The state of understanding the impacts of beach nourishment activities on infaunal communities

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It has been documented that dredge and fill operations associated with beach nourishment projects cause the mortality of infaunal organisms found within the wet beach and benthic environments (Saloman, 1974; Oliver *et al.* 1977; NRC 1995; USACE 2001). Dredging activity involves the removal of sediment, including the benthic infauna residing within the substrate. The placement of fill material upon the beach and the intertidal area has the potential to smother and kill the existing infauna community within the swash zone and nearshore benthic habitats. The resultant temporary loss of these lower trophic level organisms has cascading effects on a wide range of species that prey upon them. These include commercially and recreationally important fish as well as threatened and endangered species such as the piping plover and red knot. As such, state and federal regulatory agencies have previously required multi-year pre- and post-construction infaunal monitoring program as a condition of a project's permit in order to document the effect these actions have on these important biological resources.

To date, many studies cited in both primary and grey literature have been performed to examine the recovery rates of infaunal organisms in response to beach nourishment projects. The results of these studies, dating back several decades, suggest a range of recovery rates. It is often suggested the rates of recovery are improved by construction practices such as the use of compatible beach fill material and implementing wintertime construction.

The goals of this white paper are: 1) to summarize the current level of understanding of the recovery rates of benthic infaunal organisms from dredge and fill activities, and 2) to identify best management practices that may be employed to help expedite recovery of these communities back to baseline levels. In an attempt to reduce environmental impact, minimize biological monitoring requirements and ultimately reduce overall project costs, we recommend that applicants include select best management practices into their proposed project design. In addition, to alleviate regulatory agency concerns, applicants should incorporate pertinent results from previous monitoring studies (as cited below) into National Environmental Policy Act (NEPA) documents and permit applications to communicate a thorough understanding of the causes and implications of, as well as tools for reducing, potential adverse effects to infaunal communities.

SYNTHESIS OF GREY AND PRIMARY LITERATURE

As stated above, it is generally accepted that dredging and sand placement results in the mortality of the benthic infaunal community due to mechanical damage during dredging, entrainment in the dredge pipe, burial at the fill site, and crushing by heavy equipment as the material is shaped and graded on the beach. State and federal regulatory agencies have required multi-year monitoring programs designed to document the recovery of the benthic invertebrates as permit requirement for beach nourishment projects. The results of these monitoring efforts are commonly reported in the grey, non-peer reviewed literature. The effects of nourishment on benthic infauna have also been explored within the primary literature but to a lesser extent. A number of studies and reviews provide a comprehensive summary of these past major studies as well as the most important results (see Greene 2002; Peterson and Bishop 2005; Wilber *et al.* 2008; Wooldridge *et al.* 2016). Most of these studies have taken place within the southeast region of the United States, although there are a number of recent studies conducted outside this region (Burlas *et al.* 2001; Colosio *et al.* 2007; Manning *et al.* 2014).

Review of recovery rates and factors driving them

The taxa most frequently studied in benthic monitoring assessments, considered to be "core intertidal taxa" (Wooldridge *et al.* 2016) include: polychaetes (*Scolelepis* sp., primarily *Scoplelepis squamata*), bean clams/coquina clams (*Donax* sp., primarily *Donax variabilis*), amphipods, and mole crabs (*Emerita talpoida)*. Populations of the macrobenthos typically follow a cyclic, seasonal pattern in which they move offshore during the winter months, thereby reducing their presence in the sandy, intertidal, and subtidal beach environments. Recruitment of the macrobenthos from the plankton to the beach typically occurs during a spring pulse. Recruitment of mole crabs typically occurs slightly later; for example, in central North Carolina recruitment for this species occurs from June to July (Diaz 1980). While these aforementioned species are some of the more commonly studied organisms in beach nourishment impact studies, other localized macroinvertebrate species of concern may warrant consideration during nourishment projects. For example, horseshoe crab eggs found on select beaches in New Jersey from May through June are a highly important resource for migrating shore birds like the red knot. Because the migratory and reproductive success of red knots is inherently tied to this resource, it would therefore be prudent to consider the seasonality of horseshoe crab presence in nourishment projects (Botton *et al.* 1994).

The reported recovery rates of these infaunal communities, as cited from within the literature, vary and are dependent upon the taxa studied. Furthermore, there are a number of factors associated with construction practices that drive these rates. A recent study by Wooldridge *et al.* (2016) offers a useful summary of key peer-reviewed literature on the subject. As cited in Wooldridge *et al.,* recovery rates were documented to be within one year or less for amphipods (Jones *et al.* 2008; Leewis *et al.* 2012; Schlacher *et al.* 2012), mole crabs (*Emerita* spp.) (Hayden and Dolan 1974; Leewis *et al.* 2012; Peterson *et al.* 2014), bean clams (*Donax* spp.) (Leewis *et al.* 2012) and polychaetes, most notably the spionid polychaetes *Scolelepis squamata* (Leewis *et al.* 2012; Manning *et al.* 2014). Other studies report complete recovery within one year of these and other infaunal taxa such as isopods and other bivalves (Burlas *et al.* 2001; Peterson *et al.* 2006, Jones *et al.* 2008; CZR Incorporated and CSE Inc. 2013; CZR Incorporated and CSE Inc. 2014).

