Using Historical Data and Meta-analyses to Improve Monitoring and Management of Beach Nourishment in South Carolina

Final Report

Prepared by:

Derk C. Bergquist

Stacie E. Crowe

South Carolina Department of Natural Resources
Marine Resources Research Institute
217 Fort Johnson Road
Post Office Box 12559
Charleston, SC 29412

Submitted to:

South Carolina Department of Health and Environmental Control
Office of Ocean and Coastal Resource Management
1362 McMillan Avenue, Suite 400
Charleston, SC 29405

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EXECUTIVE SUMMARY

Beach nourishment has become the primary tool for combating beach erosion in the southeast US, but the costs of nourishment practices to the sustainability of the physical and biological resources of nourished beach and dredged subtidal ecosystems remain largely unresolved. A large number of studies have been performed to address the impact of dredging and nourishment, but few studies have documented general patterns of environmental response to these impacts. The inability to draw broad conclusions stems from a number of factors including: 1) statistical problems resulting from the nature of the impact being studied, 2) lack of specified goals and data needs for evaluating the impacts of these practices, and 3) inconsistent and/or inappropriate study designs and data collection methodology. The goal of the current study was to begin the process of centralizing and quantitatively synthesizing data from beach nourishment monitoring studies by focusing on only those projects performed in South Carolina. Specifically, the objectives were to: 1) assemble a central library of beach nourishment environmental impact assessments performed in South Carolina, 2) create a digital database of beach nourishment environmental impact assessment results, 3) use meta-analyses to address beach nourishment environmental impacts, 4) synthesize study results into recommendations to improve beach monitoring and management as they relate to nourishment in South Carolina.

Forty-five projects that involved either placing sand on a beach or moving sand within the beach system for purposes of countering erosion were identified. Of these, 25 projects involved placement of new material into the littoral sand budget from a nearshore subtidal sand source (a borrow area) and were the focus of this study. Reports containing environmental monitoring data were identified for sixteen individual projects but data useable in the meta-analysis were available for only nine of those projects. Almost all monitoring studies performed in South Carolina have employed a Before-After-Control-Impact study design, but few have statistically analyzed the data in such a way as to maximize the power and interpretability of that study design. As a whole, past studies suffer from a lack of consistency in collection methodology, parameters measured, and reporting of many ecologically-important project characteristics (dredge depth, change in beach slope, etc.).

Application of meta-analysis to the monitoring data identified several consistent and significant environmental impacts of dredging and nourishment during the 12-15 months following completion of the activities (the time frame during which most monitoring data has been collected). In beach environments, sediments did not tend to change substantially following nourishment, but a slight tendency toward courser material was noticeable. The numbers of invertebrate species occupying beach sediments decreased and the taxonomic composition of the invertebrate community changed following nourishment, but no changes were observed in overall invertebrate density. These results suggest that beaches are rapidly recolonized after the placement of beach fill but that the composition of that community may be quite different from that present pre-nourishment. Borrow areas consistently refilled with sediments that were much finer and organically rich than those that were removed. This tendency to accumulate fines may prevent reuse of these areas for future nourishment projects, thus requiring dredging of previously unimpacted areas of seafloor increasingly farther from shore. The biological community responded to dredging through a significant decrease in the number of species and a shift towards dominance by polychaetes. This likely reflects the strong change in sediment composition and flow regime that occurs in the dredge pits and recolonization by disturbance-tolerant taxa adapted to these conditions.

Practically every parameter examined in this study identified a highly significant amount of variability among the responses of different beaches to nourishment and borrow areas to dredging. This suggested that all of these parameters were capable of discriminating amongst

projects of different characteristics, and that environmental setting, timing and/or project design characteristics could make a large difference in the impact of any given dredging and nourishment project. Due to small sample sizes, inconsistent monitoring study design and incomplete reporting of project characteristics, determining the causes of these differences was generally problematic, but a few comparisons were possible. The season during which nourishment or dredging occurred primarily affected biological responses of the impacted systems. These changes likely reflect a combination of interference with local recruitment and favoring of the recolonization and survival of disturbance-tolerant species. Borrow areas located downdrift of tidal inlets or within inlets or tidal rivers/creeks accumulated larger amounts of fine sediments and organic material than those borrow areas not located further from sources of estuarine influence. Future borrow areas should either be located outside of estuarine sediment plumes or dredged shallow enough to prevent the accumulation if fine sediments.

General patterns in the response of beach systems to nourishment and subtidal benthic systems to dredging were detected. The meta-analysis approach was capable of identifying both broad classes of environmental impacts (fine sediment accumulation, decreased numbers of species, etc.) from these disturbances and of discriminating among dredge/nourishment projects of different characteristics (such as season and location). This approach could prove very useful in investigating the impacts of many other human activities in coastal systems. Recommendations to improve monitoring study design, sample collection, data analysis and report writing are proposed based on several published sources and data presented here. Additional recommendations are made to fill gaps in our understanding of the impacts of nearshore dredging and beach nourishment.

BACKGROUND

Beach nourishment has become the primary tool for combating beach erosion in the southeast US and much of the world, and the incidence of nourishment projects has increased substantially over the past 20 years (Valverde et al., 1999; Hanson, 2003; Finkl et al., 2006). The nourishment process involves the removal of presumably beach-compatible sediment from a "borrow" area (in South Carolina, typically by dredging a nearshore subtidal shoal) followed by the placement of that material onto a beach (NRC, 1995). Due to the large scale of these projects, the costs are high and the environmental impacts are potentially widespread. While sometimes controversial, the financial costs of nourishment generally are thought to be offset by the protection of coastal infrastructure, the cost of nourishment relative to other management alternatives, and the maintenance of the multi-billion dollar beach tourism industry (Stronge, 1995; Leatherman et al, 2001; Wakefield and Parsons, 2003; Houston, 2008). However, the costs of nourishment practices to the sustainability of the physical and biological resources of impacted beach and subtidal ecosystems remain largely unresolved.

Nourishment Impacts in Beach and Borrow Systems

Beach systems form the interface between the marine and terrestrial environments and play critical roles in the life cycles of many plants, sea turtles, shorebirds, fish, and invertebrates, including many commercially- and recreationally-important taxa and threatened and endangered species (Feagin et al., 2005; Defeo and McLachlan, 2005; Schlacher et al., 2008). The response of the beach ecosystem to nourishment varies amongst projects. For example, while restoration of the beach provides more habitat for sea turtle nesting, the material placed on the beach may be of such low quality that it is detrimental to nesting (Crain et al., 1995; Dickerson et al., 2006). The responses of surf zone fish communities appear to be behavioral and species specific and driven by the turbidity plume formed by nourishment operations (Wilber et al., 2003). Further, some studies have suggested that dominant intertidal invertebrates of beaches respond negatively to nourishment over time scales of weeks to months (Reilly and Bellis, 1983; Peterson et al., 2000; Bilodeau and Bourgeois, 2004). Other studies have found that these same organisms may recover within a few months following nourishment (Van Dolah et al., 1992, 1994; Jutte et al., 1999; Jones et al., 2008). In many cases, the response of a beach's biological community likely reflects how well the material placed on the beach matches the native sand. Incompatible sediments may negatively affect sea turtle nest success (Dickerson et al., 2006), shorebird feeding (Peterson et al., 2006), and invertebrate burrowing and distributions (McLachlan, 1996; Dugan et al. 2000; Nel et al., 2001). In South Carolina, sediment match has generally been good (Van Dolah et al., 1992, 1994; Bergquist et al., 2008), but poor sediment matches have resulted in degradation of beach and nearshore habitat in other locations (Gorzelany and Nelson, 1987; Rackocinski et al., 1996; Peterson et al., 2000).

Compared to nourished beaches, sediment borrow areas have received far less attention from researchers. These areas vary widely in morphology, water depth, proximity to land, inlets, and rivers, and orientation relative to currents and tides. These sand deposits may play important roles in sediment budgets and local currents and provide habitat for many different fish and invertebrates. Dredging of these deposits necessarily removes surficial sediments, thus the documented changes in sediment characteristics and biological communities in these areas (Van Dolah et al., 1992, 1994; Jutte et al., 1999a, 2000, 2001a,b; Bergquist et al., 2008) is not surprising. As a result, the most relevant management-related issue becomes the rate at which these sites and their associated communities recover. Amongst different borrow areas, recovery

varies widely in terms of the refill rate, the quality of sediment refilling the pit, and the identity, density, and diversity of recolonizing organisms (Van Dolah et al., 1992, 1994; Jutte et al., 1999a, 2000, 2001a,b; Bergquist et al., 2008). Across these studies, the recolonization of borrow pits with communities similar to those present prior to dredging was more common when the sediment characteristics changed very little following dredging. However, several studies have suggested that planning and management decisions could influence recovery rates. Van Dolah et al. (1998) documented that shoals located within or near major tidal inlets at the north ends of barrier island tend to refill with fine material while those located at the south ends of barrier islands tend to refill quickly and with beach compatible material. Jutte et al. (2002) compared the performance of borrow areas excavated by hopper and by hydraulic pipeline dredges and found that benthic communities recovered much more quickly in the area dredged by hopper.

The results of these studies have shown the response of both the borrow area and the beach to be highly variable. This variability potentially arises from a host of factors including differences in indicators and measurements used to monitor impact, methodology used to collect data, geographic locations of projects, timing of dredging and nourishment, sizes of impacted areas, local physical environmental conditions, and local and regional management policies. Clearly, these diverse results must be synthesized and general patterns elucidated before well-informed management decisions and policies are devised.

Environmental Impact Assessments of Beach Nourishment

Environmental impact assessments, along with a relatively small number of directed research projects published in the white literature, have been the primary sources of information regarding the effects of individual nourishment projects on borrow areas and beaches. Despite the large number of studies involving the impact of dredging and nourishment, few studies have documented general patterns of environmental response to these impacts, documentation that is needed to inform future management decisions. This failure results from three primary issues: 1) statistical problems resulting from the nature of the impact being studied, 2) lack of specified goals and data needs for evaluating the impacts of these practices, and 3) inconsistent and/or inappropriate study designs and data collection methodology.

Analysis of the environmental impacts of human activities such as dredging and beach nourishment present numerous statistical problems common to analyses of other large-scale anthropogenic disturbances (Hurlbert ,1984; Stewart-Oaten et al., 1986; Eberhardt and Thomas, 1991; Nelson, 1993; Peterson and Bishop, 2005). Because beach nourishment projects tend to affect one or only a few very large areas of beach, treatment replication often is not possible. Although multiple locations within the borrow area or nourished beach may be monitored, these may be considered pseudoreplicates (Hurlbert, 1984), not replication of a nourishment treatment such as could be accomplished with multiple impacted locations. Also, in a well-designed study, treatments are randomly-assigned amongst potential experimental units (here, beaches or potential borrow areas), however, beaches are never nourished and borrow areas are never dredged randomly in space. Typically, those beaches with the most valuable infrastructure, protective capabilities, or tourism values are the most likely to be nourished, borrow areas are chosen to most closely match beach sediment characteristics, and control locations are chosen to be similar to the impact areas yet far enough away to not be affected by activity at the impact location. Good study design also includes interspersion of treatments, but this is often not possible in nourishment and dredging studies as the impact occurs in a single large area.

Numerous study designs and data analysis procedures have been recommended to provide the “best possible” impact assessment. One of the more commonly employed designs is referred to as Before-After-Control-Impact (BACI) (Green, 1979). As the name suggests, a BACI study involves measurement of parameters of interest at an expected impact location and

an un-impacted control location both before and after the impact occurs. The idea is that the un-impacted control location provides a baseline against which changes at the impacted site may be detected. The core assumption of this approach is that the control and impact locations would behave similarly through time in the absence of the disturbance, and evidence to the contrary is due to the effect of the disturbance. The primary problem that emerges in a simple BACI design is that the impact and control locations may change differently through time simply due to random natural variability ("temporally interactive", sensu Underwood, 1994). Thus, the BACI design can be improved by sampling the impact and control areas at multiple time points before and after impact to improve replication (Stewart-Oaten et al., 1986) and by sampling multiple control locations to improve power in temporally interactive data sets (Underwood, 1994). However, the improvements suggested by Stewart-Oaten et al. (1986) and Underwood (1994) often do not find their way into BACI-based beach nourishment impact assessments for a variety of reasons including technical feasibility, cost, and/or lack of investigator knowledge with these designs. Numerous other study designs and analytical procedures may used in impact assessments depending on the question of interest and the nature of the disturbance (Ellis and Schneider, 1997; Hobbs and Hilborn 2006), but these are generally not as common in practice.

The downside to the BACI approach (as well as other study designs common to impact assessments) is that because each assessment is place and time specific, the investigator cannot draw the broader conclusions that are necessary to identify impacts to natural resources and to make sound management decisions. In a sense, each nourished beach and its associated non-nourished control beach represents one replicate of an experiment. Presumably, by combining the results from many studies performed along a coastline, the replication problems listed above could be reduced if not eliminated. Several descriptive reviews have sought to synthesize the results of past nourishment studies (USACE, 1973; Nelson, 1993; NRC, 1995; Nordstrom, 2005; Peterson and Bishop, 2005; Spreybroeck et al., 2006). These syntheses have provided *qualitative* descriptions of the kinds of environmental impacts that can occur, often under specific circumstances. Lacking is a *quantitative* synthesis of the cumulative experience of decades of beach nourishment projects and associated assessments. A field of statistics known as meta-analysis provides the tools needed to evaluate general trends in dredging and nourishment impacts in a more quantitative manner.

Meta-analysis

Meta-analysis refers to any quantitative handling of data from multiple studies. A formal methodology has been employed for decades by the medical and social sciences (Glass, 1976), but such formalization for the ecological and environmental sciences has been only recently achieved (Gurevitch et al., 1992; Gurevitch and Hedges,1999; Osenberg et al., 1999; Pullin and Stewart, 2006). At the heart of this approach, each study is treated as a single observation in a larger statistical analysis. This involves 1) calculating for each study an "effect size" that describes the magnitude of the measured response to some treatment relative to a control, and 2) comparing these effect sizes across all studies using more traditional inferential statistics such as ANOVA. Using this method, the lack of true replication in impact assessments can be solved by treating each impact location as a treatment replicate and pairing these with their respective control locations. The effect sizes for all studies then comprise a population of observations with a mean and variance that is suitable for analysis. Meta-analysis has rarely, if ever, been applied to BACI designed impact assessments, but the strength of such a "Meta-BACI" approach to addressing management-relevant questions over large spatial scales has been demonstrated (Conner et al., 2007).

Objectives

The goal of the current study was to begin the process of centralizing and quantitatively synthesizing data from beach nourishment monitoring studies by focusing on only those projects performed in South Carolina. Specifically, the objectives were to: 1) assemble a central library of beach nourishment environmental impact assessments performed in South Carolina, 2) create a digital database of beach nourishment environmental impact assessment results, 3) use meta-analyses to address beach nourishment environmental impacts, 4) synthesize study results into recommendations to improve beach monitoring and management as they relate to nourishment in South Carolina. This first involved collecting publications, summarizing them in an annotated bibliography, and entering the data from those EIAs into a single database. Following these initial steps, a meta-analysis approach was used to address questions regarding the physical and biological responses of borrow areas to dredging and beaches to nourishment. The importance of project design parameters (seasonal timing, dredge and fill depth, etc) to the environmental responses was also explored but was limited by the lack of consistent reporting of many parameters.

METHODS

Central Library

Library assembly involved searching South Carolina Department of Natural Resources (SCDNR) files and contacting study authors, reporting agencies and funding agencies to obtain lists of projects and related published reports. The primary outside sources of project information were South Carolina Department of Health and Environmental Control – Office of Ocean and Coastal Resource Management (DHEC-OCRM), US Army Corps of Engineers-Charleston Office, Olsen and Associates, Coastal Science and Engineering LLC, Coastal Science Associates, Inc., and Applied Technology and Management (Appendix 1). Hardcopies of these publications were gathered and placed on file at the Marine Resources Research Institute (MRRI). As few reports were available in electronic format, hardcopies were scanned into a computer and saved in portable document format (pdf) using Adobe Acrobat 8.0. These files were copied to DVDs for transfer to outside parties. A full bibliography of all beach nourishment related studies was created that included all reports assembled in digital and hardcopy format as well as references that could not be assembled but that were cited within other reports or that were included in citation lists from outside sources (Appendix 2). All assembled reports were annotated within the bibliography. The bibliography was included as part of the project database.

Digital Project Database

A digital relational database was constructed in Microsoft Access (Microsoft Corp.) to handle physical and biological environmental data, nourishment project design specifications, geographical information, and permitting data. Digital raw data was formatted and imported into the database. When raw data were not accessible in digital format, it was extracted from hardcopy reports and entered by hand. The database consisted of 13 tables which store and display data including basic collection information, sediment data, benthic faunal data, beach data, project-specific data, and a bibliography of beach nourishment publications from projects in South Carolina (Appendix 3). To date, there are more than 7,000 records of collection information from fourteen nourishment projects available. Any of the individual records can be linked to faunal and/or sediment data as well as project-specific data, summary statistics, and bibliographic records for the associated nourishment project.

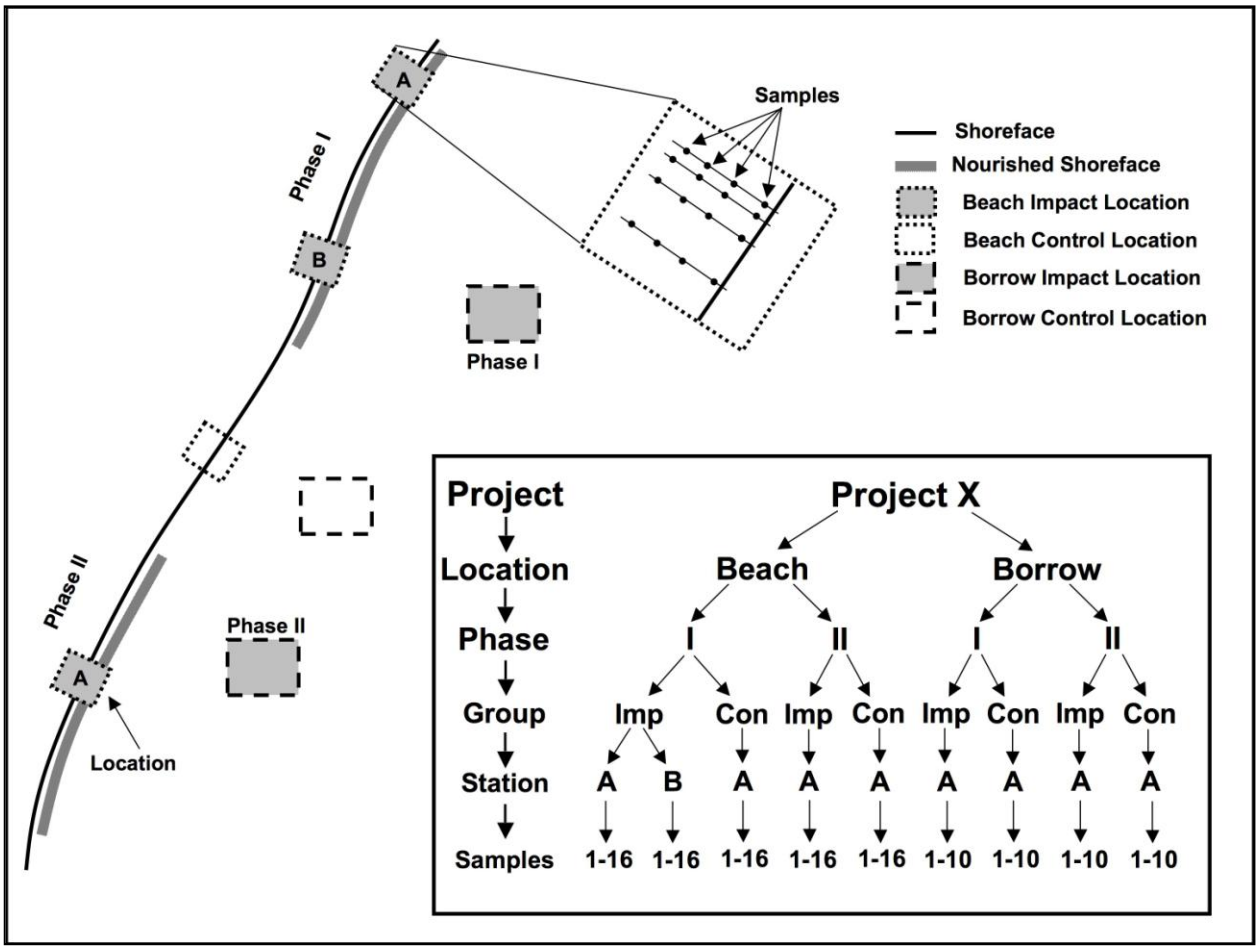

Figure 1. Hierarchical database structure used to standardize monitoring study designs. Imp—Impact group, Con—Control group

A hierarchical scheme was developed to standardize data structure across studies of sometimes very different design and to simplify data extraction from the database (Figure 1). A "Project" was defined as a single permitted or designed dredge and fill operation. In most cases, each Project consisted of two "Locations", the borrow area(s) and the beach(es) that were affected by operations. Within each Location, one or more "Phases" were designated as individual borrow pits or spatially discrete beach segments. Each Phase had impact and control "Groups". Within each Group, one or more "Stations" were studied at which one or more individual "Samples" (push cores, sediment grabs, etc) were collected. While studies varied greatly in the arrangement of samples in time and space, they could all be adapted to this structure. Additional data columns were added to house study-specific sampling design characteristics not easily handled by the hierarchical database design used here (for example, beach samples collected at different tidal levels, etc.).

Meta-analysis

Meta-analyses were limited to those studies that utilized a Before-After Control-Impact (BACI) study design. Impact areas were those where nourishment was performed (nourished beach) or from which sediment was removed (borrow area). Control areas were those areas of similar tidal strata where nourishment was not performed (beach control) or areas where sediment was not removed (borrow control), and that were sampled concurrently with the impact areas. Analyses were further limited to the most commonly collected parameters at borrow and beach areas,

Table 1. Target response parameters for meta-analysis

Parameter	**Unit**
Sand, silt/clay, calcium carbonate/shell, total organic matter content	Percent of total mass (%)
Sand phi size	Mean phi (ϕ)
Faunal densities	Number per square meter (No./m^2)
Number of Species	Number per collection
Relative abundances of major taxa (polychaetes, amphipods, molluscs)	Percent of total (%)

and data were converted to standard units across reports (Table 1). Infaunal macroinvertebrates (those retained on a 0.5mm sieve) were the most common component of the biological community for which data were available, so all calculations were restricted to these taxa.

Because this study started with raw rather than summary data, it is useful to define a replicate impact site (one observation in the meta-analysis) and differentiate it from a replicate sample (one of presumably several data points within a location). For the meta-analysis of dredging impacts on borrow areas, a replicate impact site was defined simply as a single borrow area. For many smaller beaches, a single borrow area was used for nourishment; for larger projects two to three borrow areas were used but these were at least 8-10 km apart. In a few cases, a borrow control was used for more than one borrow area, and although they were not strictly independent replicates (compared to same control, sampled at the same time by the same staff, etc.), they were treated as impact replicates. This was because the different borrow areas were all located in different types of environments, so the loss of information would have been considerable had those data been pooled. For the analysis of nourishment impacts on beach systems, a replicate impact location was considered a monitored area of beach positioned at least 2.0 km from any other monitoring areas. This conservative distance was based on doubling the greatest distance at which Peterson et al. (2006) found no significant spatial autocorrelation in beach macroinvertebrate densities. This distance is likely applicable to sediment characteristics as well because sediment characteristics can vary substantially within a borrow area and result in noticeable differences in sediments placed on the beach at scales of much less than 2 km. The replicate samples within an impact or control site represent the individual sample units used to calculate the mean, standard deviation and sample size for the impact or control location in the meta-analysis. In terms of the database structure described above (Figure 1), a single observation in the meta-analysis was defined as the impact-control pair within each Phase.

The traditional study design for which meta-analysis techniques were developed involves repeated measures on replicate individual "subjects" (here, replicate samples) through time in an experimental and a control group. A change in each subject is then calculated, and the mean and standard deviation of the changes in the two groups are calculated. Environmental impact assessments that use a BACI study design generally adopt one of two broad sampling strategies: repeated measures at fixed sampling stations (the traditional study design described above) or spatially-randomized measures within a more general area (Figure 2). In a repeated-measures study, each measure taken for a sample replicate before the impact (x_{Bi}) was paired with the measure taken for that same sampling replicate after the impact (x_{Ai}) and the difference between the two time periods (x_{Ai} - x_{Bi}) was calculated. Assuming multiple sampling replicates were collected within each of the impact and control locations, the mean, standard deviation and sample size for the impact location (X_I, S_I, N_I, respectively) and the control location (X_C, S_C, N_C) were calculated from these sampling replicate differences. Many of the beach nourishment environmental impact assessments in South Carolina sampled at randomized positions within a

more general area indicative of the impact or control sites rather than at fixed sites (Figure 2). When this sampling strategy was used, a general impact area was delineated as well as an un-impacted control (or reference) area. Within each area, sample replicate positions were chosen randomly in space before the impact event and again after the impact event. Thus, individual sampling replicates were independent among time periods within the delineated area, resulting in means and standard deviations within the impact location before (X_{IB} and S_{IB}, respectively) and after (X_{IA} and S_{IA}) and the control location before (X_{CB} and S_{CB}) and after (X_{CA} and S_{CA}) the impact. The difference between the after and before means was calculated for the impact (X_{IA} - X_{IB} = X_I) and control ($X_{CA} – X_{CB} = X_C$) locations; the standard deviation of the difference was calculated as the pooled standard deviation of the before and after data at the impact (S_I) and control (S_C) locations. Sample size was calculated conservatively as the average sample size of the before and after time periods for the impact (N_I) and control (N_C) locations.

Practically every beach nourishment study involved sampling the impact and control locations at multiple time periods following the impact, but only a few included sampling at multiple time periods prior to the impact. Each sampling time period following the impact was treated separately as described above, and three time periods were defined: immediate post-impact (within 2 months following impact), 6-month post-impact (between four and eight months following impact), 12-month post-impact (between 10 and fourteen months following the impact). Collectively, these periods were referred to as "after". No analyses were performed beyond twelve months as very few nourishment or borrow locations were monitored beyond that time period. With few exceptions (three borrow locations and two beach locations), sampling occurred only in a single time period prior to the impact. As a result, the very last sampled time period prior to the impact was used as the "before" against which each of the "after" time periods

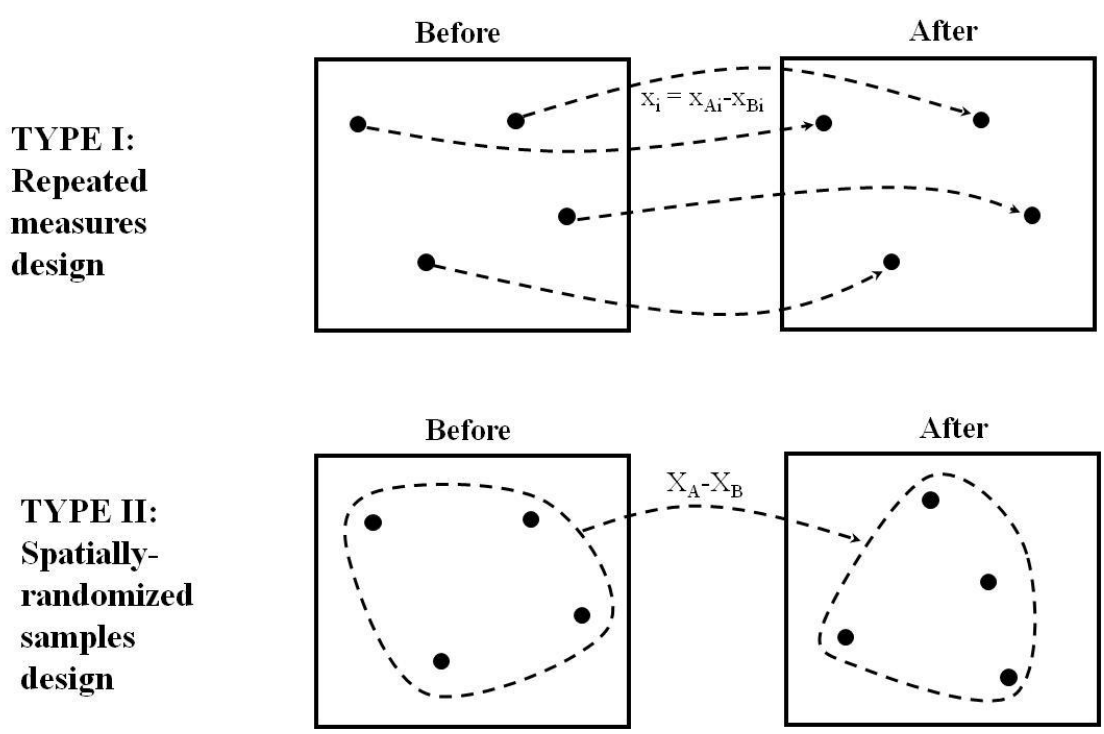

Figure 2. The two most common types of BACI study designs used in environmental impact assessments.

was compared. Although beyond the scope of the current effort, the few studies that sampled multiple "before" time periods could be used to examine whether this additional data improves detection capability in a meta-analytical framework.

