# LESSONS LEARNED FROM BIOLOGICAL MONITORING OF BEACH NOURISHMENT PROJECTS

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## ABSTRACT

The combination of rising sea level, more frequent and intensive storms, and increasing rates of coastal development have led to increased demands for the restoration of eroding sandy shorelines, and consequently, beach nourishment projects. Understanding and communicating the potential environmental impacts of these projects to the lay-public and broader scientific community, therefore, is an important responsibility of researchers. Several recent reviews of biological monitoring studies of beach nourishment projects have questioned both the validity of past monitoring efforts and the interpretation of results that indicate minor impacts. We reexamine the same monitoring literature (along with more recently published studies) and summarize the results. In addition, the following recommendations are made based on monitoring results (1) When logistically and economically feasible, avoid active beach nourishment activities during seasons of peak larval recruitment to the benthos (e.g., the spring for the eastern US). (2) To the extent practical, use compatible sediments (e.g., matching grain size distributions between fill and native beach sediments) to minimize recovery times and retain similar benthic macrofaunal community composition. (3) Avoid creating deep pits with steep side-slopes at borrow areas such that depositional and water quality conditions are substantially altered. (4) Locate borrow sites in areas that are likely to refill rapidly with beach compatible sediments (e.g., in relation to net direction of sediment bedload transport and littoral drift, or areas with high sand accretion rates). (5) Focus monitoring effort on potential mechanisms of impact rather than changes to mean abundances for target biota that are highly variable in space and time. (6) Identify monitoring objectives and select methodologies that contribute to a better understanding of biological responses to nourishment-related disturbance, including a determination of meaningful effect sizes. (7) Use BACI (Before-After Control-Impact) monitoring designs such that the magnitude and duration of effects that are biologically meaningful can be detected.

**Keywords** Beach replenishment, impact assessment, macrofauna, benthic recovery, habitat restoration

## INTRODUCTION

Beach nourishment has become a standard and relatively recent method of restoring eroding shorelines throughout the world (Speybroeck et al. 2006). The fixed nature of most coastal development coupled with high population densities in coastal areas exacerbates the economic impact of shoreline erosion and fuels the demand for restoration projects. Currently, thirty percent of the U.S. population resides in coastal counties that border the open ocean or associated estuaries and embayments (Crowell et al. 2007). Past approaches to addressing coastal erosion involved using “hard” stabilization measures such as seawalls and groines, however, it is widely recognized that these armoring structures frequently lead to increased erosion, usually downdrift from the construction site (Pilkey and Wright 1988, Charlier and DeMeyer 2000, Speybroeck et al. 2006). In the absence of a coherent shoreline retreat policy for coastal development, and in light of the widespread acknowledgement that armoring the shoreline causes unacceptable erosion problems, beach nourishment has become the inevitable erosion control measure for sandy shorelines where erosion is perceived to be a problem and restoration is desired. As such, it is imperative that environmental scientists concerned with minimizing the ecological impacts of beach nourishment projects are forthright in their communications within the scientific community, to policy making institutions and to the public at large about environmental impacts of these projects.

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For many years, very few environmental impact papers associated with beach nourishment were published in the peer-reviewed literature (Nelson 1993). In recent years, however, both case studies and review papers have become more common in peer-reviewed journals. The relative paucity of published papers in past decades was not due to an absence of relevant studies because biological monitoring is frequently required as a permit condition for beach nourishment activities in the United States. Rather, study results were published in government reports and the gray literature, which are not as widely accessible and suffer from a reputation of being less scientifically rigorous than the refereed literature (Peterson and Bishop 2005). Perhaps it is the low profile of the gray literature that has led some researchers to incorrectly conclude that direct examination of the impacts of beach nourishment activities on biological resources are "rare" (e.g., Colosio et al. 2007, Fanini et al. 2007).

The emerging focus on of biological monitoring studies associated with beach nourishment projects being published in the peer-reviewed literature is encouraging and broadens the knowledge base of biological impacts. Reviews provide a condensed overview of the scattered literature and interpret conclusions, which is useful for resource managers and the lay public who are concerned about ecological impacts, but may be overwhelmed by the primary sources. A high degree of responsibility, therefore, resides in publishing reviews that provide a balanced accounting of study results, both positive and negative. Several recent reviews of beach nourishment impacts deliver a negative assessment of past biological monitoring practices (Greene 2002, Peterson and Bishop 2005), claiming that ecological impacts from beach nourishment activities have been grossly underestimated and underreported due to flawed sampling designs, field methodologies, and statistical analyses. We examine the primary literature dealing with beach nourishment impacts to reevaluate the nature of impacts and the adequacy of monitoring methodologies, addressing both the complexities of biological responses to beach nourishment and the challenges faced by scientists trying to discern the best ways to define and detect biologically meaningful impacts from beach nourishment activities. We will address some of the negative assertions made in the Peterson and Bishop (2005) review concerning beach nourishment impacts and monitoring studies. In particular, their characterization that impacts are severe and underreported and their findings that monitoring studies are poorly designed and sampling methodologies are flawed.

## REVIEW OF REPORTED IMPACTS

### Macroinvertebrates

Reported recovery rates (Table 1) of macroinvertebrates at beach fill sites range from less than one month (Gorzelany and Nelson 1987) to between one and two years (Rakocinski et al. 1996). Factors potentially associated with observed differences in recovery times include seasonal timing of the nourishment activity and degree to which the fill and native beach sediments matched in terms of grain size distributions and other geotechnical properties (often referred to as "compatible.". Among those studies in which beach nourishment avoided the spring larval recruitment period and sediment match was good, estimated recovery times were relatively rapid (Hayden and Dolan 1974, Gorzelany and Nelson 1987). When beach nourishment occurred during the spring and sediment match was poor, either because of the introduction of a higher silt/clay fraction (Rakocinski et al. 1996) or shell hash (Peterson et al. 2000), recovery times were either longer (Rakocinski et al. 1996) or a short-term impact was documented and subsequent monitoring was not conducted (Peterson et al. 2000).

