitats? If not, what impact would removing or disturbing these features have on local fauna?

3.1.2 Require Better Multi-disciplinary Integration and Collaboration

From the beginning, physical oceanographers and biologists should jointly plan study methods. True interdisciplinary study requires collaboration up front and then joint sharing of research platforms, ongoing discussion during data analysis and interpretation, and integrated collaboration during report preparation. Placement of instruments should take into consideration the biological questions being addressed (e.g., effects of currents on larval transport). Many (perhaps all) biological samples require, or at least would benefit from, long-term data on temperature, salinity, dissolved oxygen, and currents variability. The RFP should clearly state that proposals will be critically reviewed for evidence that there is true integration among the disciplines.

A better balance in regional context versus intensive site-specific sampling is recommended. For instance, some of the projects report on exhaustive site-specific biological sampling, but without any physical context. Instead of just cataloguing a standard set of samples for a given area, there might be more value in providing a broader regional context for what is sampled. In other words, is there thought to be any uniqueness to the distribution of biota in the study site or is this distribution likely to be typical of the broader surroundings? If unique, then there must be a concern shown for the potential loss of biota. If the study site has similar biota as elsewhere, then it becomes easier to quantify the loss as a percentage of area to be disturbed by a given project relative to the surrounding areas of a similar nature.

Also of interest are the physical factors that might affect species distributions. Are there any circulation features associated with a site that would promote non-homogeneous distributions in biota? A thorough review of the questions being asked by the biological sampling is recommended. Not only would this potentially save money; it might also result in a much improved product.

3.1.3 Continue and Enhance Peer Review of Proposals and Draft Reports

Proposal reviewers should include outside experts who can assist MMS in conducting a strong technical review of submitted proposals and draft reports. It will be important to avoid the potential for conflicts, so perhaps an ad hoc review board could be formed to review all the proposals for a specific site. Knowledge that the draft report will undergo a formal peer review should provide incentive for production of the highest quality analysis.

3.1.4 Follow Adaptive Management Principles as Studies Evolve

As studies are completed, the requirements for future studies should shrink or change to reflect the current understanding or knowledge base. The idea is how to avoid just repeating the same sampling every time the study location or timing changes. The key may be in understanding more of the functionality of a feature or determining whether the feature works the same way as in other areas that are well known. By gaining a process-based understanding of how the physics of current flows, bottom bathymetry and topography, sedimentology, and bottom biota interact, one can achieve more confident predictive capacity and thus limit the need for some routine data collections in monitoring associated with future projects.

3.1.5 Require Standard Protocols for Data Collection and Analysis, or Justification for Other Methods

Our review of the set of past studies provides motivation for suggesting improvements and perhaps standardization of some common protocols for future studies. First, the frequent use of outmoded indices of diversity that failed to lead to any insight into process, true impact on parameters of value of importance, or mitigation for impacts was noted. Second, while many studies had employed the most powerful analytic tools for detecting, characterizing, and understanding causes of community pattern (imbedded in the PRIMER software package), several relied on older techniques of cluster analysis that do not provide the same degree of insight into either pattern or process generating that pattern.

While it is important not to stifle or control creative analyses, use of some of the blanket, generic analyses that have been part of past studies should be discouraged. Use of analytical parameters such as H' diversity indices should be discouraged unless they can be well supported by logic and literature. There is a substantial body of conceptual literature in high-profile ecological journals (e.g., papers by Hurlbert, Huston, and others), arguing that these "information theoretic" diversity indices provide very little true insight into important ecological functions, are biased by sample-size dependencies, and can be fundamentally misleading in most contexts. Some clustering types of analyses are also of limited value unless these are accompanied by good evaluations of what data groupings mean and how they are related to independent (typically physical/geological in this case) variables (as can be had with PRIMER software).

Proper use of the PRIMER software package that allows highly resolved ordinations of multivariate data sets to detect spatial and temporal patterns and includes software that facilitates analysis of how independent data (such as sedimentology here) explains multivariate groupings (such as benthic communities and fish communities) should be encouraged. This explicitly achieves another level of interdisciplinary integration and analysis. If trawls are used, we discourage conversion of catches to standard densities unless accompanied by data on efficiency and bias of the gear used. A safer tactic is to apply standard trawl methods throughout a zoogeographic region. All comparisons then become relative. Field sampling should be better standardized, but analyses can be less so. The point with analyses is that they be appropriate to the data collected (meet various assumptions) and address the questions and hypotheses proposed in the beginning. This includes a need to identify which of the benthic invertebrates are the energetically most important prey for key demersal consumers, especially any that are strongly associated with any shoal features or habitats. Then analyses of habitat specificity of these components of the benthos that have such dietary importance can be conducted for demersal fishes and crustaceans of high value and high habitat specificity.

3.1.6 Require Biophysical Habitat Mapping

Accurate habitat maps of the area to be dredged and some amount of surrounding territory are necessary for all aspects of impact assessment and development of mitigation measures. The strategy is to develop a biophysical classification system that captures the key impacts and recovery processes. For example, substrates and related sediment mobility and net circulation patterns with specific benthic assemblages and perhaps dispersal mechanisms would form specific groups.

Better habitat definition and description are essential components for developing state and federal Fishery Management Plans, implementing the EFH initiative (ASMFC, 1996), and facilitating the habitat protection goals of both state and federal Coastal Zone Management Programs. Even though the importance of habitat to aquatic biota is widely accepted, our understanding of habitat function is still developing. Central to this problem is the general lack of detailed, accurate habitat maps despite the fact that "simple" habitat mapping is required in the Magnuson-Stevens Fishery Conservation Act provisions for EFH (NOAA, 1997). Without a better understanding of habitat distribution, including its temporal and spatial variability, it is difficult to assess habitat function and thus, the status and trends in habitat quality and productivity (Kostylev et al., 2001). Defining habitat (i.e., the total physical, chemical, and biological surroundings of an organism) is a critical research area, especially if one accepts an emerging consensus that much of the variation in fish recruitment may be habitat based (e.g., Parrish et al., 1997). Distribution and abundance patterns of organisms in an ecosystem can result from selection for preferred habitats or, in the absence of selection, differential mortality or growth related to habitat abiotic and biotic attributes (Sogard, 1992; Hoss and Thayer, 1993; Ross and Moser, 1995). Whether species select habitat or not, initial settlement patterns of organisms may control ultimate productivity and community structure (Rosenzweig, 1995). Most species use multiple habitats through various life stages, and habitat diversity and variability help determine numbers of species and individuals (Greenstreet et al., 1997). Thus, assessment of habitat heterogeneity and extent is critical for evaluating an area's contributions to productivity, species conservation, and population dynamics.

Habitat mapping should involve high-resolution multibeam and/or sidescan sonar surveys. Where economically practical, multibeam is preferred. Multibeam mapping, including analyses of backscatter, can be quite effective for classifying benthic habitats, but visual ground truthing is an important component of such classifications (Kostylev et al., 2001; Lundblad et al., 2004). Coupled with the multibeam surveys would be ground truth data collection, involving such techniques as direct observations (ROV, drop camera), coring, or dredging. Habitat mapping can happen simultaneously with literature reviews but should precede any sampling, even for basic characterization. The mapping must also include a consideration of the flow characteristics, and specifically, the circulation patterns (flow speed and direction and residual flow) and sediment mobility. These maps, along with a synthesis resulting from the literature review, will guide the design of any future physical or biological sampling, and perhaps even the dredging. In the construction of such maps, however, it should be recognized that basic sampling theory must be followed to avoid aliasing and biasing. Hence shipboard surveys are insufficient; time-series data must be collected at sampling rates that will resolve all essential processes and over time intervals that will at least establish seasonal variations owing to both large scale forcing functions and stratification. This information also provides the necessary basis for the development of plausible (environmentally and economically acceptable) long-term dredging plans as explained below. Detailed habitat maps will also be instrumental in determining the appropriate spatial scale for various studies.

As discussed in Section 3.1.2 the larger-scale context within which a given study site exists is important, maybe more than the details of the site itself. Since a project will result in an alteration to the environment, the question is: to what extent will this impact the environment? If the distribution of biota is not unique then the result of project activities will be much more easily quantifiable than if the site is unique. Broader scale biophysical habitat mapping is the only way to address this question.

There is some concern that the higher resolution habitat mapping recommended in this review may not be affordable or that the cost/benefit ratio may be high. In some cases the techniques for visually acquired data (for example from ROV) may be too costly and specialized. Such techniques could be applied as needed and/or as suggested from other less expensive characterizations. For instance, if multibeam mapping identifies "interesting" targets, more explicit data on those targets may be required.

However, having identified some cases where cost savings may be applied, it is important to make improvements over past, somewhat cursory, habitat classifications. These improvements may cost more, but this must be justified on the basis of the need for better data. Continuing to apply older methods does not advance the cause of achieving a better understanding of the environment or environmental impacts, nor does that allow for better monitoring designs. This report strongly recommends more detailed multibeam mapping to acquire better bathymetry and habitat data, facilitating study designs. While the initial costs of such data are higher than those of older techniques, the gain in high resolution, large area coverage warrants this expense. Furthermore, these data may not be as expensive as once thought. As an example, one of the authors (SWR) recently conducted a multibeam mapping of deep-water habitats off North Carolina and South Carolina. In about a 36-hour period an area greater that 6 x 27 km was mapped with complete coverage. A research technician on board, with little training, was able to learn how to manage these data. For the area noted above, data were cleaned and archived at sea, and were ready to use very soon after they were collected. Many unknown topographic features were discovered, and it was abundantly clear that such mapping would have significant changed research plans in this area in the previous six years. More was learned about bottom features in this day and a half of mapping than in all the previous six years combined. The argument that this technique was too expensive is based on a false economy because, lacking these data, the research teams spent expensive ship and research time looking for relevant features. We believe that the improvement in data quality from multibeam techniques is in line with its cost.

3.1.7 Require Recommendations for Testing/Use of Mitigation Measures

There is an important need to actually test some of the hypotheses that have been proposed to minimize impacts on the benthos in the short- and long-term. Researchers should be required to recommend specific mitigation measures that could reduce impacts and speed recovery from dredging activities. This should not be just a list of generic approaches. The study approach in proposals should specifically address this issue and describe how the study results will be used to make detailed recommendations.

Dr. Bob Randall of Texas A&M completed a review of dredging technologies and an assessment of the cost implications of implementing some key recommendations such as dredging in strips to encourage benthic recovery. His report is included as Appendix C to this report.

3.1.8 Improve the Understanding of the Current Patterns and Morphologic Response of Dredged Areas

This question has not been answered in any of the previous studies, partly due to the fact specific dredge areas, depths of excavation, and equipment type are unknown when the studies are underway. Nevertheless, with the assistance of coastal engineers, geologists, and dredging experts, a range of possible dredge plans could be developed to provide input conditions for evaluation of geomorphic recovery processes (including rate and manner of infilling). This type of evaluation could also yield valuable information on larval transport in, around, and within the dredged area.

3.2 Recommendations for Three Types of Studies of OCS Borrow Sites

Based on the evaluation of past studies and our understanding of the future needs of the Marine Minerals Program, three types of studies of OCS borrow sites are recommended and discussed in the following sections:

- Characterization studies at all new sites
- Focused model studies at specific sites to answer current key questions
- Long-term monitoring studies at specific sites to determine long-term impacts

3.2.1 Characterization Studies

Characterization studies would be conducted at each new borrow site to provide the baseline data needed to support environmental assessment for leasing. MMS has already conducted site-specific studies at multiple shoals (but not buried channels) throughout the Gulf of Mexico and along the Atlantic coast from Florida to New York, as listed in Table 1. Based on these studies, MMS has a basic understanding of the ecological processes on the shoals in these areas. The characterization studies would produce the information needed to confirm what is expected–that no serious environmental impact would be expected, based upon observations at the proposed new dredging site(s) and process-oriented understanding and empirical information from past studies.

An MMS study is currently being undertaken to develop generic guidelines for evaluating physical and biological impacts associated with buried channels (i.e., low-stand valley fill deposits). At sites where sand is removed from buried channels, the muddy seabed sediment (and relief, by definition) is usually homogeneous and there is much less concern for destroying unique habitat. In addition, pits dredged in muddy seabed environments will infill naturally with time and any impacts will be limited in duration to, at most, the time required for infilling (i.e., they will be eliminated once the pit fills in).

Characterization studies would consist of the following components:

<u>Literature/data review and synthesis</u>: The foundation for any study should be a thorough documentation of what is known for the target area and its fauna and some meaningful summary of these data. This should include published and unpublished data, but the relative utility and quality of these data should be evaluated. From this starting point, expectations for future sampling can be expressed and obvious ecologically important data gaps can be noted.

<u>Establish logical study area boundaries</u>: This is one of the most difficult topics to approach with objective criteria. Thus, most study areas are designated somewhat arbitrarily, relying on investigator experience or controlled by study logistical limits and costs. Central to this issue has been a lack of large-area, detailed habitat maps (see below). When designing adequate studies to evaluate uniqueness, it is especially difficult to determine the appropriate spatial scales. There are no clear guidelines for what size "box" to put around a study area that would include the required control and impact sites. The current trend seems to be that each

research group has somewhat arbitrarily chosen study area size often dictated by sampling logistics and costs.

Habitat mapping and characterization: Each site should be mapped using multibeam mapping (where economically feasible), ground truthing of sediments or other structures (mounds, hills). Remotely operated video (ROV) or drag camera transects could be used with multibeam sonar. These data, in combination with results from sediment and biota sampling and the modeling of waves and currents, can be used to create biophysical habitat maps of the study areas.

Modeling of physical processes: There is a need for analyzing and modeling the physical processes (waves, current, and sediment transport) as part of the habitat characterization assessment and before heading out into the field. Modeling almost always leads to other questions that require some field measurements, therefore, the sooner it is done, at least in a preliminary manner, the better. Numerical modeling is best performed as an iterative process that helps our understanding of complex processes to converge with added information and model iterations.

Limited biological sampling: The purpose of this limited sampling is to conduct a routine examination of whether any important biological resource(s) is (are) associated with the proposed dredge sites in such a tightly coupled way that the disturbance induced by dredging might be judged unreasonably injurious. Biological sampling should be based on habitat maps that identify locations of shoals and their habitat features in the context of the regional setting. Biological work would include standardized replicate, intensive, habitat-specific sampling (benthic grabs, demersal trawls) for benthic invertebrate (and associated sediments) and demersal fish-crustacean communities by habitat as identified in the initial mapping. Diurnal sampling of the nekton (trawling) should be included in the design. A preliminary description of the trophic web should be attempted from analysis of gut contents of dominant demersal fishes and crustaceans caught by habitat-specific techniques.