The means (X_I and X_C), standard deviations (S_I and S_C) and sample sizes (N_I and N_C) were then used to calculate effect size, Hedges *d*, in each study included in the meta-analysis. Following the conventions in Rosenberg et al. (2000), Hedge's *d* and the effect size standard deviation (S) was calculated for each response. All meta-analyses were performed using MetaWin2 (version 2.1.5) to address specific hypotheses regarding the impacts of nourishment activities. The analyses were structured to address the broad questions: 1) Does the physical and biological environment respond to dredging/nourishment activity?, 2) Does the environment recover from dredging/nourishment activity within one year?, 3) What are the relationships between changes in physical environmental parameters and the response of the biological community?, and 4) What project design specifications, geographic considerations, and permitting conditions most minimize environmental impact? The first question was addressed by calculating effect sizes between the before and immediate post-impact time periods for each response parameter and applying a one-way ANOVA with location type (impact vs. control) as the main factor. The second question was addressed using the same methodology but by calculating effect sizes between the before and each of the 6-month post-impact and 12-month post-impact time periods. To examine the third question, multiple regression was used to compare the effect sizes of the biological measures (responses) and the effect sizes of the sediment characteristics (predictors). As discussed in more detail later, because of the limited number of monitoring projects with useable data, the fourth objective proved intractable for statistical analysis. To test for significant between-project differences, total heterogeneity (Q_T; Hedges and Olkin, 1985) was calculated. Significant total heterogeneity could provide evidence for which measures are most capable of detecting differences in impact amongst various dredging and nourishment projects.

RESULTS AND DISCUSSION

Summary of Beach Nourishment Monitoring in South Carolina

Forty-five projects that involved either placing sand on a beach or moving sand within the beach system for purposes of countering erosion were identified (Table 2). Of these, 16 involved moving sand from one location on the beach to another using land-based equipment (for example, beach-scraping). The remaining 29 projects involved placement of new material into the littoral sand budget and were the focus of the meta-analysis. Four of these used upland sand sources and the remaining 25 dredged a nearshore sand resource for fill material. Reports containing environmental monitoring data were identified for sixteen individual projects performed in South Carolina, and data useable in the meta-analysis were available for nine of those projects (Table 2). The projects described in these reports were distributed from near the North Carolina-South Carolina border (North Myrtle Beach) to the southernmost South Carolina barrier island (Daufuskie Island) (Figure 3). Most of the Grand Strand and most of the major barrier islands in the state have been nourished at least once, and a majority of those areas have been nourished more than once. At least 21 spatially-distinct subtidal borrow areas have been used as sources of fill in these projects, and only a few (along the Grand Strand) have been used more than once. At the time of this report, nourishment of the Grand Strand using three borrow areas had been recently completed and monitoring data was not yet available. Those areas most commonly nourished included the Grand Strand, Folly Beach, and Hilton Head Island, areas with substantial development in close proximity to the shoreface and tourism-based economies centered on beach access.

*Table 2. Nourishment projects identified in South Carolina. Included are the project start dates, type of project (D—subtidal dredging, L—intertidal land-based operations, U—upland source), and source organization for information (see Appendix 1). When environmental monitoring reports were found, the following are included: areas monitored (Bor—borrow, Bch—beach, Near—nearshore), the organization that performed monitoring (see Appendix 1), and whether the data were used in the meta-analyses. *--Ongoing projects not complete enough to include. †—inlet relocation*

Project Location	Start	Project Type	Source Org.	Locations Monitored	Monitor Org.	Used in Analysis	Environmental Monitoring References
Daufuskie Island	1998	D	ATM	Bor	CSA	Yes	CSA, 2001
Debidue Beach	1990	L	CSE				
Debidue Beach	1997	L	CSE				
Debidue Beach	2006	D	ATM	Bch, Bor	CSA	Yes	CSA, 2006, 2007, 2008
Edisto Beach	1954	D	USACE				
Edisto Beach	1995	D	CSE				
Edisto Beach	2000	D	CSE				
Edisto Beach	2006	D	CSE				
Folly Beach	1993	D	USACE	Bch, Bor	SCDNR/CCU	Yes	Van Dolah et al., 1994
Folly Beach	1998	D	USACE				
Folly Beach	2005	D	USACE	Bch, Bor	SCDNR	Yes	Bergquist et al., 2008
Folly Beach	2007	D	USACE	Bor	SCDNR	Yes	Bergquist et al., 2009
Garden City	1990	U	CSE				
Grand Strand	1996	D	USACE	Bch, Near, Bor	SCDNR/CCU	Yes	Jutte et al., 1999a,b,c, 2001a,b; Gayes et al., 2001; Ojeda et al., 2001
Grand Strand	2007	D	USACE	Bch, Near, Bor	SCDNR/CCU	No*	
Hilton Head Island	1990	D	OA	Bch, Bor	SCDNR/CSA	Yes	CSA 1991; Van Dolah et al., 1992, 1993
Hilton Head Island	1997	D	OA	Bor	SCDNR	No	Jutte and Van Dolah 1999, 2000
Hilton Head Island	1999	D	OA				
Hilton Head Island	2006	D	OA	Bch,Bor	SCDNR	Yes	Bergquist et al., in preparation
Hunting Island	1968	D	USACE				

Table 2. continued.

Project Location	Start	Project Type	Source Org.	Locations Monitored	Monitor Org.	Used in Analysis	Environmental Monitoring References
Hunting Island	1971	D	USACE				
Hunting Island	1975	D	USACE				
Hunting Island	1980	D	USACE				
Hunting Island	1991	D	CSE	Bor	CSE	Yes	CSE, 1992
Hunting Island	2006	D	CSE				
Isle of Palms	1982	L	CSE				
Isle of Palms	1984	D	CSE				
Isle of Palms	2008	D	CSE	Bor,Bch	CSA-South/CSE	No	CSA-South, 2008; CSE 2009
Kiawah Island	1996	L	CSE	Bch	SCDNR	No	Levisen and Van Dolah, 1996
Kiawah Island	2006	L	CSE				
Myrtle Beach	1982	L	CSE				
Myrtle Beach	1985	U	CSE	Bch	CSE	No	Baca and Lankford, 1987, 1988
Myrtle Beach	1989	U	CSE				
N. Myrtle Beach	1989	L	CSE	Bor	CSE	No	Baca et al., 1990
Pawleys Island	1988	L	CSE	Bch	CSE	No	Lankford et al., 1988
Pawleys Island	1990	L	CSE				
Pawleys Island	1999	L	CSE				
Seabrook Island	1983	L	CSE				
Seabrook Island	1990	D	CSE	Bor, Near	CSA	No	CSA, 1990
Seabrook Island	1996	L	CSE				
Seabrook Island	1998	L	CSE				
Seabrook Island	2000	L	CSE				
Seabrook Island	2007	L	CSE				
Seabrook Island	1998	L	CSE				
Surfside Beach	1990	U	CSE				

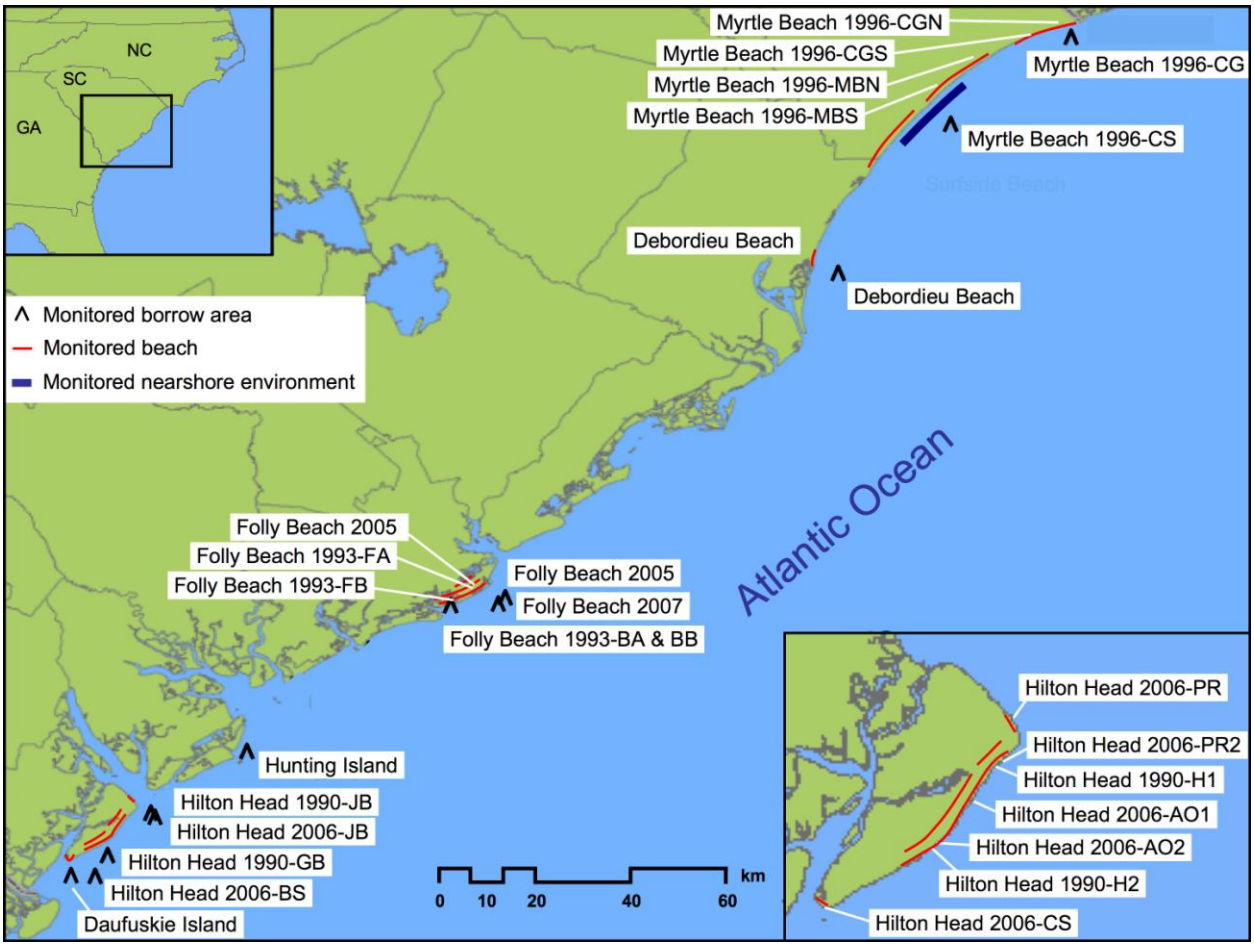

Figure 3. Nourished beach and borrow area phases in South Carolina for which appropriate environmental monitoring data were available. Borrow phase labels are shown over ocean; beach phase labels are shown over land. Inset at lower right shows close-up of Hilton Head Island with monitored beach phase labels. Red lines represent approximate areas nourished and multiple lines indicate repeated nourishment. "^" = borrow site. Blue line indicates area where nearshore monitoring has been performed.

Monitoring Study Designs

The monitoring efforts completed as part of these projects varied greatly in sampling scheme and methodology. Most studies employed a basic BACI design, with at least one sampling event before the impact and two or more sampling events after the impact. Several of the studies sampled at multiple time points prior to the impact, typically for one year (Van Dolah et al., 1992, 1994; Jutte et al., 1999a,b, 2001a,b). In only one monitoring study was a BACI design not used. Monitoring of the 1997 Hilton Head Island borrow area lacked any Before sampling events due to default by the consulting firm that collected the samples; SCDNR collected the After samples and performed what comparisons were possible between the Impact and Control sites (Jutte and Van Dolah, 1999, 2000). In general, South Carolina nourishment monitoring has followed the preferable BACI study design for detecting spatially-distinct impacts. This should continue with future projects having multiple Before sampling events to more fully characterize natural temporal variability in the systems under study.

Inconsistency in sampling methodology and measured parameters was partially due to changes in methodology and study focus through time. For example, the Hilton Head 1990 study used divers to collect multiple push cores of sediments at a small number of locations in the borrow and control areas in order to reduce the number of dives necessary to complete the work (Van Dolah et al., 1992). More recent SCDNR studies have used a benthic grab that allowed a single sample to be collected at each of a larger number of stations (for example, Jutte et al., 1999a, 2001a). The diver and core methodology was also used by other organizations (CSE, CSA, CSA-South) during earlier projects (CSE, 1992), but when grabs became the standard, some organizations collected multiple grabs at a small number of stations (for example, CSA 2006). Beach sampling methodology has also changed substantially through time. Early projects sampled small areas of beach very intensively (Van Dolah et al. 1992, 1994), while later projects adopted a more randomized sampling approach across a wider stretch of shoreline (Jutte et al., 1999b, 2001b). While no single approach is appropriate for all projects and questions, all monitoring projects should utilize methods that provide an adequate representation of the environment. This should include ensuring that the spatial and temporal scales of sample collection are adequate to detect patterns of change, that replication is sufficient to allow statistical analysis, and that the collection/survey devices operate properly and do not have unacceptable sampling biases.

Measured parameters also changed as knowledge regarding the response of the environment to dredge and nourishment operations increased. For example, earlier monitoring projects examined changes in the entire infaunal community on the beach but excluded larger burrowing macrofauna such as ghost crabs and ghost shrimp. These projects generally found recovery of beach infaunal communities within six months of nourishment (Van Dolah et al., 1992, 1994; Jutte et al., 1999b,c; Jones et al., 2008), leading to a relaxation of monitoring requirements on this component of the beach system. In response to studies in other areas that suggested larger burrowing beach macrofauna responded significantly to nourishment (Reilly and Bellis, 1983; Peterson et al., 2000; Peterson et al., 2006), recent studies in South Carolina shifted monitoring efforts to these beach fauna (Bergquist et al., 2008). Similarly, several past monitoring efforts in South Carolina also investigated changes in fish and phytoplankton communities, but they found little detectable impact of dredging or nourishment (Van Dolah et al., 1992, 1994), and monitoring of these resources subsequently ceased. These changes in parameters, while intended to improve design or to ease the financial burden of monitoring efforts, have resulted in several undesirable consequences. First, by eliminating monitoring on resources that showed little response to impact in past projects, the ability to detect projects that perform poorly in the future may be greatly reduced. Second, the lack of consistency through time or amongst monitoring organizations complicates important between-study comparisons upon which broader management decisions are based. This also caused a problem for performing the meta-analyses in this study as similar measures obtained using similar methodologies are not available across a large number of monitoring efforts. Clearly, a balance must be struck between maintaining impact detection capability, collecting datasets upon which management decisions may be based, continued monitoring of uninformative parameters, and examining previously uninvestigated response parameters.

Data Analysis and Reporting

Although many studies collected data using a BACI-type design, the data have rarely been analyzed in such a way as to maximize the statistical power of that design. Peterson and Bishop (2005) sharply criticized the statistical approaches, or sometimes lack thereof, used in beach nourishment studies as being too weak to detect nourishment impacts. Examination of dredge and nourishment projects in South Carolina reveals a mix of statistical methods in use. In

some isolated cases, individual data points have been described without any summary statistics or inferential statistical analyses (CSA Inc., 1991, 2001, 2007). However, in most cases, inferential statistics (t-tests, ANOVA, Mann-Whitney U-test, etc) were used to make a series of pair-wise comparisons amongst before and after and impact and control conditions (for example: Van Dolah et al., 1992, 1994; Jutte et al 1999a,b, 2001a). While pair-wise comparisons can detect impacts when combined with careful interpretation of summary statistics (means, medians, standard deviations, etc.) (Hurlbert 1984), they do not have the strength of multi-factor general linear models (GLM's) to directly discern impacts from underlying natural spatial and temporal variation (Stewart-Oaten et al., 1986; Underwood, 1992; Stewart-Oaten and Bence 2001). The GLM approach is certainly among the more powerful tools for detecting impact effects and should be applied when possible. Unfortunately, the study designs needed to perform such analyses can prove very costly and may not be feasible within the budgetary constraints of smaller beach nourishment projects. However, the simplest BACI designed study (with at least one Before and one After sampling event at each of a Control and Impact location) can still be analyzed using a two-way ANOVA (a basic GLM).

Reporting of basic project characteristics was common but not always consistent. Most reports mentioned total volumes of material removed from a borrow area or placed on the beach and linear kilometers nourished, but many other ecologically-important measures were often missing. For example, numerous studies of borrow areas suggested that the depth that the borrow area was dredged below grade greatly affected the kind of material that refills the pit and the rate of recolonization of that area by the natural community (Van Dolah et al., 1998; Jutte et al., 2002; Bergquist et al., 2008). Measures such as the average depth below grade or the volume of sediment removed per square meter of seafloor could inform these conclusions more quantitatively. Although these measures are commonly calculated and presented in engineering reports, they are often lacking from environmental monitoring reports. Determination of beach profiles is the most common monitoring technique and it provides the data necessary to calculate the volumes of material actually placed on a shoreface and rates of sediment loss following project completion. Often, simple ecologically-relevant measures, such as changes in beach width and slope and elevation of the berm, are missing from environmental monitoring reports. Reporting of these measures is critical to the between-project comparisons upon which management decisions are based. This, combined with inconsistent environmental monitoring, also affected the current study by preventing the analysis of the importance of most project design parameters (seasonal timing, dredge and fill depth, etc) to environmental responses.

The reports examined here also varied widely in the information presented. To be useful to the technical public, planners and resource managers, final reports (the final product of monitoring) should be written much like any technical document by summarizing existing knowledge of the field of study, fully describing methodology, thoroughly analyzing and presenting the data, and interpreting the results in a scientifically appropriate manner. Many of the final reports issued for beach nourishment projects in South Carolina have included these components. A few, however, have excluded some or practically all of this information (CSA 2001, 2007). While exclusion of some information may be justifiable under certain circumstances (repetition across multiple closely-related reports, for example), it requires a reader to search for additional documents in order to clarify the report's purpose, methods, or findings and should be avoided when possible. To ensure that reports meet these basic requirements, a state-wide system of peer-review is needed.

Results of Meta-analysis

The limited number of nourishment projects in South Carolina with available BACI-based environmental monitoring data restricted the scope of the meta-analyses possible here.

This was further limited by the narrow range of parameters available across the different monitoring studies. While these studies measured a diverse range of response parameters, those most commonly measured were various sediment and infaunal community characteristics (Table 1).

Proper interpretation of the effect sizes (*d*) resulting from the meta-analysis of BACI design data deserves special attention. In the simplest sense, effect size is the difference between the response of a control group and an experimental (impact) group. The "response" of a group in a BACI-design study is the change between the pre-impact condition and the post-impact condition of a measure. The effect size, then, is the difference between the change that occurs in the impact group and the change that occurs in the control group. For any given parameter, an effect size of zero indicates the impact and control group changed identically following the impact, a positive effect size indicates the impact area became elevated relative to the control area following the impact, and a negative effect size indicates the impact area became depleted relative to the control area following the impact (Figure 4). Because the effect size is a value weighted by study variance (technically the standard deviation), the effect size is not a literal difference between the two groups. For example, an effect size for silt and clay of 1.0 does not mean that the change in silt and clay in the impact group was only 1.0% greater than the change at the control group. The purpose of this weighting procedure is to reduce the influence of studies with high variance or small sample size relative to those studies with lower variance or greater sample size. The important interpretation is whether the effect size is significantly different than zero.

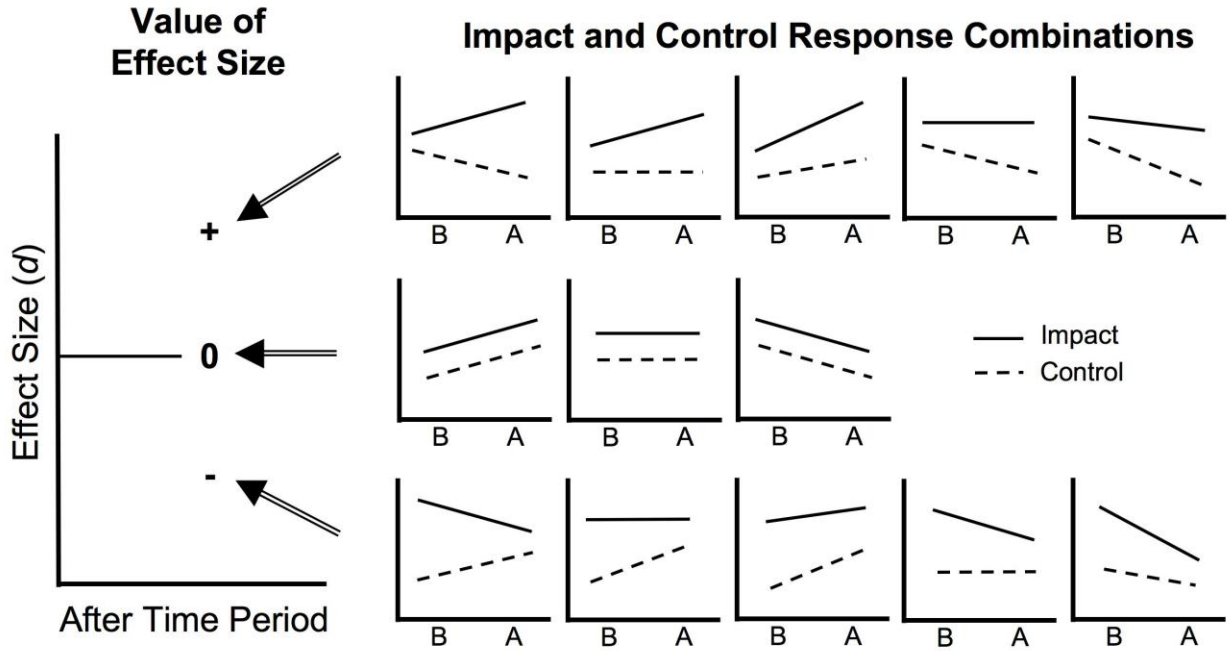

Figure 4. Combinations of parameter responses at impact and control sites between the Before (B) and After (A) time frames that result in effect sizes with zero (0), positive (+) or negative (-) values for a particular After time period. Zero values result when both areas change identically following the impact (middle row), positive values result when the impact increases more or decreases less than the control following impact (top row), and negative values result when the impact decreases more or increases less than the control (bottom row).

Beach Response to Nourishment

The response of beach systems to nourishment has not been monitored in a consistent manner in South Carolina, resulting in a dataset not easily amenable to meta-analysis. Only six nourishment monitoring studies collected comparable data on sediment characteristics and only four projects collected somewhat comparable biological data. In order to maximize sample size, the assumption was made that beach areas separated by at least 2 km but monitored as part of the same project were independent. This was based partially upon data presented by Peterson et al. (2006) showing that invertebrate densities on a North Carolina beach were no longer correlated at distances greater than 1 km. Within a nourishment context this assumption was further justified by the fact that nourishment projects take time to complete resulting in different areas of the beach (and presumably different monitored project phases or stations) being impacted at different times (sometimes many months apart) and receiving fill material dredged from different locations within the borrow area and sometimes from different borrow areas entirely. The result was that comparable sediment data was available for 17 beach stations and biological data was available for 9 stations. Nine of the 17 stations with sediment data were associated with either the Myrtle Beach 1996 (4 stations) or the Hilton Head 2006 (5 stations) renourishment projects, and all other projects (Hilton Head 1990, Folly 1993, Folly 2005, Debordieu 2006) were represented by no more than two stations. Four of the nine locations with biological data were also associated with the 1996 Myrtle Beach renourishment project, and all other projects (Hilton Head 1990, Folly 1993, Debordieu 2006) were represented by no more than 2 locations. This means that a few projects performed under a given set of conditions have a very large influence on the overall outcome of the meta-analysis. As discussed further below, this also limited our ability to compare amongst projects of differing characteristics.

In South Carolina beach environments, sediment composition was not found to significantly change in a consistent and predictable manner following nourishment (Figure 5). The most sustained pattern was a tendency of beach sand to become slightly courser, as reflected in lower phi size, following nourishment (Figure 5B). Individual beach areas responded very differently though time to placement of dredged material (Figure 6). Four of the five monitored beach areas monitored for the 2006 nourishment of Hilton Head Island showed a tendency for sustained reduced sand and increased silt/clay content relative to non-nourished areas (Figure 6A,C). Two areas monitored during the 1996 Myrtle Beach nourishment project showed evidence of initially elevated silt/clay and organic matter content and reduced sand content immediately following sand placement, but this dissipated within six months (Figure 6A,C,E). By comparison, monitoring of other projects, such as the Hilton Head 1990 nourishment, found little change in these same parameters. Individual monitoring efforts reported in the state have generally found minor changes in sediment characteristics following nourishment (Van Dolah et al., 1992, 1994; Jutte et al., 1999), a finding that likely reflects sizeable beach-compatible sediment deposits accessible for use in nourishment projects in this state. However, based on poor sediment matches that have sometimes occurred in other states (Peterson et al., 2006), every effort should be made to continue to identify the best beach-compatible sediment sources and to monitor the quality of material actually placed on the beach.

Consistent and significant biological changes among South Carolina's nourishment projects were limited. The number of species declined significantly following nourishment and remained low six to nine months later (Figure 7B). Within the first few months following placement of fill material, amphipod crustaceans increased and polychaete worms decreased in relative abundance (Figure 7C,D), but mollusc relative abundance and total macroinvertebrate densities did not change (Figure 7A,E). The reduction in species richness coupled with a relatively constant invertebrate density suggests that nourishment changes the beach environment

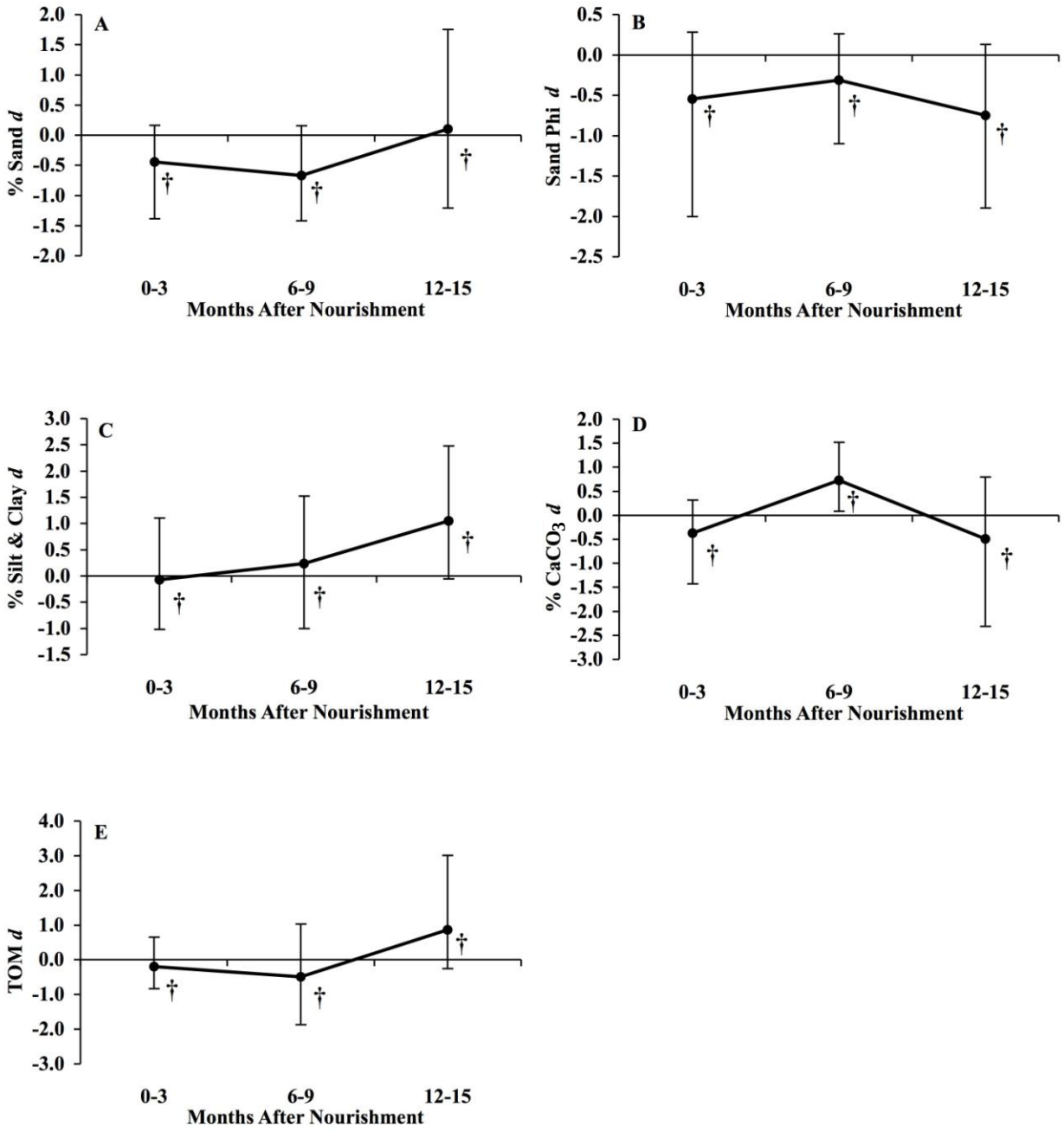

Figure 5. Effect sizes (Hedge's d) for beach sediment characteristics. Values represent the standard deviation-weighted difference between the change at the impact site and the change at the control site between the Before time period and three After (0-3 months, 6-9 months, and 12-15 months after nourishment) time periods. †--between-study heterogeneity (Q_T) significant. See figure 4 for details on interpretation.