Recovery was reported to occur within one year in both studies that examined impacts at offshore sand "borrow" sites (Johnson and Nelson 1985; Posey and Alphin 2002). In one of these studies (Posey and Alphin 2002), there were few statistically significant differences in infaunal densities between borrow and control areas, but qualitative differences in community dominance patterns were observed within the borrow area between the pre- and post-dredging sampling periods. The authors emphasized the importance of completing sediment removal before the spring recruitment period to minimize potential impacts to the benthos. The other dredging study (Johnson and Nelson 1985) monitored benthic recovery within a 3.5 m deep depression created by sand removal. The resultant bathymetric depression trapped finer sediments and subsequent shifts in benthic community composition were attributed to the decrease in sediment grain size.

Table 1. Peer-reviewed studies (excluding conference proceedings) that address beach nourishment impacts on sandy beach invertebrates. The degree to which fill sediments matched those of the native beach is indicated.

| Macrofauna Studies | Sediment Match | Location of samples | Dominant Taxa Examined | Metric(s) used to determine recovery status |
|---|---|---|---|---|
| Bilodeau and Bourgeois 2004 (Louisiana) | poor | intertidal | ghost shrimp | presence/absence |
| Colosio et al. 2007 Italy | poor ( | shallow subtidal (1 m depth) | polychaetes bivalves | density, species richness |
| Fanini et al. 2007 Italy | none (marble pebbles) | supralittoral | amphipod | abundance |
| Fenster et al. 2006 Chesapeake Bay, VA | good | intertidal | Tiger beetle | abundance |
| Gorzelany and Nelson 1987 (East coast of FL) | good | intertidal zone to 3 m depth | *Donax* | density, species richness |
| Harriague and Albertelli 2007 Italy | good | swash, surf, and subtidal | polychaetes | density, community structure |
| Hayden and Dolan 1974 (Cape Hatteras, NC) | good | swash zone | *Emerita* | density |
| Jones et al. 2008 New South Wales, Australia | good | intertidal | amphipod | density |
| Menn et al. 2003. Germany | poor (coarser) | intertidal zone to 7 m depth | macrofauna | density |
| Peterson et al. 2000 (Bogues Bank, NC) | poor (shell hash) | intertidal | *Donax* *Emerita* | density |
| Peterson et al. 2006 (Bogues Bank, NC) | poor (coarser) | intertidal | *Donax*, *Emerita* amphipods polychaetes | density |
| Rakocinski et al. 1996 (West coast of FL) | poor (more silt/clay) | intertidal zone to 6 m depth | polychaetes | density, species richness, community structure |

Rakocinski et al. (1996) monitored benthic recovery following conventional sediment placement on exposed beach habitat as well as offshore profile nourishment (sediment deposited by hopper dredge in shallow water rather than pumped onto the beach face, often referred to as "nearshore placement"). Nearshore resident assemblages are well-adapted to shifting sediments (Nelson 1993) and responded to nourishment with "fairly rapid macrobenthic recovery" (Rakocinski et al. 1996). Offshore (up to 800 m from the beach and at 6m depth) where the environment is relatively more stable and less frequently exposed to disturbances, macrobenthic assemblages took longer to recover. Rakocinski et al. (1996) associated these shifts in macrobenthic community structure with silt/clay loading that had occurred in the offshore area.

The importance of matching grain size distributions between native and deposited sediments was demonstrated in Italy where three beaches were nourished at the same time. Two of the three beaches had poor matches in sediment characteristics, and remained nearly defaunated one year later, whereas the macrofaunal assemblage at the third beach with a good sediment match did not differ from that of non-nourished beaches (Colosio et al. 2007). The nature of a second Italian nourishment project (Fanini et al. 2007) was very different from typical beach nourishment projects in which there is an attempt to match sediment grain sizes. In this study, marble pebbles were used as filled material changing the mean grain size of nourished beaches by a factor of 1000. Good sediment match resulted in fast recovery of macrofaunal assemblages on beaches on the Ligurian coast of Italy (Harriague and Albertelli 2007), whereas slow recovery of the deep burrowing ghost crab abundances on barrier island beaches in Louisiana was attributed to the poor sediment match of a beach restoration project (Bilodeau and Bourgeios 2004). Mean grain size and sediment compaction were important factors in habitat creation for the threatened northeastern tiger beetle on Chesapeake Bay beaches that were nourished (Fenster et al. 2006). Monitoring results for this study indicate a short-term positive impact of beach nourishment on beetle habitat. Likewise, a good sediment match for a project in Australia resulted in recovery of amphipod abundance within one year of nourishment (Jones et al. 2008).

Statistical approaches used to analyze the monitoring data may affect determinations of recovery status as well. For example, in studies where both uni- and multivariate analyses were used, univariate statistics on variables such as total density and species richness suggested more rapid recovery than multivariate statistical techniques (Principal Components Analysis), which examined all measured community structure parameters at one time (Rakocinski et al. 1996, Posey and Alphin 2002). Multivariate techniques, therefore, may be a more sensitive indicator of community change although more attention is needed to examine the recovery of functional groups rather than the return of individual species (Wilber and Stern 1992). A criticism concerning the perceived absence of analytical rigor raised by Peterson and Bishop (2005) erroneously stated that none of the studies they reviewed applied non-metric multidimensional scaling (n-MDS) to examine multi-variate responses. However, this analysis was used to examine intertidal, nearshore, and offshore benthic macroinvertebrate community data for a northern New Jersey beach nourishment project (Burlas et al. 2001, Chapters 2 and 8).