Limited sampling will not define all aspects of how an area is used or by which fauna. Nor will it capture all physical and seasonal variability. Nevertheless, such an assessment has a main goal of determining whether any truly valuable benthic shellfish species or demersal consumer makes unexpectedly habitat- or shoal-specific use of the prospective dredge site and/or whether the prey of valuable demersal consumers is restricted to a specific shoal or habitat type. This assessment is really intended in some generic way to determine the degree to which an area "looks" or "acts" like what is expected on the basis of previous assessments. Because this sampling represents a rapid reconnaissance of the area, all shoals may not be sampled. Intensive sampling of one or a few sites to provide habitat-specific information may be most appropriate to the scope and costs. This limited assessment is justified by past funding of similar studies that have provided a growing body of scientific information that allows prediction of impacts without large new, site-specific sampling efforts.

Linking of biophysical relationships: By collecting sediments associated with each benthic sample, analyzing them for size distribution, and considering the local flow characteristics and sediment mobility, this initial site characterization provides the basic information needed to address how sediments differ between the shoal and nearby seafloor habitats and among different topological features of the shoal itself. Such information provides the fundamental physical driver of benthic biological differences so that the data can be interpreted based on basic understanding of animal-sediment relationships.

Discussion on benthic recovery mechanisms for different dredging scenarios: Each site characterization study should discuss the relative environmental gains and losses from alternative dredge scenarios, based upon what is known from past assessments. This includes discussion of scenarios such as dredging in strips as opposed to disturbing large areas and dredging a few sites to greater depth as opposed to many sites to shallower depth. Until long-term monitoring of dredging recovery from a controlled comparison of alternative mitigation procedures has been completed, this discussion of consequences of alternative dredging scenarios will necessarily remain inconclusive.

Recommended dredge plans and mitigation measures: With the availability of habitat maps and data on which to interpret biophysical relationships, the research team will have the best information on which to make specific recommendations on how to dredge a site to optimize ecological recovery and minimize negative impacts. Thus, MMS will have a stronger technical basis for developing lease stipulations to both speed recovery and maximize future use of a site that undergoes repeat dredging.

We propose a two-pronged approach to developing more site-specific, economic, and scientifically justified mitigation measures.

One major obstacle to developing specific recommendations for mitigation measures to avoid or reduce impacts and/or improve recovery from impacts is the fact that, in many instances, specific dredge plans are unknown at the time of study. Therefore, a key first step that should be taken (the first prong) is for dredging experts and geologists to work together to define a series of most plausible plans. These dredge plan scenarios would define: 1) the location of the dredging (which shoal or which part of a buried channel); 2) the lateral boundaries of the dredge area; and 3) the depth of dredging (the latter two providing the estimate of dredged quantity). The possibility of multiple dredging events should also be considered in developing the scenarios. It will not be possible to fully define the actual dredge plans because the necessary site-specific information from boreholes and vibracores will not be available at this stage. Nevertheless, a plausible range of outcomes can be defined that should allow for a site-specific consideration of impacts and mitigations measures. This step would also provide direct information on estimates of the cost implications of different dredging procedures, such as dredging in strips or leaving islands for the scenario plans developed. Later this information will allow resource managers to compare the cost implications to the likely success of proposed mitigation measures.

In most locations the primary biological concern relates to the degree of short-term and duration of long-term damage to benthic communities. This occurs through direct removal and destruction of the substrate, alteration of bottom sedimentary habitat through sedimentation within and adjacent to the dredged area (for soft, hard and live bottom), and potential water quality changes (anoxia/hypoxia) in the bottoms of pits. The primary physical effect of dredging (aside from those that lead to biological impacts) is the potential influence on shoreline changes. Thus, the second prong of the approach is to develop an understanding of the possible impacts for the plausible dredge plans. The primary physical impact of shoreline change has been addressed in most of the past site-specific studies, at least as it applies to changes to wave transformation over the shoal. The area that has not been fully addressed at the level of features (habitats) with the shoals is the question of whether long-lasting biological impacts will emerge within benthic communities. It is recommended that more scientific effort and focus be devoted to answering this question. A truly biophysical approach is required to reduce impacts and improve recovery potential. There are two primary focal points of the required biophysical investigation: 1) understanding the benthic assemblages and relationships to sediment and hydrodynamic characteristics throughout the potential dredge areas in order to define the most resilient and least valuable benthic communities residing in an area of beach-compatible sediment; and 2) understanding the re-colonization processes that will depend on maintenance of oxygenated bottom water, restoration of pre-disturbance sedimentology, and whether recovery is substantially enhanced by colonization from nearby undisturbed areas. This assessment is based upon both benthic biology and confident prediction of the hydrodynamic processes associated with conditions after the area is dredged. Necessarily this also requires an assessment of the geomorphic evolution of the dredged area – how it is infilled with time, the extent to which areas beyond the edge of the pit are eroded as part of the infilling process, and for multiple dredge events in shoals, how the geomorphic integrity of the shoal itself may be influenced.

The two prongs must be performed in an iterative manner. Dredge plans cannot be developed until at least the first focal point of the biophysical investigation is completed, together with the evaluation of shoreline impacts. On the other hand, specific modeling addressing the hydrodynamic and geomorphic responses to the dredged plan cannot be completed until the dredged plan is known. Furthermore, the development of an understanding of the biophysical process itself is iterative, relying on results of field measurements and modeling, one influencing the other.

In essence, the goal of this two-pronged approach is to develop various environmentally and economically acceptable dredging and mitigation plans for the study areas (that may include multiple dredging events over a series of years). Inevitably, more information will be available to the eventual designers of dredge plans, but nevertheless, the designers and the resource managers will have a framework of acceptable possibilities to measure against.

<u>Generation and delivery of spatial data</u>: MMS should require that spatial and tabular data generated during the characterization studies at specific sites be submitted in standard formats so that these data can be readily shared with the scientific community and regional benthic habitat mapping initiatives.

3.2.2 Focused Model Studies

Focused model studies are equivalent or similar to what have been previously referred to as "generic" studies by the Marine Minerals Program. Such studies are designed to answer key questions needed to support environmental assessments and sound management of sand borrow sites. The questions are critical ones that we cannot currently answer. These model studies would be conducted first in one region and ultimately in others to evaluate whether specific characteristics of the region (its biota or sediments or marine geology) determine or greatly influence the outcomes of these interdisciplinary hypothesis tests. A scientific panel/MMS would identify sites where these studies would provide results of broadest applicability. Key questions to be addressed by these focused model studies would include:

- What is the new equilibrium bottom topography and sedimentology that is approached after completion of dredging and how rapidly is it approached, as a function of alternative dredging scenarios? This study would require information on local environmental conditions at least including: wave climate, currents, background suspended sediment concentration levels, and sediment conditions surrounding the dredged area. This could include the application of analytical techniques, 2D or 3D models as shown in Nairn et al. (2007) for morphologic evolution of the Holly Beach Dredge Pit. Approximate cost of this effort would be $100,000 to $150,000 for data collection on oceanographic and sedimentologic parameters and $100,000 to $200,000 for analysis/modeling depending on the approach taken. The data collection efforts would also benefit other aspects of an impact assessment, including the biological impacts. In terms of benefit, an understanding of the morphologic and sedimentologic evolution of a dredged area is essential for quantifying the impacts to benthic communities and higher trophic levels. This physical study is of high priority because it sets the stage for evaluating habitat and thus ecological recovery.

- Along with site-specific, long-term monitoring is the need for detailed model process studies. For instance, how are the flow fields modified by dredged pits or deposited bumps of various configurations? Needed are 3D, density-dependent, high-resolution numerical circulation model experiments. Assuming that the project dredging aspect ratio is small enough, these models may be hydrostatic primitive equation models of the type readily available as public domain model codes. Such experiments can be run for the circulation alone, but also for the combined effects of circulation and waves by utilizing state of the art sediment resuspension and transport modules. Objectives will be to determine whether or not favorable or unfavorable habitat is formed by virtue of project dredging and how long might it take for a site to recover after project dredging. Approach and costs would similar to those outlined above. This study is of moderate-high priority.

- What factors determine the rate of infilling of pits on shoals and over buried channels and how can we predict the likelihood of developing hypoxia/anoxia as a function of pit depth under different suites of oceanographic conditions? These questions have been addressed in part in a recent MMS project by Nairn et al. (2007). A key recommendation of that report was to collect near-continuous temporal history of dissolved oxygen, temperature, and salinity stratification through the water column over a dredged pit and in an undisturbed area adjacent to the pit. MMS or the eventual proponent of the project should consider collecting these data for the proposed Sandy Point dredged pit on the west flank of the Mississippi River delta. Cost of collecting this data for a period of one year would be approximately $50,000 to $75,000. This study is of moderate priority.

- To what extent and how fast do dredged areas evolve in terms of changes to depths (within dredged area and adjacent areas) and sediment characteristics for different dredging plans? Along with site-specific, long-term monitoring is the need for detailed model process studies. For instance, how are the flow fields modified by dredged pits or deposited bumps of various configurations? Needed are 3D, density-dependent, high-resolution numerical circulation model experiments. Assuming that the project dredging aspect ratio is small enough, these models may be hydrostatic primitive equation models of the type readily available as public domain model codes. Such experiments can be run for the circulation alone but also for the combined effects of circulation and waves by utilizing state of the art sediment resuspension and transport modules. Objectives will be to determine whether or not favorable or unfavorable habitat is formed by virtue of project dredging and how long might it take for a site to recover after project dredging. An investigation is currently being performed for MMS on the influence of shoals on wave and current patterns, focusing on the Isle of Wight shoal off the Maryland/Delaware border. A key gap that remains is the evaluation of the morphologic evolution of a dredged area on a shoal. Such a study would include both monitoring and modeling of waves, currents, sea bed, and suspended sediment and could likely be performed for a budget similar to the Nairn et al. (2007) study on dredged pit evolution in a muddy non-topographic setting (approximately $300,000). This study is of high priority.

- What level of shoreline change caused by impacts to wave transformation and longshore transport gradients is acceptable? There appears to be need for partnership here. The models of shoreline change must first be shown to be capable of reproducing historic and existing conditions; it could be argued that this is the responsibility of shoreline restoration project proponents (i.e., those requesting the OCS sand in the first place). The shoreline change must be predicted with and without proposed dredging projects on the OCS, and not simply the change in longshore sand transport or wave-height gradients as has been applied in studies completed to date. In areas near inlets there is a need to apply coupled wave transformation, hydrodynamic, and sediment transport/morphologic models to understand their impact on natural shoreline stability. This is a substantial investigation and would require a wide range of data collection over a large area and over a significant period of time as outlined under Section 2.4.1. If the work was completed independently of any other projects, it could cost in the range of $500,000 to $1,000,000. However, if it could capitalize on existing state or county monitoring programs the costs could be significantly reduced. The benefit of this proposed investigation is that it will provide the evidence required to confirm that concerns regarding shoreline impacts are unfounded for most OCS projects. In fact, the project could be phased in the sense that the proposed wave transformation model evaluation project, noted below, could be completed first. If this project resulted in a definitive measure of the impact to waves inshore of a dredged area, and it could be shown that waves are influenced within a certain distance of the pit, perhaps normalized against the width of the pit, it may not be necessary to complete the full-blown investigation extending to shoreline and nearshore change. This study is of moderate to high priority.

- What are the pathways and mechanisms by which a project area receives its nutrient flux? Application of regional scale, 3D, density-dependent, numerical circulation models is a first step. These models must be complete enough to include the interactions that occur between the coastal ocean and the deep ocean and between the coastal ocean and the estuaries since nutrients derive from both sources. For these models to be relevant they must be both baroclinic (density-dependent) and three-dimensional since, for the shallow coastal ocean, it is the interaction between the surface and bottom Ekman layers that largely determines the across-shelf transports. To model the Ekman layers correctly, there must be a correct enough specification of the vertical distribution of turbulence, which is determined in part by the stratification. 2D models are incapable of specifying these properties. The same pathways and mechanisms that give rise to nutrient fluxes also control the movements of any passive quantities such as larvae for the repopulation of dredged areas. Such models are necessary to provide the underpinnings for modeling primary productivity and as such they are the foundation for higher trophic level modeling. Since no one agency can hope to cover all aspects of coastal ocean science there is again a necessity for MMS to engage via the emergent RCOOSs. This could be addressed in conjunction with some of the proposed investigations above related to the measurement and modeling of oceanographic conditions with and without dredging projects. It is of moderate priority.

- Different wave model are being applied, primarily STWAVE, SWAN, and most recently WABED. What is needed are quantitative comparison between these models gauged against in-situ data for areas inshore of pits. This investigation could be completed as the fist step towards evaluating shoreline impacts as noted above. Nairn et al. (2007) compared the results of these three phase-averaged wave transformation models to a phase-resolving Boussineq wave model for changes to waves passing over the Holly Beach Dredge Pit offshore the western coast of Louisiana. Wave measurements inshore and offshore of the Holly Beach Dredge Pit were not available as this was not the main focus of the study. Required measurements would include waves measured offshore of the pit and measurements at several locations adjacent to and inshore of the pit. An investigation could be completed for approximately $150,000 to $250,000. The benefit of this investigation is that it may preclude the need to complete the much more far-reaching and higher-cost shoreline impact assessment, providing that generic guidelines could be developed related the impact of pits, possibly based on the ratio of pit width to distance from shore or other related normalized parameters. It is of moderate to high priority.

- How ecologically unique or special are sand shoals as habitats for valuable benthic resources like clams or sea scallops and/or for fish, crabs, and shrimps of value? What are the uses of shoals made by the consumer species of value, and how well can other seafloor habitats substitute for shoals, particularly in the context of provision of benthic invertebrate prey? This task could begin with a relatively inexpensive literature and/or database (as in unpublished surveys) review that could be completed by one person in about 3 months for most local areas. This would attempt to evaluate what is known about the area of impact compared to its larger surroundings. Ultimately, some type of sampling may be required for a more targeted view of habitat usage. A rapid assessment during a season of high usage (perhaps learned through the literature/data review) could probably be accomplished for less than $100,000 over about a three-month period. This would provide a fairly minimal view of the dominant fauna and general locations of its members. More detailed data on habitat usage and feeding patterns would rapidly expand study costs.