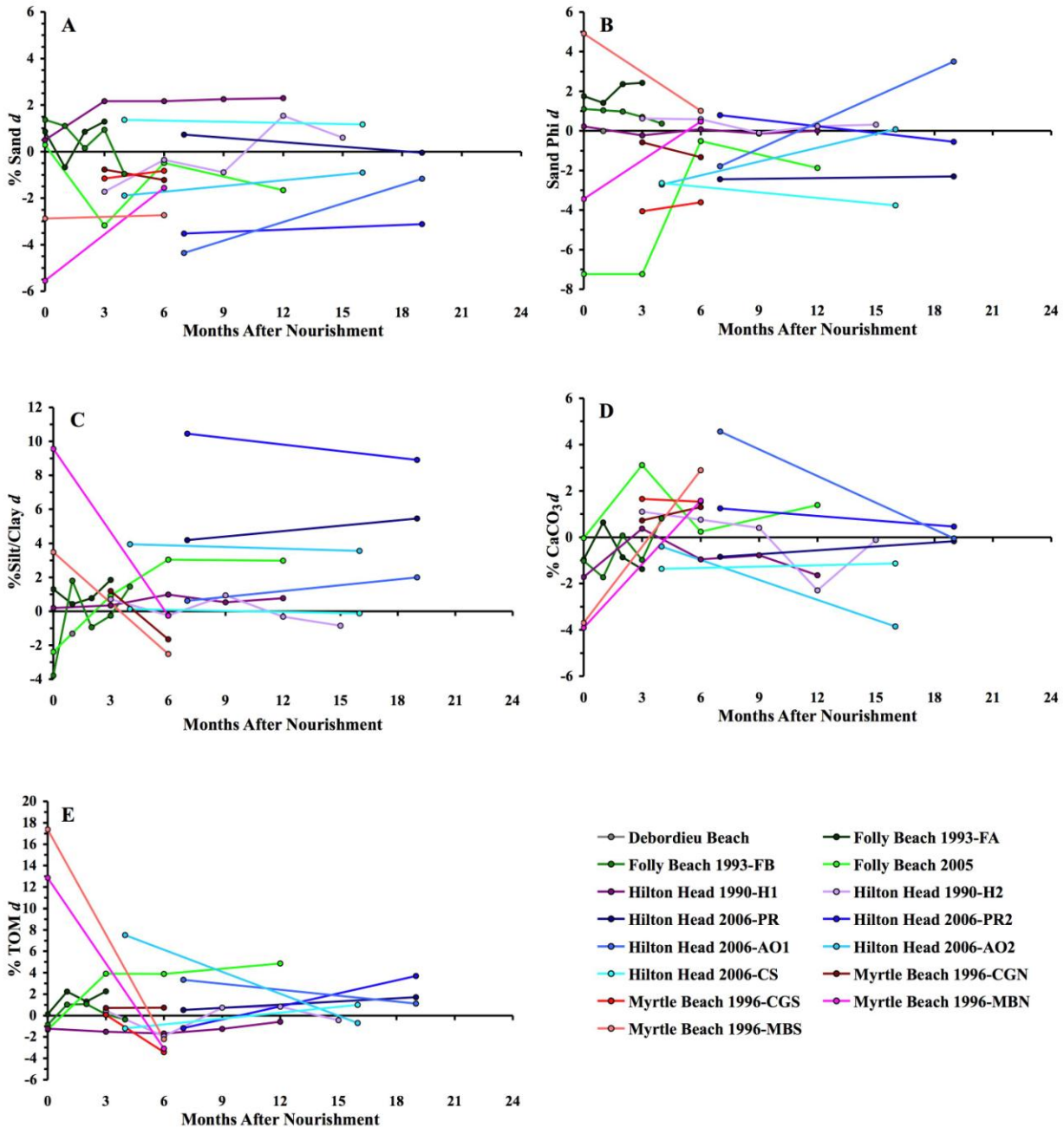

Figure 6. Effect sizes for sediment through time at beach areas monitored in South Carolina. Labels match those used in figure 3. See figure 4 for details on interpretation.

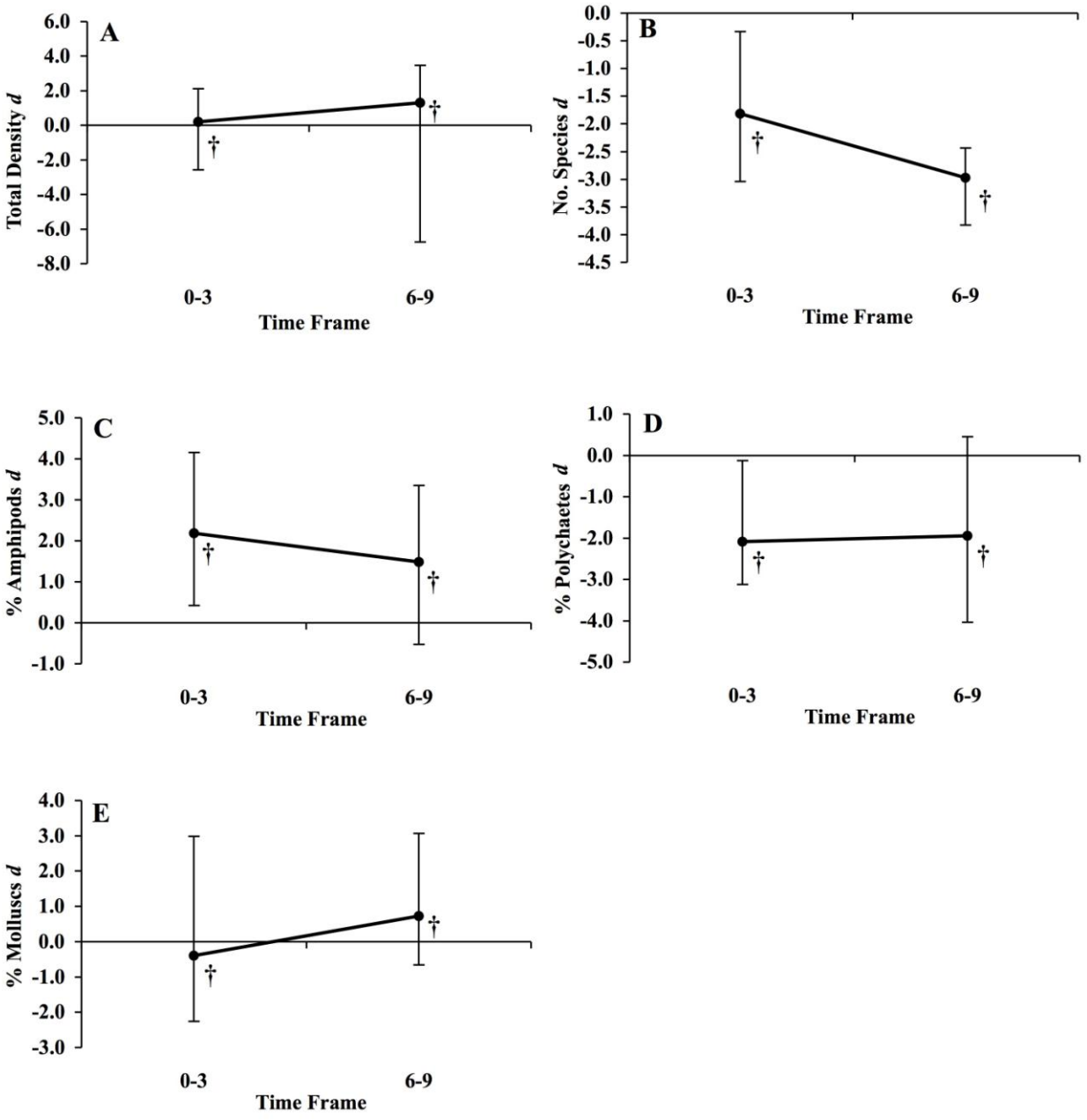

Figure 7. Effect sizes (Hedge's d) for beach infaunal community measures. Values represent the standard deviation-weighted difference between the change at the impact site and the change at the control site between the Before time period and two After (0-3 months and 6-9 months) time periods. †--between-study heterogeneity (Q_T) significant. See figure 4 for details on interpretation.

in such a way that favors rapid recolonization by a subset of species. In general, the changes appear to favor amphipods over polychaetes, potentially through a coarsening of beach sediments (for example, through the small decrease in sand phi size). Infaunal invertebrate community structure is strongly influenced by sediment composition (Gray 1974), but few consistent relationships were found between the physical and biological changes identified here. The change in the relative abundance of polychaetes following nourishment was significantly and positively correlated with the change in silt and clay content and shell content, but other biological measures analyzed here did not show significant relationships with changes in sediment characteristics (data not shown). This suggests that the changes driving the shift in community structure found here were not related primarily to changes in sediment characteristics, but rather to other changes such as beach slope or wave energy (Defeo and McLachlan, 2005).

Although the meta-analyses suggest that some general changes in sediment and biological characteristics may occur following nourishment, different nourishment projects appeared to result in very different environmental responses. Between-study variability measured by total heterogeneity (Q_T), was highly significant for every parameter examined in this study (Figures 5 & 7). This indicates that the response of beach physical and biological parameters to nourishment activities depend strongly on a combination of the local and regional environment in which the beach is embedded, the timing of nourishment activities, and methods and material used to restore the beach. This further suggests that all of the measures examined here are useful indicators of nourishment impacts on beach systems, because they are capable of differentiating amongst the impacts of different nourishment projects performed in South Carolina.

Borrow Area Response to Nourishment

Overall, borrow areas dredged for use in beach nourishment projects in South Carolina have been monitored more consistently and represent a more spatially discreet impact area than beaches. As a result, the borrow area monitoring data form a more robust dataset than was available for nourished beaches. Similar data were available for sediment characteristics at 12 individual borrow areas and for biological characteristics at 13 borrow areas.

Meta-analysis of statewide borrow area monitoring data showed a consistent and statistically significant pattern of decreased sand content, reduced sand grain size (higher phi size indicates finer sands), and increased silt and clay content and total organic matter immediately following dredging (Figure 8A-C,E). These sediment characteristics showed little sign of recovering, with sand content remaining lower, silt clay content higher, and total organic matter higher in dredged areas even one year after dredging (Figure 8A,C,E). Although not significant, sand grain sizes were finer in borrow areas one year following dredging, continuing the broad trend seen immediately after dredging (Figure 8B). No consistent or significant change in shell (calcium carbonate, $CaCO_3$) content of borrow area sediments was found (Figure 8D). The few studies that monitored beyond one year suggest that recovery of native sediment characteristics in dredged borrow areas is unlikely even within two years (Hilton Head 1990-JS, Myrtle Beach 1996-CS & -CG and Folly Beach 2005-FA in Figure 9).

The depressions formed on the seafloor by dredging for beach fill appear to consistently trap fine material transported in bottom currents. In some borrow areas, such as those used in the Grand Strand, the magnitude of fine accumulation was quite small (Jutte et al., 1999, 2001), but in other areas fines have comprised over 25% of the material that refills the resulting pit (Van Dolah et al., 1992; Jutte and Van Dolah, 2000; Bergquist et al., 2008). Over several years, this can change benthic habitat conditions, produce a community very different from surrounding sediments, and change the value of those communities for foraging fishery species. In the

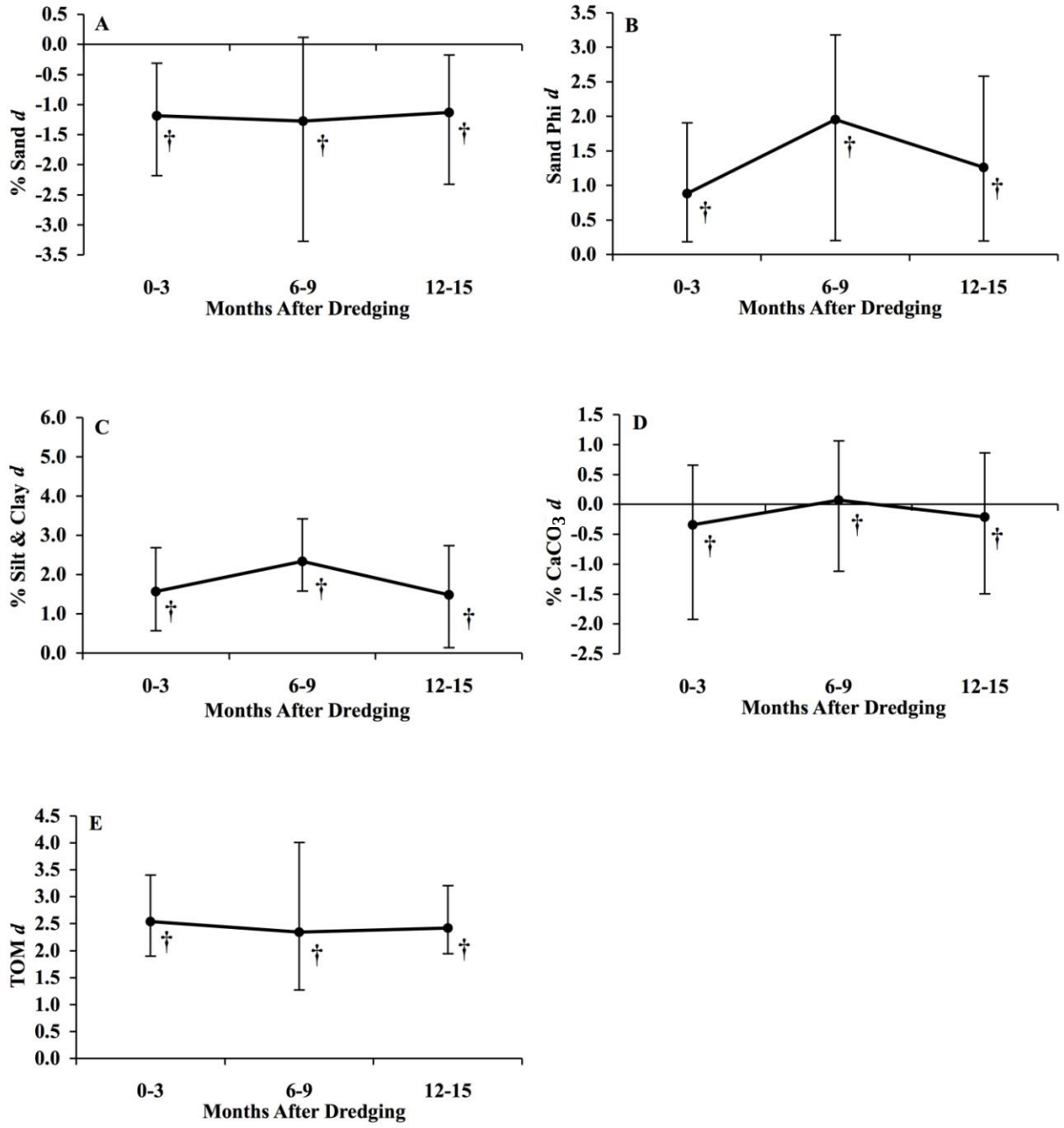

Figure 8. Effect sizes (Hedge's d) for borrow area sediment characteristics. Values represent the standard deviation-weighted difference between the change at the impact site and the change at the control site between the Before time period and three After (0-3 months, 6-9 months, and 12-15 months after nourishment) time periods. †--between-study heterogeneity (Q_T) significant. See figure 4 for details on interpretation.

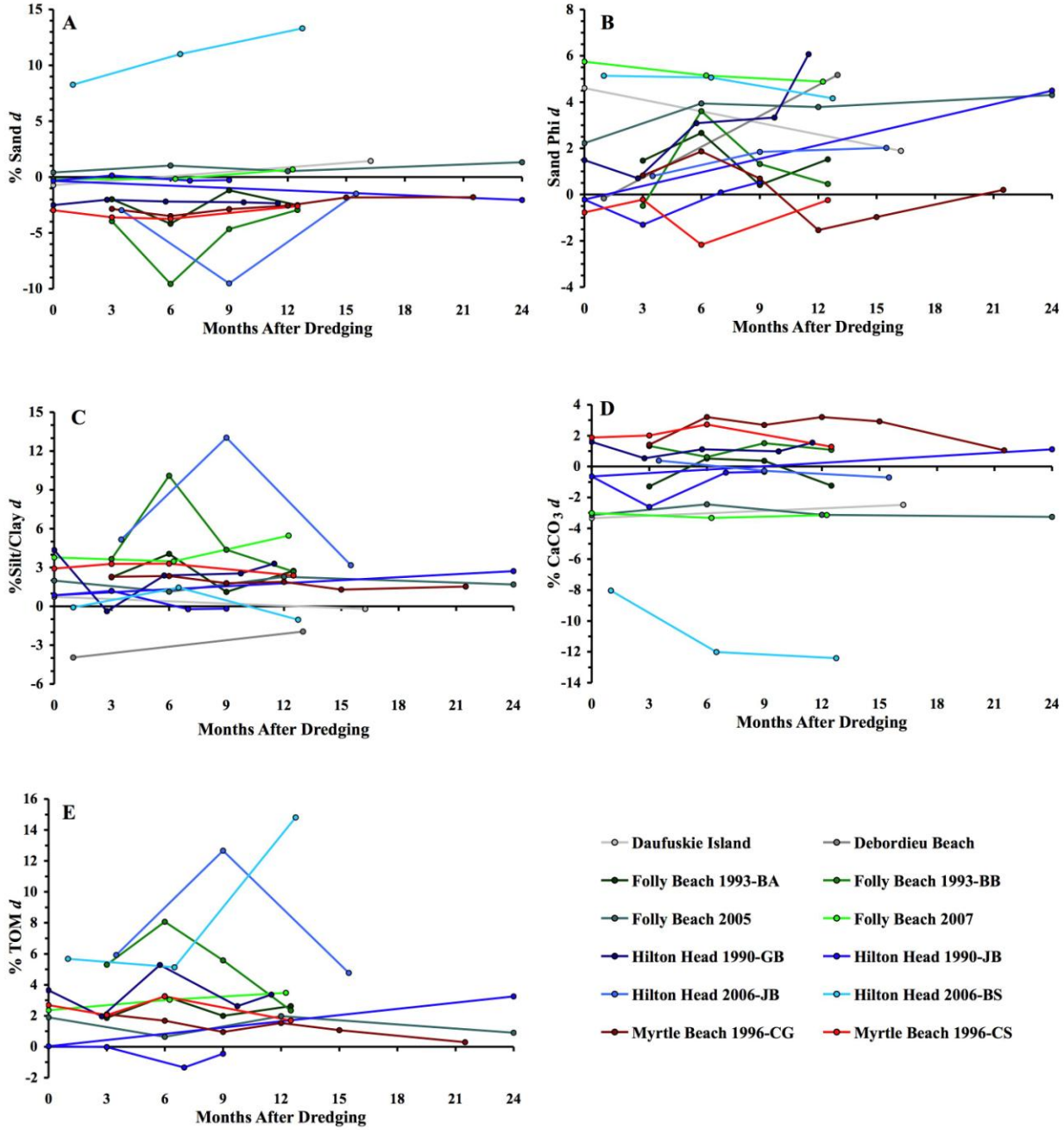

Figure 9. Effect sizes for sediment through time at borrow areas monitored in South Carolina. See figure 4 for details on interpretation.

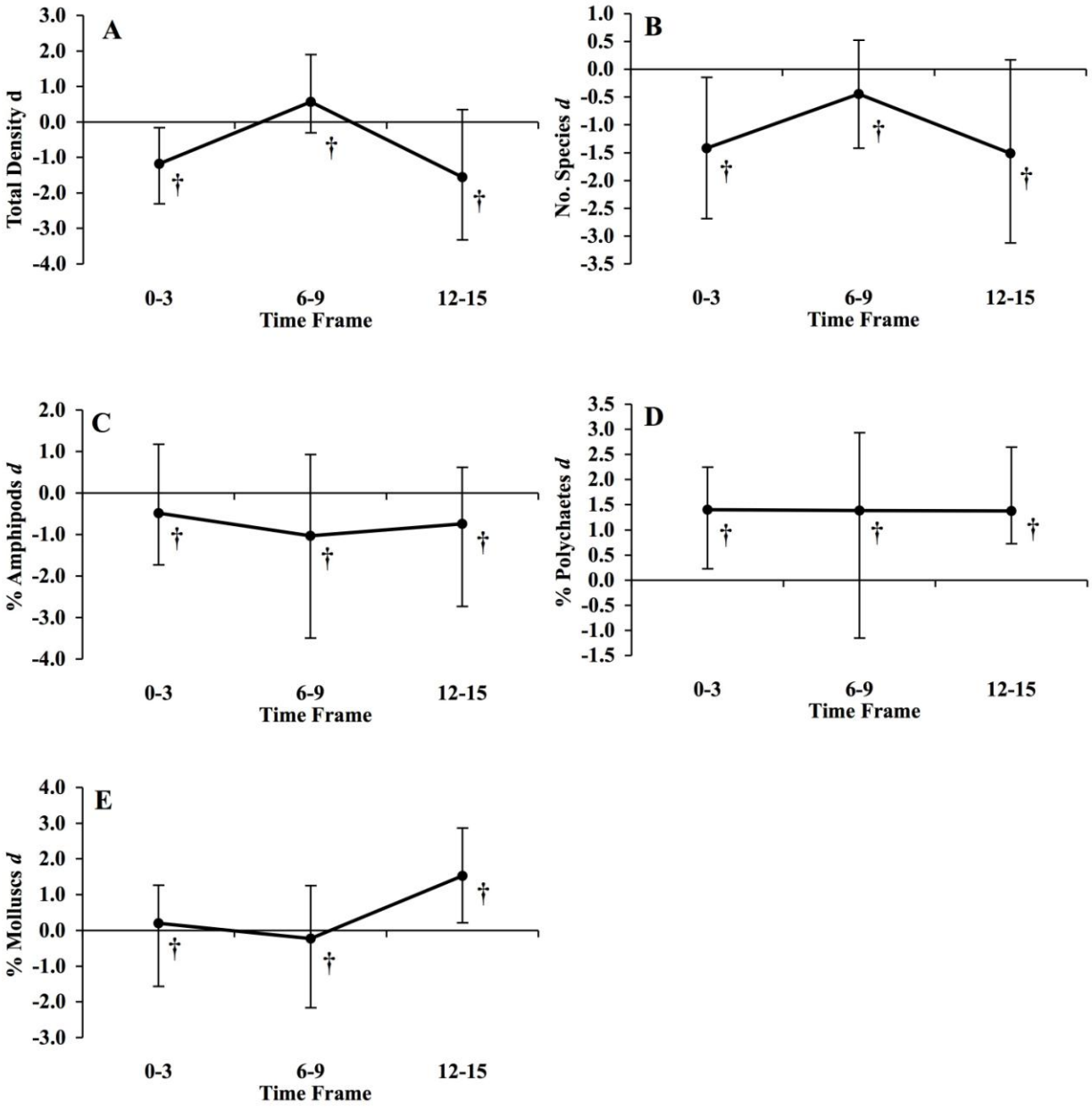

Figure 10. Effect sizes (Hedge's d) for borrow infaunal community measures. Values represent the standard deviation-weighted difference between the change at the impact site and the change at the control site between the Before time period and three After (0-3 months, 6-9 months, and 12-15 months after nourishment) time periods. †--between-study heterogeneity (Q_T) significant. See figure 4 for details on interpretation.

longer-term, these fines may become buried under a lens of sand and interfere with future use of the area as a source of beach fill (Van Dolah et al., 1998). More research is needed to determine the processes controlling the accumulation of fine material in dredge pits and to create models for improving the location of future borrow pits so as to minimize bottom impacts under a range of environmental conditions.

Biological responses to dredging examined here were highly variable and only a few changes were significant or persistent. The most consistent broad changes to the benthic infaunal community were decreased number of species and increased relative abundance of polychaetes following dredging (Figure 10D). The number of species declined significantly following dredging and remained reduced, although not significantly, through one year. The shift towards polychaetes in dredge pits was accompanied by a non-significant decrease in amphipods and "other taxa" such as nematodes and echinoderms ("other taxa" not shown). The reduction in numbers of species and, to a lesser extent, total faunal density immediately following dredging reflects the physical removal of surficial sediments and their associated communities. The general recovery of faunal density and continued lower numbers of species through the following year suggest that a smaller suite of more specialized, disturbance-tolerant species begin to recolonize the dredge pit. In marine benthic systems, polychaetes are often the first organisms to recolonize a disturbed habitat, a pattern that is consistent with the increased relative abundance of polychaetes following dredging identified here. Additionally, polychaetes have been observed to be either the dominant, or among the dominant taxa in muddy sediments in South Carolina's undisturbed estuarine and coastal habitats (Van Dolah et al, 1984, 1991). The continued elevated polychaete dominance of dredge pits one year after the cessation of dredging suggests that one year is generally not enough time for recovery of normal benthic communities.

Few biological changes in borrow areas were predictable based on changes in sediment characteristics. Changes in polychaete relative abundance were significantly and positively correlated with changes in silt and clay content, and changes in amphipod abundance were significantly and negatively correlated with changes in total organic matter. This reflects a general well-documented shift in benthic communities within estuarine systems from polychaetes to crustaceans along a gradient of increasing sediment grain size.

As with the beach monitoring data, between-study variability measured by total heterogeneity (Q_T), was highly significant for every parameter examined in this study (Figures 8 & 10). This indicates that the response of dredged borrow area physical and biological parameters to nourishment activities depend strongly on a combination of the local and regional seafloor environment, the timing of dredging activities, methods used to dredge beach fill, and/or the design of the dredge pit relative to the surrounding seafloor. This also suggests that the measures examined here provide potentially useful indicators of dredging impacts on nearshore benthic systems, because they are capable of differentiating amongst the impacts occurring in different borrow areas.

Factors Potentially Driving Between-Project Variability

Practically every parameter examined in this study identified a highly significant amount of variability amongst the responses of different beaches to nourishment and borrow areas to dredging. While this suggests that the common parameters measured by past monitoring efforts are capable of discriminating amongst projects of differing characteristics, it does not identify important characteristics of the dredge and nourishment projects. The between study variation could arise from a wide array of geologic, oceanographic, seasonal, and project design differences. For example, beach nourishment projects may differ in many characteristics including background erosion rate, sediment supply, wave and current climate, the amount of

material placed, and the change in beach width and slope. Borrow areas may also differ in a wide array of characteristics including sediment budget, predominant bottom boundary layer conditions, orientation with respect to other bottom features, water depth, depth below grade they were dredged, and time of year they were dredged.

Examining the potential sources of between-study differences on nourished beach systems in South Carolina (shown in Figures 5-7) is currently highly problematic. Small sample sizes and an uneven distribution of projects along gradients of potential characteristics generally hindered effective analysis. For example, although 17 locations were analyzed for changes in sediment characteristics, nine of these were associated with only two projects (Hilton Head 2006 and Myrtle Beach 1996). This greatly reduced the potential variability in the project characteristics that could be used to explain physical and biological differences between studies/projects. Further research and data mining may lead to additional data being available to investigate some project characteristics in the future, but the current state of data availability is not sufficient for most characteristics. Also, expansion of the dataset, through consistent monitoring of future projects and inclusion of projects from other states, could make future analysis possible by increasing sample size and expanding the range of conditions under which beach nourishment has been performed.