**Sea Turtles**

Insofar as sea turtle nesting habitat might be lost to natural erosion in the absence of beach nourishment, nourishment activities can be viewed beneficially. Nourishment activities, however, can also change beach characteristics such that nest site selection, digging behavior, clutch viability, and hatchling emergence are adversely affected (reviewed in Crain et al. 1995). Rumbold et al. (2001) used a Before-After-Control-Impact-Paired-Series (BACIPS) approach to examine nesting and false crawl frequencies on nourished and non-nourished beaches near Jupiter Beach, Florida. Nesting frequency was reduced and false crawl frequencies were higher on nourished areas of the beach the summer following a spring nourishment event. One year later, nesting frequencies on the nourished beach returned to pre-nourishment values (Rumbold et al. 2001), therefore the impact to turtle nesting in that study was short-term (one season). In a project completed one week before loggerhead nesting began in central east Florida (Brock et al. 2009), nesting success rates decreased for the first post-nourishment nesting season and returned to rates equivalent to those on adjacent non-nourished beaches and historical rates two seasons after nourishment. The initial reduction in nesting success was attributed to a steeper beach profile associated with nourishment. When the beach profile equilibrated the following nesting season, loggerhead nesting success rates were higher (Brock et al. 2009).

Davis et al. (1999) found no relationship between turtle nesting frequencies and sand compactness on three nourished beaches. Turtle nesting frequencies were higher on nourished beaches compared to nearby non-nourished areas. The authors concluded that turtles appear to be able to nest anywhere there is a dry beach, but acknowledged that other important factors such as lighting, temperature, and vegetation were not addressed in their study. One study (Holloman and Godfrey 2004) examining several of these important factors monitored sea turtle nesting on Bogue Banks, North Carolina over the nesting seasons that have occurred since beach nourishment began in 2001. Loggerhead sea turtles have successfully nested (produced hatchlings) on nourished beaches at frequencies equal to that of non-nourished beaches (Holloman and Godfrey 2004). Nests on nourished beaches, however, were warmer than nests on non-nourished beaches, which may have resulted from the darker color of the fill sediments absorbing more solar radiation. Incubation temperatures affect hatchling sex determination in loggerhead sea turtles with warmer temperatures yielding greater numbers of females (Mrosovsky 1988). Consequently, the implications of beach nourishment effects on sea turtle sex ratios and population dynamics are a valid cause for concern. Sand compaction was not associated with nesting success, but the method used (penetrometer) to quantify substrate firmness, and thus suitability for sea turtle nesting, was deemed to be ineffective in assessing the sand resistance encountered by turtles that excavate nests in a non-vertical manner with their rear flippers (Davis et al. 1999, Holloman and Godfrey 2004). The short- and long-term consequences of beach nourishment activities for sea turtle populations require more attention from the scientific community.

**Fishes**

Fish responses to beach nourishment have not been the focus of many studies published in the peer-reviewed literature even though deleterious impacts to fishes are commonly cited as potential impacts of beach nourishment projects. Nearshore hard bottom habitat in Broward County Florida was buried by an unquantified depth of sediment associated with a nearby beach nourishment project. Fish species richness and overall abundance were reduced for the 15-month post-nourishment duration of the study (Lindeman and Snyder 1999), and the fish community was dominated (over 80% of all individuals) by early life stages of fishes. The magnitude of this impact may have been increased by the timing of sedimentation, having occurred just prior to peak spring and summer larval fish recruitment to the area. No consistent differences were found in fish abundances, species richness or community structure (using MDS analyses) between nourished and never nourished sites in the same area of Florida (Baron et al. 2004). These authors concluded that nearshore hardbottom is an important, but not obligate habitat for the juvenile fishes that occur in that area.

A study that examined surf zone fish responses to a beach nourishment project on the northern coast of New Jersey found impacts were restricted to localized attraction (northern kingfish, *Menticirrhus saxatilis*) and avoidance (bluefish *Pomatomus saltatrix*) of active beach nourishment operations (Wilber et al. 2003). Food habits analyses of Atlantic silversides *Menidia menidia* and northern kingfish revealed that, when prey (primarily polychaetes and mole crabs) biomass in the guts of these fish differed significantly, it was greater in fish captured near nourished than near reference areas. There was no indication that the nourishment activity either limited prey consumption or caused a dietary shift for the surf zone fishes that were studied.

The challenges of demonstrating impacts on fish abundances are exemplified by the New Jersey study in which power analysis (post-hoc) revealed that statistical power in that study was sufficient to detect an approximate three-fold difference in mean fish abundance. Wilber et al. (2003) conducted an intensive sampling effort consisting of 2190 seine hauls over 5 years that captured nearly 300,000 fishes. In spite of this unprecedented effort, the intrinsically high spatial and temporal variability of surf zone fish abundances resulted in low statistical power. The authors suggested that subsequent monitoring studies of surf zone fishes (or other taxa with high spatial and temporal variability) may benefit from focusing on specific mechanisms of impact to species of concern rather than using mean abundance as an ecological indicator of potential impacts (Wilber et al. 2003), especially if a smaller sampling effort (which would be typical of almost all monitoring studies) is anticipated.

## REVIEW OF MONITORING STUDY METHODOLOGIES

Peterson and Bishop (2005) asserted that 87% of monitoring studies were terminated before recovery was demonstrated. Given the literature that they reviewed, this would equate to only six of the 46 studies finding recovery, or substantial recovery by the end of the study. Our review of a subset (n = 34) of the same literature revealed that authors of 16 studies determined that recovery, or substantial recovery, had occurred prior to project termination (Table 2). In reality, the optimal duration of post-nourishment monitoring is a function of project specific conditions and the management goal of what constitutes "recovery" (sensu Wilber and Clarke 2007).