In a robust assessment of past studies within the primary and grey literature, Wilber *et al.* (2009) reviewed a large body of monitoring studies, also analyzed previously by Peterson and Bishop (2005). In those studies focusing on the intertidal macrofauna (benthic organisms, including infaunal species, greater than 1mm) at fill sites, the reported macroinvertebrate recovery rates ranged from less than one month (Gorzelany and Nelson 1983), through less than one year (Parr *et al.* 1978; Jutte *et al* 2002a and b), and to up to two years (Rakocinski *et al.* 1996). Factors contributing to the recovery rates, as cited in these studies, included the seasonality of construction and the similarity of sediments used as fill material to the native beach sediments. Projects incorporating well-matched sediments (with respect to grain size, sorting, carbonate content, and percent fines) and construction periods that avoided the spring recruitment pulse were associated with faster recovery rates. By contrast, springtime construction and a poor sediment match (too coarse, shelly, or fine) led to longer recovery times.

Burlas *et al.* (2001) reached similar conclusions after a comprehensive study of impacts to intertidal and nearshore benthos following a large beach nourishment project in New Jersey. Following initial declines in biomass, abundance and taxa richness, the authors reported compete recovery of the intertidal assemblages occurred 2-6.5 months following the placement of beach fill. The authors also concluded recovery was quickest when filling was completed by October, before the seasonal decline of infaunal abundance occurred. When filling continued into the winter when the seasonal decline was underway, the recovery times were longer; the authors postulated that timing of filling prevented recolonization before the seasonal decline.

It should also be noted that biological populations are inherently variable and exhibit large natural abundance and diversity fluctuations at a site under same-season comparisons. This natural variability poses a challenge to distinguish between natural and nourishment-induced impacts without a high-frequency- and -density sampling program, which is time consuming and expensive for quantitative analyses. Attributed to the substantial monitoring investment (~$8 million to $10 million), Burlas *et al.* (2001) is one of the more comprehensive, and potentially relevant, studies providing analyses based on the high density of sampling, the number of parameters measured, and the area covered.

In contrast to the above discussions, a number of recent studies have also reported substantially longer recovery periods, or that no recovery of the infauna was observed through the duration of the monitoring study (Colosio *et al.* 2007; Manning *et al.* 2014; Peterson *et al.* 2014; Wooldridge *et al.* 2016). However, consideration of the construction practices implemented in the associated beach nourishment projects may help explain the varied results, as well as provide valuable insight for best management practices of beach nourishment projects.

In a study conducted in Italy where three beaches were nourished at the same time with varying levels of sediment compatibility, it was observed that the two beaches receiving poorly matching sediments remained nearly free of macrofaunal organisms one year following nourishment. On the beach that received sediment similar to the native beach, the macrofaunal assemblage did not differ significantly from the non-nourished nearby beach following construction (Colosio *et al.* 2007).

Other studies also demonstrate reduced recovery times that were likely driven by use of unnatural or incompatible sediments for nourishment. A study by Manning *et al.* (2014) examined physical and biological impacts resulting from two dredge spoil disposal events occurring in consecutive years (1999 and 2000) using sediments obtained from maintenance dredging of a navigation channel. The 1999 disposal event continued from April to June and therefore coincided with the spring recruitment period for macroinvertebrates; by contrast, the 2000 disposal event was completed prior to the benthic invertebrate recruitment period. Results demonstrated that sites receiving the disposal material exhibited finer grain size and an increase in sorting as compared to control sites. Invertebrate abundance subsequently remained depressed for all taxa throughout the warm season except the polychaete *Scolelepis squamata*, which responded positively to the finer sediments. Importantly, the disposal event occurring before the recruitment period of benthos resulted in fewer negative impacts to abundance than the disposal project conducted after the recruitment season. Although recovery occurred within one year after the 1999 disposal event, abundances were again depressed with the implementation of the second disposal event in 2000, highlighting the critical importance of adequate recovery periods incorporated into nourishment cycles, as well as the potential adverse impacts associated with using nourishment material that is finer than the native beach.