Because most of the individual beach stations considered "independent" in the meta-analyses presented above were actually replicates within individual projects, analysis of spatial or project level (length of filled beach, change in beach width, etc.) characteristics were most problematic. However, several well-monitored projects occurred over many months resulting in different beach areas being impacted at different times of the year, making an analysis of seasonal differences possible. In order to perform a simple seasonal comparison, monitored beach stations were placed into one of two seasonal windows: April-September ("summer") and October-March ("winter"). In general, during the summer biological activity is greater, wave energy is lower and erosion is slower (London et al., 1981) than during the winter, thus nourished beaches may be expected to respond differently to nourishment during these two seasonal windows. When the effect sizes of sediment characteristics of the most readily-transported sediment fraction (fine material and organic matter) are compared amongst beaches nourished in the winter and summer, few differences were apparent (Figure 11A,C,E). A slight tendency of beach sediments to be coarser following winter nourishment activities (lower phi size, lower silt and clay) may reflect greater winnowing out of fines in the beach fill (which already tends to be slightly coarser than the native beach sand) by higher winter wave energies. Winter nourishment projects tended to be associated with reduced infaunal abundances relative to summer nourishment events, while nourishment activities in both seasons tended to produce reduced numbers of species (Figure 11B,D). Particularly striking is the lower density of infauna 6-9 months following a winter nourishment event. The lower densities of fauna and lower metabolic rates typical of beach invertebrates during the winter may make populations of these organisms especially susceptible to stress caused by a large scale disturbances. This could then result in reduced recruitment from local invertebrate populations during the following spring and summer and produce lower densities than would otherwise be present.

The significant between-study variability detected in practically every sediment and infaunal parameter during almost every time period suggests that, like beach systems, the subtidal borrow habitats differ greatly in their response to dredging (Figures 8-10). Although a reasonable number of borrow areas have been monitored in South Carolina, they did not evenly represent many of the potential factors that may drive the differences among them. However, two key comparisons were possible: between predominantly winter and summer dredging operations and between borrow areas downdrift of inlets and those not downdrift of inlets.

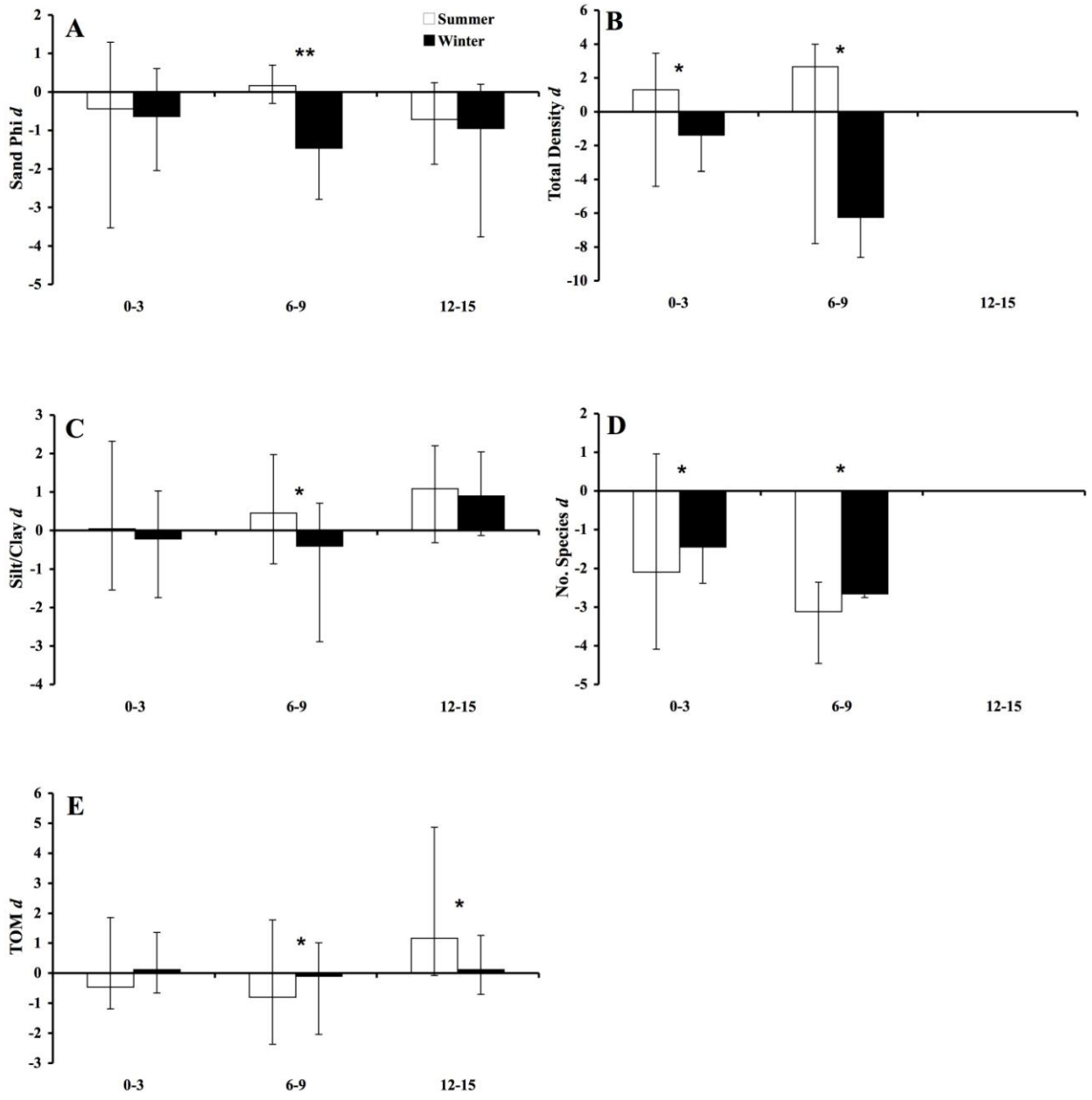

*Figure 11. Comparison of the effect sizes (Hedge's d) for several sediment characteristics and biological community measures between beaches nourished during the summer or during the winter. *=significant difference at p < 0.05 using comparison to chi-square distribution, ** = significant difference at p < 0.10 using the more conservative randomization test.*

As with beach sites, borrow areas dredged during the fall/winter may respond differently than those dredged during the spring/summer due to seasonal variation in biological recruitment and sediments transported on bottom currents. In order to perform a simple seasonal comparison, monitored borrow areas were placed into one of two seasonal windows based upon the time period during which a majority of dredging occurred: April-September ("summer") and October-March ("winter"). Fine sediment fractions increased in borrow pits following dredging in both seasons (Figure 12A,C,E). Total organic matter, the least dense portion of sediments, was significantly higher in pits dredged during the winter (Fig. 12E), a pattern that persisted for at least a year following dredging. This pattern may reflect enhanced transport of fine material during winter when southerly and southeasterly wind and wave energy dominates. However, the inconsistent seasonal differences in silt/clay and sand phi size argue against this as a plausible mechanism for the higher deposition of TOM following winter dredging. It is also possible that borrow areas dredged during the winter capture organic material during biologically productive spring and summer seasons before the pit refills substantially with sediment. By contrast, borrow areas dredged during the summer may capture less organic material due to lower rates of productivity during the following fall and winter. Biological responses tended to be more strongly negative in borrow areas dredged during the summer than during the winter (Fig. 12B,D). The strongest and most consistent difference was a greater reduction in the number of species in borrows dredged in summer. In the shorter term (less than one year following dredging) this may be due to greater numbers of species being present in subtidal benthic habitats prior to a summer dredge event than prior to a winter dredge event, thus more species are likely to be removed by dredging during the summer. Over longer time scales (greater than one year), the biological response to dredging in the two seasons was similarly negative, likely indicating that fewer species were capable of recolonizing these disturbed benthic environments. Preliminarily this suggests that summer dredging has a greater impact on benthic communities in the short-term, but dredging in either season results in similar responses over the longer-term.

Van Dolah et al. (1998) observed that borrow pits located at the north ends of barrier islands in South Carolina may be more susceptible to refilling with fine sediments as compared to borrow areas located at the south ends of barrier islands. Significant sand deposits located at the north ends of barrier islands tend to be ebb-tidal shoals associated with the downdrift sides of major tidal inlets, especially in the beach ridge barrier/transgressive geomorphic zone of the state's coastline, while those at the south end of islands tend be updrift of inlets and downdrift of beaches (London et al., 1981). The result is that fine and organically-rich materials carried through inlets with outgoing tides are more readily deposited in the downdrift ebb-tidal shoals on the north ends of barrier islands. As a corollary, borrow areas located in estuarine environments (tidal rivers, bays/sounds, inlets, etc.) would be expected to show a similar pattern of fines accumulation, and those borrow areas in the arcuate strand geomorphic zone of the coast (from Little River to Winyah Bay), where the beaches are connected to the mainland and lack substantial tidal creek systems, should not show substantial fines accumulation. When effect sizes for fine sediment components were compared between these two classes of borrow areas, those borrow areas downdrift of major inlets or located within inlets or tidal rivers had compositions significantly more skewed towards fines than did as compared to borrow areas not associated with these features (Figure 13A-C). This same pattern can be seen at a finer scale by examining the silt and clay content of two borrow areas used in the most recent nourishment of Hilton Head Island. The borrow area located in Barrett Shoals (HH2006-BB in Figure 8) at the south end of the island and on the updrift side of Calibogue Sound did not show substantially elevated fines within the first six months after dredging. By contrast, the borrow area located in Joiner Shoals (HH2006-JS in Figure 8) at the north side of the island and on the downdrift side of Port Royal Sound showed the greatest amount of fines accumulation of all the borrow areas

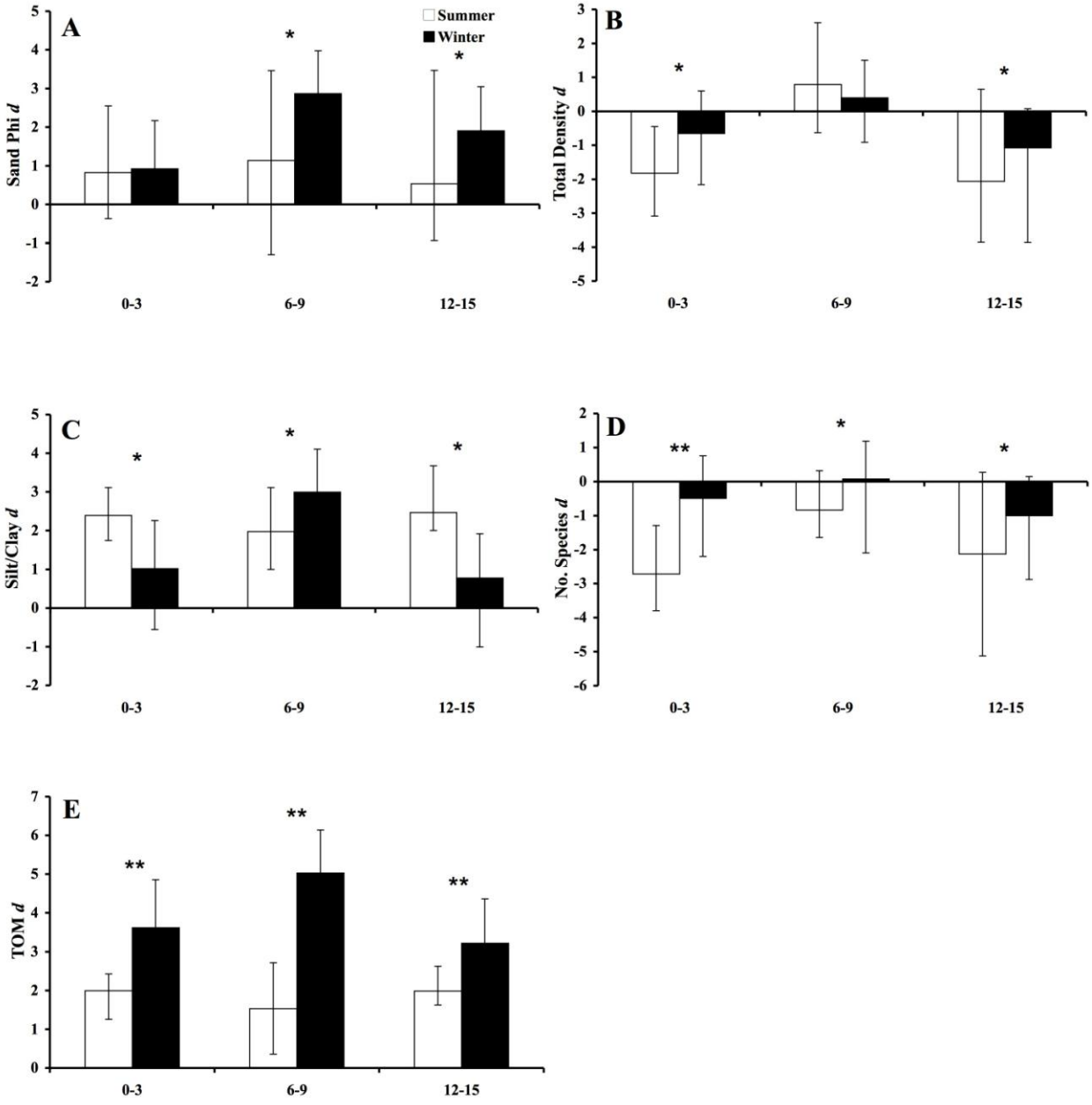

*Figure 10. Comparison of the effect sizes (Hedge's d) for several sediment characteristics and biological community measures between borrow areas dredged predominantly in the summer or the winter. *=significant difference at $p < 0.05$ using comparison to chi-square distribution, ** = significant difference at $p < 0.10$ using the more conservative randomization test.*

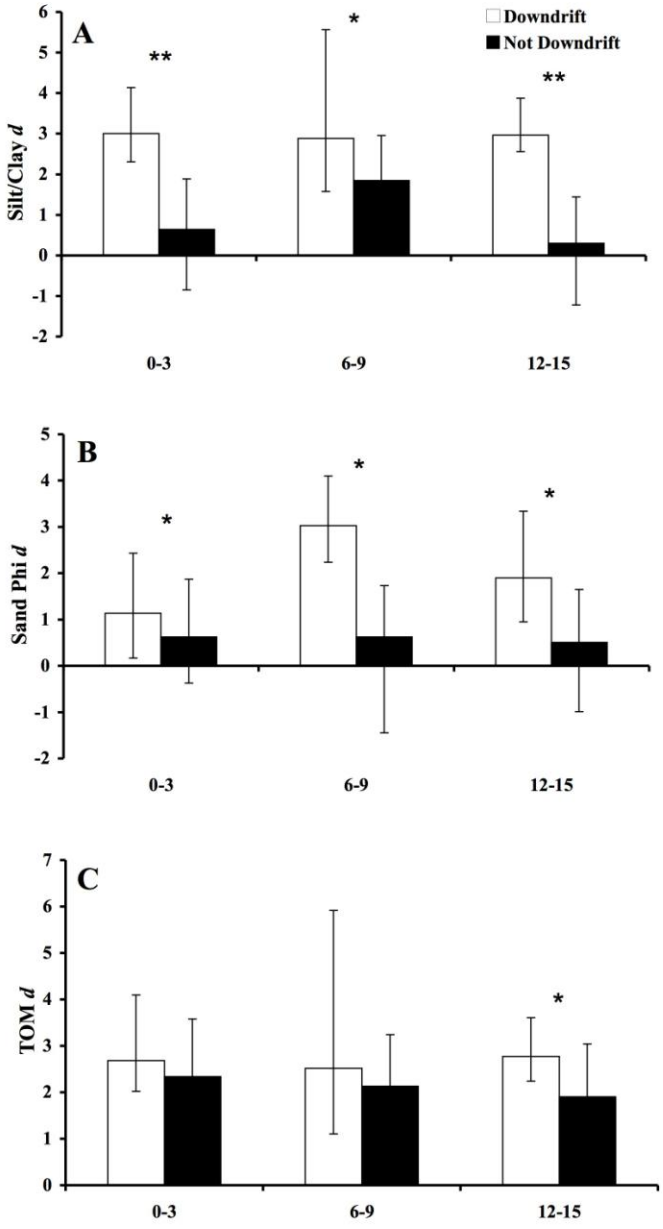

*Figure 10. Comparison of the effect sizes (Hedge's d) for several sediment characteristics borrow areas dredged downdrift of or within inlets or tidal creeks/rivers and those not located in those environments. *=significant difference at $p < 0.05$ using comparison to chi-square distribution, ** = significant difference at $p < 0.10$ using the more conservative randomization test.*

monitored. The implication of this broad pattern is that borrow areas placed in locations within or downdrift of major tidal inlets will likely refill with material incompatible with beach sediments and so will not provide a sustainable source of beach fill.

Application of Meta-analysis to Beach Nourishment Studies and Other EIAs

The application of formal meta-analysis to BACI designed EIAs solves many of the statistical problems associated with the analysis and interpretation of these studies in a broad context. Complex BACI study designs and analyses stem primarily from a pseudoreplication in more simple BACI designs (Hurlbert 1984) and the need to account for natural spatial and temporal variability (Stewart-Oaten et al. 1986; Underwood 1992, 1994). Meta-analysis treats each separate impact event (or EIA) as a single data point, thus eliminating the within-study pseudoreplication common in EIAs, and multiple impact events and EIAs represent true replicates. Treating the data in this manner does not remove the effects of natural variation, but the effect sizes (Hedge's d) from many events/studies form a sampling distribution that includes this variation. As a result, even the simplest BACI design study can be used in tests to elucidate general environmental responses to anthropogenic disturbances under a wide range of conditions

Application of meta-analysis to beach nourishment monitoring studies in South Carolina demonstrated that consistent and predictable changes occur in borrow areas and, to a lesser extent, on nourished beaches. Although the small number of monitored nourishment projects and inconsistent study designs limited the direct management questions that could be empirically addressed, the analyses that were possible showed the value of using a meta-analysis approach to study large scale environmental issues. The database created during the course of this project now has a general structure that can accept data from a wide array of sources, including studies out-of-state. Expansion of the database to include projects performed in other southeastern states (and eventually beyond) should provide the sample sizes needed to expand the scope of the current study. The adaptation of meta-analytic procedures to handle BACI-design data resulting from common EIAs should find application to a wide array of resource management questions outside of beach nourishment as well.

RECOMMENDATIONS

Monitoring Program Design and Analysis

No single monitoring scheme will fit all situations, however, a substantial body of literature exists on rigorous sampling and analysis protocols relevant to beach nourishment projects. Table 3 summarizes the recommendations of five different sources as they relate either to detecting dredging and nourishment impacts or to sampling beach environments. When combined with the results of the meta-analysis performed as part of this study, these provide a solid foundation for a series of broad recommendations to standardize dredging and nourishment impact monitoring. These recommendations are listed below and are expanded upon in a following section.

Study Design:

***Recommendation 1*: All beach and borrow monitoring programs should utilize a Before-After-Control-Impact (BACI) design.**

***Recommendation 2*: When feasible, impact and control locations should be sampled at multiple time points both before and after the impact event occurs.**

***Recommendation 3*: Where feasible, multiple impact (when possible) and multiple control locations should be monitored, and control and impact locations should be spatially interspersed.**

***Recommendation 4*: Monitoring should begin as much as one-year in advance of the impact and continue following the impact until recovery has been documented.**

***Recommendation 5*: Preliminary data should be collected or historical data mined to determine efficacy of sampling protocols and to calculate minimum sample sizes through power analysis.**

Sample Collection:

***Recommendation 6*: Sampling stations should be established randomly within delineated impact and associated control locations.**

***Recommendation 7*: Physical and biological parameters should be collected concurrently within stations, transects, and/or samples.**

***Recommendation 8*: At a minimum, the following physical environmental parameters should be monitored/calculated in borrow areas and their associated control locations: bottom topography (borrow only), average depth of dredging below grade, refilling rates (borrow only), and surficial sediment composition.**

***Recommendation 9*: At a minimum, the following physical environmental parameters should be monitored/calculated in nourished beach areas and their associated control locations: beach width, berm elevation, beach slope, and surficial sediment characteristics.**

***Recommendation 10*: At a minimum, the following biological parameters should be monitored/calculated in borrow areas and their associated control locations: benthic infauna densities, number of infaunal species, identities and densities of individual species, and densities of major taxonomic groups.**

***Recommendation 11*: At a minimum, the following biological parameters should be monitored/calculated in nourished beach areas and their associated control locations: densities of major beach invertebrate taxa/species.**

***Recommendation 12*: Within a single EIA, project protocols including sample sizes and sampling gear should be consistent through time.**

Data Analysis and Reporting:

***Recommendation 13*: Appropriate summary statistics (mean, median, standard deviations, sample sizes, etc.) should be calculated and shown in tables or figures to illustrate temporal changes in the impact and control locations.**

***Recommendation 14*: Appropriate inferential statistics should be used to determine the significance of any effect of dredging or nourishment on physical and biological characteristics of beach and borrow locations.**

***Recommendation 15*: Biological community data should be analyzed using modern multivariate statistical techniques.**

***Recommendation 16*: Within one year of the final monitoring event, a report analyzing, presenting and appending all data from the entire monitoring effort should be completed.**

***Recommendation 17*: All reports should include clear interpretation of broad patterns and trends, including discussion of significant statistical results (or lack thereof) and relevant environmental, ecological, and/or geologic consequences.**

***Recommendation 18*: Establish a scientific peer-review process for monitoring reports.**

***Recommendation 19*: All final monitoring reports should be disseminated to relevant state and federal agencies as well as the town and county governments funding or affected by the nourishment project.**

Research Needs:

***Recommendation 20:* Perform statistical power analysis on existing monitoring data to constrain minimum sample sizes needed to detect dredging and nourishment impacts.**

***Recommendation 21:* Determine whether identifying benthic infauna to a courser taxonomic resolution and increasing sample sizes can improve statistical power and reduce cost.**

***Recommendation 22*: Broaden monitoring priorities to include less-studied organisms, habitats, and ecological processes.**

***Recommendation 23*: Develop and improve models for the physical and biological processes driving dredging and nourishment impacts under a range of environmental conditions.**

Justification and Feasibility of Recommendations

***Recommendation 1*: All beach and borrow monitoring programs should utilize a Before-After-Control-Impact (BACI) design.**
Justification--The BACI study design ensures that natural spatial and temporal variability are taken into account when the data are collected and analyzed. This design incorporates two key components: 1) sampling at both the impacted location (borrow area or nourished beach) and un-impacted control locations (of same habitat type as the impacted areas but not affected by dredging or nourishment), and 2) sampling both before and after the impact at both the impacted and control locations. The purpose of this design is to allow the researchers to examine whether the impacted location changed differently than the control location between the before and after time points. Without the control locations, any changes that occurred at the impact site would be confounded with natural temporal variability. Without before and after sampling at both locations, differences between the impact and control locations would be confounded with natural spatial variability. The core assumption of the BACI design is that if the impact event had no effect, the control and impact areas would be expected to change the same through time, thus any differences between their before and after changes would reflect the influence of the impact event. Because this core assumption is not likely to be universally true, several researchers have offered improvements on the basic BACI design (see recommendations 2 and 3).
Feasibility--*Most beach nourishment monitoring studies performed in South Carolina have employed a simple BACI design, so implementation of this recommendation should not be difficult.*

***Recommendation 2*: When feasible, impact and control locations should be sampled at multiple time points both before and after the impact event occurs.**
Justification--Stewart-Oaten et al. (1986) pointed out that a single "before" and a single "after" sampling event produces only a single data point for each time period, resulting in a temporally unreplicated study design. They recommended that a temporally replicated design could be attained, at least within the study, by collecting data at multiple random time points both before and after the impact event.
Feasibility--*All monitoring studies performed in South Carolina have included sampling at multiple times after the impact, but some have not included sampling at multiple times before the impact. The lack of additional sampling before the impact typically results from short project time scales due to inadequate planning, lack of sufficient funding and failure of agencies/organizations to clearly communicate time tables, thus implementation of this recommendation would require better planning and communication amongst the parties involved. Although random time points are preferable in a strict statistical sense, multiple time points sampled at fixed intervals (for example, immediately after, 6 months after, one year after, etc.) are probably preferable when funding and the number of sampling opportunities is limited.*

Table 3. Summary of recommendations for the monitoring and analysis of dredge and nourishment impacts based on six different sources. Schlacher et al. (2008) described sampling methodologies for beach macroinvertebrates in general rather than for detecting beach nourishment impacts. Peterson and Bishop (2005) is primarily a critique of monitoring studies, but many recommendations were implied.

Study Characteristic	USACE (1973)	Nelson (1993)	NRC (1995)	Peterson and Bishop (2005)	Schlacher et al. (2008)
Study Design					
Controls	Beach: *Physical and Biological*—Spatial; before, during, and after Borrow: *Physical and Biological*—Spatial; before, during, and after	Beach: *Biological*--Temporal and spatial; Before-After-Control-Impact type	Beach: *Physical and Biological*—Spatial; before, during, and after Borrow: *Physical and Biological*—Spatial; before, during, and after	Beach: *Physical and Biological*—Before-After-Control-Impact type Borrow: *Physical and Biological*—Before-After-Control-Impact type	
Interspersion		Beach: *Biological*--When feasible; at least, multiple sampling locations separated by kilometers within impact area		Beach: *Physical and Biological*—When feasible; at least bracket impact location with control locations; ensure independence of impact and control locations Borrow: *Physical and Biological*—When feasible; at least bracket impact location with control locations	
Preliminary Studies		Beach: *Biological*—evaluate efficacy number of replicates needed; species area curves and power analysi	Beach: *Biological*—evaluate appropriate sample design and sample size Borrow: *Biological*—evaluate appropriate sample design and sample size	Beach: *Physical and Biological*—power analysis Borrow: *Physical and Biological*—power analysis	

Study Characteristic	USACE (1973)	Nelson (1993)	NRC (1995)	Peterson and Bishop (2005)	Schlacher et al. (2008)
Study Design					
Timing and Duration	Beach: *Physical and Biological*—Monitoring short-term and project-oriented; Fundamental research longer-term Borrow: *Physical and Biological*— Monitoring short-term and project-oriented; Fundamental research longer-term	Beach: *Biological*—At least 3 months before and 12 months after impact	Beach: *Physical and Biological*—Before impact and for lifetime of project after impact	Beach: *Physical and Biological*—prior to impact and until recovery demonstrated Borrow: *Physical and Biological*—prior to impact and until recovery demonstrated	
Other Aspects				Beach: *Physical and Biological*—Experimental manipulations; Modelling Borrow: *Physical and Biological*—Experimental manipulations; Modelling	
Sample Collection					
Location		Beach: Align monitoring locations positions with coast or geodetic survey markers			
Sample layout within location		Beach: *Biological*—Nested sampling; Several shore-perpendicular transects across intertidal and subtidal zones;		Beach: *Physical and Biological*—Spatial and temporal nesting	Beach: *Biological*—samples distributed randomly through sampling area; shore-perpendicular transects;

Study Characteristic	USACE (1973)	Nelson (1993)	NRC (1995)	Peterson and Bishop (2005)	Schlacher et al. (2008)
***Sample* Collection**					
Sample layout within location cont…		Sample based on physical features (swash, etc) instead of a-priori distances or positions; Minimize number of transects to allot effort to additional locations		Borrow: *Physical and Biological*—Spatial and temporal nesting	samples collected in drift line, mid-shore, low-water swash zone, and surf zone
Sample size within location		Beach: *Biological*--Collect replicate samples; equal numbers when possible; at finest sampling level, more smaller samples; 10 7.6 cm cores from each location-time combination			Beach: *Biological*—total across shore collection area of 0.3 m^2; replicate samples taken at each across-shore level
Collection apparatus	Borrow: *Physical and Biological*--Divers	Beach: *Biological*--handheld-corer with 7.6 cm diameter	Nearshore: *Physical*—diver and underwater video; side-scan sonar; underwater camera and video; subbottom profiling	Beach: *Physical and Biological*—Push cores Borrow: *Physical and Biological*—Push cores	Beach: *Biological*—circular frames in the form of large cores; core to depth of 25cm
Parameters measured	Beach: *Physical*—Sediment and turbidity; Sedimentation; Substrate characteristics; Benthic-pelagic coupling; *Biological*—Material and energy flow; Biotic-abiotic interactions Borrow: *Physical*—Rates of refilling; Turbidity; Sedimentation;	Beach: *Biological*—Macrofauna retained on 0.5mm sieve; simple measures best such as densities, identities, and number of species	Beach: *Physical*—habitat type; nearshore turbidity; measures needed for sand budget, site history, and profiles; sediment characteristics including mineralogy, specific gravity, mean grain size, grain size distribution, and settling velocity; photographic	Beach: *Physical*—Turbidity; Mean grain size; Sediment grain size distribution; Hard substrata (shell and rock); Mineralogy; Organic content; Compaction; Surface topography *Biological*—Demersal fish; Shore birds; Abundance and biomass of all macroinvertebrate	Beach: *Physical*—wave, wind, tide regime; wave height and period, profile slope, sediment grain size, tidal range; geomorphological data; swash dimensions and climate; depth of reducing sediment layer *Biological*—Macrofauna retained in 1.0mm mesh sieve bag