Peterson and Bishop (2005) also stated that inappropriate sampling devices were used in 39% of studies, citing the use of grab samplers instead of cores to sample soft-sediment invertebrates. However, we found that cores were used to sample benthic macroinvertebrates in 92%, 73%, and 54% of intertidal, nearshore, and offshore/borrow area habitat monitoring efforts, respectively (Table 3). Thus, their estimate that cores were used in only 39% of studies differs substantially from our review of the same studies. Additionally, we disagree with their assertion that grabs are an inappropriate sampling device in deeper subtidal environments. The peer-reviewed literature on benthic communities is replete with studies that use grab samplers. Properly used, grab sampling can result in less bias than diver collected cores, and randomly located grab sampling throughout a study area minimizes the risk of "pseudo-replication" (sensu Hurlbert 1984) than more closely spaced replicate cores often collected by divers.

Finally, Peterson and Bishop (2005) fault 89% of the studies with failing to use a BACI (before-after, control-impact) analytical approach. This, again, would indicate that only five of the 46 studies they reviewed used such an approach. In our review of the same studies, sampling was conducted both before and after dredging/nourishment and at both control and impact sites in 21 of the 34 studies (62%) we examined. Although the BACI sampling design was not always followed by analogous statistical analyses (sensu Stewart-Oaten et al. 1986), analytical approaches employed were more often appropriate for the study objectives. Approximately a third of the studies are over twenty years old, which undoubtedly relates to the statistical techniques employed. For example, decades ago species accumulation curves were commonly used as a precursor to designing sampling protocols as opposed to the *a priori* power analyses that are currently in vogue. Perhaps a more important question than what percentage of studies used a BACI design is what are the impact magnitudes that are important to detect and do they differ by target species? Although statistical power has infrequently been reported for most beach nourishment monitoring studies, the majority of studies in Table 3 report statistically significant results, indicating power was sufficient to detect differences in the reported results. Ideally, environmental impact assessments are designed such that a sufficient number of samples are collected and effectively allocated to detect a predetermined effect size (Underwood 1992), which begs the question, what is an appropriate effect size for beach nourishment studies? What constitutes a biologically meaningful effect size has been discussed with relation to stock depletions in fisheries research (e.g., Peterman 1990) and population size declines in conservation biology (e.g., Reed and Blaustein 1997). That there is no available guidance concerning relevant effect sizes for beach nourishment impacts (Wilber et al. 2003) may be a factor contributing to the paucity of studies that report power analyses even if those analyses were conducted. Consideration of the target biota is also important when determining relevant effect sizes. For instance, it seems unlikely that a biologically meaningful effect size for detected changes in polychaete densities would be well suited for loggerhead sea turtle nesting frequencies. Prior to the New Jersey monitoring study (Burlas et al. 2001), coordination meetings with representatives of multiple federal and state agencies led to a consensus that a meaningful effect size for benthic macroinvertebrates was one standard deviation from the mean density. Preliminary data were used to decide how to best partition sampling effort (Wilber 1994) and the resulting monitoring study of benthic macrofauna achieved the prescribed statistical power (beta $\geq$ 0.80) at an effect size of one standard deviation.

Also of key importance is determining the biological characteristics most sensitive to the impact in question. Although most impact assessments compare the densities of target organisms or assemblages between nourished and non-nourished beaches and/or between pre- and post-nourishment time periods to indicate recovery status (e.g., see metrics listed in Table 1), it appears that assessments focused on more sensitive biological attributes may provide more relevant information for a number of taxa. For instance, impacts to sea turtles may not be apparent through monitoring nesting frequencies if the mode of impact is a change to hatchling sex ratios (Holloman and Godfrey 2004). Likewise, given the high spatial and temporal variability in surf zone fish distributions, relying on comparisons of mean fish abundances as an indicator of potential impacts is not a sensible approach. Examining suspected mechanisms of impacts, for example through stomach content analysis (Wilber et al. 2003) or examinations of gill epithelial tissue for fish captured in the vicinity of sediment plumes, may prove to be more revealing monitoring methods. Fanini et al. (2007) use a novel approach to assess habitat suitability and stability by studying macrofaunal behavior (sandhopper orientation) following a nourishment project that substantially altered the beach sediment composition.

Table 2. Peer-reviewed studies that address beach nourishment impacts in the United States. The sampling duration both pre- and post-nourishment or dredging activity is given.