- Bioenergetics – modeling based on site-specific data on trophic partitioning, stable isotope analysis of whole system, and caloric contents. Bioenergetics studies of whether demersal fish and crustaceans obtain sufficient benthic food resources after dredging should assess the prey value of different habitats, including the ones at risk of disruption or indefinite modification by dredging. One approach not yet applied would be to identify those benthic prey resources of most value to the important demersal fish and crustaceans. Then bottom sampling for abundances of those benthic species by habitat could be used in combination with known or estimated productivity to biomass ratios to compute habitat-specific secondary production of natural and disturbed habitats as a more process-oriented way of assessing impacts on the demersal consumers. This type of analysis could include assessment of production of fish and crustacean prey on sand shoals vs. on the seafloor adjacent to the shoals vs. in depressions that go deeply enough to be infilled by fine muddy sediments after completion of dredging. Creating such depositional basins is a risk of mining too deeply below the depth of the surrounding sediment plain. It is known from some studies that, under circumstances of conversion from sands to muds, there is a dramatic switch in benthic fauna. What is unknown is the consequences to demersal consumers. One way to explore that is to study how productivity of fish and crustacean prey differ between undisturbed habitats and mud-filled depressions after dredging. In addition, if benthic prey resources on the nearby seafloor off the shoals provide adequate energetic substitutes for what may be lost on the sand shoal, then the demersal fishes, crabs, and shrimps may not be negatively affected, even by extraction of all the sand resource of the shoal.

Recommendations are made for improvements to the sampling methods to be used in these focused field studies, and the strengths and weaknesses of these different methods are discussed below.

Trawl – This gear has the advantage of covering a large area inexpensively; it is good for capturing specimens for biological data (feeding, reproduction, etc.). Sample replication is easy, but because of usually high variability in catches, a statistically valid number of samples to assess differences may not be feasible. Disadvantages of using trawls include lack of knowledge about specific habitats covered, and integration of habitats throughout a tow, unknown efficiencies and biases (not good for largest fishes). Sampling with this gear should be standardized. We recommend 30-minute tows (most common time in large databases) at a ground speed around 2-3 knots. Choice of nets is more problematic, and this may need to vary with region to match historical databases.

ROV (and/or other camera systems) – These systems are expensive but deliver more explicit data on habitat usage and faunal behaviors. Data can be archived and reviewed multiple times (video storage). They are mostly limited by water visibility. Photo mosaics are possible. They could be important in the initial habitat mapping, and they can be equipped with conductivity-temperature-depth (CTD) or other instruments. These instruments could address unanswered questions of how closely valuable demersal consumers are associated with particular features of the sand shoals (e.g., leading edge of shoals or troughs) and what their behavioral and functional relationship(s) is (are) to those features by enabling observations to be made on finer scales and with simultaneous knowledge of position relative to habitat features, something not possible with trawls.

Benthic lander – These platforms could support low-light video cameras and other instruments (e.g., current meters, CTD, still photos, sediment traps). They can accommodate some experiments. While limited to few replications, this gear has immense potential to deliver a variety of long-term data at a reasonable cost. The resulting observations on fish association with shoal feature (habitat) could be more reliable than similar observations from ROVs because these data could come from a stationary platform and not be biased by movement of the gear through the water.

Tagging/sonic tracking of fish – These new and improving technologies allow tagging of moderate-sized fishes with long-term tags (several month duration), and new monitoring arrays allow for unattended data collection over several square kilometers. The disadvantage is high set-up cost, potential loss of tags, and tags/fish leaving the area before sufficient data are collected. But the type of data delivered on short term and diurnal habitat usage are types of data currently missing. Such studies could be conducted only on one or a few key species and at a tagging intensity of about 10-15 individuals per species. This would presumably be used only in an interdisciplinary process study (or its repetition(s) in other biogeographic regions.)

Applications of passive acoustics – Repopulations of certain fish species may be ascertained through the use of passive acoustics. For instance, pre-dredging monitoring may be able to determine a background level associated with certain species that can then be post-dredging monitored to determine repopulation.

Sonar: high resolution, 3D – New instruments can resolve 3D fish schools with higher resolution than previously possible over large areas (Makris et al., 2006). A disadvantage is that species resolution is usually not possible. This may be a good supplement though for estimating macrofaunal water column biomass.

Benthic meiofauna sampling – Grab sampling and subsampling the meiofauna from grabs on board ship is not likely to provide an adequate characterization of the benthic meiofauna, if they prove important to shrimp resources and thus a necessary target where shrimp fisheries are valuable. Box cores or diver-operated coring provide far less winnowing of fine sediments and loss of small benthos like meiofauna. This recommendation matches the methods used in most past and ongoing MMS studies of meiofauna.

Epibenthic sled sampling – Small epibenthic (bentho-pelagic) crustaceans, especially mysids, are typically not sampled effectively with bottom grabs. These and other small crustaceans are clearly key prey species for many demersal fishes, and our understanding of their habitat associations, their abundances, and where they are fed upon (water column or bottom) is incompletely known, in part because of past sampling constraints. Mysids are best collected with an epibenthic sled sampling the bottom 1 m of the water column, which is where they are found during daylight hours (Barnett, 1987). This sampling needs to be done by habitat so as to relate the mysid abundance to habitat features that may be disrupted by mining.

Profiling floats – Profiling floats designed for use on continental shelves provide a new technique for monitoring temperature, salinity, oxygen, and other biologically important environmental variables throughout the water column. Deployable unattended for long durations with telemetry to shore, such floats add greatly to what can be achieved by shipboard surveys alone. Coupled with the use of gliders, a combined float/glider deployment can serve to map key variables over an extended region and time. These could be incorporated with benthic landers as well.

3.2.3 Long-term Monitoring Studies

Baseline studies are at specific sites where MMS anticipates they will get requests for leases to dredge. These projects serve mostly as site characterizations, providing information suitable to model and anticipate any physical and biological impacts of the dredging activity. Field data collected during these baseline assessments could, and we suspect will, be used in some cases to pair with later post-dredging surveys to provide empirical assessments of how well actual impacts were anticipated. No explicit plans for such post-dredging studies now exist. Some questions, especially those related to consequences of alternative dredging methods and those related to recovery rates of and anoxia development within pits, can best be answered by identifying and funding opportunities that arise to make rigorous comparisons between or among dredging methods or over time, respectively. Such empirical tests will add dramatically to the scientific basis on which impact assessment is done and will lead to improved capacity for avoidance, minimization, and mitigation of impacts. Hence, longitudinal (time-line) studies of some projects should be planned in advance where the most important unanswered questions can be addressed empirically and funding sought, perhaps involving partner agencies, to provide resources necessary for initial and follow-up sampling. Careful planning to get the maximum benefit from long-term monitoring studies, particularly to assess cumulative impacts, is extremely important considering ongoing budget restraints within the MMP. The monitoring interval and program required can not be fully known until the response and recovery can be documented at representative sites.

Some of the key unanswered questions that are best addressed by long-term monitoring are those on how rapidly pit infilling occurs and with what evolution of water quality impacts over time and how benthic biological impacts and recovery rates vary with pit depth and between dredging in strips or as single large pits. These issues affect both dredging of sand from shoals and from buried deposits in buried channels. Long-term sampling is also the most compelling means of testing for cumulative effects as given sand deposits are repeatedly mined or as so many sand shoals are mined that this habitat becomes less abundant in a given region.

Long-term physical monitoring using various instrumentation is relatively inexpensive and some amount of that should be required over the course of a project. Biological monitoring is more difficult, but some long-term sampling at a reduced number of sites would be useful. MMS should build close relationships with all the IOOS and National Ecological Observatory Network (NEON) coastal observing work now developing and develop strategies whereby important physical measurements may be made without cost by inclusion of appropriate instruments on those observing platforms. Where any study shows incomplete convergence of the benthic community and/or the demersal fish community or both after completion of dredging a shoal site, then continued monitoring would seem to be very important so as to evaluate long-term and perhaps also cumulative impacts. The entire issue of cumulative impacts deserves targeted consideration and perhaps establishment of long-term monitoring as one means of testing for their importance.

From a physical perspective this is covered in the Protocols Report (Document 1), the key necessary things to monitor are: 1) bathymetry change with time (i.e., the geomorphic evolution of the dredged area) and any changes to sediment type; and 2) shoreline change. Once the large-scale circulation and the waves have been measured and modeled, both before dredging and possibly after dredging (both these need to be added to the Protocols), there is no further need to monitor these. However, as the Protocols recommend, there is a need to track the wave conditions that are experienced at a given site during the recovery process and also to determine the variations to the circulation on the scale of the project dredging. For instance, are there any modifications to the flow field that impacts either local habitat or the ability of a dredged region to recover. Site-specific, long-term monitoring throughout a recovery interval might be a prudent project addition.

While site-specific observations may be necessary, the larger-scale observations and even models should eventually derive from the emergent RCOOS. Such RCOOS, as envisioned by the U.S. Commission on Ocean Policy, the President's response thereto, and the interagency office Ocean U.S., are emergent around the continental U.S. As these RCOOS become populated with coastal oceanographic instrumentation, in augmentation to the existing array of NOAA-NBDC weather buoys and NOAA-National Water Level Observation Network sea level stations comprising the so-called national backbone, there will be in place the long-term monitoring assets needed to describe the large-scale coastal ocean circulation and wave fields. Here it is recommended that the MMS join with other agencies in helping to facilitate the evolution of these RCOOSs as this will work toward satisfying many of the (physical oceanographic) observing needs of the MMP. Since pilot RCOOS activities have been ongoing for several years, it is further recommended that the MMS first seek existing information in the vicinity of projects as part of their environmental studies. Not only are there many recent improvements to the observational database, there are also applications of state-of-the-art numerical modeling systems, some even in pilot nowcast/forecast mode that can greatly improve on the 2D models that are presently being applied in some of the project studies. This recommendation is equally applicable to the USACE in their WIS program. With the Ocean.US being a multi-agency office and the emergent RCOOS being a multi-agency program, all concerned parties will benefit from improved coordination of efforts. Each agency should not have to pursue its own measurements. Examples for which long-term measurements and long-term model integrations already exist in regions under MMP interest are off the coasts of west Florida and New Jersey.

Whereas the emergent RCOOSs have keyed on physical oceanographic measurements and models primarily on the basis of existing resources, these RCOOS are predicated on multidisciplinary study needs associated with a broader set of societal-based objectives, not the least of which is improved applications of ecologically based management practices. So while such biologically oriented observations and models are still in development, these will also benefit from multi-agency coordination of effort. An example of technologies already in place include long-term monitoring of fish via underwater cameras, some including real-time telemetry (e.g., at the Grays Reef marine sanctuary, http://fishwatch.dnr.sc.gov). New technologies being employed by emergent RCOOS that can facilitate improved environmental monitoring on time and space scales previously unavailable to the MMP include profiling floats and gliders as instrument delivery systems and also passive acoustics for fish monitoring. It is recommended that the MMP work to entrain these RCOOS activities into their studies to the extent possible.

Long-term biological monitoring would be done in a design that matched the initial baseline monitoring done before initiation of the dredging, so as to achieve rigorous comparability. This may constrain choices of projects suitable for long-term monitoring; it may restrict possibilities to those for which baseline monitoring met criteria of adequacy of replication and sufficient characterization of the actual areas that was then later dredged and areas that remained undisturbed that can serve as controls, both on sand shoals and on nearby seafloor habitat. Biological monitoring would target the benthic invertebrate resources of high value such as surf clams (if any) and those serving as prey for demersal consumers (fishes, crabs, shrimps) as well as these demersal consumers directly. Monitoring of the biology would be closely aligned with continued monitoring of the physical habitat, especially the bottom topography (bathymetry) and sedimentology, as well as water quality (oxygen concentrations and turbidity).

If such methods as benthic landers are deployed for long-term physical monitoring (currents, temperature, etc.), these could include some devices for longer-term biological monitoring (e.g., time lapse video or still photography, settling plates, passive acoustics). Depending on abilities to maintain active acoustic tags in an area, stationary hydrophone arrays can monitor long-term movements of organisms. The goals of such long-term biological monitoring would be to create an interdisciplinary understanding of the recovery process, thereby testing the accuracy of predictions made earlier and enhancing the capacity to avoid, minimize, and mitigate future impacts.

4.0 SUMMARY

Review of the past site-specific studies of potential offshore sand borrow sites conducted by the MMS Marine Minerals Program has identified the need for a new approach to future such studies. Recommendations are divided into two categories: general guidelines that would improve the study products; and suggestions for the types of studies to be conducted in the future. Cost and data effectiveness of each are briefly noted. General guidelines include:

- Improve the Scope of Work specified in the Request for Proposals to include key study questions whose answers will lead to an ability to minimize negative impacts of dredging, determine allowable actions, and improve predictions of impacts. This recommendation could be implemented at no additional cost.
- Require better multi-disciplinary integration and collaboration during all phases of the study. This recommendation could be implemented at no additional cost.
- Follow adaptive management principles as studies evolve, to reflect the current understanding or knowledge base. The goal is to limit the need for some routine types of monitoring of future projects. This recommendation could be implemented at no additional cost.
- Require biophysical habitat mapping that will guide the design of any future physical or biological sampling, and development of plausible (environmentally and economically acceptable) long-term dredging plans. Such biophysical mapping should be aimed at placing the site to be dredged in the context of the surroundings in order to ascertain if there are any unique aspects to the borrow site. If not then the site-specific surveys may be performed at greatly reduced scope and cost since any loss can be quantified as a percentage of the surrounding area.
- Require recommendations for mitigation measures to test some of the hypotheses that have been proposed to minimize impacts on the benthos in the short- and long-term. This recommendation could be implemented at no additional cost.
- Improve the understanding of the current patterns and morphologic response of dredged areas to provide input conditions for evaluation of geomorphic recovery processes (including rate and manner of infilling). Increased costs would be on the order of $200,000-$350,000 per site.

Future studies of offshore sand borrow sites should fall into three types, listed in order of priority:

- <u>Characterization studies</u> at all new sites to provide the baseline data needed to support environmental assessment for leasing. These studies would include biophysical habitat mapping, modeling of physical processes, limited biological sampling, and analysis of the results to support linking of biophysical relationship, development of recommended dredge plans and site-specific mitigation measures, and an understanding of the benthic recovery mechanisms for different dredging scenarios.

These studies would be similar to the costs of current site-specific studies with the additional of the biophysical mapping, which would add $30-50,000 per site.