Study Characteristic	USACE (1973)	Nelson (1993)	NRC (1995)	Peterson and Bishop (2005)	Schlacher et al. (2008)
Sample Collection					
Parameters measured cont…	Types of sediments, Currents and tides; Substrate characteristics; Benthic-pelagic coupling; *Biological*--Biotic-abiotic interactions; Biological community succession		documentation *Biological*—species composition, abundance and distribution <u>Nearshore:</u> *Physical*—Reef habitat *Biological*—fishery resources <u>Borrow:</u> *Physical*—sediment characteristics including mineralogy, specific gravity, mean grain size, grain size distribution, and settling velocity	fauna and selected taxa; size frequencies; biodiversity indices; physiological state; Process rates of predation, recruitment, etc. <u>Nearshore:</u> *Physical and Biological*—sedimentation of reef habitats <u>Borrow:</u> *Physical*—Turbidity; grain size; Sediment grain size distribution; Hard substrata (shell and rock); Mineralogy; Organic content; Surface topography; Sedimentation *Biological*— Abundance and biomass of all macroinvertebrate fauna and selected taxa; size frequencies; biodiversity indices; physiological state	
Sampling interval	<u>Beach:</u> *Physical and Biological*—frequent intervals during activities <u>Borrow:</u> *Physical and Biological*—frequent during activities	<u>Beach:</u> *Biological*—at least monthly for 3 months prior to impact and 9-12 months following impact; biweekly for two months following impact			

Study Characteristic	USACE (1973)	Nelson (1993)	NRC (1995)	Peterson and Bishop (2005)	Schlacher et al. (2008)
Sample Collection					
Other aspects					Beach: *Biological*—collect during low tide; collect during low recruitment seasons; do not fix specimens in sediment
Data Analysis					
Inferential Statistics		Beach: *Physical and Biological*—Nested analyses to investigate several levels of variation; Multifactor ANOVA to test differences in area and time simultaneously with "area by times" interaction; Analyze different beach levels separately with 2-way ANOVA instead of 3-way		Beach: *Physical and Biological*—Nested analysis to partition out scales of variability; Analysis of variance to isolate impact from natural spatial and temporal variability; Analyzing relationships between physical and biological factors Borrow: *Physical and Biological*—Nested analysis to partition out scales of variability; Analysis of variance to isolate impact from natural spatial and temporal variability; Analyzing relationships between physical and biological	

Study Characteristic	USACE (1973)	Nelson (1993)	NRC (1995)	Peterson and Bishop (2005)	Schlacher et al. (2008)
Data Analysis					
Multivariate Statistics				Beach: *Biological*—Use multivariate techniques to assess community-level response; non-metric Multidimensional Scaling (n-MDS) to test hypotheses and relate biological changes to physical changes Borrow: *Biological*—Use multivariate techniques to assess community-level response; non-metric Multidimensional Scaling (n-MDS) to test hypotheses and relate biological changes to physical changes	
Modelling	Beach: *Biological*—Construct mathematical models Borrow: *Biological*— Construct mathematical			Beach: *Biological*—Models for fish dynamics Borrow: *Biological*—Models for fish dynamics	

***Recommendation 3*: Where feasible, multiple impact and multiple control locations should be monitored, and control and impact locations should be spatially interspersed.**
Justification--Underwood (1992, 1994) indicated that a BACI designed study with only one impact and one control location is spatially unreplicated and the power to detect temporal interactions across the two locations is low. He suggested that although the impact sampling may be restricted to a single location (and by necessity will be unreplicated), an asymmetrical design involving sampling at multiple control locations could detect impacts when different locations show temporal interaction (different locations naturally change differently over time). To minimize the influence of natural spatial and temporal variability on study results, impact and control locations should be interspersed as much as possible (Hurlbert 1984). At the very least, an impact location should be bracketed by two control locations.
Feasibility--*Several monitoring programs have used more than one control, a practice more commonly employed on the beach than in borrow areas. A few studies have interspersed impacts and controls on the beach, but this, also, has not been done for borrow areas. Typically no more than a single borrow area is used on a single project, but a single borrow area could be bracketed by two control areas.*

***Recommendation 4*: Monitoring should begin as much as one-year in advance of the impact and continue after the impact until recovery has been documented.**
Justification--No general guidelines are available regarding when impact monitoring should begin or end. Because both physical and biological processes vary somewhat predictably over the course of a year, capturing this variation both before and after impact is appropriate. Nourishment impacts to beach systems tend to be short-term, showing evidence of biological recovery with 3-6 months. Borrow area impacts tend to occur more slowly and persist for longer periods of time. The data presented here suggest that recovery of bottom sediment characteristics (critical to the reuse of an area in future nourishment projects) may not occur even within two years at some locations. No projects have monitored beyond two years, so the length of time for recovery is not known.
Feasibility--*All beach nourishment monitoring studies performed in South Carolina have included sampling for at least one-year after the impact and a few have continued annually for two years, so this part of the recommendation should prove feasible. Due to the problems with project time tables described in recommendation 2, sampling for one year prior to the impact may not be possible for all projects, but it is recommended that sample collection begin as soon as the intended borrow area and the nourished beach have been delineated and funding has been secured. To ensure sufficient pre-impact sampling has occurred field samples could be collected at the earliest possible time in the permitting process and laboratory processing of those samples (the most costly component of a monitoring study) could be delayed until funding is secured.*

***Recommendation 5*: Preliminary data should be collected or historical data mined to determine efficacy of sampling protocol and to determine minimum sample sizes through power analysis.**
Justification--Statistical power is the ability of a study to detect a difference when a difference truly exists, and a formal power analysis can show the analyst both the magnitude of difference detectable by the study and the sample size needed to detect a difference of a given magnitude (Peterman 1990; Sheppard 1999). Peterson and Bishop (2005) argued that low statistical power arising from improper sampling design and sample sizes has contributed significantly to the failure of past studies to detect nourishment impacts.

Feasibility--*No formal power analysis has been reported from any of the monitoring projects performed in South Carolina. For minimal effort, small preliminary studies or historical data records could provide the data necessary to estimate sample variance and calculate sample size needed to detect an impact.*

***Recommendation 6*: Sampling stations should be established randomly within delineated impact and associated control locations.**
Justification--Randomization is crucial to avoiding investigator bias and is a key assumption of most statistical procedures. For example, choosing to monitor a borrow area at its shallowest point because those are most accessible would bias the entire collection to shallow environments while not collecting any information of the deeper environments.
Feasibility--*Studies performed in South Carolina have generally randomized sampling stations within impact and control locations. However, some studies (especially those on the beach) have either haphazardly chosen stations or aligned stations with some other existing monitoring component. Excepting situations where impact monitoring needs to coincide with some other study component, true randomization is simple and should be feasible.*

***Recommendation 7*: Physical and biological parameter measurements should be collected concurrently within stations, transects and/or samples.**
Marine benthic systems are extremely patchy, thus to examine the relationships between physical and biological changes resulting from an impact, these measures must be collected concurrently.
Feasibility--*Paired physical and biological measurements are simple to perform and have been used by most monitoring projects performed in South Carolina*

***Recommendation 8*: At a minimum, the following physical environmental parameters should be monitored/calculated in borrow areas and their associated control locations: bottom topography (borrow only), average depth of dredging below grade, refilling rates (borrow only), and surficial sediment characteristics (silt, clay, sand, shell/calcium carbonate, and organic matter content).**
Justification—Characteristics of the borrow area that may influence the impact and recovery of benthic habitats are often not reported and yet are critical to interpreting other environmental data and to understanding the conditions under which borrow areas recover most quickly. Sediment characteristics including mud, (silt and clay), sand, shell, and organic matter content and sand grain size are important controlling factors of benthic communities. Continued collection of these sediment characteristics adds to a strong historical data record for sand borrow areas that will prove increasingly important to improving borrow area site selection. Sand grain size measures (phi, sorting, etc.) should be determined when possible, but the greater cost of performing this analysis does not justify requiring it, especially considering the similarity in response to dredging between phi size and silt/clay content (both represent measures of fine material accumulation).
Feasibility—*These recommended parameters (or at least the data needed to calculate them) are already routinely collected for many borrow areas.*

***Recommendation 9*: At a minimum, the following physical environmental parameters should be monitored/calculated in nourished beach areas and their associated control locations: beach width, berm elevation, beach slope, and surficial sediment characteristics (mud, sand, shell/calcium carbonate, and organic matter content).**
Justification—These parameters describe the most basic characteristics of the beach environment. In many cases these measures are important to both the native biological

communities as well as to the people using the beach. Although South Carolina has not seen substantial changes in beach sediment characteristics following nourishment, such changes have occurred in other states with significant negative consequences for the functioning of beach systems.
Feasibility— *Many of these recommended parameters (or at least the data needed to calculate them) are already routinely collected.*

***Recommendation 10*: At a minimum, the following biological parameters should be monitored/calculated in borrow areas and their associated control locations: benthic infauna densities, number of infaunal species, identities and densities of individual species, and densities of major taxonomic groups.**
Justification—Benthic invertebrate communities serve as prey for a wide range of fish and other important epibenthic invertebrates (such as crabs and shrimp). While changes in the biological communities of borrow areas may reflect in part changes in local sediment characteristics, this study showed that the latter can not be used to reliably predict the former.
Feasibility—*Benthic infaunal community measures were the most common parameters reported from monitoring studies. Further studies into the use of higher taxonomic levels (for example, genus or family) in place of species-level identifications could make these time-consuming and complex measures more feasible.*

***Recommendation 11*: At a minimum, the following biological parameters should be monitored/calculated in nourished beach areas and their associated control locations: densities of major beach invertebrate taxa/species.**
Justification—Beach invertebrate fauna are important to beach food webs, forming a majority of the diet for many shorebirds and surf zone fish. These fauna are diverse, but the dominant taxa are surprisingly homogenous over broad spatial scales. Most studies on South Carolina's beaches have found a rather rapid recovery of the biological community, but in other states substantial changes have been documented in taxa also found here: surf clams (*Donax* spp.), mole crabs (*Emerita* spp.), and burrowing ghost crabs (*Ocypode* spp). There is also evidence that some fauna show a pattern of long-term (one year or more) impacts (SCDNR, unpublished data). This suggests that these important invertebrate taxa respond to at least severe changes in beach characteristics following nourishment and thus represent an important indicator of nourishment impact, even if substantial impacts have not been documented in previous projects in this state.
Feasibility—*Beach infaunal communities are simpler than those found in borrow areas and have been examined in several past monitoring studies. By focusing on some of the dominant taxa important to beach food webs rather than identifying all organisms, collection should be simple and processing times short as these species are easy to locate and identify.*

***Recommendation 12*: Within a single EIA, project protocols including sample sizes, sampling gear, and sample processing methodology should be consistent through time.**
Justification—Consistent sampling methodology and sample processing is a pre-requisite to ensure data are interpretable. Without this consistency, any changes resulting from dredging and nourishment activities could be confounded with changes in methodology.
Feasibility—*Most monitoring studies already use consistent sampling methodology throughout the monitoring period*.

***Recommendation 13*: Appropriate summary statistics (mean, median, standard deviations, sample sizes, etc.) should be calculated and shown in tables or figures to illustrate temporal changes in the impact and control locations.**
Justification--It is almost impossible to draw broad conclusions about the effects of an impact from large amounts of individual data points. Summary statistics whether parametric (mean, variance, standard deviation) or non-parametric (median, interquartile range) allows large amounts of data to be clearly presented and trends elucidated. Without these, the results of the monitoring effort will not be interpretable or informative to the public or the state and federal agencies that require the data.
Feasibility--*With only a few exceptions, South Carolina reports have included necessary summary statistics.*

***Recommendation 14*: Appropriate inferential statistics should be used to determine the significance of any effect of dredging or nourishment on physical and biological characteristics of beach and borrow locations.**
Justification—Summary statistics can illustrate trends and differences, but they do not indicate whether those trends or differences are significant. Inferential statistics, those that allow the testing of a hypothesis such as "sand content will decrease following dredging in the borrow area", are critical to an EIA. The techniques for applying general linear models (Analysis of Variance, Regression, etc.) to BACI study designs has been well-developed in the literature (Green 1979; Stewart-Oaten et al. 1986; Underwood 1992, 1994), and should be used when possible. Several well-known statistics texts clearly describe the theory and application of these methods (Sokal and Rohlf 1995; Zar 1999).
Feasibility--*Even if the more complex methods described by the sources cited above do not apply to specific study designs, more simplistic statistical analyses can be performed (albeit with often less clear interpretation and lower statistical power). The software available to perform these analyses is widely available.*

***Recommendation 15*: Biological community data should be analyzed using modern multivariate techniques.**
Justification--Community-level biological data sets are extremely complex. While some individual taxa may provide useful information (for example, when a species in known to be sensitive to changes in sediment characteristics), analysis of the entire community is necessary to understand broad changes resulting from an impact, which species respond most strongly, and what physical environmental changes drive community changes. Such analyses can be performed using a wide range of multivariate statistics including Principle Components Analysis (PCA), Canonical Correspondence Analysis (CCA), and non-metric Multi-Dimensional Scaling (n-MDS), among others.
Feasibility--*An array of multivariate techniques have been applied to beach nourishment impact assessments in South Carolina. The computer programs to perform these analyses are affordable and readily available from a number of sources.*

***Recommendation 16*: Within one year of the final monitoring event, a report analyzing, presenting, and appending all data from the entire monitoring effort should be completed.**
Justification—A final report that includes all summarized and raw data and analytical results is critical to identifying the impact and performance of beach nourishment projects. This final report should present all data from the entire monitoring effort, although this may be separated into component-specific reports (for example: beach impacts and borrow area impacts). We recommend that interim reports describing individual time period assessments, such as pre-

impact conditions only) be optional and at discretion of the funding agency. Interim reports of ecological impact serve little purpose in the absence of potential remedial action resulting from monitoring findings.
Feasibility—*Many agencies impose shorter deadlines on these reports, so this recommendation only ensures that all monitoring is ultimately reported. The recommendation that interim reports be optional reduces workload and allows more effort be placed into creating a higher-quality final product of greater long-term use to managers.*

Recommendation 17: All reports should include clear interpretation of broad patterns and trends, including discussion of significant statistical results (or lack thereof) and relevant environmental, ecological, and/or geologic consequences.
Justification—Clear and informed interpretation including comparisons to other projects and studies provides managers the take-home messages needed to judge project performance and impact. This should include concise interpretation of the results of statistical analyses in terms that a reasonably well-informed technical reader can understand. This should also include comparisons with other nourishment projects and descriptions of the environmental, ecological, and/or geologic consequences of the changes (or lack thereof) detected through sampling and analysis.
Feasibility—*Any agency/entity performing these studies should have an individual on staff trained in the relevant scientific discipline that is capable of interpreting the patterns detected. Any agency/entity lacking such expertise will have to acquire it, potentially at significant cost.*

Recommendation 18: Establish a scientific peer-review process for monitoring reports.
Justification—Peer review is the most basic form of checks and balances for the scientific community. It is critical to ensuring that data have been collected and analyzed properly, presented clearly, and interpreted accurately. A list of potential reviewers and their fields of specialization should be compiled and made available to those performing beach nourishment monitoring.
Feasibility—*Many beach nourishment monitoring reports have been reviewed at some level, although this is often a rather informal process. Although sometimes time-consuming, performing peer-review of technical documents is a basic obligation of all scientists, so a formal review process is a realistic goal.*

Recommendation 19: All final monitoring reports should be disseminated to relevant state and federal agencies as well as the town and county governments funding or affected by the nourishment project.
Justification—Communication amongst federal, state, and local governments, various private companies, and academic interests regarding the design, implementation, schedule, and results of monitoring activities is often inconsistent or non-existent. At the very least, all final reports documenting project performance and impact should be disseminated to resource management agencies (USACE, USFWS, DHEC-OCRM, and SCDNR) as well as the local governments affected by the nourishment activities. This ensures managers obtain the most recent data on beach nourishment and improves public access to the results of monitoring efforts.
Feasibility—*Printing (or digitizing) is common for these reports, and many are already provided to some agencies per contract requirements, thus mailing of reports to critical parties should be feasible at little additional cost.*

Recommendation 20: Perform statistical power analysis on existing monitoring data to constrain minimum sample sizes needed to detect dredging and nourishment impacts.

Justification—Currently, the statistical power of beach nourishment monitoring studies (the ability to detect an impact when an impact has occurred) is either moderate to low or is unknown. Statistical power can be improved by increasing sample size, but a coordinated power analysis is necessary to determine realistic sample sizes and statistical power for monitoring studies. Little if any published analyses are available to guide decisions regarding sample size and the power of statistical tests for beach nourishment and nearshore dredging studies. Until such analyses are performed, recommendations regarding minimum sample sizes are not possible.
Feasibility—*Existing data for monitoring studies extending the full length of South Carolina's coast could be used to estimate variance in various physical and biological responses of interest. With this, minimum sample sizes for monitoring the beaches and borrow areas under different environmental conditions could be derived.*

***Recommendation 21:* Determine whether identifying benthic infauna to a courser taxonomic resolution and increasing sample sizes can improve statistical power and reduce cost.**
Justification—Among the greatest costs in monitoring studies is the staff time required to identify benthic infauna to the species level. As a result, costs are usually controlled by processing some minimum number of samples to characterize an impact or control area, a practice that potentially adversely affects statistical power. Studies in other systems have shown that family and genus level identifications can provide a good representation of species at a fraction of the cost of identifying samples to the species level (James et al. 1995, Balmford et al. 1996, Sanchez et al. 2006). If this is also true on beaches and in subtidal sand flats used for borrow areas, statistical power could be improved without loss of impact detection capability by identifying organisms at a coarser taxonomic resolution in larger number of samples without a substantial increase in cost.
Feasibility—*The large volumes of existing data on South Carolina's beaches and subtidal sand flats means little if any new data would be needed to perform these analyses. The techniques involved in these analyses are well-described in the literature. This kind of analysis is both feasible and urgently needed.*

***Recommendation 22:* Broaden monitoring priorities to include less-studied organisms, habitats, and ecological processes.**
Justification--Many important ecological responses to beach nourishment have been under-investigated or entirely ignored, yet deserve closer attention. The response of fish (including many economically important species), birds, and terrestrial wildlife have rarely been studied in a systematic manner. While some studies have shown the impacts to be minor and short-lived (finfish: Wilber et al. 2003, Van Dolah et al. 1992, 1994), other studies have shown significant changes (shorebirds: Peterson et al. 2006). Entire habitats such as the subtidal nearshore and habitats surrounding borrow areas have received only limited study, yet may be impacted (Rakocinski et al. 1996). Most nourishment monitoring has involved measurement of state variables (standing crop densities, volume, etc) with no attention given to ecological processes such as production, respiration, trophic energy transfer and nutrient and material cycling. Measurement of process rates is common when assessing nourishment project performance (rate of sediment loss, rate of erosion, etc), yet it receives no attention from an ecological perspective.
Feasibility—*Addressing this recommendation should be feasible as a long-term goal, but will require careful planning, identification of priorities, and cooperation amongst monitoring agencies.*

***Recommendation 23*: Develop and improve models for the physical and biological processes driving dredging and nourishment impacts under a range of environmental conditions.**
Justification—Determining the optimum locations and times for dredging and nourishment will require substantial research and accurate models of environmental responses to these large-scale disturbances. This study has shown that environmental responses vary widely across different dredging and nourishment projects, suggesting that better project design is possible. Project design could be much more well-informed with a better understanding of the effect of a range of factors including local geologic conditions, sediment transport processes, recruitment patterns, and import and export of biological production on the impact of nourishment operations. Due to the complex nature of the many interactions involved, modeling is likely the best option for predicting and minimizing future impacts
Feasibility—*This recommendation should be considered a longer-term and iterative goal, but the knowledge base and expertise exists to begin addressing many of these issues.*

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Appendix 1. Primary sources of data and reports included in this study.

Applied Technology and Management, Inc
360 Concord St. Suite 300
Charleston, SC 29401
Phone: (800) 275-6488
Website: http://www.appliedtm.com/
Current Contacts: Paul Carroll

Coastal Science and Engineering, LLC
PO Box 8056
Columbia SC 29202-8056
Phone: (803) 799-8949
Website: http://www.coastalscience.com/
Current Contacts: Dr. Tim Kana

Coastal Science Associates, Inc.
5000 Thurmond Mall
Columbia, SC 29201
Phone: (803) 256-5547
Current Contacts: Stephen Florey, Chris Potter

Coastal Science Associates, Southern Affiliate, Inc.
840 Natures Cove Road
Dania Beach, FL 33004
Phone: (954) 926-5426
Website: http://csasouth.com/
Current Contact: Dr. Bart Baca

Olsen Associates, Inc
4438 Herschel Street
Jacksonville, Florida 32210 USA
Phone: (904) 387-6114
Website: http://www.olsen-associates.com/
Current Contacts: Chris Creed

South Carolina Department of Health and Environmental Control
Office of Ocean and Coastal Resource Management
1362 McMillan Ave., Suite 400
Charleston, SC 29405
Phone: (843) 953-0200
Website: http://www.scdhec.net/environment/ocrm/
Current Contacts: Braxton Davis, Bill Eiser

South Carolina Department of Natural Resources
Marine Resources Research Institute
217 Fort Johnson Road
P.O. Box 12559
Charleston, South Carolina 29422-2559
Phone: (843) 953-9819
Website: http://www.dnr.sc.gov/marine/mrri/mrri.htm
Current Contacts: Dr. Robert Van Dolah, Dr. Derk Bergquist

US Army Corps of Engineers—Charleston District
69A Hagood Ave.
Charleston, SC 29403
Phone: (843) 329-8044
Website: http://www.sac.usace.army.mil/
Current Contacts: Shawn Boone, Patrick O'Donnell, Phillip Wolfe,

Appendix 2. Annotated bibliography of beach nourishment reports and publications in South Carolina

Daufuskie Island, South Carolina

CSA, Inc. 2001. Daufuskie Island Beach Nourishment Final Post-Dredge Monitoring Study. Final Report prepared by Coastal Science Associates, Inc. Columbia, South Carolina for Applied Technology & Management, Inc. Mt. Pleasant, South Carolina. 16pp. + appendices.

This report presents the results of the data collected during the final post dredge monitoring event. Sampling for this study was conducted on July 6, 7, and 11, 2000. All sampling and analyses for this study were performed in accordance with CSAi's SCDHEC approved Standard Operating Procedures Manual and Quality Assurance Plan (CSAi, 1999).

Debordieu Beach, South Carolina

CSA, Inc. 2006. Debordieu Beach Nourishment Pre-Dredge Environmental Monitoring Study November 2005. Monitoring Report prepared by Coastal Science Associates, Inc. Columbia, South Carolina for Debordieu Home Owners Association, Georgetown, South Carolina and Applied Technology & Management, Inc. Mt. Pleasant, South Carolina. 20pp. + appendices.

The community of Debordieu Beach in Georgetown County, South Carolina has placed approximately 600,000 cubic yards of sand over 8,000 linear feet of beachfront on Debidue Island, South Carolina (Figure 1). The sand was dredged from a borrow site located approximately 3 miles off Debordieu Beach, using a hydraulic cutter head and a hopper dredge (Figure 2). The project was approved by the Office of Ocean and Coastal Resource Management on December 14th, 2004.
The purpose of this report is to present the results of the pre-dredge monitoring survey. The report includes an assessment of the existing biological communities and provides a baseline reference data set for future macroinvertebrate impact studies. Sampling was conducted from November 15, 2005 through November 18, 2005.

CSA, Inc. 2007. Debordieu Beach Nourishment Post-Dredge Environmental Monitoring Study May 2006. Monitoring Report prepared by Coastal Science Associates, Inc. Columbia, South Carolina for Debordieu Home Owners Association, Georgetown, South Carolina and Applied Technology & Management Mt. Pleasant, South Carolina. 70pp. + appendices.

The community of Debordieu Beach in Georgetown County, South Carolina has placed approximately 600,000 cubic yards of sand over 8,000 linear feet of beachfront on Debidue Island, South Carolina (Figure 1). The sand was dredged with a hydraulic cutter head and a hopper dredge from a borrow site located approximately 3 miles off Debordieu Beach (Figure 5). The project was approved by the Office of Ocean and Coastal Resource Management on December 14th, 2004.
The purpose of this report is to present the results of the first post-dredge monitoring survey. The report includes a survey of the existing biological communities and provides and assessment of the impact of the dredge and fill event on the benthic macroinvertebrate population. Sampling was conducted from May 15, 2006 through

May 17, 2006. The first monitoring event was conducted in November 2006, prior to the dredge and fill event, to provide baseline data.

CSA, Inc. 2008. Debordieu Beach Nourishment Post-Dredge Environmental Monitoring Study May 2007. Monitoring Report prepared by Coastal Science Associates, Inc. Columbia, South Carolina for Debordieu Home Owners Association, Georgetown, South Carolina and Applied Technology & Management Mt. Pleasant, South Carolina. 36pp. + appendices.

The community of Debordieu Beach in Georgetown County, South Carolina has placed approximately 600,000 cubic yards of sand over 8,000 linear feet of beachfront on Debidue Island, South Carolina (Figure 1). The sand was dredged with a hydraulic cutter head and a hopper dredge from a borrow site located approximately 3 miles off Debordieu Beach (Figure 5). The project was approved by the Office of Ocean and Coastal Resource Management on December 14th, 2004.
The purpose of this report is to present and analyze the results of three surveys to date; it supercedes and replaces all previous reports. The report provides an assessment of the impact of the dredge and fill event on the benthic macroinvertebrate population. Sampling for this third survey was conducted on May 15, 16, and 24, of 2007.

Edisto Beach, South Carolina

CUBIT. 1981. Edisto Beach groin field evaluation. Prepared by Cubit Engineering, Ltd., Charleston, South Carolina for Town of Edisto Beach, South Carolina.

CUBIT. 1987. Shorefront management plan, Edisto Island: Jeremy Inlet to Big Bay Creek, South Carolina. Vol. I. Management Program. Vol. II. Supporting Studies. Prepared by Cubit Engineering, Ltd., Charleston, South Carolina for South Carolina Coastal Council. 2 Volumes

PRT. 1989. Beach nourishment proposal: Edisto Beach State Park. Prepared by South Carolina Department of Parks, Recreation and Tourism, Division of Engineering and Planning, Columbia, South Carolina for South Carolina Coastal Council. 10pp + attachments.

CSE. 1990. Erosion assessment and beach restoration alternatives for Edisto Beach State Park, South Carolina. Feasibility Study prepared by Coastal Science & Engineering, Inc. Columbia, South Carolina for South Carolina Department of Parks, Recreation and Tourism Columbia, South Carolina. 59pp + appendices.

This report outlines findings and recommendations regarding beach restoration alternatives for Edisto Beach State Park. South Carolina. It is prepared in connection with an erosion assessment study of Hunting Island and Edisto Beach State Parks by Coastal Science & Engineering. Inc. (CSE), under contract to the South Carolina Department of Parks. Recreation and Tourism (PRT). Recommendations herein are limited to Edisto Beach State Park.

The report outlines key findings of previous studies, new surveys accomplished, and an updated analysis of erosion rates. Because of previous studies covering the area, including a 1987 shorefront management plan for all of Edisto Beach by Cubit Engineering, Ltd. (CUBIT), lengthy discussions of old data have been omitted. Instead, the emphasis of the present report is on alternatives. There are several reports on Edisto Beach's erosion problem dating back to 1949, and reviewers of this report and its recommendations are directed to the original reports annotated in Table 1 for further background information.

CSE. 1992. Edisto Beach Nourishment Project: Geotechnical Studies, Bathymetric & Beach Surveys, Wave Modeling Studies. Engineering Report prepared by Coastal Science and Engineering, Columbia, South Carolina submitted to the South Carolina Department of Parks, Recreation and Tourism, Columbia, South Carolina and Town of Edisto Beach, Edisto Beach, South Carolina. 120pp + appendices.

This report presents a detailed summary of Phase II engineering analyses for the design of a beach nourishment project for Edisto Beach State Park and the Town of Edisto. It builds on information and conclusions gained during the preparation of the Phase I feasibility study, Erosion Assessment and Beach Restoration Alternatives for Edisto Beach State Park (CSE, 1990a) and the Edisto Beach Reconnaissance Report for Storm Damage Reduction (USACE, 1990).

Coastal Science and Engineering-Baird. 1996. Edisto Beach Groin Repair & Beach Nourishment Project; Postproject Borrow Area Survey, Edisto Island, South Carolina. Survey Report, Coastal Science and Engineering - Baird, Columbia, South Carolina submitted to the Town of Edisto Beach, Edisto Island, South Carolina. 8pp + appendices.

This report presents results of a post dredging survey of the offshore borrow area used in the 1995 Edisto Beach nourishment project. One requirement of the permit (P/N 94-IT-009) was to obtain borings in the borrow area one year after nourishment for purposes of determining the sediment distribution and qualitatively assessing the rate of infilling. Surveys were performed the week of 27 May 1996.

Folly Beach, South Carolina

Katuna, M.P., M.W. Colgan, S. Weatherford, and J. Meisburger. 1993. Investigation of the offshore bathymetry and sedimentology of Folly Island, S.C.: Determination of Potential Offshore Sand Reserves for Beach Renourishment. In Beach Nourishment, Engineering and Management Considerations, Coastlines of the World, American Society of Civil Engineers, p.212-225.