| Study | Target Biota | Important Results | Process | Recovery Time | Monitoring Duration | |
|---|---|---|---|---|---|---|
| | | | | | Pre- | Post- |
| Davis et al. 1999 (West coast of FL) | Loggerhead sea turtle | No relationship between turtle nesting and beach sediment compactness. | Fill | No significant impact detected | None | 2 years |
| Gorzelany and Nelson 1987 (East coast of FL) | Macroinvertebrates | No change in density or species richness associated with beach nourishment | Fill | < 1 month | 1 wk before | Quarterly for one year |
| Hayden and Dolan 1974 (Cape Hatteras, NC) | Mole Crab | Decrease in mole crab density immediately down-current from discharge | Fill | < 2 weeks | None | Time of discharge |
| Johnson and Nelson 1985 (East coast of FL) | Macroinvertebrates | Immediate 50% decrease in infaunal abundance, 6% decrease in taxonomic richness | Dredge | 9-12 months | At the time of dredging | Quarterly for one year |
| Lindeman and Snyder 1999 (East coast of FL) | Hardbottom fishes | Reduced fish abundances and species richness for up to 15 months post-nourishment | Fill | > 15 months | Monthly for 12 months | Monthly for 15 months |
| Peterson et al. 2000 (Bogues Bank, NC) | Mole crab, bean clam and ghost crab | Reduced densities of mole crabs, bean clams and ghost crab burrows 10 weeks post nourishment. | Fill | Not given | none | Samples at 5 and 10 weeks |
| Posey and Alphin 2002 (Southeastern NC) | Macroinvertebrate community | Shifts in abundance at both control and dredged sites. | Dredge | 9 months | 5 sampling per. over 2 yrs | 5 sampling per. over 2 yrs |
| Rakocinski et al. 1996 (West coast of FL) | Macroinvertebrate community | Decreased species richness and total density | Fill | Between 1 and 2 years | 1 survey 1 year prior | 8 surveys over 2 years |
| Rumbold et al. 2001 (East coast of FL) | Loggerhead sea turtle | Increase in false crawls and decrease in nesting 1-4 mo. post-nourishment. Return to pre-nourishment. values one year later. | Fill | 1 year | 3 years | 2 years |
| Wilber et al. 2003 (Northern coast of NJ) | Surf zone fishes | No change to fish food habits. Localized, short-term attraction and avoidance of active fill area by different fish species | Fill | No significant impact detected | 12 sampling periods over 2 years | 15 sampling periods over 3 years |

Table 3. Summary of selected characteristics from 34 studies cited in Table 1 of Peterson and Bishop (2005). Recovery status is indicated by Y (yes), N (no), or NID (no impact detected), along with the duration of post-nourishment monitoring. Recovery determinations are based on the authors' conclusions. The final two columns indicate whether sampling was conducted according to a before-after-control-impact (BACI) design and whether any significant results were reported, indicating sufficient statistical power to demonstrate change (albeit not necessarily biologically meaningful).

| Study | Area Monitored | Sample method | Target Organism(s) | Recovery Status | BACI Design | Any sig. results? |
|---|---|---|---|---|---|---|
| Bowen and Marsh 1988 | Borrow | Core | Macrofauna | No control | N | N |
| Broadwell 1991 | Sandy Beach | Nests | Turtles | NID | N | Y |
| Burlas et al. 2001 | Intertidal | Core | Macrofauna | Y w/in 7 mo | Y | Y |
| | Nearshore | Grab | Macrofauna | Y w/in 7 mo | Y | Y |
| | Offshore | Grab | Macrofauna | Y at 12 mo | Y | Y |
| | Surf | Seine | Fish | NID | Y | Y |
| | Offshore | Trawl | Fish | N at 12 mo | Y | N |
| | Surf/Nearshore | Plankton net | Ichthyoplankton | NID | Y | N |
| Courtenay et al. 1980 | Nearshore | Visual | Fish | N at 7 yrs | N | N |
| | Offshore | Visual | Fish | Y at 7 yrs | N | N |
| Culter and Mahadevan 1982 | Borrow | Core | Macrofauna | No Control | N | ? |
| | Intertidal | Core | Macrofauna | No Control | N | ? |
| Davis et al. 1999 | Sandy Beach | Nests | Turtles | Y at 2 yrs | N | N |
| Fisher et al. 1992 | Nearshore | Core | Macrofauna | N at 3 mo | Y | Y |
| | Offshore | Quadrat | Coral | N at 3 mo | Y | N |
| Goldberg 1985 | Nearshore | Quadrat | Coral | NID at 15 mo | N | N |
| Gorzelany and Nelson 1983 | Intertidal | Core | Macrofauna | Y by 1 mo | Y | Y |
| | Nearshore | Core | Macrofauna | Y by 1 mo | Y | Y |
| Hayden and Dolan R 1974 | Intertidal | Quadrat | Mole crab | Y at 0.5 mo | N | N |
| Holland et al. 1980 | Intertidal | Seine | Fish | NID | Y | N |
| | Offshore | Trawl | Fish | NID | Y | N |
| Johnson and Nelson 1985 | Borrow | Grab | Macrofauna | Y at 12 mo | N | Y |
| Jutte et al. 2002a and b | Intertidal | Core | Macrofauna | Y at 5-6 mo | Y | Y |
| Jutte et al. 2002a and b | Borrow | Grab | Macrofauna | Y at 27-30 mo | Y | Y |
| Lindeman and Snyder 1999 | Nearshore | Visual | Fish | N at 15 mo | Y | Y |
| Marsh et al. 1980 | Intertidal | Core | Macrofauna | N | N | Y |
| | Nearshore | Core | Macrofauna | N | N | N |
| Nelson et al. 1987 | Upper | Nests | Turtles | N at 12 mo | Y | Y |
| Parr et al. 1978 | Intertidal | Core | Macrofauna | Y at 6 mo | Y | Y |
| | Nearshore | Core | Macrofauna | Y at 6 mo | Y | Y |
| Peterson et al. 2000 | Intertidal | Core | Macrofauna | N at 2.5 mo | N | Y |
| Posey and Alphin 2002 | Borrow | Grab | Macrofauna | Y at 9 mo | Y | Y |