- Focused model studies at selected sites that are designed to answer key questions such as how the borrow sites respond to dredging events, what are acceptable levels of shoreline change, how ecologically unique or special are sand shoals as habitats for valuable benthic and fish resources, and how are bioenergetics changed after dredging events? These focused studies should employ appropriate study methods and technologies to generate the data needed to provide definitive answers to these key questions.

- Long-term monitoring studies at selected sites to determine the long-term effectiveness of different mitigation measures and for assessment of cumulative impacts. Only through long-term monitoring will MMS be able to achieve its goal of environmentally sound management of these sand resources. MMS should be an active partner in Regional Coastal Ocean Observing Systems, sharing in the design, implementation, and costs of these multi-agency efforts to collect and distribute physical and biological data for coastal ecosystems.

The assessment of dredging options to reduce potential impacts to benthic resources included in Appendix C came to the following recommendations:

- The trailing suction hopper dredge is expected to be the most economical dredging technique using a submerged pipeline connection from the beach to pump the sand to the beach.
- Not allowing the discharge of overflow would prevent the formation of sediment plumes at an increase in time and cost of dredging by an estimated 35%.
- Dredging of alternative strips (if shown to increase the rate of recolonization) is estimated to increase the time and cost of dredging by 10%, but only if overflow is not permitted.

Although the recommendations in this report have been developed for the MMS Marine Minerals Program, it should be noted that most of these principles and approaches are directly applicable to other marine assessment studies. In particular, the MMS has new responsibilities over offshore renewable energy and related uses under the Energy Policy Act of 2005. MMS will have to conduct scientific assessments and studies to improve their understanding of the likely effects of offshore alternative energy projects and to support decision making for best management of resources. The recommendations made here should also assist MMS in the proper design and implementation of a research program to support alternative energy uses in the OCS.

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APPENDIX A

EVALUATION SUMMARY OF SITE-SPECIFIC STUDIES METHODS:

PHYSICAL PROCESSES

Appendix A: Evaluation Summary of Site-Specific Studies Methods: Physical Processes

CATEGORY	1. Design of a Monitoring Protocol/Plan for Environmentally Sound Management and Development of Federal Offshore Sand Borrow Areas Along the United States East and Gulf of Mexico Coasts (OCS Study 2001-089	2. Biological Characterization/Numerical Wave Model Analysis within Identified Borrow Sites Offshore the Northeast Coast of Florida – SEA NE FL Cruise Plan, Model Grid, Benthic Sorting	3. Biological Characterization/Numerical Wave Model Analysis within Identified Borrow Sites Offshore the West Coast of Florida/Physical Implications of Sand Dredging on the Topography of the West Florida Shelf - SEA West FL Cruise Plan, Model Grid, Benthic Sorting, and other documents	4. Utilization of Benthic Communities by Fish Populations on Ridge and Shoal Features (Ship Shoal) – USGS Study Proposal	5. Numerical modeling evaluation of the cumulative physical effects of offshore sand dredging for beach nourishment – MMS 2001-098	6. Wave-Bottom Interaction and Bottom Boundary Layer Dynamics in Evaluating Sand Mining at Sabine Bank for Coastal Restoration, Southwest Louisiana – Stone Sabine Bank Technical Proposal
Wave Climate	Wave buoy (>5 years) or WIS + wave buoy (one year)	US Army Corps of Engineers (USACE) Wave Information System (WIS) Station 427 for Volusia County work.	Unknown at time of this report	Not addressed	WIS	NDBC Wave Buoy
Wave Transformation	Spectral/phase-averaged (STWAVE, MIKE21 NSW, SWAN, GHOST) and phase resolving (MIKE21 BW, FUNWAVE, REF/DIF S, MIKE21 PMS) are reviewed and strengths/limitations presented.	The Wave Action Balance Equation Diffraction (WABED) model of the USACE was applied (see Lin et.al., 2006). WABED is a spectral wave model that theoretically considers the influences of diffraction and to a limited extent, reflection.	STWAVE	Not addressed	STWAVE	STWAVE and SWAN
Hydrodynamics	Not addressed	M2D, "resolved distances down to 100 m", tidal forcing from constituents supplied by USACE.M2D is linked to WABED within SMS.	M2D	Not addressed	Not addressed	Two near-bed ADVs
Sedimentology/ Geomorphology of the Dredged Area	Not addressed	Unknown at time of this report	Unknown at time of this report	Not addressed	Not addressed	Not addressed
Dredged Area Evolution (substrate change inside and beyond pit)	Through bathymetric monitoring	WES-CHL Lund Formula linked to WABED and M2D to provide morphologic change with and without the dredging (at a 80 to 100 m resolution at best)	WES-CHL Lund Formula?	Not addressed	Not addressed	Local sediment transport using Meyer-Peter Muller and Wiberg for bedload and concentration profile for suspended load, both combination of measurements (OBS) and theoretical techniques
Turbidity/Plume (if applicable)	Not addressed	Unknown at time of this report	Unknown at time of this report	Not addressed	Not addressed.	Not addressed

CATEGORY	1. Design of a Monitoring Protocol/Plan for Environmentally Sound Management and Development of Federal Offshore Sand Borrow Areas Along the United States East and Gulf of Mexico Coasts (OCS Study 2001-089	2. Biological Characterization/Numerical Wave Model Analysis within Identified Borrow Sites Offshore the Northeast Coast of Florida – SEA NE FL Cruise Plan, Model Grid, Benthic Sorting	3. Biological Characterization/Numerical Wave Model Analysis within Identified Borrow Sites Offshore the West Coast of Florida/Physical Implications of Sand Dredging on the Topography of the West Florida Shelf - SEA West FL Cruise Plan, Model Grid, Benthic Sorting, and other documents	4. Utilization of Benthic Communities by Fish Populations on Ridge and Shoal Features (Ship Shoal) – USGS Study Proposal	5. Numerical modeling evaluation of the cumulative physical effects of offshore sand dredging for beach nourishment – MMS 2001-098	6. Wave-Bottom Interaction and Bottom Boundary Layer Dynamics in Evaluating Sand Mining at Sabine Bank for Coastal Restoration, Southwest Louisiana – Stone Sabine Bank Technical Proposal
LST Changes/Shoreline Impacts	GENESIS and monitoring	WES-CHL Lund Formula is applied together with WABED and M2D and net difference in LST are given for the year 1999. Differences are compared to the natural temporal (year to year) variability in LST rates and judged to be small but measurable. Suggest predicted transport rates for pre-dredge (existing) condition compare within an order of magnitude to known rates but no direct comparisons are made.	WES-CHL Lund Formula?	Not addressed	Spatial and Temporal Variations in Wave Climate Approach (first developed in this report)	Not addressed
Dredging Techniques Discussion	Not addressed	Unknown at time of this report	Unknown at time of this report	Not addressed	Not addressed	Not addressed
Biophysical Considerations	Linkages between benthic impacts and substrate changes are addressed and this was the basis for recommending surveys of changes to substrate through time together with benthic surveys to develop understanding of relationships between benthic communities and substrate and how these may change after dredging.	Unknown at time of this report	Unknown at time of this report	Appears to be none – focus is on isotopic analysis.	Not addressed	Not addressed

CATEGORY	7. Investigation of Finfish Assemblages and Benthic Communities within Potential Borrow Areas Inside Federal Waters Offshore SE Texas and Southwest Louisiana – USGS Work Plan, Benthic Polychaete Assemblage Plan, Cruise Report	8. Ship Shoal, Louisiana: Sand, Shrimp, and Seatrout Investigation – Condrey Study Plan	9. Environmental Investigation of the Long-Term Use of Ship Shoal Sand Resources for Large-Scale Beach and Coastal Restoration in Louisiana (Cooperative Agreement with Louisiana State University) – Stone Proposal and First Report	10. Field Testing of a Physical/ Biological Monitoring Methodology for Offshore Dredging and Mining Operations – VIMS March 2006 Report, RPI Team Comments, and VIMS Response to RPI Comments	11. Comparisons Between Marine Communities Residing on Sand Shoals and Uniform-Bottom Substrate in the Mid-Atlantic Bight - OCS Study MMS 2005-042	12. Environmental Surveys of Potential Borrow Areas Offshore Northern New Jersey and Southern New York and the Environmental Implications of Sand Removal for Coastal and Beach Restoration. OCS Study MMS 2004-044
Wave Climate	Not addressed	Not addressed	NDBC and WAVCIS	NDBC and other measurements.	Not addressed	20-year wave climates developed by OCTI to provide spectral input at STWAVE boundaries (for these reasons selected over WIS), likely that OCTI used WAVAD, only two stations – one for Long Island and another for NJ coast; no indication of validation of OCTI hindcast
Wave Transformation	Not addressed	Not addressed	SWAN (to capture non-stationary nature of wave generation with wind from WAVCIS, NDBC and COAMPS)	Experimental X-Band Radar	Not addressed	STWAVE using 200 m grid over the dredge sites and 20 m grid nearshore, used spectra input (instead of simply summary parameters)
Hydrodynamics	Not addressed	Not addressed	Two near bed ADVs	Not addressed	Not addressed	General description from the literature; used existing ADCP measurements from 10 to 20 km away from dredge sites; refer to results of modeling by others of the entire NJ/NY coast (unclear if 2D or 3D), no direct comparison between modeling/measurements (both by others); direct impacts on hydrodynamics are not discussed or evaluated (Section 7.3, p. 206)
Sedimentology/ Geomorphology of the Dredged Area	Not addressed	Not addressed	Not addressed	Grab samples for grain size analysis and SPI (Sediment Profile Imaging)	Limited literature review	Comprehensive review of surface and subsurface conditions based on sediment samples, cores and geophysical work; Grab samples, sediment grain size analysis and SPI

CATEGORY	7. Investigation of Finfish Assemblages and Benthic Communities within Potential Borrow Areas Inside Federal Waters Offshore SE Texas and Southwest Louisiana – USGS Work Plan, Benthic Polychaete Assemblage Plan, Cruise Report	8. Ship Shoal, Louisiana: Sand, Shrimp, and Seatrout Investigation – Condrey Study Plan	9. Environmental Investigation of the Long-Term Use of Ship Shoal Sand Resources for Large-Scale Beach and Coastal Restoration in Louisiana (Cooperative Agreement with Louisiana State University) – Stone Proposal and First Report	10. Field Testing of a Physical/ Biological Monitoring Methodology for Offshore Dredging and Mining Operations – VIMS March 2006 Report, RPI Team Comments, and VIMS Response to RPI Comments	11. Comparisons Between Marine Communities Residing on Sand Shoals and Uniform-Bottom Substrate in the Mid-Atlantic Bight - OCS Study MMS 2005-042	12. Environmental Surveys of Potential Borrow Areas Offshore Northern New Jersey and Southern New York and the Environmental Implications of Sand Removal for Coastal and Beach Restoration. OCS Study MMS 2004-044
Dredged Area Evolution (substrate change inside and beyond pit)	Not addressed	Not addressed	Sediment transport predicted locally based on current and suspended sediment (OBS) measurements	Not addressed	Not addressed	Existing conditions assessed through review of historic changes, evaluated pit infilling using 1D estimate of transport using approach of Madsen (1987) to consider combined wave-current friction factor; found infilling rates were low due to depths (20 m), unclear whether reported transport rates are m3/yr for full pit or m3/m/yr; suggest shoals once removed will not reform (see Section 7.4.2, P. 209); shoals fully removed but no pits
Turbidity/Plume (if applicable)	Not addressed	Not addressed	Not addressed	Not addressed	Not addressed	Discussed in generic terms in Section 7.5.1.2 and 7.5.1.3
LST Changes/Shoreline Impacts	Not addressed	Not addressed	Not addressed	Shoreline change through air photos, surveys, nearshore profiles and swath bathymetry. No predictive techniques applied.	Not addressed	Used CERC and Kamphuis (1990) to estimate LST, estimated at each 20 m grid cell. Estimates completed with and without dredging, found length of impact was 3 times alongshore length of borrow area; developed 20-yr average annual LST and +/-0.5 StdDev along the shore. Compared gradients in LST to measured shoreline change at 30 m intervals. Significance of impact was evaluated using the approach of Kelly (2004) – specifically whether the changes due to dredging change the LST beyond the 0.5 s.d. limits of temporal variability.