Folly Island, South Carolina, one of Charleston's oldest beach communities, has had a long history of coastal erosion. The construction of the Charleston Harbor jetties (completed in the late 1800's) has restricted the longshore sediment supply and contributed to the erosion of offshore shoals resulting in a long-term erosion problem

for Folly and nearby Morris Island. A beach renourishment project was started in January 1993, in an attempt to reestablish a high tide beach along most of Folly Island. The objectives of this study were threefold: 1) to locate potential borrow sites for renourishment sand, 2) to determine the presence and distribution of offshore shoals, and 3) to determine what affect, if any, did Hurricane Hugo have on offshore bottom topography. Side-scan sonar transects were conducted to map the physiography of the offshore zone immediately seaward of Folly and Morris Islands. In addition, bottom grab samples were collected along these transects, and standard grain size analyses were performed to determine the location of beach quality renourishment sand. Analysis of the side-scan sonar records indicated that large-scale bedforms (shoals) do not exist in close proximity to the coast, and that small-scale bedforms are confined to the narrow surf zone. The sediment surface seaward of Folly Island is essentially featureless and consists primarily of hard packed shelly-sand. Large scale bedforms were observed only within tidal channels and along the periphery of ebb tidal deltas. It appears that the offshore migration of large quantities of storm eroded beach sediment did not occur (even with the passage of a major hurricane), or that such deposits were quickly eroded and dispersed into adjacent coastal environments. The side-scan records revealed that the offshore region seaward of Folly Island is a sediment starved segment of the coastline. Analysis of the composite mean grain size for the samples indicated that the sediments within the three sampling areas were coarser grained than the existing beach sand, and significantly coarser than the sediment located within the borrow site. The three sites located in this study could provide a suitable alternative sand source for current and/or future beach replenishment projects. However, additional studies are needed to determine the feasibility of these sites for future sand reserves.

Lynch, A.E. 1994. Macroinfaunal Recolonization of Folly Beach, South Carolina, After Beach Nourishment. Master's Thesis, Graduate Program in Marine Biology, University of Charleston, Charleston, SC. 105pp.

Long-term erosion of Folly Beach, South Carolina, prompted a major beach nourishment operation during the Spring of 1993. Intertidal and subtidal beach macroinfauna were monitored to evaluate the beach fauna prior to nourishment and recovery of the species assemblages after this impact. Two treatment transects and one reference transect were sampled at three tidal elevations from the mid-intertidal to the surf zone. Benthic samples were analyzed for abundance, species number, diversity, etc., and sediments were analyzed for composition and grain size. In addition to the beach transect sampling, the contributions of recolonizing infauna from the dredge pipe, vertical migration through nourishment sediments, and adjacent areas were evaluated. These potential sources of infauna were studied by sampling near the dredge pipe outfall and through burial experiments on dominant taxa. Results of the beach sampling indicated that impact to the communities at one transect was more pronounced than at the other. Effects of the benthos at all tidal levels were brief, and the abundance and number of species were least affected in the lower intertidal and surf zones. Polychaetes increased in relative abundance during the three-month post-nourishment sampling period, but species assemblages were otherwise little affected by nourishment. Entrainment of organisms through the dredge pipeline was not a recognizable source of fauna to the new beach. Of four species subjected to burial

experiments, the amphipods *Haustorius canadensis*, *Neohaustorius schmitzi*, and *Parahaustorius longimerus*, and the mollusc *Donax variabilis*, a substantial number of individuals was able to extricate themselves from 60 or more cm of dredge sediments within four days. Vertical migration of movile macroinfauna through nourishment sediments combined with considerable recolonization of organisms from adjacent areas both appear to be important mechanisms of recolonization to this beach.

Van Dolah, R.F., R.M. Martore, A.E. Lynch, M.V. Levisen, P.H. Wendt, D.J. Whitaker, and W.D. Anderson. 1994. Environmental Evaluation of the Folly Beach Nourishment Project. Final Report, Marine Resources Research Institute, South Carolina Department of Natural Resources, Charleston, South Carolina submitted to U.S. Army Corps of Engineers, Charleston District, Charleston, SC.

The U.S. Army Corps of Engineers (USACOE), Charleston District initiated a major beach nourishment project during January of 1993 that involved placing approximately 2.5 million cubic yards of fill material along 5.7 miles of shoreline at Folly Beach, South Carolina. The fill material for this project was obtained from an estuarine borrow area in the Folly River that extended from behind the western end of Folly Island to Bird Key near the Stono River.

CSE. 2001. Monitoring and Analyses of the 1993 Folly Beach Nourishment and Groin Repair Project. Final Report Volume 1 prepared by Coastal Science & Engineering, Inc. Columbia, South Carolina for City of Folly Beach PO Box 48, Folly Beach, South Carolina. 58pp.

Predictions of beach changes for the first year since nourishment were porr, but were much improved over a longer eight-year period. Overall and in most reaches, predictions matched measured sand losses well. Exceptions were underprediction of erosion at the south end of the island (in and near the park) and over prediction of erosion at the renovated groins. The restored groins have apparently helped to slow erosion even more than originally predicted.

Bergquist, D.C., S.E. Crowe, M.V. Levisen, and R.F. Van Dolah. 2008. Change and recovery of physical and biological characteristics at beach and borrow areas impacted by the 2005 Folly Beach renourishment project. Technical Report. Charleston, SC: South Carolina Marine Resources Division. Technical Report No. 102. 112p.

The response and recovery of subtidal sediment borrow areas and beach ecosystems to nourishment activities remain poorly understood. Folly Beach, SC, was nourished between April and October 2005 using sediment from a nearshore subtidal borrow area. The South Carolina Department of Natural Resources monitored both the borrow area and the beach to determine the impacts associated with these activities and to determine whether these systems showed evidence of recovering over a one year period following the impacts.
Benthic sediment samples were collected from the dredged borrow area and a nearby non-dredged reference area prior to dredging and at multiple time points following dredging in order to compare temporal changes in sediment characteristics and benthic infaunal community composition. Sediments within the borrow area became

increasingly fine (more silt/clay, larger sand phi size, less calcium carbonate) following dredging and showed little evidence of recovery one year after completion of dredging. The biological community also changed following dredging and continued to diverge from the reference area over the next year, likely in response to changing sediment characteristics. The refilling of the borrow area with fine (muddy) material is probably due to dredging to 3 meters below grade and the proximity of the borrow area to Charleston Harbor, a source of terrigenous sediments. The current accumulation of muddy sediments could prevent this area from being used in future nourishment projects. We recommend that, whenever possible, borrow areas in South Carolina be dredged to less than 3 meters below grade and located at the southern ends of barrier islands where beach-compatible sands tend to accumulate.

Shore-perpendicular transects in nourished areas and non-nourished reference areas of Folly Beach were monitored prior to dredging and during multiple time points following dredging to evaluate temporal changes in sediment characteristics and densities of burrowing macro-invertebrates, specifically the ghost crab *Ocypode quadrata* and the ghost shrimp *Callichirus major*. Subaerial beach width increased substantially following nourishment but decreased to less than half of the post-nourishment width within one year. Sediment characteristics did not change following nourishment. Burrowing macro-invertebrates showed little evidence of nourishment impact. The only exceptions were a tendency of 1) densities of ghost crabs within the dunes to decrease along a gradient of increasing beach width and 2) ghost shrimp to increase following nourishment. Differences in ghost crab densities between nourished and reference areas prior to nourishment, perhaps as a result of differences in development and pedestrian traffic may have interfered with the ability to detect impacts from nourishment activities. We recommend that careful matching of beach sands and well-replicated and designed monitoring studies continue as part of future nourishment projects to ensure nourishment activities have minimal impact on South Carolina's beach ecosystems.

Hilton Head, South Carolina

Olsen Associates, Inc. 1986. Geotechnical Exploration of Offshore Sand Sources, Hilton Head Island, SC. Engineering report prepared by Olsen Associates, Inc., Jacksonville, FL for the Town of Hilton Head Island, South Carolina.

Olsen Associates, Inc. 1986. Hilton Head Island Beach Monitoring Study: September 1986 Survey. Engineering report prepared by Olsen Associates, Inc., Jacksonville, FL for the Town of Hilton Head Island, South Carolina.

Olsen Associates, Inc. 1987. Wave Refraction Analysis of the Existing Bathymetry and Potential Impact of Offshore Sand Borrowing, Hilton Head Island, SC. Engineering report prepared by Olsen Associates, Inc., Jacksonville, FL for the Town of Hilton Head Island, South Carolina.

Olsen Associates, Inc. 1987. Engineering Evaluation of a Beach Restoration Strategy for Hilton Head Island, SC. Engineering report prepared by Olsen Associates, Inc., Jacksonville, FL for the Town of Hilton Head Island, South Carolina.

Olsen Associates, Inc. 1987. Hilton Head Island Beach Monitoring Study: January 1987 Survey. Engineering report prepared by Olsen Associates, Inc., Jacksonville, FL for the Town of Hilton Head Island, South Carolina.

Olsen Associates, Inc. 1987. Hilton Head Island Beach Monitoring Study: September 1987 Survey. Engineering report prepared by Olsen Associates, Inc., Jacksonville, FL for the Town of Hilton Head Island, South Carolina.

Olsen Associates, Inc. 1988. Hilton Head Island Beach Monitoring Study: January 1988 Survey. Engineering report prepared by Olsen Associates, Inc. Jacksonville, FL for the Town of Hilton Head Island, South Carolina.

Olsen Associates, Inc. 1988. Hilton Head Island Beach Monitoring Study: September 1988 Survey. Engineering report prepared by Olsen Associates, Inc. Jacksonville, FL for the Town of Hilton Head Island, South Carolina.

CSA. 1991. Biological monitoring report for assessment of beach nourishment impacts: Hilton Head Island, South Carolina. Final Report prepared by Coastal Science Associates, Inc. Columbia, South Carolina for Palmetto Dunes Resort Hilton Head, South Carolina. 14 pp.

Pre and post nourishment benthic samples were taken on the beach at Palmetto Dunes Resort, Hilton Head Island, to determine nourishment impacts. *Donax* clams and nematode worms were dominant prior to nourishment and it is assumed that nourishment had an impact on the clams and possibly nematodes and other organisms. Post nourishment samples, when compared with control stations, showed little or no residual impact of the nourishment on amphipods, polychaete worms, or clams.

Van Dolah, R.F., P.H. Wendt, R.M. Martore, M.V. Levisen, and W.A. Roumillat. 1992. A Physical and Biological Monitoring Study of the Hilton Head Beach Nourishment Project. Final Report prepared by Marine Resources Research Institute, South Carolina Department of Natural Resources, Charleston, South Carolina for Town of Hilton Head Island, South Carolina and South Carolina Coastal Council, Charleston, South Carolina. 159pp.

In 1990, the Town of Hilton Head Island completed a major beach nourishment project to improve 6.6 miles of the island's front beach. This required dredging approximately 2.5 million cubic yards of sand from two offshore shoals located at Joiner Shoals and Gaskin Bank. Due to the size of this project and the lack of sufficient data to evaluate the biological impacts of beach nourishment operations in South Carolina, a physical and biological monitoring study was conducted by the Marine Resources Research Institute of the South Carolina Wildlife and Marine Resources Department. Specific objectives of this study were to: 1) document changes in the bottom-dwelling invertebrate communities and sediment characteristics of areas affected by the nourishment operation, 2) quantify the density of early life stages of economically important finfish and crustacean species at risk of being affected by the nourishment operation, 3) identify the finfish species of recreational importance present at the offshore borrow sites, and 4) measure bottom turbidity levels in areas affected by the nourishment operation.

Olsen Associates, Inc. 1992. Hilton Head Island Beach Restoration Project Monitoring Report: Year 1. Engineering report prepared by Olsen Associates, Inc., Jacksonville, FL for the Town of Hilton Head Island, South Carolina.

Olsen Associates, Inc. 1993. Hilton Head Island Beach Restoration Project Monitoring Report: Year 2. Engineering report prepared by Olsen Associates, Inc., Jacksonville, FL for the Town of Hilton Head Island, South Carolina.

Olsen Associates, Inc. 1993. Port Royal Entrance Channel Maintenance Project, Section 933 Preliminary Evaluation Report. Engineering report prepared by Olsen Associates, Inc., Jacksonville, FL for the Town of Hilton Head Island, South Carolina.

Van Dolah, R.F., R.M. Martore and M.V. Levisen. 1993. Physical and Biological Monitoring Study of the Hilton Head Beach Nourishment Project. Supplemental Report, Marine Resources Research Institute, South Carolina Marine Resources Division, Charleston, South Carolina submitted to Town of Hilton Head Island, South Carolina. 10pp.

In March, 1992 the South Carolina Marine Resources Research Institute submitted a Final Report to the Town of Hilton Head Island which described results from a study funded by the Town to evaluate the physical and biological changes resulting from the Hilton Head Beach Nourishment Project (Van Dolah, et al., 1992). Data obtained during that study documented alterations in the abundance, diversity and species composition of benthic (bottom-dwelling) invertebrates inhabiting the beach and borrow sites following the nourishment operation, but the biological effects at most of the sites studied were short-term (< 1 yr). The borrow site at Joiner Shoals, however, showed no evidence of recovery in the species composition of benthos within the one-year post-nourishment survey period, and it was hypothesized that it may take several years before the area returned to pre-nourishment conditions. This was attributed to a major change in sediment composition at the borrow site due to the accumulation of silts and clays. Based on the study results, the Town of Hilton Head authorized a supplemental study to re-sample the Joiner Shoals borrow site during the spring of 1992 to determine conditions at that site approximately two years after completion of the dredging activities. This report summarizes our findings from that supplemental sampling effort.

Olsen Associates, Inc. 1994. Hilton Head Island Beach Restoration Project Monitoring Report: Year 3. Engineering report prepared by Olsen Associates, Inc., Jacksonville, FL for the Town of Hilton Head Island, South Carolina.

Olsen Associates, Inc. 1995. Port Royal Plantation Shoreline Erosion Study, Hilton Head Island, SC. Engineering report prepared by Olsen Associates, Inc., Jacksonville, FL for the Town of Hilton Head Island, South Carolina.

Olsen Associates, Inc. 1995. Offshore Sand Search Study, Hilton Head Island, SC. Engineering report prepared by Olsen Associates, Inc., Jacksonville, FL for the Town of Hilton Head Island, South Carolina.

Olsen Associates, Inc. 1995. Memorandum of Findings: Sand Sampling Investigation - Port Royal Harbor Entrance Channel. Memo by Olsen Associates, Inc., Jacksonville, FL to the Town of Hilton Head Island, South Carolina.

Olsen Associates, Inc. 1996. Monitoring Plan for Town of Hilton Head Island, S.C. Beach Renourishment Project: DHEC Permit Nos 96-1A-038-P and 96-1A-066-P. Monitoring Plan prepared by Olsen Associates, Inc. Jacksonville, Florida for South Carolina Department of Health and Environmental Control Office of Ocean and Coastal Resource Management Charleston, South Carolina. 13pp + appendices.

The objective of the Town of Hilton Head Island Beach Renourishment Project Monitoring Plan will be to monitor the performance of the Beach Renourishment and Channel Relocation Projects. The monitoring program will be divided into two tasks which include (1) physical monitoring and (2) biological monitoring.
The physical monitoring program is intended to document beach and borrow site change related to the beach renourishment and channel relocation projects. Monitoring of the beach will identify erosion and accretion patterns along the nourished beach and any physical benefits and/or adverse impacts which may potentially be attributable to the projects as constructed. Monitoring of the two borrow site offshore borrow site will accurately document the volume of sand removed from the sites, the shape and size of the dredged areas, and the volumetric recovery rates and eventual reconfiguration of each site.
The biological monitoring program will include benthic community and surficial sediment surveys at the two borrow sites and at a control site. The control site will be located offshore of Hilton Head Island where the water depth, distance offshore, and sediment characteristics are similar to the borrow sites. The benthic community surveys will be used to determine the rate of recovery in benthic infaunal communities to pre-dredge and/or control site conditions. Sediment samples will be used to determine changes in surficial sediment composition and the effect of any changes on the benthic communities within the borrow sites following dredging. The sediment sampling will also be used to determine whether the sediments refilling the borrow area are compatible for use in future nourishment projects.

Olsen Associates, Inc. 1996. Hilton Head Island Beach Restoration Project Monitoring Report: Year 4. Engineering report prepared by Olsen Associates, Inc., Jacksonville, FL for the Town of Hilton Head Island, South Carolina.

Olsen Associates, Inc. 1997. Hilton Head Island Beach Restoration Project Monitoring Report: Year 5. Engineering report prepared by Olsen Associates, Inc., Jacksonville, FL for the Town of Hilton Head Island, South Carolina.

Olsen Associates, Inc. 1998. South Beach Shoreline Erosion Study, Hilton Head Island, SC. Engineering report prepared by Olsen Associates, Inc., Jacksonville, FL for the Town of Hilton Head Island, South Carolina.

Olsen Associates, Inc. 1998. Pine Island/Dolphin Point Shoreline Erosion Study. Engineering report prepared by Olsen Associates, Inc., Jacksonville, FL for the

Hilton Head Plantation Property Owners Association, Hilton Head Island, South Carolina.

Wright, E., P.T. Gayes, P. Donovan-Ealy, and W. Baldwin. 1998. Assessment of Beach Renourishment Resources on the Inner Shelf off Hilton Head Island, South Carolina. Final Report, Center for Marine and Wetland Studies, Coastal Carolina University, Conway, South Carolina submitted to Minerals Management Service Herndon, Virginia.

This study examined the sand resources offshore of Hilton Head Island using over 270 trackline-km of high-resolution seismic data, 63 surficial sediment samples and 8 vibracore samples. The findings suggest that the previously idintified landward portion of Gaskin Banks (Olsen and Associates, Inc., 1986) remains the closest and best sand resource site. The seaward portion of the site is composed of a thin (<2m) clean sand layer overlying prograding clinoforms. The sand, however, has lower Ra values. In deeper water to the south fo the Banks, an area of clean sands with higher carbonate values was indicated through surficial sediment analysis. The depth of the surface layer, however, was unobtainable with the high-resolution seismic data collected. In the deeper water to the southwest of the banks, higher mud content in the surficial samples, and increasing mud content within the first meter of the cores, eliminate this area as a potential resource site.

Jutte, P.C. and R.F. Van Dolah. 1999. An Assessment of Benthic Infaunal Assemblages and Sediments in the Joiner Shoals and Gaskin Banks Borrow Areas for the Hilton Head Beach Renourishment Project. Final Report, Marine Resources Research Institute, South Carolina Department of Natural Resources, Charleston, South Carolina submitted to Olsen Associates, Inc. and The Town of Hilton Head Island. 33 pp.

The 1997 Hilton Head Island Beach Renourishment Project placed approximately 2.9 million cubic yards of sand along the eastern portion of Hilton Head Island's shoreline and over 400,000 cubic yards of sand along a portion of the Port Royal Sound shoreline. The results of this study are summarized as follows: •Hydraulic dredging of the Joiner Shoals (JS) and Gaskin Banks (GB) borrow area was conducted from May through November of 1997. Benthic infaunal and sediment samples were collected at the JS and GB borrow areas and a control site shortly after dredging was completed (4-7 months for the JS borrow area, 1-4 months for the GB borrow area), and approximately one year later, which represented 14-17 months of recovery at the JS borrow area and 11-14 months of recovery at the GB borrow area. Pre-dredging samples were collected by another sub-contractor, but critical data were lost and the samples could not be included in SCDNR analyses.
•Hydrographic data indicated only seasonal variability among sites, with no limiting water quality conditions.
•During the one year sampling period, sediments had not recovered to conditions similar to those observed at the control site, which should be representative of conditions at both borrow areas prior to dredging. Sediments at the JB borrow area shortly after dredging was completed were 90% sand with a mean phi size of 2.8, and well-sorted. One year later, sediment composition decreased to 75% sand and silt/clay content increased by 13%. The GB borrow area shortly after dredging had sediments

consisting of 84% well-sorted sands with mean phi size of 3.1. Approximately one year later, sand content declined to 72% and silt/clay content increased by 13%.
•Since it is desirable for beach nourishment quality sands to have less than 10% silt/clay, the sediments collected in both borrow areas in October 1998 would not be suitable for use in future nourishment operations. Future monitoring is warranted to resolve how quickly these muddy sediments are capped or replaced with sandier sediments. If future monitoring indicates that the silt/clay content in the JB and GB borrow areas has not been displaced by sand, then these areas are not likely to be useful in beach nourishment activities.
•A total of 4,172 organisms were identified during this study, representing 138 taxa. The twenty most abundant organisms comprised greater than 80% of the total abundance.
•Benthic infaunal communities in the JB borrow area showed significant effects related to dredging activities. The number of species collected per grab, abundance of dominant taxa, higher taxonomic composition, and diversity indices were altered after dredging occurred, particularly after 14-17 months of recovery.
•The benthic infaunal communities at the GB borrow area were also impacted by dredging activities. Faunal abundance, the number of species per grab, the abundance of dominant species, higher taxonomic composition, and diversity indices were altered approximately one year after dredging (11-14 months post-dredging), although some of the changes would not be considered adverse effects.
•The biological effects of dredging activities were different at the JB borrow area compared to the GB borrow area. Some of the differences in faunal abundance values, diversity indices, and higher taxonomic structure may be explained in part by a 200-fold increase in density of the gastropod *Acteocina candei*.
•The decreased benthic infaunal abundance of several taxa in the 1998 sampling season versus the 1997 sampling season may be explained by increased predation by white shrimp. White shrimp reach peak abundances in South Carolina coastal waters in October, the month that 1998 samples were collected.
•The JB borrow area was dredged earlier than the GB borrow area (JB—May 18-August 9, 1997; GB—August 12- November 9, 1997), and the two borrow areas were at different stages of recovery when sampling occurred. Differences in the biological conditions between the two sites may therefore represent time-scale effects.
•Biological conditions in the JB and GB borrow areas had not recovered to conditions observed in an undredged area during the one year sampling period. Annual monitoring in fall 1999 (approximately two years post-dredging) is warranted.

Olsen Associates, Inc. 1999. Hilton Head Island 1997 Beach Renourishment Project: Monitoring Report No. 1. Monitoring Report prepared by Olsen Associates, Inc., Jacksonville, Florida for the town of Hilton Head Island, South Carolina. 86pp + appendices.

This monitoring report describes the construction and first year performance of the 1997 Hilton Head Island Beach Restoration Project. The project included the placement of approximately 2,971,700 million cubic yards (MCY) of sand along approximately 7.2 miles of the island's Atlantic shoreline, relocation of a marginal tidal channel adjacent to a section of the Port Royal Sound shoreline, and the placement of approximately 421,300 cubic yards of sand as beach fill along the Port Royal Plantation's Port Royal Sound shoreline.

Olsen Associates, Inc. 1999. Town of Hilton Head Island, SC Beach Nourishment Project: Post-Construction Report. Engineering report prepared by Olsen Associates, Inc., Jacksonville, FL for the Town of Hilton Head Island, South Carolina.

Jutte, P.C., and R.F. Van Dolah. 2000. An Assessment of Benthic Infaunal Assemblages and Sediments in the Joiner Shoals and Gaskin Banks Borrow Areas for the Hilton Head Beach Renourishment Project. Final Report, Marine Resources Research Institute, South Carolina Department of Natural Resources, Charleston, South Carolina submitted to Olsen Associates, Inc. and the Town of Hilton Head Island. 34 pp.

The 1997 Hilton Head Island Beach Renourishment Project placed approximately 2.9 million cubic yards of sand along the eastern portion of Hilton Head Island's shoreline and over 400,000 cubic yards of sand along a portion of the Port Royal Sound shoreline. The results of this study are summarized as follows:

•Hydraulic dredging of the Joiner Shoals (JB) and Gaskin Banks (GB) borrow area was conducted from May through November of 1997. Benthic infaunal and sediment samples were collected at the JB and GB borrow areas and a control site shortly after dredging was completed (4-7 months for the JB borrow area, 1-4 months for the GB borrow area), approximately one year later (14-17 months for the JB borrow area, 11-14 months for the GB borrow area), and approximately two years later (26-29 months for the JB borrow area, 23-26 months for the GB borrow area). Pre-dredging samples were collected by another sub-contractor, but critical data were lost and the samples could not be included in SCDNR analyses. Pre-dredging samples were available from the previous nourishment project in 1990 (Van Dolah et al. 1992), but were of limited usefulness due to seasonal differences in sample collection.

•Hydrographic data indicated only seasonal variability among sites, with no limiting water quality conditions.

•Sediment conditions at the JB and GB borrow area approximately two years after dredging were compared to conditions observed at the control site, which should be representative of conditions at both borrow areas prior to dredging. Sediments at the JB borrow area shortly after dredging was completed were 90% sand with a mean phi size of 2.8, and well-sorted. One year later, sediment composition was composed of 75% sand and 13% silt/clay content. Two years after dredging occurred, sand content had increased to 92% with a mean phi size of 2.2. Sediments at the GB borrow area shortly after dredging consisted of 84% well-sorted sands with mean phi size of 3.1. Approximately one year later, sand content declined to 72% and silt/clay content increased by 13%. Two years after dredging, the mean sand content at the GB borrow site was 74%, with a mean phi size of 3.1, and well-sorted.

•Surficial sediment characteristics found at the JB borrow site approximately two years after the completion of dredging fell in the range of beach nourishment quality sands (i.e. greater than 90% sand content). To determine if this trend continues, and to determine if the borrow area has filled with compatible sediments, or been capped by compatible sediments, we recommend additional bathymetric assessments be conducted at least every other year for a minimum of two more survey periods (four years). We also recommend that at least one of these surveys include bottom cores at several locations within the borrow site (minimum of three) to identify whether the surface sediments are capping a layer of mud.

•Sediment composition at the Gaskin Banks borrow area two years after the completion of dredging did not consist of beach nourishment quality sediments. We recommend that Olsen Associates, Inc. continue to assess the type and depth of sediments that refill the borrow area. The surveys should be conducted at two year intervals from the last survey, and include a minimum of three sediment cores during at least one of these surveys. The cores should be taken to depths sufficient to determine whether the borrow area includes muddy material capped by sands. If further monitoring indicates that the silt/clay content in the GB borrow areas has not been displaced by sand, then this area is not likely to be useful in future beach nourishment activities.
•A total of 5,765 organisms were identified during this study, representing 193 taxa. The twenty most abundant organisms comprised greater than 79% of the total abundance.
•Benthic infaunal communities at the JB borrow area showed significant effects related to dredging activities shortly after dredging and approximately one year after dredging occurred. The number of species collected per grab, abundance of dominant taxa, higher taxonomic composition, and diversity indices were altered after dredging occurred, particularly after 14-17 months of recovery. The biological condition at the JB borrow area approximately two years after dredging was completed had recovered to conditions similar to the control site. Additional biological monitoring of the JB borrow site is not warranted.
•The benthic infaunal communities at the GB borrow area were also impacted by dredging activities. Faunal abundance, the number of species per grab, the abundance of dominant species, higher taxonomic composition, and diversity indices were altered approximately one year after dredging (11-14 months post-dredging), and two years after dredging (23-26 months post-dredging), although some of the changes would not be considered adverse effects. Additional biological monitoring of the GB borrow area is not recommended, but continued bathymetric assessments, and a more thorough investigation of sediments through coring should be completed.

Olsen Associates, Inc. 2000. Hilton Head Island 1997 Beach Renourishment Project: Monitoring Report No. 2. Monitoring Report prepared by Olsen Associates, Inc., Jacksonville, Florida for the town of Hilton Head Island, South Carolina. 86pp + appendices.

This monitoring report describes the construction and performance of the 1997 Hilton Head Island Beach Restoration Project over the two year survey period following its completion. The project included the placement of approximately 3.1 million cubic yards (MCY) of sand along 7.2 miles of the island's Atlantic shoreline and the relocation of a marginal tidal channel adjacent to a section of the Port Royal Sound shoreline. It likewise resulted in the coincidental placement of 385,800 cy of sand displaced as part of the channel relocation, and the placement of an additional 421,300 cubic yards of sand as beach fill along the Port Royal Plantation's Port Royal Sound shoreline.

Olsen Associates, Inc. 2000. Historical Shoreline Change Study, Port Royal Sound Shoreline. Engineering report prepared by Olsen Associates, Inc., Jacksonville, FL for the Town of Hilton Head Island, South Carolina.

Olsen Associates, Inc. 2000. Hilton Head Plantation Port Royal Sound Revetment Assessment. Engineering report prepared by Olsen Associates, Inc., Jacksonville, FL for the Hilton Head Plantation Property Owners Association, Hilton Head Island, South Carolina.

Olsen Associates, Inc. 2001. Hilton Head Island 1997 Beach Renourishment Project Monitoring Report No. 3. Engineering report prepared by Olsen Associates, Inc., Jacksonville, FL for the Town of Hilton Head Island, South Carolina.