| Table 3. continued | | | | | | |
|---|---|---|---|---|---|---|
| Study | Area Monitored | Sample method | Target Organism(s) | Recovery Status | BACI Design | Any sig. results? |
| Rakocinski et al. 1996 | Nearshore | Core | Macrofauna | Y at 24 mo | Y | Y |
| | Offshore | Core | Macrofauna | N at 24 mo | Y | Y |
| Raymond 1984 | Upper | Nests | Turtles | Y at 18 mo | N | Y |
| Reilly and Bellis 1983 | Intertidal | Core | Macrofauna | N at 3 mo. | Y | N |
| Rumbold et al. 2001 | Upper | Nests | Turtles | Y at 12 mo | Y | Y |
| Ryder 1993 | Upper | Nests | Turtles | NID | N | Y |
| Salomon et al. 1982 | Borrow | Core | Macrofauna | Y at 12 mo | Y | N |
| Salomon and Naughton 1984 | Intertidal | Core | Macrofauna | Y at 2 mo | Y | Y |
| | Nearshore | Core | Macrofauna | NID | Y | Y |
| Turbeville and Marsh 1982 | Borrow | Core | Macrofauna | Y ≤ 6 mo | Y | Y |
| Van Dolah et al. 1992 | Intertidal | Core | Macrofauna | Y < 3 mo | Y | Y |
| | Borrow (a) | Core | Macrofauna | Y < 1 yr | Y | Y |
| | Borrow (b) | Core | Macrofauna | N at 1 yr | Y | Y |
| | Surf | Seine | Fish | Limited Imp. | Y | Y |
| Van Dolah et al. 1994 | Intertidal | Core | Macrofauna | Y at < 4 mo. | Y | Y |
| | Borrow (a) | Grab | Macrofauna | Y at < 12 mo | Y | Y |
| | Borrow (b) | Grab | Macrofauna | Y at > 12 mo | Y | Y |
| | Borrow | Trawl | Fish | Y at < 6 mo | Y | Y |
| Versar Inc. 2004 | Intertidal | Grab | Macrofauna | N at 12 mo | Y | Y |
| | Nearshore | Grab | Macrofauna | N at 12 mo | Y | Y |
| | Offshore | Grab | Macrofauna | Y at 12 mo | Y | Y |
| | Surf | Seine | Fish | NID | Y | Y |
| | Offshore | Trawl | Fish | NID | Y | Y |
| | Surf/Nearshore | Bongo net | Ichthyoplankton | NID | N | N |
| Wilber et al. 2003 | Surf | seine | Fish | NID | Y | Y |

Determining biologically relevant effect sizes and identifying consistent, objective and quantifiable indicators of impact have required the cumulative efforts of many scientists over many years, and yet these goals still remain illusive. These researchers have dedicated themselves to addressing issues central to advancing our understanding of these complex biological systems and how best to manage them in the face of growing human encroachment. Thus, it is important that reviews of beach nourishment impact studies, which may have a wider readership than the primary source material, offer both an accurate synopsis of the literature as well as some insights in terms of solutions.

## CONCLUSIONS

Concerns over the increased use of beach nourishment activities in the United States are generated by environmental issues as well as the engineering performance of nourished beaches and the economic return of these projects (e.g., National Research Council 1995, Hillyer et al. 1997, Trembanis et al. 1999, Nordstrom 2005). Certain aspects of beach nourishment projects assuredly deserve caution and further investigation. For example, the cumulative impacts on populations from multiple dredging events, and long-term consequences of depletion of sand from finite, potentially non-renewable offshore sources deserve considered attention. The removal of shoals and perhaps permanent shifts in associated fish and shellfish habitat functions merits evaluation by the scientific community. Protection of environmental resources, however, will be best advanced by discussions that build on an objective and accurate synopsis of past studies rather than the emphasis of select cases that are not representative of the relevant literature.

## REFERENCES


Baron, R.M, Jordan, L.K.B., and Spieler, R.E., (2004). "Characterization of the marine fish assemblage associated with the nearshore hardbottom of Broward County, Florida, USA." *Estuarine, Coastal and Shelf Science* 60, 431-443.

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

Bowen, P.R. and Marsh, G.A. (1988). "Benthic faunal colonization of an offshore borrow pit in southeastern Florida," *Miscellaneous Paper D-88-5,* US Army Engineer Waterways Experiment Station, Vicksburg, MS.

Broadwell, A.L. (1991). "Effects on beach renourishment on the survival of loggerhead sea turtles." Masters Thesis, Florida Atlantic University, Boca Raton, FL. 52 pp.

Brock, K.A., Reece, J.S., and Ehrhart, L.M. (2009). "The effects of artificial beach nourishment on marine turtles: differences between loggerhead and green turtles." *Restoration Ecology* 17, 297-307.

Burlas, M., Ray, G.L., and Clarke, D.G. (2001). *The New York District's biological monitoring program for the Atlantic coast of New Jersey, Asbury Park to Manasquan Section beach erosion control project. Final Report*. Prepared by U.S. Army Engineer Research and Development Center for U.S. Army Engineer District, New York.

Charlier, R.H. and De Meyer, C.P. (2000). "Ask nature to protect and build-up beaches." *Journal of Coastal Research* 16, 385–390.

Colosio, F., Abbiati, M., and Airoldi, L. (2007). "Effects of beach nourishment on sediments and benthic assemblages." *Marine Pollution Bulletin* 54, 1197-1206.

Courtenay, Jr., W.R., Hartig, B.C., and Loisel, G.R. (1980). "Ecological evaluation of a beach nourishment project at Hallandale (Broward County), Florida. Volume 1. Evaluation of fish populations adjacent to borrow areas of beach nourishment project, Hallandale (Broward County), Florida." *Miscellaneous Report* 80-1, US Army Engineer Coastal Engineering Research Center, Fort Belvoir, VA. 23 pp.

Crain, D.A., Bolton, A.B., and Bjorndal, K.A. (1995). "Effects of beach renourishment on sea turtles: review and research initiatives." *Restoration Ecology* 3**,** 95–104.

Crowell, M., Edelman, S., Coulton, K., and McAfee, S. (2007). "How many people live in coastal areas?" *Journal of Coastal Research* 23, iii-vi.

Culter, J.K. and Mahadevan, S. (1982). "Long-term effects of beach nourishment on the benthic fauna of Panama City Beach, Florida." *U.S. Army Corps of Engineers Coastal Engineering Research Center Miscellaneous Report* No. 82-2. 57 pp.