CATEGORY	7. Investigation of Finfish Assemblages and Benthic Communities within Potential Borrow Areas Inside Federal Waters Offshore SE Texas and Southwest Louisiana – USGS Work Plan, Benthic Polychaete Assemblage Plan, Cruise Report	8. Ship Shoal, Louisiana: Sand, Shrimp, and Seatrout Investigation – Condrey Study Plan	9. Environmental Investigation of the Long-Term Use of Ship Shoal Sand Resources for Large-Scale Beach and Coastal Restoration in Louisiana (Cooperative Agreement with Louisiana State University) – Stone Proposal and First Report	10. Field Testing of a Physical/ Biological Monitoring Methodology for Offshore Dredging and Mining Operations – VIMS March 2006 Report, RPI Team Comments, and VIMS Response to RPI Comments	11. Comparisons Between Marine Communities Residing on Sand Shoals and Uniform-Bottom Substrate in the Mid-Atlantic Bight - OCS Study MMS 2005-042	12. Environmental Surveys of Potential Borrow Areas Offshore Northern New Jersey and Southern New York and the Environmental Implications of Sand Removal for Coastal and Beach Restoration. OCS Study MMS 2004-044
Dredging Techniques Discussion	Recommendations for temporal windows for dredging along the Gulf shelf to promote recovery and reduce impact to fisheries feeding on benthic communities: they suggest dredging in late autumn would allow the greatest interim for recovery between recruitment which occurs mainly in spring and summer. They also suggest dredging in strips may help.	Not addressed	Not addressed	Not addressed	Not addressed	p. 203, Discusses choice between CSD and TSHD, both are seen as possible candidates (inshore of 8 km and large projects being suited to CSD); suggest dredging the leading edge of a migrating shoal (p. 204), see also Section 7.5.3 on direct removal, plume and sedimentation effects of dredging – but not quantitative
Biophysical Considerations	Found linkages between Polycheate assemblages (species composition, richness, abundance, biomass, and grain size distributions. Considered in very general terms the local current speed/direction and salinity characteristics.	No direct mention of investigating linkages between biological and physical processes in the proposal.	Investigate possible linkages between substrate and benthic communities unique to Ship Shoal	Not addressed	Evaluated linkages between substrate/bedform and: shell cover, biogenic structure, benthic communities and fish species.	p. 211, Section 7.5.1.1, speak in general terms about relationships between benthic communities and sediment transport and sedimentologic characteristics; impact and recovery/re-colonization (Section 7.5.2) discussed mostly in general terms, however with some examples of findings from nearby studies; site-specific discussions ARE presented in Section 7.5.3

CATEGORY	**13. Environmental Surveys of Potential Borrow Areas on the East Florida Shelf and the Environmental Implications of Sand Removal for Coastal and Beach Restoration. OCS Study MMS 2004-037**	**14. Collection of Environmental Data within Sand Resource Areas Offshore North Carolina and the Environmental Implications of Sand Removal for Coastal and Beach Restoration. OCS Study MMS 2000-056**	**15. Surveys of Sand Resource Areas Offshore Maryland/Delaware and the Environmental Implications of Sand Removal for Beach Restoration Projects. OCS Study MMS 2000-055**	**16. Wave Climate and Bottom Boundary Layer Dynamics with Implications for Offshore Sand Mining and Barrier Island Replenishment, South-Central Louisiana. OCS Study 2000-053**	**17. Environmental Surveys of OCS Sand Resources Offshore New Jersey. OCS Study MMS 2000-052**	**18. Environmental Survey of Identified Sand Resource Areas Offshore Alabama. OCS Study MMS 99-0051**
Wave Climate	Completed literature review of available measured wave data; used WIS data with summary parameters only.	Literature survey, used WIS (summary parameters)	Used NDBC 44009 for offshore data, also used MD001 and MD002 from the Corps for nearshore data	Considered winds, classified meteorological event, but no offshore measurements or predictions completed	WIS data was used with general comparisons to NOAA buoy and LEO-15 (Long-Term Ecosystem Observatory Data from Rutgers U) data	Used WIS but verified against NDBC buoy data
Wave Transformation	STWAVE v2.0, developed spectra from WIS summary parameters (applying directional spreading and frequency distribution), used 200 m far field and 20 m near field (shoreline) grid spacings	First used WAVETRAN (from SMS) for far field transformation from WIS station to STWAVE boundary, STWAVE v2.0, developed 2D spectra from summary parameters for input, developed 200 m medium field and 20 m near field grids	Applied REF-DIF 1, chosen through a model selection process including REF-DIF S, RDE, SWAN, HISWA and STWAVE;	STWAVE v3.0, validated against measurements	Applied REF-DIF S, created synthetic 2D spectra from the summary parameter wave data provided with WIS; offshore grids 200 m resolution, nearshore 5 m (cross-shore) by 20 m (longshore)	Applied REF-DIF S, created synthetic 2D spectra from the summary parameter wave data provided with WIS; offshore grids 200 m resolution, nearshore 5 m (cross-shore) by 20 m (longshore)
Hydrodynamics	General description from the literature; site specific ADCP measurements by towing made over one of the shoals (Thomas) on three separate occasions; hydrodynamic models (2D or 3D) were not applied, therefore no quantitative assessment of the impact of dredging on hydrodynamics.	Literature survey; analyzed ADCP current measurements from the FRF pier, no direct measurements at proposed dredge sites; no 2D or 3D modeling of currents	Evaluated impacts to storm surges using the SLOSH model; applied 300 by 600 m grid with 3D POM model to evaluate impact to tidal currents – verified against tidal levels measured at the shore	Deployed ADVs, pressure gages to measure currents/waves at Ship Shoal	Literature review; analyzed nearby measurements of currents from other studies; some estimates made through application of REF DIF S to predict orbital velocities and use of radiation stresses to drive currents over the shoals.	Literature review; analyzed nearby measurements of currents from other studies; two towed ADCP deployments were undertaken to measure currents at the target dredge areas; nearshore longshore currents developed from radiation stresses output from REF-DIF S
Sedimentology/ Geomorphology of the Dredged Area	Comprehensive review of surface and subsurface conditions based on sediment samples, cores and geophysical work; Grab samples, sediment grain size analysis and video/photographs	Comprehensive review of surface and subsurface conditions based on sediment samples, cores and geophysical work; Grab samples, sediment grain size analysis and SPI	Review of previous geomorphic interpretations; Grab samples, sediment grain size analysis, SPI, side scan sonar and video	Limited literature review of geology and geomorphology	Comprehensive review of surface and subsurface conditions based on sediment samples, cores and geophysical work; Grab samples and sediment grain size analysis	Comprehensive review of surface and subsurface conditions based on sediment samples, cores and geophysical work; Grab samples and sediment grain size analysis
Dredged Area Evolution (substrate change inside and beyond pit)	Existing conditions assessed through review of historic changes, evaluated pit infilling using 1D estimate of transport using approach of Madsen (1987) to consider combined wave-current friction factor; found infilling rates were low due to depths (20 m), unclear whether reported transport rates are m3/yr for full pit or m3/m/yr; no pit morphology modeling (2D/3D)	Based on consideration of historic bathymetric changes in the areas of the proposed dredging; evaluated pit infilling using 1D estimate of transport using approach of Madsen (1987) to consider combined wave-current friction factor; found infilling rates were low due to depths (20 m), unclear whether reported transport rates are m3/yr for full pit or m3/m/yr; no pit morphology modeling (2D/3D)	Looked at changes to near-bed shear stress using the Grant-Madsen-Glenn approach, find no “significant” changes	Deployed OBS in addition to ADVs to evaluate local sand transport potential; local sediment transport estimates using both Meyer-Peter Muller adapted by Wiberg et al (1994) and a Grant-Madsen-Rouse (GMR) approach	Completed detailed bathymetric change estimates; sediment transport estimates over and around the shoals estimated using Madsen and Grant (1976) with wave and currents defined by REF DIF S	Completed detailed bathymetric change estimates; used Madsen/Grant to evaluate local sediment transport for given wave conditions

CATEGORY	13. Environmental Surveys of Potential Borrow Areas on the East Florida Shelf and the Environmental Implications of Sand Removal for Coastal and Beach Restoration. OCS Study MMS 2004-037	14. Collection of Environmental Data within Sand Resource Areas Offshore North Carolina and the Environmental Implications of Sand Removal for Coastal and Beach Restoration. OCS Study MMS 2000-056	15. Surveys of Sand Resource Areas Offshore Maryland/Delaware and the Environmental Implications of Sand Removal for Beach Restoration Projects. OCS Study MMS 2000-055	16. Wave Climate and Bottom Boundary Layer Dynamics with Implications for Offshore Sand Mining and Barrier Island Replenishment, South-Central Louisiana. OCS Study 2000-053	17. Environmental Surveys of OCS Sand Resources Offshore New Jersey. OCS Study MMS 2000-052	18. Environmental Survey of Identified Sand Resource Areas Offshore Alabama. OCS Study MMS 99-0051
Turbidity/Plume (if applicable)	Discussed in generic terms	Discussed in general terms only	Not addressed	Not addressed	Discussed in mostly general terms only, but with some reference to resilience of local benthic communities	Discussed in general terms only
LST Changes/Shoreline Impacts	Literature review of LST completed. Used Rosati et al (2002) approach to estimate LST (simple CERC-like formula related to longshore component of breaking wave energy), estimated at each 20 m grid cell? Estimates completed with and without dredging, found length of impact was 3 times alongshore length of borrow area; developed 20-yr average annual LST and +/-0.5 StdDev along the shore. Compared gradients in LST to measured shoreline change at 30 m intervals. Significance of impact was evaluated using the approach of Kelly (2004) – specifically whether the changes due to dredging change the LST beyond the 0.5 s.d. limits of temporal variability.	Literature survey, Used CERC and Kamphuis (1990) to estimate LST, estimated at each 20 m grid cell. Developed 20-yr average annual LST and +/-0.5 StdDev along the shore. Compared gradients in LST to measured shoreline change at 30 m intervals. Significance of impact was evaluated using the approach of Kelly et al (2001) – specifically whether the changes due to dredging change the LST beyond the 0.5 s.d. limits of temporal variability.	Considered through changes to the breaking wave height calculated with REF-DIF 1 and specifically changes to the gradients in wave heights (recognizing this influence gradients of LST that in term drive shoreline erosion/accretion) – what they refer to as Breaking Wave Height Modulation (BHM) – but this is the total BHM for a long reach of shore and does not consider changes to gradients at different locations along the shore; also, BHM is only considered (can only be considered) for given offshore wave height conditions – there is not integration to determine LST	Not addressed	Literature review; completed detailed historic shoreline change estimates; compared shoreline change to predicted spatial variation of wave height; significance of impact is judged on basis of % change in wave height for a range of conditions without linkage to quantitative impacts in terms of shoreline change; also estimated longshore currents using radiation stresses from REF-DIF S, applied Bodge and Dean (1987) combined with measured shoreline change to estimate distribution and rate of longshore sand transport with and without dredging; compared LST gradients to shoreline change; suggest that 7 to 20% differences in LST are within the range of uncertainty of the predictive capabilities for LST (+/-25 to +/-35%)	Literature review, completed detailed historic shoreline change estimates; compared shoreline change to predicted spatial variation of wave energy; used approach of Bodge and Dean (1987), Bodge (1989) to estimate LST rates, compared results to shoreline change estimates; they then related changes with/without dredging to uncertainties of LST predictors (+/-35%) and justified that the change was not significant compared to uncertainties of predictions
Dredging Techniques Discussion	Discusses choice between CSD and TSHD, both are seen as possible candidates, plume and sedimentation effects of dredging – but not quantitative; no recommendations on buffers for hard bottom areas of East Florida	Suggest dredging the leading edge of a migrating shoal, discussed in general terms comparing CSD to TSHD	Suggest leaving islands in dredge areas to promote benthic recovery, no details provided on quantitative impact on recovery or required size of islands	Not addressed	General discussion of types of dredges that could be used	General discussion of types of dredges that could be used; suggest the possibility of leaving un-dredged islands but no specifics provided
Biophysical Considerations	Speak in general terms about relationships between benthic communities and sediment transport and sedimentologic characteristics; impact and recovery/re-colonization discussed mostly in general terms	Relationships between sediment composition and benthic assemblages for NC are discussed, but mostly generic and not site-specific to target dredging areas	Discussed in general terms	Not addressed	Surfclam and ichthyoplankton larval transport by currents is discussed in general. Correlation between sediment composition and benthic assemblages discussed in general terms and based on NJ offshore data.	Correlation between sediment composition and benthic assemblages discussed in general terms

CATEGORY	**19. Use of Federal Offshore Sand Resources for Beach and Coastal Restoration in New Jersey, Delaware, Maryland and Virginia. OCS Study MMS 99-052**	**20. Environmental Studies Relative to Potential Sand Mining in the Vicinity of the City of Virginia Beach, Virginia. OCS Study MMS 99-036.**	**21. Wave Climate Modeling and Evaluation Relative to Sand Mining on Ship Shoal, Offshore Louisiana, for Coastal and Barrier Island Restoration. OCS Study MMS 96-059.**	**22. Environmental Investigation of the Long-Term Use of Trinity and Tiger Shoals as Sand Resources for Large Scale Beach and Coastal Restoration in Louisiana (2006-2009)**
Wave Climate	General description of existing data sets, measurements, hindcasts (WIS) and forecasts	WIS Stations 58 and 59	WIS Stations 19, 20 and 21, compared statistical summary data to NDBC 42017 and 42001 and LATEX 16	SWAN
Wave Transformation	Some generic REF-DIF S results are presented	REF/DIF S, developed synthetic 2D spectra for input, 250 m grid resolution	Model selection between RCPWAVE, REF-DIF 1, REF-DIF S and STWAVE, selected STWAVE, considered the role of wind-forcing	Propose to use SWAN and make comparisons to STWAVE, SWAN to have a 4 km grid across the Gulf and 300 m grid near Tiger and Trinity Shoals; will compare predictions to NDBC and WAVCIS wave measurements; also propose to use MIKE 21 SW (Spectral Wave)
Hydrodynamics	General discussion of patterns, measurements, data availability	Project-specific towed ADCP measurements completed	Not addressed	Propose to apply the 2D MIKE21 HD FM (Flexible Mesh) model and verify against WAVCIS measurements
Sedimentology/Geomorphology of the Dredged Area	Comprehensive review of surface and subsurface conditions based on sediment samples, cores and geophysical work	Grab samples, sediment grain size analysis and SPI	Not addressed	Not addressed
Dredged Area Evolution (substrate change inside and beyond pit)	Not addressed	Not addressed	Not addressed	Propose to apply the MIKE21 ST and MT modules (for sand and mud transport) together with SW and HD modules; also will predict sediment transport using OBS and velocity measurements using a variety of approaches to theoretically interpolate/extrapolate the measured data
Turbidity/Plume (if applicable)	Discussion of the generation of plumes from different dredging operations	Not addressed	Not addressed	Not addressed
LST Changes/Shoreline Impacts	General discussion of known rates estimated by others	Historic shoreline and profile change analysis	Evaluated the completed removal of Ship Shoal for Hurricane Andrew conditions (Hs=6m, T=11 s) and for three lesser conditions (4m/9s, 2m/6s, 1m/5s).	Not addressed
Dredging Techniques Discussion	Detailed discussion of the range of dredging equipment and procedures available, but in site-specific terms; some generic recommendations are made for mitigation measures such as avoiding deep pits, alternating locations for periodic dredging of same location	Not addressed	Not addressed	Not addressed
Biophysical Considerations	Discussed in general terms	Not addressed	Not addressed	Propose to investigate how benthic populations and communities are related to environmental factors (substrate composition, water depth, water quality)

APPENDIX B

EVALUATION SUMMARY OF SITE-SPECIFIC STUDIES METHODS:

BIOLOGICAL PROCESSES

Appendix B: Evaluation Summary of Site-Specific Studies Methods: Biological Processes - BENTHOS