Olsen Associates, Inc. 2004. Hilton Head Island, SC, 2005/06 Beach Renourishment Project Offshore Sand Search Investigation. Engineering report prepared by Olsen Associates, Inc., Jacksonville, FL for the Town of Hilton Head Island, South Carolina.

Olsen Associates, Inc. 2004. Town of Hilton Head Island, SC, 2005/06 Beach Renourishment Project Offshore Sand Search Investigation. Engineering report prepared by Olsen Associates, Inc., Jacksonville, FL for the Town of Hilton Head Island, South Carolina.

Olsen Associates, Inc. 2004. FEMA Transect Formulation (Primary Dune to Toe of Beach). Report prepared by Olsen Associates, Inc., Jacksonville, FL for submittal to the USACE Charleston District for the purposes of the FEMA remapping investigation.

Olsen Associates, Inc. 2005. Harbour Town Golf Links 18th Green Shoreline Erosion Study. Engineering report prepared by Olsen Associates, Inc., Jacksonville, FL for the Sea Pines Resort, LLC, Hilton Head Island, South Carolina.

Olsen Associates, Inc. 2007. Lands End Groin Rehabilitation Project, Hilton Head Island, SC. Engineering report prepared by Olsen Associates, Inc., Jacksonville, FL for the Town of Hilton Head Island, South Carolina.

Olsen Associates, Inc. 2008. Town of Hilton Head Island 2006/07 Beach Renourishment Project Post-Construction Engineering Summary Report. Engineering report prepared by Olsen Associates, Inc., Jacksonville, FL for the Town of Hilton Head Island, South Carolina.

Olsen Associates, Inc. 2008. Hilton Head Island, SC, North Island Shoreline Change Study. Engineering report prepared by Olsen Associates, Inc., Jacksonville, FL for the Town of Hilton Head Island, South Carolina.

Hunting Island, South Carolina

Shealy, M.H., B.B. Boothe, Jr, and C.M. Bearden. 1975. A Survey of the Benthic Macrofauna of Fripp Inlet and Hunting Island, South Carolina, Prior to Beach Nourishment. Technical Report Number 7, Marine Resources Research Institute

and Office of Conservation and Management, South Carolina Wildlife and Marine Resources Department, Charleston, South Carolina submitted to U.S. Army Corps of Engineers, Charleston District. 29pp.

The present study was initiated on 29 June 1973 by the Division of Marine Resources, South Carolina Wildlife and Marine Resources Department, in cooperation with the U. S. Army corps of Engineers. The primary objectives of this study were to:
(1) collect and evaluate benthic samples from selected stations at the mouth of Fripp Inlet, just offshore from Hunting Island, and in the intertidal area along Hunting Island Beach;
(2) conduct low-altitude aerial surveys of the Fripp Inlet estuary and adjacent areas with infrared photography to indicate sand dispersion patterns in the Inlet and along Hunting Island Beach; and
(3) estimate, using all available information, the potential environmental effects of obtaining borrow material from each of the following alternate areas not sampled in this study: (a) the inland borrow area on Hunting Island, (b) sandbars and shoals near the mouth and just inside of Johnson Creek, © Harbor River about 1200 m (4000 feet) from South Carolina Highway 21 bridge.
These objectives were considered to be most significant in evaluating the general environmental condition of the study area and in providing base line information which could be used in the future determination of ecological effects of the proposed beach nourishment project. The present project was a short-range study designed to meet the specific needs outlined, and was not intended to be a general or comprehensive environmental impact study of the Hunting Island-Fripp Inlet area.

Swearington, G.R. 1990. Identification of Benthic Faunal Samples for Hunting Island Beach Nourishment Project. Report submitted to Coastal Science and Engineering, Inc., Columbia, South Carolina. 6pp.

This report presents species abundance results from benthic faunal samples collected by Coastal Science and Engineering, Inc. at Hunting Island, South Carolina, August 19, 1990.

CSE. 1990. Erosion assessment and beach restoration alternatives for Hunting Island, South Carolina. Report prepared by Coastal Science & Engineering, Inc. Columbia, South Carolina for South Carolina Department of Parks, Recreation and Tourism Columbia, South Carolina. 66pp + appendices.

This report outlines findings and recommendations regarding beach restoration alternatives for Hunting Island. South Carolina. It is prepared in connection with an erosion assessment study of Hunting Island and Edisto Beach State Parks by Coastal Science & Engineering. Inc. (CSE). Under contract to the South Carolina Department of Parks, Recreation and Tourism (PRT). Recommendations herein are limited to Hunting Island and are based on PRT review of draft findings and tailored to funding availability at this time.
The emphasis of this report is on alternatives rather than presentation of historical data. We outline key findings of previous studies. New surveys accomplished. And a conceptual model of erosion. While detailed station-by-station results and statistical analyses have been included in appendices. Lengthy discussions of these data have

been omitted. There are a considerable number of reports on Hunting Island's erosion problem available through the early 1980s. And reviewers of this report and its recommendations are directed to the original reports annotated in Table 1 for further background information.

CSE. 1991b. Geotechnical study for the Hunting Island Beach Nourishment Project. Survey report prepared by Coastal Science & Engineering, Inc. Columbia, South Carolina for South Carolina Department of Parks, Recreation and Tourism Columbia, South Carolina. 35pp + appendices.

This report presents results of a detailed geotechnical survey of the proposed borrow area for the Hunting lsland beach nourishment project. It follows preparation of a feasibility report. Erosion Assessment and Beach Restoration Alternatives for Hunting lsland, South Carolina (CSE, 1990), and submission of a permit application for the project (PIN 90-2T-320-P) by South Carolina Department of Parks. Recreation and Tourism (PRT) in August 1990. The feasibility report outlined a proposed borrow area for nourishment sand about two miles seaward of the Hunting lsland lighthouse. The preliminary recommendation was based on ten vibracores collected between Fripp Inlet and Johnson Creek in June 1990. Core HI-4, described in the feasibility report, contained relatively clean, well-sorted sand closely matching native sediments on the beach. On the basis of these results, a target borrow area around HI-4 was delineated encompassing *1.0 mile by 0.5 mile of ocean bottom. This general area was recommended for additional sampling and confirmation of sediment quality.

CSE. 1991a. Hunting Island State Park 1991 Beach Nourishment Project. Survey report prepared by Coastal Science & Engineering, Inc. Columbia, South Carolina for South Carolina Department of Parks, Recreation and Tourism Columbia, South Carolina. 24pp + appendices.

CSE. 1992. Hunting Island State Park Beach Nourishment Project: Environmental Surveys. Final Report prepared by Coastal Science & Engineering, Inc. Columbia, South Carolina and Coastal Science Associates, Inc. Columbia, South Carolina for South Carolina Department of Parks, Recreation and Tourism Columbia, South Carolina. 29pp.

This report is submitted as part of the requirement for environmental monitoring following the 1991 Hunting Island nourishment project. The report presents results of offshore benthic surveys in and around the borrow area and sand compaction tests in the fill. Preliminary environmental data were submitted to South Carolina Wildlife and Marine Resources Department with the permit application in the fall of 1990. The present study contains results of pre nourishment sampling (February 1991) and post nourishment sampling (April 1991, November 1991, and March 1992).

CSE. 1992. Hunting Island State Park 1991 Beach Nourishment Project. Survey Report No. 2 prepared by Coastal Science and Engineering, Inc. Columbia, South Carolina for South Carolina Department of Parks, Recreation & Tourism Columbia, South Carolina. 16 pp. + appendices.

This report presents results of four quarterly beach surveys following the 1991 Hunting Island nourishment project. The report is the second in a series initiated after completion of the project in March 1991 and covers surveys made in September 1991, December 1991, March 1992, and June 1992. The results are compared with the post project survey of March-April 1991 reported to CSE (1991a). The first year after the fifth nourishment of Hunting Island saw accelerated erosion along the project area, principally at North Beach and South Beach where extra fill had created unnatural bulges in the shoreline. Erosion of these primary recreation areas averaged around 25-30 cy/ft for the period March 1991 to June 1992. If considered over the one year through March 1992, erosion at the bulges ranged from 22 to 25 cy/ft. This range is about 20 percent higher than the ~2.5 year annual averages following the 1971 and 1980 nourishment projects at the lighthouse reach (CSE, 1990). Erosion over the entire length of Hunting Island remained exceedingly high compared to most beaches in South Carolina (Kana, 1988).

Coastal Science and Engineering-Baird. 1996. Survey Report: 1991 Beach Nourishment Project; Postproject Borrow Area Survey, Hunting Island, South Carolina. Survey Report, Coastal Science and Engineering - Baird, Columbia, South Carolina submitted to the South Carolina Department of Parks, Recreation and Tourism, Columbia, South Carolina. 14pp + appendices.

This report presents results of a postdredging survey of the offshore borrow area used in the 1991 Hunting Island nourishment project (Permit No. P/N 90-2T-320-P). It is completed as part of a postproject performance review. Previous reports by Coastal Science & Engineering, Inc. (now CSE-Baird) present results of beach monitoring and post-project sediment sampling along the shoreline. A list of related reports is given in Table 1. The most recent beach survey involving closely spaced transects to closure depth was completed in Spring 1995 (CSE, 1995)

CSE. 1992. Hunting Island State Park beach nourishment project environmental surveys. Final Report prepared by Coastal Science & Engineering, Inc.and Coastal Science Associates, Inc. Columbia, South Carolina for the South Carolina Department of Parks, Recreation, and Tourism. 29 pp.

This study was conducted at Hunting Island, South Carolina, at the request of state and federal agencies, to assess the ecological impact of offshore dredging on benthic macroinvertebrate communities. Biological communities were sampled quantitatively from dredged and control areas before dredging (7 February 1991) and after dredging (30 April 1991 and 31 March 1992). The information gathered indicated that no negative changes in community composition occurred as a result of dredging. Short-term (less than one year) recovery rates by infauna were unusually rapid at the borrow sites. General observations of the fill indicated beach compaction increased significantly in the project area from CIV values around 260 before nourishment to about 375 after nourishment. However, the higher value remained under acceptable values for turtle nesting. Visual observations of inshore sediments before dredging confirmed the presence of muddy patches in the lower foreshore about 800-1200 feet from the fore dune. Unconsolidated mud at the bed tended to decrease offshore in the vicinity of the borrow area. However, after dredging, thick accumulations (>60cm) of mud were observed in portions of the borrow pit. More detailed transects would be

required to determine whether infilling of the pit is primarily by mud or, as we believe more likely, sand from adjacent shoals.

Isle of Palms, South Carolina

Lankford, T.E. and B.J. Baca. 1987. A Biological Study of Macrofaunal and Supratidal Communities in Response to a Proposed Beach Scraping Project at Wild Dunes Development, Isle of Palms, South Carolina. Prepared by Coastal Science & Engineering, Inc. for Wild Dunes Associates, Isle of Palms, South Carolina. 20pp.

The present study was designed to assess the potential impacts on fauna of a beach-scraping and dunelberm rebuilding program proposed for Wild Dunes, Isle of Palms, South Carolina. Recent storms of December 1986 and January 1987 have deemed dune restoration efforts necessary at two areas on Isle of Palms. Work area 1 contains a detached, ebb-tidal delta shoal which has welded to the shoreline and around which wave refraction has created two erosional arcs. Work area 2, located along Dewees Inlet, suffered recent erosional damage to the existing dunes. Beach scraping was the proposed method of rebuilding dunes in these two areas, as specified in detail by Williams (1987). This study examined the benthic fauna of two intertidal areas proposed as borrow sites and fauna inhabiting the dune regions of two upper beach zones proposed as corresponding fill areas. It is intended that data obtained through this study be coupled with post scraping sample data to further knowledge of the ecological impacts associated with this beach nourishment alternative.

CSA South, Inc. 2008. First Pre-Dredge Monitoring Report Beach Nourishment Borrow Areas at Isle of Palms, SC P/N 2007-02631-2IG. Monitoring Report prepared by Coastal Science Associates South, Inc. Dania Beach, Florida for City of Isle of Palms, SC. 45pp.

An ecological study is required under P/N 2007-02631-2IG to assess the impacts of dredging for beach nourishment on benthic invertebrates at the Isle of Palms, SC site. This study is based on guidelines established for use at nourishment projects in collarboration with SC Department of Natural Resources (SCDNR), Marine Resources Division, the U.S. Fish and Wildlife Service, and the U.S. Army Corps of Engineers.

Kiawah Island, South Carolina

Katmarian, E. and T. W. Kana. 1995. Shoreline Assessment and Recommendations for Dune/Beach Restoration, Kiawah Island, South Carolina. Final Report prepared by Coastal Science & Engineering, Inc. Columbia, South Carolina for the Town of Kiawah Island, South Carolina. 42pp + appendices.

The winter of 1994 saw a number of significant northeast storms which resulted in dune erosion along sections of Kiawah Island. In many places, the erosion was clearly visible and caused concern among residents that the health of the beach was

deteriorating. The elevated concern prompted the Town of Kiawah Island to retain Coastal Science and Engineering, Inc. (CSE) to conduct a detailed analysis of the state of Kiawah's beaches and provide general alternatives and cost estimates for dunelbeach restoration. Over the summer of 1995, swells associated with many offshore hurricanes, some of which were coincident with spring tides, have caused continued erosion. The past summer's erosion is most evident in the vicinity of Eugenia Avenue, Mariners Watch Villas, and Windswept Villas. This report presents the results of CSE's investigation into shoreline change since 1949 with emphasis on the recent erosional events.

The report is divided into a number of sections. A brief synopsis of previous studies and monitoring is given in Section 2. Section 3 is a general discussion of the natural processes which affect the movement of sand along Kiawah Island; it is included to provide a context in which the following results can be interpreted. Section 4 deals with linear shoreline trends based on aerial photographs dating back to 1949. Section 5 contains a detailed "sediment budget" outlining volumetric changes in sand quantities on the beach as well as outlining erosion or accretion trends over the past 13 years as well as over the past five years. In Section 6, a number of dune/beach restoration alternatives are considered, and cost estimates for their implementation are given. Section 7 contains concluding remarks and CSE's recommendations for beach maintenance actions to be taken at the present time.

Coastal Science and Engineering-Baird. 1996. Final Report: 1996 Beach Scraping; Kiawah Island, South Carolina. Final Report, Coastal Science and Engineering - Baird, Columbia, South Carolina submitted to the Town of Kiawah Island, South Carolina. 4pp + appendices.

This report summarizes the results of a beach scraping project performed by the Town of Kiawah Island under Permit No. OCRM 96-027-H, which took place on Kiawah Island between 16 April and 15 May 1996.

Levisen, M.V. and R.F. Van Dolah. 1996. Environmental Evaluation of the Kiawah Island Beach Scraping Project. Final Report, Marine Resources Research Institute, South Carolina Department of Natural Resources, Charleston, South Carolina submitted to the U.S. Army Corps of Engineers, Charleston District for the Town of Kiawah Island. 15 pp.

A beach scraping project was conducted by the Town of Kiawah Island in April and May of 1996. Approximately 30,000 cubic yards of sand were scraped from the lower beach to the escarpment crest. Results indicated that the beach scraping project at Kiawah Island did not cause any long-term adverse impacts to the beach infaunal communities. In fact, recovery appeared to have occurred quite rapidly (<60 days) since conditions at the scraped and reference sites were quite similar with respect to the abundance and diversity of the overall faunal complex, and similarity in the abundances of dominant taxa found at the scraped and reference areas. The rapid recovery and recolonization of organisms to the scraped beach was probably due to drift transport of adults and juveniles from adjacent areas.

Myrtle Beach, South Carolina

Kana, T.W., W.J. Sexton and M.L. Williams. 1983. Survey of Offshore Sand Deposits for Beach Nourishment: Myrtle Beach South Carolina. Feasibility Study prepared by Research Planning Institute, Inc. Columbia, South Carolina for City of Myrtle Beach, South Carolina. 52pp + appendices.

This report presents results of an investigation of offshore sediments along Myrtle Beach to determine the feasibility of borrowing sand for beach nourishment. The purpose of the study was to survey an area approximately 10 miles (mi) long by 1.5 mi wide directly off the Myrtle Beach oceanfront for existing any sand deposits which would be suitable for beach nourishment. The survey involved bathymetric mapping of water depths using electronic positioning equipment, shallow coring and grab samples of surface sediments, a side scan sonar survey of bottom topography and bedforms, and shallow seismic recording of the substrate. Field work was conducted in June 1982 (bathymetry, side scan, and seismic track lines) under an authorization for that phase of the study given by the City of Myrtle Beach on 25 June 1982. Cores, grab samples, data analysis, and report preparation were completed between February and June 1983 under an authorization dated 30 November 1982.

Kana, T.W., S.M. Siah and M.L. Williams. 1984. Analysis of historical erosion rates and prediction of future shoreline positions, Myrtle Beach, South Carolina. Project Report prepared by Research Planning Institute, Inc., Columbia, South Carolina for the City of Myrtle Beach, South Carolina. 130pp.

Siah, S.J., E.J. Olsen, and T.W. Kana. 1985. Myrtle Beach nourishment project, engineering report. Project Report prepared by Research Planning Institute, Inc., Columbia, South Carolina for the City of Myrtle Beach, South Carolina. 160pp + appendices.

Baca, B.J.,and T.E. Lankford. 1987. Myrtle Beach Nourishment Project: Biological Monitoring Report - Years 1. Report R-09 to City of Myrtle Beach; Columbia, S.C., pp. 24.

Under Phase I of the Myrtle Beach nourishment project a maximum of 500,000 cubic yards (yd3) of sand were to be placed on approximately 16.500 linear feet of beach. The sand was to be compatible (grain size presented later) and from an upland source. The primary environmental concerns were as follows:
1) Fill material may smother supratidal or intertidal fauna.
2) Turbidity or runoff from fill material may impact subtidal or intertidal fauna.
The present study was initiated a t the request of U.S. Fish and Wildlife Service (USFWS). South Carolina Wildlife and Marine Resources Department (SCWMRD), and South Carolina Coastal Council (SCCC) to determine the long-term environmental impacts of the nourishment project. This report covers the first year of the three-year study. The following section is a description of the methodology used, followed by the results and conclusions.

Kana, T.W., and C. P. Jones. 1988. Myrtle Beach nourishment project, beach monitoring report, 1987. Final Report prepared by Coastal Science & Engineering, Inc. Columbia, South Carolina for the City of Myrtle Beach, South Carolina. 77pp + 4 appendices.

Baca, B.J.,and T.E. Lankford. 1988. Myrtle Beach Nourishment Project: Biological Monitoring Report - Years 1,2,3. Report R-11 to City of Myrtle Beach; Columbia, S.C., pp. 50.

A detailed. 25-month biological monitoring study was conducted for the 1986-87 Myrtle Beach nourishment project. The purpose of the study was to examine the environmental effects of placing approximately 853.350 cubic yards (~ d)) of compatible sand along 8.5 miles of Grand Strand beach. The results of this study are provided in the following report.

Jones, C.P., and W.C. Eiser. 1989. Myrtle Beach nourishment project, beach monitoring report, 1989. Final Report prepared by Coastal Science & Engineering, Inc. Columbia, South Carolina for the City of Myrtle Beach, South Carolina. 23pp + appendices.

CSE, Inc. 1989. Myrtle Beach nourishment project, beach monitoring report--1988. Final Report prepared by Coastal Science & Engineering, Inc. Columbia, South Carolina for the City of Myrtle Beach, South Carolina. 35pp + appendices.

CSE, Inc. 1990. North Myrtle Beach emergency nourishment project: April 1990 beach survey. Final Report prepared by Coastal Science & Engineering, Inc. Columbia, South Carolina for the City of North Myrtle Beach, South Carolina. 40pp + appendices.

Dingman, J.S., and T.W. Kana. 1990. Myrtle Beach emergency nourishment project: April 1990 beach survey. Final Report prepared by Coastal Science & Engineering, Inc. Columbia, South Carolina for the City of Myrtle Beach, South Carolina. 47pp.

Baca, B.J., C.E. Nation and T.W. Kana. 1990. Biological Monitoring of Beach Nourishment at Hog Inlet, North Myrtle Beach, South Carolina. Preproject Report prepared by Coastal Science Associates, Inc. Columbia, South Carolina and Coastal Science & Engineering, Inc. Columbia, South Carolina for City of North Myrtle Beach, South Carolina. 8pp.

This report is the first of a study to assess the environmental impacts of borrowing sand from Hog Inlet shoals for emergency nourishment along North Myrtle Beach. It is being performed in connection with construction management of the project by CSE and its subcontractor CSA. While this environmental survey is not a specific requirement of the project, the City of North Myrtle Beach requested certain environmental analyses be performed. We believe the data collected during the study will help state and federal resource agencies evaluate the impacts of such nourishment projects.

Stender, B.W., R.F. Van Dolah, and P.P. Maier. 1991. Identification and location of live bottom habitats in five potential borrow sites off Myrtle Beach, SC. Final Report, Marine Resources Research Institute, South Carolina Department of Natural Resources, Charleston, South Carolina submitted to U.S. Department of the Interior, Fish and Wildlife Service. 20pp + appendices.

The purpose of the present study was to conduct a survey to identify whether live bottom habitats were present within five areas which had been identified as potential sources of sand by the U. S. Army Corps of Engineers (Jim Woody, pers. Comm.). Mapping the location and extent of these habitats would enable protective measures to be taken to minimize damage to these sensitive areas. In addition, because the sessile invertebrates that comprise live bottom communities must be attached to a hard substrate with only a thin layer of overlying sand. Mapping the location of these areas would identify sites that would not provide sufficient sand resources for beach renourishment.
Two secondary objectives were also incorporated into the study as a result of the methodologies. These included:
1. Evaluating the capabilities of a state-of-the-art side scan sonar system for detecting live bottom areas having little or no relief, and
2. Evaluating the feasibility of correlating sonar graphs with color television recordings for verification of bottom characterization.

CSE, Inc. 1990. Myrtle Beach emergency nourishment project. Survey Report prepared by Coastal Science & Engineering, Inc. Columbia, South Carolina for the City of Myrtle Beach, South Carolina. 28pp + appendices.

CSE. 1992. Myrtle Beach Nourishment Project, Sixth Annual Survey - May 1991 to May 1992. Final Report prepared by Coastal Science & Engineering, Inc. Columbia, South Carolina for the City of Myrtle Beach, South Carolina. 41pp + appendices.

This report is the sixth annual beach monitoring report following nourishment of Myrtle Beach. The City of Myrtle Beach completed an 853,350 cubic yard (cy) nourishment project in May 1987, one of the largest such projects ever performed using trucks and an inland source of sand. Construction of the project required two winter seasons with the southern portion of the city nourished between January and April 1986 and the northern section during the winter of 1987.

Jutte, P.C., R.F. Van Dolah, G.Y. Ojeda, and P.T. Gayes. 1999. An Environmental Monitoring Study of the Myrtle Beach Renourishment Project: Physical and Biological Assessment of Offshore Sand Borrow Sites. Phase I – Cherry Grove Borrow Area. Final Report, Marine Resources Research Institute, South Carolina Department of Natural Resources, Charleston, South Carolina submitted to the U.S. Army Corps of Engineers, Charleston District. 79pp.

The Myrtle Beach Renourishment Project was developed by the U.S. Army Corps of Engineers (USACE) in 1993. The Cherry Grove sand borrow area was dredged using hopper dredges, an alternative dredging operation that excavated a greater area of the borrow area to a shallower depth (approx 3 feet below grade) than nourishment studies

previously monitored by SCDNR. Within 15-18 months post dredging, the sediment composition in the CG borrow site appeared to be returning to pre-dredging conditions, but further supplemental sampling 27-30 months after dredging indicated that the site had still not returned to a high sand (>90%) content. Faunal abundances did not exhibit significant effects due to dredging activities.

Jutte, P.C., R.F. Van Dolah, and M.V. Levisen. 1999. An Environmental Monitoring Study of the Myrtle Beach Renourishment Project: Intertidal Benthic Community Assessment. Phase I – Cherry Grove to North Myrtle Beach. Final Report prepared by the Marine Resources Research Institute, SCDNR, Charleston, South Carolina for the U.S. Army Corps of Engineers, Charleston District. 79pp.

The Grand Strand area beach renourishment project was designed to protect the beachfront property of South Carolina's most popular tourist area. The project, initiated by the U.S. Army Corps of Engineers (USACOE) in 1994, is one of the largest nourishment programs ever completed on the eastern seaboard of the United States. The overall project encompassed approximately 25 miles of coastline, and required more than 6.3 million cubic yards of sand. Phase I of the project encompassed 8.6 miles of the beach from Cherry Grove to North Myrtle Beach.

Jutte, P.C., R.F. Van Dolah, and M.V. Levisen. 1999. An Environmental Monitoring Study of the Myrtle Beach Renourishment Project: Intertidal Benthic Community Assessment. Phase II – Myrtle Beach. Supplemental Report, Marine Resources Research Institute, South Carolina Department of Natural Resources, Charleston, South Carolina for the U.S. Army Corps of Engineers, Charleston District. 38pp.

Phase II of the Myrtle Beach Renourishment project placed 2.25 million cubic yards of sand on 9.0 miles of shoreline between The Dunes and Springmaid Pier. This report addresses the effects observed during this second nourishment phase after a short recovery period of one week following completion of nourishment. Conditions at this time period were compared to pre-nourishment conditions and conditions six months after nourishment activities. Results indicated that the beaches recovered within six months after nourishment occurred, and showed initial signs of recovery one week post nourishment.

Gayes, P.T., M. Stutz, E. Johnstone, G.Y. Ojeda, S.J. Wells, L. Illiffe, P.C. Jutte, and R.F. Van Dolah. 2001. Grand Strand Nourishment Project: Beach Survey Study Final Report - Phase I, Phase II and Phase III. Final Report, Center for Marine and Wetland Studies, Coastal Carolina University, Conway, South Carolina, and Marine Resources Research Institute, South Carolina Department of Natural Resources, Charleston, South Carolina for the U.S. Army Corps of Engineers, Charleston District. 44pp.

This report presents the results of a program of long-beach profiles completed over the three-year period following construction of the project. Because of the staging and construction of the three phases of the overall project and associated study (North Myrtle Beach, Myrtle Beach and Surfside/Garden City) only two years of behavior of

the Surfside/Garden City Beach fill were monitored. This beach profiling study augmented the existing OCRM statewide program of monitoring beaches (Project BERM: Beach Erosion Research and Monitoring) which conducts long profiles annually at ~350 locations statewide. The BERM database provided some historical record of behavior of the areas nourished and is expected to continue to provide annual monitoring of the projects beyond the three-year period of study (for the life of the state monitoring program). Such longer term monitoring of constructed beach fills was a priority need identified by the 1995 National Research Council Report of Beach Nourishment (NRC, 1995).

In addition, this report draws on data provided by related studies associated with this study including side scan and video records collected to assess the effect of sand movement into critical hard bottom habitats on the shoreface and inner shelf adjacent to the projects. This information was invaluable as corroborating interpretation of cross shore transport of beach fill inferred from the profile data. Additional geophysical data collected as part of the Coastal Erosion Study, a large cooperative study between the US Geological Survey and State of South Carolina coordinated by the SC Sea Grant Consortium, provided additional high resolution sub-bottom profiles, vibracores and side scan sonar imagery that assisted the interpretation of the beach profile data.

Ojeda, G.Y., P.T. Gayes, A.L. Sapp, P.C. Jutte, and R.F. Van Dolah. 2001. Habitat Mapping and Sea Bottom Change Detection on the Shoreface and Inner Shelf Adjacent to the Grand Strand Beach Nourishment Project. Final Report prepared by Center for Marine and Wetland Studies, Coastal Carolina University, Conway, South Carolina and Marine Resources Research Institute, SCDNR, Charleston, South Carolina for the U.S. Army Corps of Engineers, Charleston District, Charleston, South Carolina. 48pp + appendices.

To monitor and evaluate the success of Phases I, II and III of the Grand Strand Nourishment Project, the Center for Marine and Wetland Studies in collaboration with the South Carolina Department of Natural Resources and the US Army Corps of Engineers designed and implemented an integrated approach that included (1) documentation of behavior of the beach fill over time through collection of long beach profiles along the length of the constructed projects; (2) evaluation of the impact or changes that occurred in the beach and shoreface habitats associated with the influx of additional nourished sand into the system; and (3) evaluation of the effects of excavation and physical infilling of inner-shelf borrow sites on benthic habitats.