Davis, R.A., FitzGerald, M.V., and Terry, J. (1999). "Turtle nesting on adjacent nourished beaches with different construction styles" Pinellas County, Florida. *Journal of Coastal Research* 15, 111-120.

Fanini, L., Marchetti, G.M., Scapini, F., and Defeo, O. (2007). “Abundance and orientation responses of the sandhopper *Talitrus saltator* to beach nourishment and groynes building at San Rossore natural park, Tuscany, Italy.” *Marine Biology* 152, 1169-1179.

Fenster, M.S., Knisley, C.B., and Reed, C.T. (2006). “Habitat preference and the effects of beach nourishment on the federally threatened northeastern beach tiger beetle, *Cicindela dorsalis dorsalis*: western shore, Chesapeake Bay, Virginia.” *Journal of Coastal Research* 22, 1133-1144.

Fisher, L.E., Goldberg, R.E., Messing, C.G., Goldberg, W.M., and Hess, S. (1992). "The First Renourishment at Hollywood and Hallendale (Florida) Beaches: Monitoring of Sediment Fallout, Coral Communities, and Macroinfauna: Preliminary Results." Proceedings of the 1992 National Conference on Beach Technology, FSBPA, Tallahassee, FL, 209-226.

Goldberg, W.M. (1985). “Long term effects of beach restoration in Broward County, Florida: A three-year overview.” Coral Reef Associates, Inc. Florida International University, Miami, FL. 54 pp.

Gorzelany, J.F., and Nelson, W.G. (1987). “The effects of beach replenishment on the benthos of a subtropical Florida beach.” *Marine Environmental Research* 21, 75-94.

Greene, K. (2002). *Beach Nourishment: A Review of the Biological and Physical Impacts.* Washington (DC): Atlantic States Marine Fisheries Commission. ASMFC Habitat Management Series no. 7.

Harriague, A.C. and Albertelli, G. (2007). “Environmental factors controlling macrofaunal assemblages on six microtidal beaches of the Ligurian Sea (NW Mediterranean).” *Estuarine, Coastal and Shelf Science* 73, 8-16.

Hayden, B., and Dolan, R. (1974). “Impact of beach nourishment on distribution of *Emerita talpoida*, the common mole crab.” *Journal of Waterways, Harbors, and Coastal Engineering Division* 100, 123-132.

Hillyer, T.M., Stakhiv, E.Z., and Sudar, R.A. (1997). “An evaluation of the economic performance of the U.S. Army Corps of Engineers shore protection program.” *Journal of Coastal Research* 13, 8-22.

Holland, H.T., Chambers, J.R., and Blackman, R.R. (1980). “Effects of dredging and filling for beach erosion control on fishes in the vicinity of Lido Key, Florida.” U.S. Army Corps of Engineers, PO Box 4970, Jacksonville District, FL.

Holloman, K.T, and Godfrey, M.H. (2004). “2004 Sea Turtle Monitoring Project Report, Bogue Banks, North Carolina, Interim Report.” *North Carolina Wildlife Resources Commission*, 12 pp.

Hurlbert, S.H. (1984). “Pseudoreplication and the design of ecological field experiments.” *Ecological Monographs* 54, 187-211.

Jones, A.R., Murray, A., Lasiak, T.A., and Marsh, R.E. (2008). “The effects of beach nourishment on the sandy-beach amphipod *Exoediceros fossor*: impact and recovery in Botany Bay, New South Wales, Australia.” *Marine Ecology* 29, (Suppl. 1) 28-36.

Johnson, R.O. and Nelson, W.G. (1985). “Biological effects of dredging in an offshore borrow area.” *Florida Scientist* 48, 166-188.

Jutte, P.C., Van Dolah, R.F. and Gayes, P.T. (2002a). “Recovery of benthic communities following offshore dredging, Myrtle Beach, South Carolina.” *Shore & Beach* 70, 25-30.

Jutte, P.C., Van Dolah, R.F. and Gayes, P.T. (2002b) “Erratum: Recovery of benthic communities following offshore dredging, Myrtle Beach, South Carolina.” *Shore & Beach* 70, 28.

Lindeman, K. and Snyder, D. (1999). “Nearshore hardbottom fishes of southeast Florida and effects of habitat burial caused by dredging.” *Fishery Bulletin* 97, 508-525.

Marsh, G.A., Bowen, P.A., Deis, D.R., Turbeville, D.B., and Courtenay, Jr., W.R. (1980) "Evaluation of benthic communities adjacent to a restored beach, Hallandale (Broward County), Florida; Vol II, Ecological Evaluation of a Beach Nourishment Project at Hallandale (Broward County), Florida," Miscellaneous Report 80-1, US Army Engineer Coastal Engineering Research Center, Fort Belvoir, VA.

Menn, I., Junghans,C., and Reise, K. (2003). “Buried alive: Effects of beach nourishment on the infauna of an erosive shore in the North Sea.” *Senckenbergiana marit*., 32 (1/2), 125-145.

Mrosovsky, N. (1988). “Pivotal temperatures for loggerhead turtles (*Caretta caretta*) from northern and southern nesting beaches.” *Canadian Journal of Zoology* 66, 661-669.

National Research Council. (1995). Beach Nourishment and Protection. National Academy Press, Washington DC 334p.

Nelson, D. A., Mauck, K., and Fletemeyer, J. (1987). "Physical effects of beach nourishment on sea turtle nesting, Delray Beach, Florida," Technical Report EL-87-15, US Army Engineer Waterways Experiment Station, Vicksburg, Miss.1

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

Nordstrom, K.F. (2005). "Beach nourishment and coastal habitats: research needs to improve compatibility." *Restoration Ecology* 13, 215-222.