	CATEGORY	1. Protocols Report	2. NE Florida	3. West Florida	4. Ship Shoal Utilization of Benthos by Fish USGS	7. (Benthic Polychaetes) Heald/Sabine Banks USGS	7. Fish Communities Heald/Sabine Banks USGS
Benthos							
Sampling Methods							
	Collection Method	Grab (Box/Van Veen)	Grab (Smith-McIntyre)	Grab (Smith-McIntyre)	Core (Ponar box)	Grab (Ponar box)	Grab (Box)
	Surface area covered	$0.1m^2$	$0.1m^2$	$0.1m^2$	21 x 21 cm, 5cm dia for macro.	$7531cm^3$	2.54cm dia (subsample)
	Depth of sed. penetration						5-8cm
	Sieve mesh size	0.5mm	0.5mm	0.5mm	0.5mm	0.5mm	
	Temporal freq. of sampling	Prior & 1, 3, 5, 7 years post dredge	Oct, Nov, & June	Fall/Spring	2004-2006, all seasons	Spring	Summer
	SPI/other, penetration depths	SPI	epibenthic camera sled	epibenthic camera sled			Sidescan, single-beam bathymetry, & CHIRP (fall/winter)
Target Fauna		Macrofauna	Meio/Macrofauna	Meio/Macrofauna	Benthic Invertebrates	Polychaetes/Macrofauna	sediment & epifauna (shrimp)
	meiofaunal sampling & collection methods		Meiofaunal subcores (2.5cm dia x 10cm)	Meiofaunal subcores (2.5cm dia x 10cm)			
	epibenthic dredge for semibenthic mysids						
Sampling Design							
	Large-scale spatial organization of sampling	defined, multiple strata types present in both dredged & control areas	randomly selected sites - 30 on shoal and 3 adjacent	randomly selected sites- 24 on Shoal 1, 12 on Shoal 2, 10 adjacent to shoals	random locations within 3 areas: off shoal, undisturbed shoal, & dredged	Sabine bank: 8 samples each for on/off/along bank edge; Heald Bank: 4 samples each on/off bank.	random design with 3 strata: bank interior, bank edge, & off-bank
	Finer-scale spatial organization of sampling	for sand ridges, offshore ridge slope, ridge crest, nearshore ridge slope, & swale bottom					
Benthic Analysis Methods							
	Computation of total density &/or biomass (which?) of macrobenthos	biomass & density to m^2	density to m^2	density		biomass for sorted polychaetes, density to m^2	

	CATEGORY	1. Protocols Report	2. NE Florida	3. West Florida	4. Ship Shoal Utilization of Benthos by Fish USGS	7. (Benthic Polychaetes) Heald/Sabine Banks USGS	7. Fish Communities Heald/Sabine Banks USGS
	Computation of total density of meiofauna						
	Computation of macro-benthic density &/or biomass (which?) by taxon, & level	biomass & density to m^2 ID to major taxon	density ID into broad groups (i.e. crustaceans, molluscs, polychaetes, etc)	density ID into broad groups (i.e. crustaceans, molluscs, polychaetes, etc)	ID to Functional groups, possibly to species (esp pref food items); no calculations	biomass & density of polychaetes by spp	
	Computation of meiofaunal density &/or biomass by taxon, & level						
Community Analysis							
	Separate computation/ analyses of benthic taxa known to be prey	stable isotope for C & N in each stratum			stable isotope C, N, & S for trophic level dredged/undisturbed		
	Community indices computed	sed grain size, TOC	Macrofauna: H', D, sed grain size, TOC, dominant spp/groups	Macrofauna: H', D, abundance, dominant spp/groups; sed grain size, carbonate content, % organic	sed grain size	Primer: H', J', D, sed grain size, TOC, AFDW	
	Community composition analyses (cluster, etc)	secondary productivity	dominant groups/species			Dominant species composition, ANOVA for diff in sample areas, Primer ANOSIM & SIMPER for inter & intra bank analyses, feeding guild analysis, ABC curves (Abundance Biomass comparison) for level of disturbance	
Correlation w/ Other Parameters							
	Analyses of how sedimentology predicts benthic patterns			benthic community composition comparison to sed grain size/composition		tubicolous polychaete assemblages compared with sed size	
	Analyses of how benthos varies b/w habitats				nutrient source comparison for shoal vs. open-bottom	distribution of organic content consumers compared by on/off bank analyzed by feeding guild classification	
	Analyses of how benthos varies on a finer scale						

	CATEGORY	9. Ship Shoal, LA	10. VIMS Test of Protocols	11. Mid-Atlantic Bight Versar	12. New York/New Jersey	13. East Florida	14. North Carolina
Sampling Methods							
	Collection Method	Core (Gomex box)	Grab (Smith-McIntyre or Young Mod. VanVeen)		Grab (Smith-McIntyre)	Grab (Spipek)	Grab (Smith-McIntyre)
	Surface area covered	25*25*50cm	$0.1m^2$ or $0.04m^2$, respectively		5cm dia subsample grain size	5cm dia subsample grain size	5cm dia subsample grain size
	Depth of sed. penetration						
	Sieve mesh size	0.5mm	0.5mm		0.59mm, size class: 0.3, 0.5, 0.6, 1, & 2mm	0.5mm, size class: 0.3, 0.5, 0.6, 1, & 2mm	0.5mm, size class: 0.3, 0.5, 0.6, 1, & 2mm
	Temporal freq. of sampling	Spring: one mo prior, 6 mo intervals post dredge	Spring: 6 mo prior & 4, 6, 18 mo. post dredge.		Sept & June	Sept & May	May & Sept
	SPI/other, penetration depths	STD profile	Video sled, 0.2m off bottom @ 20^o & 0.15m from sediment; SPI 3.6-6.7cm penetration	Video sled (for ref sites)	SPI 3.5-7 cm penetration	Video sled	SPI 2.2-7.7cm penetration
Target Fauna		Macrofauna	Meio/Macrofauna & epifauna (shrimp)	Macrofauna		Macrofauna	Macrofauna
	meiofaunal sampling & collection methods	Meiofaunal subcores, 50 ml syringe, 10 cm depths; nested 500, 63, & 45µm sieves					
	epibenthic dredge for semibenthic mysids						
Sampling Design							
	Large-scale spatial organization of sampling	Cross-like grid with E-W axis & 3 arms. The E-W axis runs over the 2.74m spine of the shoal to the 8.23m contour @ either end of the axis. The 3 arms of the cross intersect the axis and extend in a N-S direction to the 8.23m contour. 12 box core locations associated with the cross, 14 experimental box core locations associated with mining activities			4-10 grabs per shoal randomly selected, for 4 shoals, 1 grab at 6 offshoal sites, 6 SPI camera sites	9 shoals with 3-13 grabs per shoal, plus 7 offshoal sites	4 shoals with 2-20 sites per shoal and 2 offshoal sites
	Finer-scale spatial organization of sampling		stratified random design with 4 strata: E and W of shoal, dredged area, and not dredged shoal area				
Benthic Analysis Methods							
	Computation of total density &/or biomass of macrobenthos		biomass to m^2		density to m^2	density to m^2	density to m^2

	CATEGORY	9. Ship Shoal, LA	10. VIMS Test of Protocols	11. Mid-Atlantic Bight Versar	12. New York/New Jersey	13. East Florida	14. North Carolina
	Computation of total density of meiofauna						
	Computation of macro-benthic density &/or biomass by taxon, & level	ID to major taxon (incl. shrimp prey), except adult/juvenile copepods to spp; no calculations	biomass by major taxa		density ID to lowest practical level	density ID to lowest practical level	density ID to lowest practical level
	Computation of meiofaunal density &/or biomass (which?) by taxon, & level	ID to major taxon, except adult/juvenile copepods to spp; no calculations					
Community Analysis							
	Separate computation/ analyses of benthic taxa known to be prey		stable isotope C & N by taxon				
	Community indices computed	sed grain size, TOC	sed grain size		H', J', D, sed grain size	H', J', D, sed grain size	H', J', D, sed grain size
	Community composition analyses (cluster, etc)	Macro/Meiobenthic Copepods: Primer ANOSIM for community structure; secondary productivity for macrobenthic communities compared to prey found in shrimp; gut content shrimp proventriculi (% cover per taxon, gut fullness)	Secondary productivity, nested sieves of : 0.5, 0.71, 1, 1.4, 2, 2.8, 4, 5.6, & 8 mm, AFDW, community production; abundance/taxon		cluster (normal & inverse) analysis use similarity matrices, CDA (degree of separation among groups of vars)	cluster (normal & inverse) analysis use similarity matrices, CDA (degree of separation among groups of vars)	cluster (normal & inverse) analysis use similarity matrices, CDA (degree of separation among groups of vars)
Correlation w/ Other Parameters							
	Analyses of how sedimentology predicts benthic patterns	analysis of white/brown shrimp abundance, gut contents, gut fullness, stage of sexual maturity, & condition vs. measured biotic/abiotic factors; also macro/meiofaunal abundance vs. biotic/abiotic factors			CDA for correlation between infaunal assemblage distribution and sediment composition	CDA for correlation between infaunal assemblage distribution and sediment composition	CDA for correlation between infaunal assemblage distribution and sediment composition
	Analyses of how benthos varies b/w habitats		macrobenthic production by strata; taxonomic composition of production by strata				
	Analyses of how benthos varies on a finer scale						

	CATEGORY	15. Maryland/Delaware	17. New Jersey	18. Alabama	20. Virginia	22. Tiger, Trinity, Ship Shoal, LA
Sampling Methods						
	Collection Method					
	Surface area covered	Grab (Young)	Grab (Smith-McIntyre)	Grab (Smith-McIntyre)	Grab (Smith-McIntyre)	Core (Gomex Box)
	Depth of sed. penetration	$0.044m^2$	5cm dia subsample grain size	5cm dia subsample grain size	top mm sediment formanifera/ostracoda	25*25*50cm; 1 additional (to meio. subsamples) subscore/site @ 5-10mm intervals
	Sieve mesh size					
	Temporal freq. of sampling	0.5mm	0.5mm, size class: 0.3, 0.5, 0.6, 1, & 2mm	0.5mm, size class: 0.3, 0.5, 0.6, 1, & 2mm	0.5mm, second prod: 6.3, 3.35, 2, 1, & 0.5mm	0.5mm
	SPI/other, penetration depths	May & June	May & Sept	May & Dec	Spring/Fall	
Target Fauna		Macrofauna	Macrofauna	Macrofauna	Meio/Macrofauna & Formanifera/Ostracoda	Meio/Macrofauna
				Meiofaunal subcores, 10cm dia to 10-15cm	2 Meiofaunal subcores, 2.6cm dia to 4cm	
Sampling Design						
	randomly seleced locations within lattice pattern on and off shoal; SPI @ all stations	8 shoals with 2-11 sites per shoal and 3 offshoal sites	5 shoals with 16 sites on shoal and 4 offshoal sites	high density grid on Sandbridge Shoal, less dense grid adjacent to shoal	3 shoals, with 16 sites on shoal and 8 offshoal	9 shoals with 3-13 grabs per shoal, plus 7 offshoal sites
Benthic Analysis Methods						
	biomass & density to m^2	density to m^2	density to m^2	density, biomass to m^2	density	density to m^2
	Computation of total density of meiofauna					density
	Computation of macro-benthic density &/or biomass by taxon, & level	biomass & density ID to major taxon, usually spp	density ID to major taxon, usually spp	density ID to major taxon, usually spp	density & biomass ID to major taxon	density ID to major taxon, except copepods to spp

	CATEGORY	15. Maryland/Delaware	17. New Jersey	18. Alabama	20. Virginia	22. Tiger, Trinity, Ship Shoal, LA
	Computation of meiofaunal density &/or biomass (which?) by taxon, & level					density ID to major taxon, except copepods to spp
Community Analysis						
	Separate computation/ analyses of benthic taxa known to be prey					stable isotope analyses for shrimp on vs. off-shoal
	Community indices computed	Primer: H', J', D, sed grain size	H', J', D, sed grain size	H', J', D, sed grain size	D, abundance, sed grain size	Macro: Primer: D, H', J'; sed grain size; Gut content shrimp proventriculi
	Community composition analyses (cluster, etc)	Primer: SI (Dominance), cluster analysis use similarity matrices, constancy (assoc of spp with station), fidelity (degree spp prefer stations); secondary productivity	cluster (normal & inverse) analysis use similarity matrices, CDA (degree of separation among groups of vars)	cluster (normal & inverse) analysis use similarity matrices, CDA (degree of separation among groups of vars)	secondary productivity, AFDW	Primer ANOSIM comparison of on/off shoal
Correlation w/ Other Parameters						
	Analyses of how sedimentology predicts benthic patterns					stable isotope analyses for shrimp on vs. off-shoal
	Analyses of how benthos varies b/w habitats	Primer: H', J', D, sed grain size	H', J', D, sed grain size	H', J', D, sed grain size	D, abundance, sed grain size	Macro: Primer: D, H', J'; sed grain size; Gut content shrimp proventriculi
	Analyses of how benthos varies on a finer scale	Primer: SI (Dominance), cluster analysis use similarity matrices, constancy (assoc of spp with station), fidelity (degree spp prefer stations); secondary productivity	cluster (normal & inverse) analysis use similarity matrices, CDA (degree of separation among groups of vars)	cluster (normal & inverse) analysis use similarity matrices, CDA (degree of separation among groups of vars)	secondary productivity, AFDW	Primer ANOSIM comparison of on/off shoal

Appendix B: Evaluation Summary of Site-Specific Studies Methods: Biological Processes - FISH

	CATEGORY	1. Protocols Report	2. NE Florida	3. West Florida	4. Ship Shoal Utilization of Benthos by Fish USGS	7. (Benthic Polychaetes) Heald/Sabine Banks USGS	7. Fish Communities Heald/Sabine Banks USGS
Fish							
Fish & Other Demersal Nekton Sampling Methods							
	Sampling gear	3/4 #36 otter trawl, 1.3cm mesh, 3.5kts	7.6m otter trawl, 2.5cm mesh, 10 min tows, 2kts. 1m dia ithyoplankton net, 0.05mm mesh, 5min @ 3m below surf, 5 min @ 6m b.s., 2kts at night	7.6m otter trawl, 2.5cm mesh, 10 min tows, 2.5kts. 1m dia plankton net, 0.05mm mesh, 5min @ 3m below surf, 5 min @ 6m b.s., 2.5kts. 1m wide neuston net, 0.3m deep, 0.5mm mesh, 2.5kts, 10 min tows at night	6m otter trawl, 2cm mesh, 10 min tows. Woods Hole epibenthic sled (1m wide by 30cm high). Phyto/Zooplankton double 0.5-m diam ring net. Plankton tows <1-m @ surface & bottom		6m otter trawl, 2 cm mesh, 15 min tows at 2-2.5 kts, angling for larger species
	Target fish fauna	demersal fish	demersal & drifting water column spp	demersal, drifting water column, & neuston spp	demersal, nekton, & drifting water column spp		demersal & non-pelagic fish spp
	Temporal freq. of sampling	Prior & 1, 3, 5, 7 years post dredge (same season, pref summer)	Oct, Nov, & June	Fall/Spring	2004-2006, all seasons		Summer/Winter
	Large-scale spatial discrimination of sampling	defined, multiple strata types present in both dredged & control areas (3 day/3 night trawls per stratum)	2 shoals, 3 trawls on shoals and 3 trawls adjacent to shoal	3 trawls on 1 shoal, 3 adjacent to shoal	demersals: specific dredged vs/ undisturbed areas of shoal; plankton: water column on/off bank		13 trawls on bank, 10 on bank edge, 11 off bank; 33 CTDs
	Finer-scale spatial discrimination sampling	sand ridges, offshore ridge slope, ridge crest, nearshore ridge slope, & swale bottom					
	Fish collection for gut contents	Gut content analysis for numerically dominant/recreationally important species; processed immediately	Gut content analysis	Gut content analysis	Gut content analysis on same specimens as isotope analysis		