For purposes of evaluating the effect that redistribution of nourished sand might have exerted on offshore habitats, thirteen target sites were monitored during the last four years. Five sequential side scan sonar surveys and twenty-one submarine video-transects were acquired over these sites. The sonar surveys were classified by means of a quantitative approach that involved textural analysis of images, and training of a neural network classifier. The output of this technique was a set of maps that categorized the sonar images in terms of 'hard bottom' or 'sand'. This technique facilitated tracking of habitat changes on a pixel-by-pixel basis, and quantification of changes on each site on a percent area basis. Results of this approach indicate that offshore habitats have not been significantly impacted by effect of redistribution of nourished sand. Although changes were detected in bottom-type over the years, these changes were mainly interpreted as natural shifting of sediment within hard bottom

areas. Sediment deposition and burial of hard bottom habitats were largely balanced by erosion and exhumation of new hard bottom. Such variability is expected in shallow marine settings such as the inner shelf, and was documented in this study by observation of the most distal target site, which showed an initial rapid increase in hard bottom coverage followed by a slow decrease, on percent basis. All data available for this study and analysis of beach profiles suggest that limited nearshore loss of hard bottom habitat observed on the shoreface, seaward of the constructed beach fill, was due to localized introduction of "new" sand into the system from the beach fill, but was only marginally above the inherent variability of the system.

Jutte, P.C., R.F. Van Dolah, G.Y. Ojeda, and P.T. Gayes. 2001. An Environmental Monitoring Study of the Myrtle Beach Renourishment Project: Physical and Biological Assessment of Offshore Sand Borrow Sites. Phase II – Cane South Borrow Area. Final Report, Marine Resources Research Institute, South Carolina Department of Natural Resources, Charleston, South Carolina submitted to the U.S. Army Corps of Engineers, Charleston District. 70pp.

The Myrtle Beach Renourishment Project was developed by the U.S. Army Corps of Engineers (USACE) in 1993. Phase II of the Myrtle Beach Renourishment project was completed in July 1997, and nourished approximately 9.0 miles of beaches between The Dunes and Springmaid Pier, with sand dredged from two offshore borrow sites, the Cane North borrow area and the Cane South borrow area. The findings suggest that dredging activities affected sediment characteristics at the CS borrow area, and that these changes persisted throughout the monitoring period, 25-28 months after the completion of dredging. As of March 2000 (32-35 months post dredging), the bathymetric survey of the CS borrow area still displayed a strong signature (depression) due to dredging activities which suggests that original morphometric parameters such as local relief, slopes, aspect, and natural flow directions had not recovered to original values. With respect to benthic communities, results indicate that average faunal densities and species numbers in the CS borrow area did not appear to be impacted for a significant period of time following dredging operation.

Jutte, P.C., L.E. Zimmerman, R.F. Van Dolah, G.Y. Ojeda, and P.T. Gayes. 2001. An Environmental Monitoring Study of the Myrtle Beach Renourishment Project: Physical and Biological Assessment of Offshore Sand Borrow Sites. Phase III – Surfside/Garden City Borrow Area. Final Report prepared by the Marine Resources Research Institute, SCDNR, Charleston, South Carolina for the U.S. Army Corps of Engineers, Charleston District. 80pp.

The Myrtle Beach Renourishment Project was developed by the U.S. Army Corps of Engineers (USACE) in 1993. Phase III of the Myrtle Beach Renourishment project was completed in November 1998, and nourished approximately 7.0 miles of beaches. Findings suggest that dredging activities did not alter sediment characteristics at the SG borrow area for a significant period of time. Mean depth differences in the primary portion of the borrow area indicated that complete infilling had occurred after two years of recovery. With respect to benthic infauna, results indicate that average faunal densities and species numbers in the SG borrow area did not appear to be negatively impacted for a significant period of time following the dredging operation.

Pawleys Island, South Carolina

Lankford, T.W., B.J. Baca and C.E. Nation. 1988. Biological monitoring of beach scraping at Pawleys Island South Carolina. Final Report prepared by Coastal Science & Engineering, Inc. Columbia, South Carolina for Town of Pawleys Island, South Carolina. 36pp.

This report was prepared in connection with a 53,000 cubic yard (yd3)'beach scraping/nourishment project completed at Pawleys Island, South Carolina, in March 1988 under permit P I N 87-3T-377-P. Nourishment was a response to erosion caused by the 1987 New Year's Day storm. The project involved scraping sand from intertidal shoals at Midway lnlet and Pawleys lnlet to a maximum depth o f -1.5 feet mean sea level (ft MSL). Sand was transferred to the southern 1.2 miles (2 km) of developed shoreline and to a northern area between 1st and 3rd Streets. Construction was accomplished using scraper pans to excavate and transport sand which was placed as an artificial berm/low dune along the upper beach. Typical fill volumes were 5 yd^3/ft. Conditions on the permit included (1) preparation o f a biological monitoring study and (2) schedule limitations to avoid construction during biologically productive months. The present study was prepared in response to this monitoring requirement under contract to the Town of Pawleys Island. Primary objectives were to assess possible impacts of beach scraping/nourishment to nearshore benthic macroinvertebrate communities. Biological samples were taken at borrow, nourished. And control stations at periods before, immediately after, and 3.5 months following completion of nourishment activity. Benthic communities were characterized in terms of composition. Species richness and diversity to facilitate comparisons between treatment sites. These communities were found to be similar in structure and species abundance to those described for other South Carolina outer sand beaches, with dominant organisms being coquinas (*Donax variabilis*), amphipods (Haustoridae), and polychaete worms (primarily *Scolelepis squamata*).

Seabrook Island, South Carolina

Kana, T.W., Baca, B.J., and M.L. Williams. 1986. Beach surveys and environmental monitoring along Seabrook Island, South Carolina: August 1985-June 1986. Final Report prepared by Coastal Science & Engineering, Inc. Columbia, South Carolina for Seabrook Island Property Owners Association Charleston, South Carolina. 59pp + appendices.

This report deals with shoreline and environmental changes along Seabrook Island during the period August 1985 to June 1986. Additional comparisons are made with surveys obtained in 1983, 1984, and May 1985 after Captain Sam's lnlet relocation. The present study was the first periodic monitoring of Seabrook's shoreline since 1982* and was initiated by the Property Owners Association (POA) because of the large-scale changes along the beach following inlet relocation. The purpose of the surveys is to determine the rates of erosion and accretion at numerous points along the

shoreline, formulate sediment budgets, inventory new habitats produced by the inlet relocation, and identify potential shoreline problems. Routine monitoring is a prerequisite for cost-effective shorefront management because it provides a database for formulating solutions and developing comparative cost estimates. Included in the report are specific recommendations for improving and protecting the beach based on results of the present study.
Eighteen beach stations between Pelican Watch Villas and new Captain Sam's lnlet were surveyed quarterly from the dunes/seawall to -5 ft mean sea level (MSL) (wading depth at low tide). In addition, bathymetry surveys were completed twice across the northern channel of North Edisto lnlet to document channel and shoal movement. Biological surveys were also completed twice during the study to identify new habitats, inventory bird species, and assess the recovery of the 1983 construction area around Captain Sam's Inlet.

CSA. 1989. Beach restoration and shore protection alternatives along the south end of Seabrook Island, South Carolina. Feasibility Study prepared by Coastal Science & Engineering, Inc. Columbia, South Carolina for Seabrook Island Property Owners Association, Seabrook Island, South Carolina. 68pp + appendices.

The purpose of this report is to present alternatives for shore protection and beach restoration along the portion of Seabrook Island south of Renken Point. During the past ten years, Seabrook's shoreline has been closely surveyed under the direction of the Seabrook Island Company or the Property Owners Association (a partial list of reports is given in the references). These surveys have been used to calculate sand quantities lost or gained along the beach and measure rates of inlet and channel movement. Such information has been basic to predicting future trends and formulating specific solutions, such as the relocation of Captain Sams Inlet in 1983. While the shoreline in 1988 is greatly improved compared to 1983, problems remain.

CSA. 1990. Plankton monitoring for assessment of beach nourishment impacts: Seabrook Island, South Carolina. Draft Final Report prepared by Coastal Science Associates, Inc. Columbia, South Carolina for Coastal Science & Engineering, Inc. Columbia, South Carolina. 16 pp.

This report was prepared in connection with a 685,000 cubic yard beach nourishment project completed at Seabrook Island, South Carolina in March 1990. Nourishment was needed to counteract the erosion that was caused by encroachment of the northern channel along the seawall south of Renken Point and the migration of Captain Sam's Inlet. The present project involved dredging two cuts in the shoal east of the northern channel to a maximun depth of -15 feet mean sea level (MSL). Sand was pumped onto the beach from Cobia court south to Pelican Watch Villas.
Typical fill volumes were 200 yd^3/ft. Primary objectives of this study were to assess possible immediate impacts of shoal dredging and beach nourishment on nearshore fishes and larger crustaceans such as shrimp and crabs. Plankton tows were taken over the shoal and at nearshore sites at periods during dredging and twelve days after dredging was completed. Plankton communities were characterized in terms of composition, species richness and diversity, and collections were compared between sites and time periods. The dominant organisms in the samples was opossum shrimp (*Neomysis americanus*), a species important to the food chain. The nearshore fish

community exhibited a significant reduction in numbers of individuals immediately after the dredging activity when compared to samples taken during dredging. This reduction in individuals (but not species count) may be attributed to the loss of shoal habitat. The large numbers of fish collected in plankton tows during dredging could be a reflection of the fish feeding on the benthic community exposed during the dredging. Importantly, few species were collected which are directly important, economically, although most are important to the ecology of the area. The results suggest that short-term impacts to certain species do occur, and the long term impacts, if any, are unknown.

CSE. 1992. Seabrook Island, South Carolina Beach Nourishment Project: Performance Evaluation and Future Needs. Survey Report No. 3 prepared by Coastal Science & Engineering, Inc. Columbia, South Carolina for Seabrook Island Property Owners Association Johns Island, South Carolina. 58pp + appendices.

This report is the third in a series following the 1990 Seabrook Island beach nourishment project. It is presented in three parts:
1) Updated analysis of beach changes and sand budgets including an estimate of the quantity of nourishment sand remaining. 2) Historical shoreline change analysis comparing detailed maps from the 1970's to the present. 3) Assessment of alternatives for shoreline improvement focusing on a schedule for a second inlet relocation. Other events relating to the oceanfront during the past year included completion and submittal of a Beachfront Management Plan by the Town of Seabrook Island (with limited assistance by CSE) and revision of baselines and setback lines by the South Carolina Coastal Council, using an updated analysis of the beach condition prepared by CSE under POA sponsorship (Attachment I). The change in baseline position was significant along South Beach reflecting the positive impact of nourishment. But the change was not sufficient to remove all development along South Beach from the setback area.

South Carolina (General Studies)

Kana, T.W. 1988. Beach Erosion in South Carolina. M. Goodwin and F. Rogers (eds.), South Carolina Sea Grant Consortium, Charleston, S.C., 55pp.

Lankford, T.E., and B.J. Baca. 1989. Comparative environmental impacts of various forms of beach nourishment. In Proc. Coastal Zone 89, ASCE, New York, N.Y. Pp. 2046-2059.

Van Dolah, R.F., M.W. Colgan, M.R. Devoe, P. Donovan-Ealy, P.T. Gayes, M.P. Katuna, and S. Padgett. 1994. An Evaluation of Sand, Mineral and Hard-Bottom Resources on the Coastal Ocean Shelf off South Carolina. Final Report, Marine Resources Research Institute, South Carolina Department of Natural Resources, Charleston, South Carolina submitted to the Minerals Management Service Office of International Activities and Marine Minerals, Herndon, Virginia. 235 pp.

In July of 1992, the State of South Carolina entered into a cooperative arrangement with the Minerals Management Service (MMS) to establish a technical working group to identify and evaluate sand resources off the coast of South Carolina. The general objectives of the State are to undertake a five year program to evaluate the sand, mineral and hard-bottom resources that exist on the shelf. During the first year, the "Task Force on Offshore Resources" was formed to conduct a detailed compilation of existing data available to document sand, mineral and hardbottom resources on the coastal ocean shelf off South Carolina, and to begin an analysis of trends in shoreline movement along eroding beaches in South Carolina.

R.F. Van Dolah, B.J. Digre, P.T. Gayes, P. Donovan-Ealy and M.W. Dowd. 1998. An evaluation of physical recovery rates in sand borrow sites used for beach nourishment projects in South Carolina. Final Report prepared by the Marine Resources Research Institute, SCDNR, Charleston, South Carolina, Center for Marine and Wetland Studies, Coastal Carolina University, Conway, South Carolina, and U.S. Army Corps of Engineers, Charleston District, Charleston, South Carolina for the South Carolina Task Force on Offshore Resources and the Minerals Management Service, Office of International Activities and Marine Minerals, Herndon, Virginia. 77pp + Appendices.

This study examined six sand borrow sites that had been dredged in South Carolina over the past eight years in order to (1) document the present size and configuration of each borrow site, (2) determine changes in the volume of sediments that had occurred over time, and (3) document the composition of surficial sediments in each borrow area. All published and non-published information available for each site was used to define the initial configuration and size of the dredged hole. Historical post-dredge surveys available for a few of the areas, combined with new bathymetric surveys completed in 1996 at five of the areas, were then used to evaluate post-dredging changes in bottom topography. The 1996 surveys also included collection of surficial sediments from five of the sites and vibracores samples from two of the sites, to evaluate surficial and subsurface sediment composition. All bathymetric data were analyzed using Geographic Information System (GIS) processing techniques to build bottom contour profiles and changes in sediment volumes over time.

Gayes, P.T., P. Donovan-Ealy, M.S. Harris, and W. Baldwin. 1998. Assessment of Beach Renourishment Resources on the Inner Shelf off Folly Beach and Edisto Island, South Carolina. Final Report, Center for Marine and Wetland Studies, Coastal Carolina University, Conway, South Carolina submitted to Minerals Management Service Herndon, Virginia.

This study examined six sand borrow sites that had been dredged in South Carolina over the past eight years in order to 1) document the present size and configuration of each borrow site, 2) determine changes in the volume of sediments that had occurred over time, and 3) document the composition of surficial sediments in each borrow area. All published and non-published information available for each site was used to define the initial configuration and size of the dredged hole. Historical post dredge surveys available for a few of the areas, combined with new bathymetric surveys completed in 1996 at five of the areas, were then used to evaluate post-dredging changes in bottom topography. The 1996 surveys also included collection of surficial

sediments from five of the sites and vibracores samples from two of the sites, to evaluate surficial and subsurface sediment composition. All bathymetric data were analyzed using Geographic Information System (GIS) processing techniques to build bottom contour profiles and changes in sediment volumes over time.

King, E.F. and M. Katuna. 1999. Evaluation of Beach Renourishment Performance in South Carolina Using GIS Analysis. Final Report, Geology Department, University of Charleston, Charleston, South Carolina submitted to Minerals Management Service Office of International Activities and Mineral Resources, Herndon, Virginia and South Carolina Task Force on Offshore Resources. 72pp.

This research examines three recently completed beach nourishment projects in South Carolina to determine project performance. Hunting, Edisto, and Hilton Head Islands were all renourished within the past nine years. Monitoring surveys were obtained for each project and incorporated into a geographic information system (GIS). Evaluation criteria consisting of changes in sediment volume and beach width were measured to determine the lifespan of each project.

Weinbach, P.R. and R.F. Van Dolah. 2001. Spatial Analysis of Bottom Habitats and Sand Deposits on the Continental Shelf off South Carolina. Final Report, Marine Resources Research Institute, South Carolina Department of Natural Resources, Charleston, South Carolina submitted to South Carolina Task Force on Offshore Resources and the Minerals Management Service Office of International Activities and Marine Minerals. 22 pp + appendices.

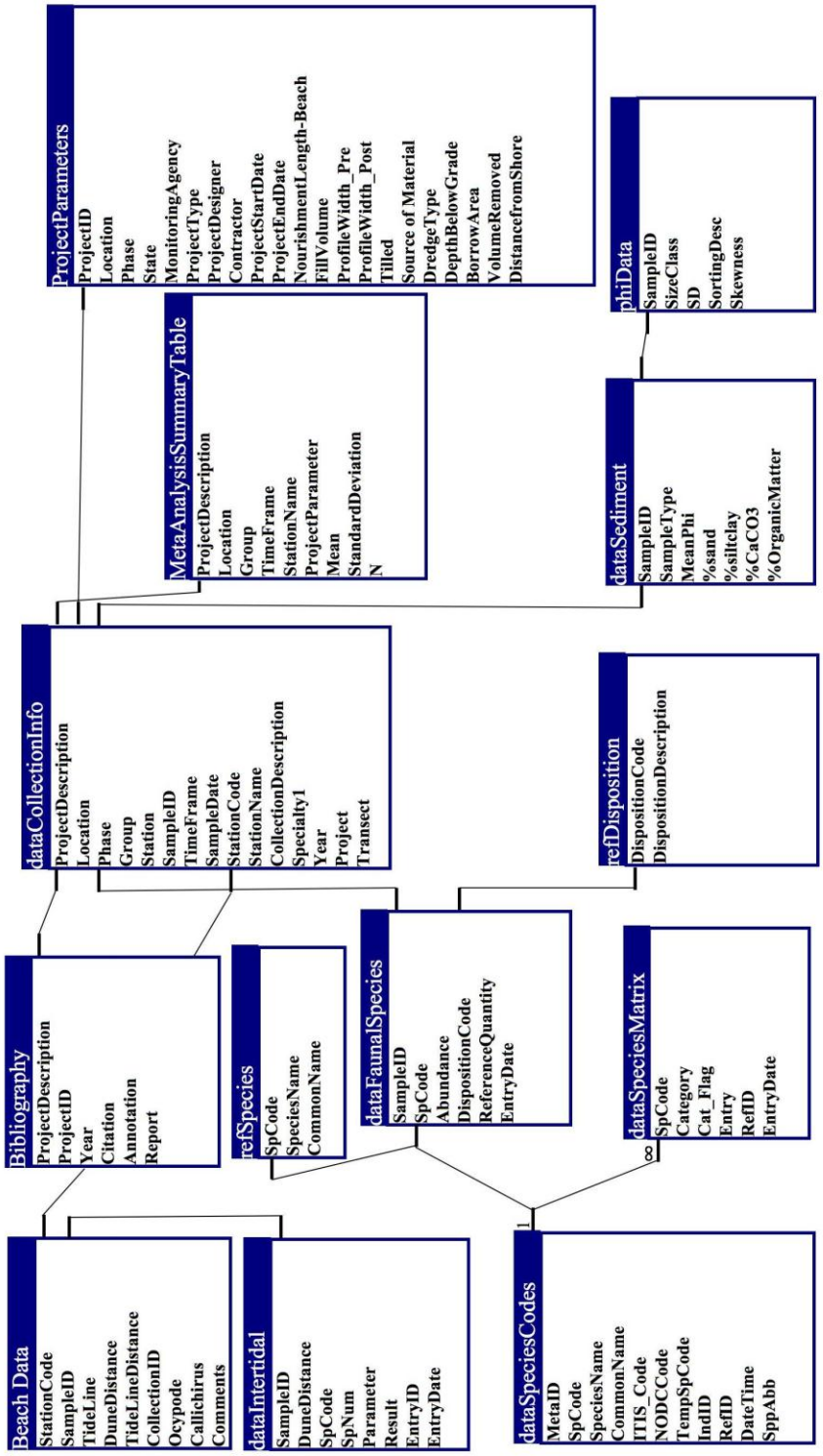
The South Carolina Task Force on Offshore Resources has compiled an extensive database on bottom habitat characteristics for the coastal waters off South Carolina, extending from the beach out to depths of approximately 200 m. The database represents a compilation of both historical data obtained from previous scientific studies conducted in the region and more recent studies that have been completed as part of a cooperative program with the Minerals Management Service (MMS) Office of International Activities and Marine Minerals (INTERMAR). The data are compiled in both Access and ArcView shape files.

The database analyzed for this report consists of 14,512 records that provide information on one or more of the following bottom characteristics: presence or absence of hard-bottom reef habitat, percent sand composition, mean grain size, and thickness of the sand layer over harder substrate or subsurface reflectors. Each of these characteristics were examined to identify the location and density of records, with emphasis placed on relating the distribution of these records to the state's beaches which are periodically nourished, or may need nourishment in the future.

Most of the hard-bottom reef habitat is located further offshore than 5-10 miles from the beach and would not be areas of concern to beach nourishment projects. However, extensive hard bottom areas are documented in the Grand Strand area. Mean grain size and sediment thickness data are not well represented in the database. Those data that are available were largely collected through studies completed for recent beach nourishment projects or the INTERMAR program. These data are critical to evaluating the suitability and location of sand deposits that could be used for nourishment operations. Information on percent sand content in the bottom sediments is more extensive and most records indicate >90% sand content. Based on the

information available in the database, there appears to be suitable concentrations of nourishment quality sand deposits in reasonable proximity to most of the state's beaches. While the database will help identify areas of potential interest, more intensive surveys will be required in some areas to identify suitable sand deposits that meet grain size and depth of sediment lens criteria. Areas where records are especially lacking in the database in within 5-10 miles of the beach include Pawleys Island, Fripp Island and Daufuskie Island. Studies have recently been completed off Pawleys Island through the South Carolina Cooperative with INTERMAR. Data from those studies have identified potential borrow sites and areas that should be avoided. Those data will be incorporated into the INTERMAR database in 2001. Additional studies are still needed to address data gaps off the other beaches of concern.

Appendix 3. Relational database structure.


ProjectParameters
ProjectID
Location
Phase
State
MonitoringAgency
ProjectType
ProjectDesigner
Contractor
ProjectStartDate
ProjectEndDate
NourishmentLength-Beach
FillVolume
ProfileWidth_Pre
ProfileWidth_Post
Tilled
Source of Material
DredgeType
DepthBelowGrade
BorrowArea
VolumeRemoved
DistancefromShore
MetaAnalysisSummaryTable
ProjectDescription
Location
Group
TimeFrame
StationName
ProjectParameter
Mean
StandardDeviation
N
phiData
SampleID
SizeClass
SD
SortingDesc
Skewness
dataSediment
SampleID
SampleType
MeanPhi
%sand
%siltclay
%CaCO3
%OrganicMatter
dataCollectionInfo
ProjectDescription
Location
Phase
Group
Station
SampleID
TimeFrame
SampleDate
StationCode
StationName
CollectionDescription
Specialty1
Year
Project
Transect
refDisposition
DispositionCode
DispositionDescription
Bibliography
ProjectDescription
ProjectID
Year
Citation
Annotation
Report
refSpecies
SpCode
SpeciesName
CommonName
dataFaunalSpecies
SampleID
SpCode
Abundance
DispositionCode
ReferenceQuantity
EntryDate
dataSpeciesMatrix
SpCode
Category
Cat_Flag
Entry
RefID
EntryDate
∞
1
Beach Data
StationCode
SampleID
TideLine
DuneDistance
TideLineDistance
CollectionID
Ocypode
Callichirus
Comments
dataIntertidal
SampleID
DuneDistance
SpCode
SpNum
Parameter
Result
EntryID
EntryDate
dataSpeciesCodes
MetaID
SpCode
SpeciesName
CommonName
ITIS_Code
NODCCode
TempSpCode
IndID
RefID
DateTime
SppAbb

Field Name	Table	Description
%CaCO3	dataSediment	Percent of calcium carbonate present in sample
%OrganicMatter	dataSediment	Percent of organic matter present in sample
%sand	dataSediment	Percent of sand present in sample
%siltclay	dataSediment	Percent of silt clay present in sample
Abundance	dataFaunalSpecies	Total abundance of organism in sample
Annotation	Bibliography	Executive summary or abstract of report or manuscript
BorrowArea	ProjectParameters	Area borrowed from - size of footprint in m2 or km2
Callichirus	Beach Data	Number of Callichirus present
Cat_Flag	dataSpeciesMatrix	Indicates that the species is a member of the category
Category	dataSpeciesMatrix	Taxonomic category to which organism is assigned
Citation	Bibliography	Reference to a source of information
CollectionDescription	dataCollectionInfo	Station name and timeframe of sample
CollectionID	BeachData	Sampling period related to nourishment project: Pre, post, 6 mo post, etc.
Comments	BeachData	Comments related to sampling effort
CommonName	refSpecies, dataSpeciesCodes	Common name of organism
Contractor	ProjectParameters	Contractor who performed dredging
DateTime	dataSpeciesCodes	Date record was added
DepthBelowGrade	ProjectParameters	Depth borrow area was dug; max depth below grade; scrape 2-3 ft.
DispositionCodes	dataFaunalSpecies, refDisposition	Indicates individuals placed in the various collections
DispositionDescription	refDisposition	Defines disposition codes
DistancefromShore	ProjectParameters	Distance of borrow area from shore: upland - blank; intertidal - 0; subtidal - distance to nearest point
DredgeType	ProjectParameters	Type of dredge used: Hopper, Hydraulic, Dump Truck if upland source
DuneDistance	Beach Data, dataIntertidal	Distance from dune line to water
EntryID	dataSpeciesMatrix, dataIntertidal	Records process of data entry
EntryDate	dataFaunalSpecies, dataSpeciesMatrix, dataIntertidal	Date record was added
FillVolume	ProjectParameters	Amount of sand placed on beach
Group	dataCollectionInfo, MetaAnalysisSummaryTable	Impact or Reference group
IndID	dataSpeciesCodes	Initials of iindividual who assigned temporary species code
IT IS_Code	dataSpeciesCodes	Integrated Taxonomic Information System code
Location	dataCollectionInfo, MetaAnalysisSummaryTable	Location of study: Beach, Borrow, or Nearshore
Mean	MetaAnalysisSummaryTable	Mean of parameter
MeanPhi	dataSediment	Mean Phi value
MetaID	dataSpeciesCodes	Identifies comments pertaining to samples
MonitoringAgency	ProjectParameters	Agency responsible for monitoring studies
N	MetaAnalysisSummaryTable	Number of samples
NODCCode	dataSpeciesCodes	National Oceanographic Data Center code
NourishmentLength-Beach	ProjectParameters	Length of beach nourished
Ocypode	Beach Data	Number of Ocypode present
Parameter	dataIntertidal	Unit being measured (length, burrow width, etc)
Phase	dataCollectionInfo, ProjectParameters	Phase of the study (so as to know which reference area corresponds)
ProfileWidth_Post	ProjectParameters	Width of beach prior to nourishment
ProfileWidth_Pre	ProjectParameters	Width of beach post nourishment
ProjectDescription	Bibliography, dataCollectionInfo, MetaAnalysisSummaryTable	Location and year of nourishment project
ProjectDesigner	ProjectParameters	Agency who designed project
ProjectEndDate	ProjectParameters	Date last nourish material was placed

Field Name	Table	Description
ProjectID	Bibliography, dataCollectionInfo, ProjectParameters	ID number as assigned by MRD or manually assigned if no MRD code exists or a non-MRD project
ProjectParameter	MetaAnalysisSummaryTable	Benthos, sediment, species name, etc.
ProjectStartDate	ProjectParameters	Date first fill was placed
ProjectType	ProjectParameters	Type of nourishment project; Dredge, Scrape, etc.
ReferenceQuantity	dataFaunalSpecies	Number of individual organisms saved as reference vouchers
RefID	dataSpeciesCodes, dataSpeciesMatrix	Numbers that identify references in dataReference table
Report	Bibliography	Coded as 0 if a copy of the report is not in the beach nourishment library, 1 if the report is in the library
Result	dataIntertidal	Data result which corresponds to Parameter
SampleDate	dataCollectionInfo	Date sample was collected as month/day/year
SampleID	Beach Data, dataCollectionInfo, dataFaunalSpecies, dataSediment, phiData, dataIntertidal	Sample identification number starting with year
SampleType	dataSediment	Identifies sample as a sediment composite
SD	phiData	Standard deviation
SizeClass	phiData	Description of phi size class
Skewness	phiData	Departure from perfect symmetry calculated in phi
SortingDesc	phiData	Variation in grain size
SourceofMaterial	ProjectParameters	Source of fill material: subtidal, intertidal flat, upland source
SpCode	refSpecies, dataFaunalSpecies, dataSpeciesCodes, dataSpeciesMatrix, dataIntertidal	Unique code assigned to each species
Specialty1	dataCollectionInfo	Any unique labeling descriptions
SpeciesName	refSpecies, dataSpeciesCodes	Name listed as genus species
SpNum	dataIntertidal	Unique number assigned to each species in a sample
SppAbb	dataSpeciesCodes	Unique 8 digit code in species code database
StandardDeviation	MetaAnalysisSummaryTable	Dispersion of the values from the mean
State	ProjectParameters	State where nourishment project occurred
StationCode	Beach Data, dataCollectionInfo, dataFaunalSpecies	Station code name
StationName	dataCollectionInfo, MetaAnalysisSummaryTable	Prefix of station code
TempSpCode	dataSpeciesCodes	Temporary species code assigned by DNR staff for newly found species
TideLine	Beach Data	Lower or Upper tide line
TideLineDistance	Beach Data	Distance from high tide line to dune(-) or water(+)
Tilled	ProjectParameters	Yes/No, whether beach was tilled after nourishment
TimeFrame	dataCollectionInfo, MetaAnalysisSummaryTable	Sampling period related to nourishment project: Pre, post, 6 mo post, etc.
Transect	dataCollectionInfo	Number corresponds to transect number; used when multiple samples were collected along a transect
VolumeRemoved	ProjectParameters	Volume of fill removed from borrow area in mcy, y3
Year	Bibliography	Year sample was collected