Parr, T., Diener, D., and Lacy, S.. (1978). "Effects of beach replenishment on the nearshore sand fauna at Imperial beach," California. Miscellaneous Report 78-4, US Army Corps of Engineers: Fort Belvoir, VA.

Peterman, R.M. (1990). "Statistical power analysis can improve fisheries research and management." *Canadian Journal of Fisheries and Aquatic Sciences* 47, 2-15.

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

Peterson, C.H., and Bishop, M.J. (2005). "Assessing the environmental impacts of beach nourishment." *BioScience* 55, 887-896.

Pilkey, O.H., and Wright III, H.L. (1988). "Seawalls versus beaches." *Journal of Coastal Research* 4, 41-64.

Posey, M, and Alphin, T. (2002). "Resilience and stability in an offshore benthic community: responses to sediment borrow activities and hurricane disturbance." *Journal of Coastal Research* 18, 685-697.

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

Raymond, P.W. (1984). "The effects of beach restoration on marine turtles nesting in South Brevard County, Florida." Masters Thesis, University of Central Florida, Orlando, Florida, 32 pp.

Reed, J.M., and Blaustein, A.R. (1997). "Biologically significant population declines and statistical power." *Conservation Biology* 11, 281-281.

Reilly, F.J., and Bellis, V.J. (1983). "The ecological impact of beach nourishment with dredged materials on the intertidal zone at Bogue Banks, North Carolina." Miscellaneous Report 83-3. US Army Corps of Engineers: Fort Belvoir, VA.

Rumbold, D.G., Davis, P.W., and Perretta, C. (2001). "Estimating the effect of beach nourishment on *Caretta caretta* (loggerhead sea turtle) nesting." *Restoration Ecology* 9, 304-310.

Ryder, C.E. (1993). "The effect of beach renourishment on sea turtle nesting and hatching success at Sebastian Inlet state recreation area east-central, Florida." Masters thesis, Virginia Polytechnic Institute and State University. Blacksburg, VA 45 pp.

Saloman, C., Naughton, S. and Taylor, J. (1982). "Benthic Community Response to Dredging Borrow Pits, Panama City Beach, Florida." Miscellaneous Report No. 82-3. U.S. Army Corps of Engineers, Coastal Engineering Research Center, Fort Belvoir, VA. March 1982.

Saloman, C.H., and Naughton, S.P. (1984). "Beach restoration with offshore dredged sand: effects on nearshore macroinfauna." Technical Memorandum NMFS-SEFC-133. National Oceanic and Atmospheric Administration (NOAA): Panama City, FL.

Speybroeck, J., Bonte, D., Courtens, W., Gheskiere, T., Grootaert, P., Maelfait, J., Mathys, M., Provoost, S., Sabbe, K., Stienen, E.W.M., Van Lancker, V., Vincx, M., and Degraer, S. (2006). Beach nourishment: an ecologically sound coastal defense alternative? A review. *Aquatic Conservation: Marine and Freshwater Ecosystems* 16, 419-435.

Stewart-Oaten, A., Murdoch W.W., and Parker, K.R. (1986). "Environmental impact assessment: "Pseudoreplication in time"?" Ecology 67, 929-940.

Trembanis, A.C., Pilkey, O.H., and Valverde, H.R. (1999). "Comparison of beach nourishment along the U.S. Atlantic, Great Lakes, Gulf of Mexico, and New England shorelines." *Coastal Management* 27, 329-340.

Turbeville, D.B. and Marsh, G.A. (1982). "Benthic fauna of an offshore borrow area in Broward County, Florida," U.S. Army Corps of Engineers Coastal Engineering Research Center, Misc. report 82-1 pp. 1-43.

Underwood, A.J. (1992). "Beyond BACI: the detection of environmental impacts on populations in the real, but variable, world." *Journal of Experimental Marine Biology Ecology* 161, 145-178.

Van Dolah, R.F., Wendt, P.H., Martore, R.M., Levisen, M.V., and Roumillat, W. (1992). "A physical and biological monitoring study of the Hilton Head beach nourishment project." Final Report submitted to the Town of Hilton Head Island and the South Carolina Coastal Council. 159 pp.

Van Dolah, R.F., Martore, R.M., Lynch, A.E., Levisen, M.V., Wendt, P.H., Whitaker, D.J., and Anderson, W.D. (1994). Environmental Evaluation of the Folly Beach Nourishment Project. Final Report. U.S. Army Corps of Engineers, Charleston District, and the Marine Resources Division, South Carolina Department of Natural Resources. 155p.

Versar Inc. (2004). Year 2 Recovery from impacts of beach nourishment on surf zone and nearshore fish and benthic resources on Bald Head Island, Caswell Beach, Oak Island, and Holden Beach, North Carolina. Wilmington District 198 pp.

Wilber, P. (1994). The New York District's biological monitoring program for the Atlantic coast of New Jersey, Asbury Park to Manasquan Section beach erosion control project. *Pilot Study Interagency Coordination Report*. 23 pp.

Wilber, P., and Stern, M. (1992). A re-examination of infaunal studies that accompany beach nourishment projects. Pp. 242-257 in *New Directions in Beach Management: Proceedings of the 5th Annual National Conference on Beach Preservation Technology*. Tallahassee: Florida Shore and Beach Preservation Association.

Wilber, D.H., Clarke, D.G., Ray, G.L., and Burlas, M.H. (2003). "Surf zone fish responses to beach nourishment on the northern coast of New Jersey." *Marine Ecology Progress Series* 250, 231-246.

Wilber, D.H., and Clarke, D.G. (2007). Defining and assessing benthic recovery following dredging and dredged material disposal. *Proceedings XXVII World Dredging Congress 2007, Orlando, Florida.*