	CATEGORY	1. Protocols Report	2. NE Florida	3. West Florida	4. Ship Shoal Utilization of Benthos by Fish USGS	7. (Benthic Polychaetes) Heald/Sabine Banks USGS	7. Fish Communities Heald/Sabine Banks USGS
Fish Stats/Analysis							
	Taxonomic discrimination level for prey in fish guts	ID prey to lowest taxon		ID prey to spp	ID prey to spp		no gut analysis; ID catch to spp
	Community indices computed	#indiv/taxon (prey), density, biomass/m^2, IRI, volume, % fullness, data by trawl per stratum	#indiv/taxon (prey)	IRI analysis on gut contents, %fullness, abundance, digestion index, dominant prey, H'	IRI analysis on gut contents		abundance, D
	Isotopic analyses of fish & their prey & what contrasts	stable isotope for C & N in each stratum			stable isotope C, N, & S for trophic level on/off shoal & dredged/un for demersals; trophic level on sand bank for nekton; samples from plankton & seds also analyzed		
	Fish community composition patterns & what contrasts				ontogenic changes in diet for selected taxa by shifts in IRI w/ predator size		
Phy/Bio Analysis							
	Analyses of how benthic communities/subsets of benthos of high use by fish vary as a function of relative topography						

	CATEGORY	9. Ship Shoal, LA	10. VIMS Test of Protocols	11. Mid-Atlantic Bight Versar	12. New York/New Jersey	13. East Florida	14. North Carolina
Fish & Other Demersal Nekton Sampling Methods							
	Sampling gear	6.1m net @ 1.5 knots, 30 min tows; angling for larger species	4.9m otter trawl, 2.5cm mesh, 0.5cm mesh liner, 10 min tows	Larger, mobile spp: 30.5m x 3m, var. mesh gillnet, 15cm tapering to 5cm. Large net spp: 16.5m wooden stern. 3-3.5kts Smaller spp: 7.6m semi-balloon otter trawl, 4cm mesh, 1.5-2kts 10 min tows except gillnet for 4hrs. Bioacoustics over the eight transects	7.6m mongoose trawl, 10m tows, 1-2 trawls per shoal, manually assigned to cross isobaths	7.6m mongoose trawl, 10m tows	7.6m mongoose trawl, 10m tows
	Target fish fauna	demersal fish	demersal fish	demersal & nekton species	demersal species	demersal species	demersal species
	Temporal freq. of sampling	Spring: 1mo prior, 1 mo & 6 mo post mining	Spring: 6mo prior, 4, 6, & 18mo post dredge	Fall	Sept & June	Sept & May	May & Sept
	Large-scale spatial discrimination of sampling	4 trawls in association with cross, 3 trawls in each sand mining area (undredged/dredged)		randomized paired design: 4 sand shoals & 4 reference sites (non-shoal), with 1 trawl & 1 replicate per site.	4 shoals with 6 trawls between the 4 shoals/survey	9 shoals with 2 trawls per shoal, N-S on the eastern and western portion of each shoal	1-2 trawls on each of 4 shoals
	Finer-scale spatial discrimination sampling		stratified random design with 4 strata: E and W of shoal, dredged area, and not dredged shoal area				
	Fish collection for gut contents	Gut content analysis for croaker & spotted seatrout; saltwater ice slurry, process at sea or frozen	Gut content analysis				
Fish Stats/Analysis							
	Taxonomic discrimination level for prey in fish guts	ID catch & prey to lowest taxon	ID prey to major taxa/life-history groups	no gut analysis; ID catch to lowest taxon	no gut analysis; ID catch to lowest practical level	no gut analysis; ID catch to lowest practical level	no gut analysis; ID catch to lowest practical level
	Community indices computed	prey: % cover per taxon, % occurrence, % abundance, prey weight	abundance, density to m^2	abundance, CPUE, D, H'	abundance, D	abundance, D, group average cluster analysis to cluster Bray-Curtis similarity index	abundance, D

	CATEGORY	9. Ship Shoal, LA	10. VIMS Test of Protocols	11. Mid-Atlantic Bight Versar	12. New York/New Jersey	13. East Florida	14. North Carolina
	Isotopic analyses of fish & their prey & what contrasts		stable isotope analysis for C & N by spp & strata				
	Fish community composition patterns & what contrasts	ANOVA croaker gut with shrimp gut contents	cluster analyses of fishes/strata	(shoal vs. ref) ANOVA , meta analysis (guild), PRIMER Multivar, MDS, ANOSIM.			
Phy/Bio Analysis							
	Analyses of how benthic communities/subsets of benthos of high use by fish vary as a function of relative topography						

	CATEGORY	15. Maryland/Delaware	17. New Jersey	18. Alabama	20. Virginia	22. Tiger, Trinity, Ship Shoal, LA
Fish & Other Demersal Nekton Sampling Methods						
	Sampling gear	2.4m beam trawl, at each location, 4 trawls each were conducted at day and night, meter wheel used to measure area trawled	7.6m mongoose trawl, 10m tows	7.6m mongoose trawl, 10m tows		30min trawl using SEAMAP protocols, DIDSON fish acoustics
	Target fish fauna	demersal species	demersal species	demersal species		demersal & nekton species
	Temporal freq. of sampling	June	May & September	May & December		Spring/Fall
	Large-scale spatial discrimination of sampling	4 locations on Fenwick Shoal at transects picked from video to represent sandy/gravel/shell habs vs. tube field habs	7 shoals with one trawl per shoal	5 shoals with 2 trawls per shoal, on north and south sides		3 shoals with 16 trawls on shoal and 8 offshoal, night and dusk trawls
	Finer-scale spatial discrimination sampling					
	Fish collection for gut contents	Gut content analysis for 3 dominant fish species				Gut content analysis on croaker
Fish Stats/Analysis						
	Taxonomic discrimination level for prey in fish guts	ID prey to lowest practical level, usually spp	no gut analysis; ID catch to lowest practical taxon	no gut analysis; ID catch to lowest practical taxon		ID prey to spp
	Community indices computed	abundance, biomass by major taxa of prey, cluster analysis of sand vs. tube habs (assoc of fish & habs)	abundance, D	abundance, D		D, CPUE
	Isotopic analyses of fish & their prey & what contrasts					stable isotope analyses on vs. off-shoal
	Fish community composition patterns & what contrasts		normal & inverse cluster analysis	normal & inverse cluster analysis		
Phy/Bio Analysis						
	Analyses of how benthic communities/subsets of benthos of high use by fish vary as a function of relative topography					

APPENDIX C

EQUIPMENT AND METHODS FOR DREDGING OFFSHORE SAND DEPOSIT

EQUIPMENT AND METHODS FOR DREDGING OFFSHORE SAND DEPOSITS

REPORT

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EQUIPMENT AND METHODS FOR DREDGING OFFSHORE SAND DEPOSITS

Background

Site-specific studies (Table 1) were reviewed to determine the effect of dredging methods on the benthic environment. The eighteen studies tabulated in Table 1 primarily address benthic biological populations, monitoring protocols, effect of borrow pits on wave climate, and fish populations in the areas of potential borrow pits for sand mining, but these environmental studies do not discuss the impacts of dredging. Drucker et al (2003) discuss the dredging process and characteristics of the borrow pits related to sand mining for the purpose of beach nourishment.

Table 1. Site Specific Environmental Studies

1. Design of a Monitoring Protocol/Plan for Environmentally Sound Management and Development of Federal Offshore Sand Borrow Areas Along the United States East and Gulf of Mexico Coasts (OCS Study 2001-089
2. Biological Characterization/Numerical Wave Model Analysis within Identified Borrow Sites Offshore the Northeast Coast of Florida – SEA NE FL Cruise Plan, Model Grid, Benthic Sorting
3. Biological Characterization/Numerical Wave Model Analysis within Identified Borrow Sites Offshore the West Coast of Florida/Physical Implications of Sand Dredging on the Topography of the West Florida Shelf - SEA West FL Cruise Plan, Model Grid, Benthic Sorting, and other documents
4. Utilization of Benthic Communities by Fish Populations on Ridge and Shoal Features (Ship Shoal) – USGS Proposal
5. Numerical modeling evaluation of the cumulative physical effects of offshore sand dredging for beach nourishment – MMS 2001-098
6. Wave-Bottom Interaction and Bottom Boundary Layer Dynamics in Evaluating Sand Mining at Sabine Bank for Coastal Restoration, Southwest Louisiana – Stone Sabine Bank Technical Proposal
7. Investigation of Finfish Assemblages and Benthic Communities within Potential Borrow Areas Inside Federal Waters Offshore SE Texas and Southwest Louisiana – USGS Work Plan, Benthic Polychaete Assemblage Plan, Cruise Report
8. Ship Shoal, Louisiana: Sand, Shrimp, and Seatrout Investigation – Condrey Study Plan
9. Environmental Investigation of the Long-Term Use of Ship Shoal Sand Resources for Large-Scale Beach and Coastal Restoration in Louisiana (Cooperative Agreement with Louisiana State University) – Stone Proposal and First Report
10. Field Testing of a Physical/ Biological Monitoring Methodology for Offshore Dredging and Mining Operations – VIMS March 2006 Report, RPI Team Comments, and VIMS Response to RPI Comments
11. Comparisons Between Marine Communities Residing on Sand Shoals and Uniform-Bottom Substrate in the Mid-Atlantic Bight - OCS Study MMS 2005-042
12. Environmental Surveys of Potential Borrow Areas Offshore Northern New Jersey and Southern New York and the Environmental Implications of Sand Removal for Coastal and Beach Restoration. OCS Study MMS 2004-044
13. Environmental Surveys of Potential Borrow Areas on the East Florida Shelf and the Environmental Implications of Sand Removal for Coastal and Beach Restoration. OCS Study MMS 2004-037
14. Collection of Environmental Data within Sand Resource Areas Offshore North Carolina and the Environmental Implications of Sand Removal for Coastal and Beach Restoration. OCS Study MMS 2000-056
15. Surveys of Sand Resource Areas Offshore Maryland/Delaware and the Environmental Implications of Sand Removal for Beach Restoration Projects. OCS Study MMS 2000-055
16. Wave Climate and Bottom Boundary Layer Dynamics with Implications for Offshore Sand Mining and Barrier Island Replenishment, South-Central Louisiana. OCS Study 2000-053
17. Environmental Surveys of OCS Sand Resources Offshore New Jersey. OCS Study MMS 2000-052
18. Environmental Survey of Identified Sand Resource Areas Offshore Alabama. OCS Study MMS 99-0051

A review of dredging equipment for excavating offshore sand deposits was conducted by Baird (2004). This study indicated the trailing suction hopper dredge is the most likely equipment to be used for dredging offshore sand deposits and is the most environmentally friendly for the marine environment. Self propelled cutter suction pipeline dredges are another type of dredging equipment that can be employed for offshore sand mining. Twelve key impacts (Table 2) due to dredging of offshore sand deposits have been identified (Newell and Seiderer 2003) and described in Baird (2004). Impacts 1, 3, 5, and 7 were addressed by Baird (2004), and the other impacts are considered insignificant or are being addressed in other studies. Recommendations from Baird (2004) include refuge areas to enhance reestablishment of benthic communities, buffer zones and monitoring for protecting sensitive habitat from sedimentation, the impact of turbidity is relatively insignificant and anti-turbidity devices are being used by trailing suction hopper dredges, and maximum pit depths should be established on a site-specific basis using analytical tools and monitoring.

Table 2. *Key Impact Concerns for Dredging Offshore Sand Deposits (Baird 2004)*

1	Short-term and cumulative impacts from dredge that lead to loss of entire benthic communities and possible re-colonization by an altered biological community
2	Impact to turtles
3	Changes in the substrate characteristics that lead to a reduction of benthic communities and suitability of the area for future dredging
4	Shoreline impacts through changes to wave climate
5	Sedimentation impacts of adjacent hard/live bottom or other sensitive habitats
6	Creation of furrows and depressions
7	Impacts from short-term increased turbidity from cutterhead or draghead and overflow from hopper dredges on benthic communities
8	Spatial and seasonal conflicts with recreational and commercial fishermen
9	Potential damage to pipelines
10	Collision with marine mammals
11	Damage to archeological resources
12	Potential harmful alteration or destruction of essential fish habitat

Objective

The objective of this report is to discuss methods and equipment for dredging of offshore sand deposits that are expected to be used for future beach nourishment projects.

Dredging Equipment

Trailing Suction Hopper Dredges

The offshore sand deposits that are being considered for sources of sand for beach nourishment projects for beaches along the US coastline are typically 10 to 20 nautical miles offshore in water depths of 9.1 to 30.5 meters (m). The trailing suction hopper dredge is one type of dredging equipment that is considered suitable for dredging sand deposits in these offshore shoal areas. These dredges have powerful dredge pumps that create a low pressure in the pump that allows the near bottom water and associated sand to enter the draghead and be placed in the large hopper in the dredge. Once the hopper is full the hopper dredge raises the two dragarms out of the water and sails to the beach placement area. The sand in the hopper is typically pumped through a submerged pipeline to the beach. Once the hopper is empty, it returns the sand deposit area and excavates another hopper load. Randall and Koo (2004) describe some of the various equipment combinations used to deliver sand to the beach along the Texas coast. Figure 1 shows the Vasco de Gama trailing suction hopper dredge operated by the company Jen de Nul, with a hopper capacity of 33,000 m^3. The draghead for the Vasco de Gama is approximately 10 m wide.

Figure 1. Jen de Nul's Vasco de Gamma (left) and Typical Draghead (right) (Courtesy of Jen de Nul)

The Manson "Bayport" and the Great Lakes Dredge and Dock "Liberty Island" hopper dredges (Fig.2) have a much smaller hopper capacity of 3,823 and 5,000 m^3, respectively. The sailing speeds for hopper dredges are typically 10-16 knots. These dredges are capable of emptying the hoppers through bottom opening doors, pump-out through pipelines, or rainbowing through a jet nozzle on the bow.

Figure 2. Manson's Bayport Hopper Dredge (left) and Great Lakes Hopper Dredge Liberty Island (right) (Courtesy of Manson Construction and Great Lakes Dredge & Dock)

Self Propelled Cutter Suction Dredges

Several self-propelled cutter suction dredges are available in the world market, but none exist in the US to date. These dredges can sail under their own power (~12 knots) and have similar sea worthy capabilities as the trailing suction hopper dredge. These dredges are relatively new and the JFJ de Nul is shown in Figure 3. These dredges advance (move forward) using a spud carriage arrangement. When dredging, the spuds are located at the bow of the vessel and the cutter is located at the stern. The cutter is mounted on the ladder and lowered to the seafloor for excavating. The current maximum water depth is 35 m. The excavated slurry of sand and water is drawn into the dredge pumps and pumped through a pipeline to a barge or placement area. Self-propelled split hull barges can be used to transport the slurry to the beach area depending on water depth and barge draft. Turbidity generation of cutter suction dredges is relatively low. These dredges can work in similar wave conditions as the trailing suction hopper dredge.

Figure 3. Self Propelled Cutter Suction Dredge JFJ de Nul (Courtesy of Jen de Nul)

The more common conventional cutter suction pipeline dredges have no propulsion and are moved to the dredging site by push boats or tugs. The Great Lakes Dredge and Dock dredge, "California", and a typical cutter head used for hard material are shown in Figure 4. These dredges can only work in wave heights up to 1 m and must be mobilized to sheltered water in case of severe storms. The dredged sand can be pumped through a pipeline or to barges for transport to the beach area. The length of the pipeline to the beach may be on the order of 32 to 64 kilometers of pipeline for offshore sand borrow sites so the use of a pipeline discharge to the beach is unlikely.

Figure 4. Great Lakes Cutter Suction Dredge California (left) and CutterHead (right) (Courtesy of Great Lakes Dredge & Dock)

Dredging Methods

The three primary methods of dredging sand from offshore borrow sites for beach nourishment are the use of a trailing suction hopper dredge, conventional cutter suction pipeline dredge, or a self-propelled cutter suction dredge. Eight different operational scenarios are summarized in Table 3. These options include the number of dragheads used, hopper capacity, use of anti-turbidity valve, and different ways of empting the hopper. Techniques for minimizing turtle intake include draghead turtle exclusion devices, trawling for turtles ahead of hopper dredge, stopping pumps when dragheads are not in contact with the bottom, and the use of environmental windows. Most hopper dredges in the US have hopper capacities between 3,823 and 7,646 m^3. Many European hopper dredges have capacities of 15, 292 to 30,584 m^3, and these large jumbo hopper dredges are currently being used in large reclamation projects around the world. The larger capacity hoppers facilitate a reduction in the number of trips. Most modern hopper dredges have and use anti turbidity valves to reduce the turbidity resulting from overflow. Overflow is used to economically load the hopper with sand and the procedure for estimating the economic time of overflow is illustrated in Figure 5. The sand water slurry is continually pumped into the hopper and the excess water containing fines (e.g. silts and clays) is allowed to overflow back to the ocean through the anti turbidity valve located near the keel of the hopper. Hopper dredges can empty the hopper using a pump-out technique or through bottom opening doors. For beach nourishment projects, the hopper commonly sails to a station near the beach that is in deep enough water (8-10 m) and connects to a submerged pipeline and subsequently pumps the contents of the hopper to the beach through a submerged pipeline. If the hopper can get within approximately 60 m of the beach, then it can pump the slurry through a nozzle (rainbowing) located on the bow to the beach. It is unlikely this approach can be used for US beaches due to depth limitations offshore of the beach. Empting the hopper through the bottom doors is another possibility, but another dredge is needed to rehandle the sand and pump it to the beach.

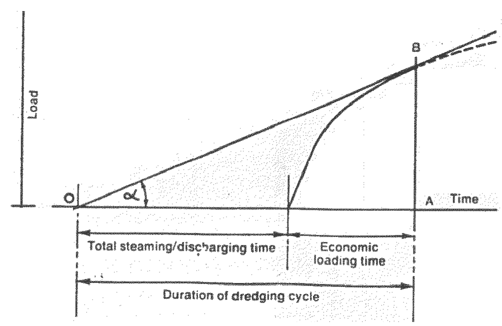

Figure 5. Schematic of Estimating Optimum Overflow Duration for Trailing Suction Hopper Dredge.

Table 3. Tabular Summary of Trailing Suction Hopper Dredge Techniques

Scenario	Number of Dragheads	Dredge Pumps (Main pump and ladder pump)	Hopper Capacity (cubic yards)	Overflow with Anti turbidity Valve	Hopper Empting Procedure
1	2	2	6,500	Yes	Pump to submerged pipeline
2	2	2	6,500	No	Pump to submerged pipeline
3	1	2	6,500	Yes	Pump to submerged pipeline
4	1	2	6,500	No	Pump to submerged pipeline
5	2	2	6,500	Yes	Rainbow
6	2	2	30,000	Yes	Pump to submerged pipeline
7	2	2	30,000	No	Pump to submerged pipeline
8	2	2	6,500	Yes	Bottom dump and redredge with a cutter suction dredge and pump to beach

Some discussions of dredging offshore sand deposits suggest that strip dredging might enhance the recovery of the benthic environment. In this case it is possible to use one or two dragheads for the excavation. Using a single dragarm takes longer to fill the hopper, but this might aid in obtaining an economic load and reduce the amount of overflow. The increased time to fill the hopper using one dragarm will increase the cost to dredging.

The current maximum hopper capacity of US hopper dredges is 11,000 cy (Stuyvesant Hopper Dredge). US hopper dredge capacities are considered economic for maintenance dredging and where the distances to the dredged material placement sites are relatively short (e.g. 3-5 nautical miles). If US dredging companies saw a market for long distance sailing routes for beach nourishment, then investment in larger capacity hopper dredges (20,000 – 40,000 cy) would be a good investment. It also may not be possible to use non-US dredges depending on the location of the borrow areas and the implications of the Jones Act.

Another possibility is to use hopper dredges and not allow overflow. Disabling the overflow reduces the amount of sand in the hopper for each load. This eliminates the discharge of fines into the water column. It also increases the time of dredging and costs.

The self-propelled cutter suction dredge is another possibility for excavating the sand borrow pits. These dredges have their own propulsion and can operate in open water similar to the hopper dredge (Table 4). Cutter suction dredges can pump the sand-water slurry through a pipeline or to split hull hopper barges. The long distances from the borrow areas to the beach (32-64 kilometers) make it unlikely that this procedure would be viable for use at offshore borrow areas. However, the use of split hull hopper barges makes it possible to transport the sand to the beach area and empty the barges in relatively shallow water in front of the beach. Overflow of the hopper barges creates a sediment plume similar to the case for overflowing the hopper dredge in order to economically fill the barges with sand. In some cases, the overflow is not allowed in order to eliminate the sediment plume. This increases the amount of time and the cost of dredging.

Table 4. Tabular Summary of Self Propelled Cutter Suction Dredge Techniques

Scenario	Dredge Pumps	Cutter Discharge Pipe Size (inches)	Discharge to Split Hull Hopper	Hopper Overflow Permitted	Hopper Empting Procedure
1	2	32	Yes	Yes	Bottom placement
2	2	32	Yes	No	Bottom placement
3	2	32	Yes	Yes	Hydraulically unload to submerged pipeline
4	2	32	Yes	No	Hydraulically unload to submerged pipeline

Example Sand Borrow Site Area

A sand borrow site dredging area of 184 by 1829 m might be considered as an example dredging area size. If one million cubic yards of in-situ sand needed to be dredged from this area, then the dredge must dig a depth of 2.1 m. If a 5000 m^3 (6,500 cy) hopper dredge that has a breadth of 18.3 m and uses a 3.05 m draghead is considered for dredging alternate strips in the dredging area, then the total area available for dredging must be increased to dredge the same one million cubic yards or the depth of the pit must be increase. Assuming 9.1 m equal width alternating strips, the area would have to be increased by nearly 100 % assuming the dredged strip is also 9.1 m. One option is to increase the width of the dredging area to 384 m. If the area is kept the same then the depth of the strips being dredged increases to 4.1 m. Perhaps the width of the non-dredged strips can be reduced and the width of the dredged strips increased. More detailed dredging plans need to be investigated to determine the increased time and cost of dredging alternating strips.

Dredging Costs

The cost of dredging depends on many factors, but reasonable estimates indicate the trailing suction hopper dredging may range from 8 to 16 dollars per cubic yard and a conventional cutter suction pipeline dredging may range between 5 and 10 dollars a cubic yard. Self propelled cutter suction dredges are recommended for sand mining projects in areas greater than 2 nautical miles offshore. The cost of using self propelled cutter suction dredges is assumed to be similar to that of a hopper dredge. Efforts to reduce the dredging effects on the benthic environment and turtles increases the cost of dredging due to the increased time to conduct the dredging and/or the reduction in production due to turtle excluding devices and procedures to minimize the impact on the benthic environment.

Estimates of the increased time and costs are illustrated in Table 5. Procedures for reducing the impacts on the benthic environment include creating alternate strips of dredged area and non-dredged area, using one dragarm instead of two dragarms, creating alternate areas of dredged and non-dredged areas, creating buffer areas near hard bottom areas, using overflow or no-overflow, possibly redredging overburden material and placing the material in the pit to create the same substrate as before dredging, and considering reseeding the borrow pit with similar benthic organisms to accelerate the recolonization. A time and cost increase of 35% is used for not allowing overflow due to the reduction of sand in the hopper. Under normal circumstances, an increase in dredging time is the same as the increase in cost. Using alternate areas and creating buffer areas are not believed to increase the time and cost of dredging. The use of alternate strips with overflow is estimated to increase the time and cost by 10 %. It is assumed the dredging area is increased to allow for dredging of the same volume of sand. The possibility of seeding the borrow area after the sand has been removed requires a hopper dredge to load and pump the seed material to the bottom and this is estimated to increase time and cost by 25%. A similar increase in time and cost is estimated for placing overburden dredged material in the borrow pit. The use of a cutter suction dredge to fill hopper barges with no overflow is estimated to increase cost by 35% because of the reduced amount of sand in the barge. There also must be sufficient barges to allow continuous operation of the cutter suction dredge. It is also anticipated the addition of devices for minimizing turtle take would increase time and cost by 10%.

Table 5. Estimate Increase in time and cost of dredging for various procedures to reduce impact on benthic organisms.

Procedure to reduce benthic effects	Dredge Type	Estimated cost increase factor	Comments
Alternate areas	Hopper (2 dragarms)	1	Area should be 184 by 1829 m (220 by 2000 yd) and the long dimension should be aligned with prevailing environmental forces.
Create buffer area near hard bottoms	Hopper (2 dragarms)	1	The amount of sand beneath buffer areas could affect available volume of sand.
Use anti turbidity valve	Hopper (2 dragarms)	1	Most modern hopper dredges have anti-turbidity valves
Overflow	Hopper (2 dragarms)	1	Most efficient operation
No Overflow	Hopper (2 dragarms)	1.35	No overflow reduces economic load and increases the number of trips to carry the same amount sand. For long sail times to/from the dredging site, no overflow greatly reduces to the amount of sand in the hopper per trip.
Alternate strips of dredging and non dredging with overflow	Hopper (2 dragarms)	1.1	If the dredging area were increased such that the same amount of sand could be dredged while leaving the undredged strip, then there would be a much smaller increase in time and cost.
Alternate strips of dredging and non dredging with overflow	Hopper (1 dragarm)	1.35	The number of passes over the dredging area would be doubled. The slower slurry inflow to the hopper is expected to reduce the time of overflow.
Alternate strips of dredging and non dredging with No overflow	Hopper (2 dragarms)	1.45	If the dredging area were increased such that the same amount of sand could be dredged while leaving the undredged strip, then there would be a much smaller increase in time and cost.
Alternate strips of dredging and non dredging with NO overflow	Hopper (1 dragarm)	1.45	The number of passes over the dredging area would be doubled. No overflow further increases the number of trips
Seed dredged area with benthic organisms	Hopper	1.25	Time for loading and pumping the seed material into the borrow pit
Place overburden dredge material back in borrow pit after removing sand.	Hopper	1.25	Redredging the overburden material and placing the material back in the borrow area increases time and costs.
Use cutter suction dredge with split hull hopper barges with overflow	Self Propelled Cutter Suction	1	Sufficient barges are needed to allow the dredge to operate continuously.
Use cutter suction dredge with split hull hopper barges with NO overflow	Self Propelled Cutter Suction	1.35	Sufficient barges are needed to allow the dredge to operate continuously. No overflow of barges causes increased time and cost.

Note: The use of turtle excluding devices and procedures are expected to reduce dredge production and increase the time and cost required to complete the dredging operation by as much as 10%.

Conclusions and Recommendations

The trailing suction hopper dredge is expected to be the most economical dredging technique using a submerged pipeline connection within 1.6 kilometer (1 mile) of the beach to pump the sand to the beach. Several options can be used to reduce the effects on the benthic environment. No overflow would prevent the sediment plume from the hopper, but this would increase time and cost of dredging by an estimated 35% due to the reduced volume of sand loaded in the hopper. Incorporating strips or alternate areas of dredged area and non-dredged area is another approach to reducing benthic effects and accelerating recolonization. Alternate strips are estimated to increase the time and cost by about 10%, but alternate areas is not estimated to increase time or costs as long as over flow is permitted. It is recommended that the concept of returning overburden sediments to the dredged area and subsequently seeding the area with similar benthic organisms before dredging be investigated. An estimated increase in time and cost of 25% is expected due to the additional activity of placing the material after the sand has been dredged from the borrow area. An area of 184 by 1,829 m is estimated to yield one million cubic yards of sand if the pit is 2.1 m deep. The use of 9.1m alternate strips would result in the depth of the dredged strips being 4.1 m.

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