A study by Peterson *et al.* (2014) reported multi-year (>3 years) impacts following two beach nourishment projects that utilized "unnaturally coarse, shelly material." Use of this material resulted in significant increases in the proportion of gravel to total sediment weight of nourished beaches following nourishment that persisted throughout the study and slowed the convergence of sediment properties between nourished and non-nourished beaches. The percent by weight of gravel did not match sediments at control locations until just over 3.5 years after nourishment occurred. Sampling revealed longer recovery rates for some invertebrate taxa than has been reported for previous studies. Bean clams (*Donax* spp.) abundances remained depressed by 70% to 90% for three to four warm seasons following nourishment when compared to non-nourished control locations. Likewise, haustoriid amphipods exhibited significantly depressed abundances throughout duration of the study (over 3.5 years) with no indication of trending toward recovery. Mole crabs (*E. talpoida*) showed small, ephemeral responses to nourishment; abundances were depressed in two years following nourishment, but not always statistically significant. Polychaetes abundances were variable, and no indication of an effect of nourishment on abundances. Total biomass of all macroinvertebrate taxa was depressed, but not significantly so, and recovered in one to two years. This study also looked at indirect impacts to the predators of invertebrates, namely ghost crabs and foraging shorebirds. The authors reported the effect on ghost crabs determined via burrow density counts, was initially negative and most pronounced on the beach flat where sand was placed. However, considerable recovery occurred by the following warm season, and the effect was no longer evident within two warm seasons. The number of foraging shorebirds was substantially reduced, but recovered two to three years after nourishment. The negative impacts on benthic infauna recovery associated with using unnaturally course sediments for nourishment has also been suggested in other studies (Peterson *et al.* 2006; Manning *et al.* 2013)

In a recent California-based study, Wooldridge *et al*. (2016) reported some infaunal taxa did not recover at the end of the 15-month monitoring period despite using sediment that was deemed compatible with the native beach. The study involved comprehensive sampling of invertebrates on eight beaches along the southern California coast. Contrary to other studies, *Emerita* sp. and *Donax* sp. recovered within one year, while other invertebrate taxa studied (amphipods

and polychaetes) remained reduced in terms of density and abundance after 15 months of monitoring. Nourishment occurred in the fall; therefore it is possible that placement of fill material depressed the population too late in the season and did not allow for recolonization prior to the seasonal population decline, as has been suggested in other studies (Burlas *et al.* 2001).

Aside from the placement area, dredging can also affect the infaunal communities at the dredge sites (also referred to as sediment borrow areas). Benthic invertebrates that inhabit the borrow areas provide a prey source, and even structural habitat, for demersal fishes (CSA *et al.* 2009). In general, the benthic community is well adapted to disturbance and therefore often recovers rapidly in dredged sites, particularly those located within the inner shelf (Johnson and Nelson 1985; Jutte *et al.* 2002; Posey and Alphin 2002; Day *et al.* 1971; Pratt 1973). The resiliency of the invertebrate assemblages in relatively unstable marine subtidal sediments is due primarily to the life histories of these benthic populations (Newell *et al.* 1998; Posey and Alphin 2002). Invertebrate larvae of soft sediment subtidal systems have a higher proportion of planktonic forms capable of an extended period of viability compared to those found in intertidal and hardbottom areas (Grantham *et al.* 2003). This can lead to the potential for the dispersal across large spatial scales. Furthermore, marine organisms may successfully recolonize unoccupied space if that space provides the species the necessary ecological conditions it requires. Because most of these marine infaunal species possess a dispersive planktonic phase of their lifecycle, they are capable of moving great distances and, therefore, there are potential colonists always available in the local and regional species pool to promote recolonization within a borrow area. In addition, recolonization of disturbed borrow areas may also be facilitated from nearby habitats containing mobile species.

The Nags Head beach nourishment project, completed in 2011, included benthic monitoring within the fill placement area as well as the offshore borrow area. Project construction spanned the months of May through October, during the peak period of benthic productivity. The 2013 Year 1 post-construction report concluded that benthic populations in the nourished beach as well as the offshore borrow area were not significantly different from control stations and demonstrated viable populations of organisms as of the one-year sample event (CZR Incorporated and CSE Inc. 2013). The Year 2 post-construction monitoring report confirmed the results of the Year 1 report (CZR Incorporated and CSE Inc. 2014). Both reports concluded benthic populations along the beach as well as the offshore borrow area were generally no different from control stations and demonstrated viable populations of organisms during the post-construction sampling events (CZR 2014). In another study, Burlas *et al.* (2001) monitored borrow sites with bathymetric high points off northern New Jersey. The results from this study demonstrated that essentially all infaunal assemblage patterns recovered within one year following the dredging disturbance with the exception of sand dollars; weight and biomass composition of these organisms required 2.5 years to recover.

TOOLS AND STRATEGIES TO MAXIMIZE RECOVERY RATES OF BENTHIC INFAUNA COMMUNITY

As discussed above, the recovery rates of infaunal communities in the nearshore and intertidal environments may be driven by several factors. Specifically, several of the studies suggest that the compatibility of borrow material to the native beach and the seasonality of the placement may have a strong influence on these recovery rates. Other strategies may also be employed to promote relatively rapid recolonization of these organisms following the dredging and placement of fill material.

For example, the beach nourishment construction process builds a new beach in small sections each day over a cumulative period of a few weeks to several months. The duration of direct impacts to any area are, therefore, measured in hours to days with biological recovery potentially initiated immediately upon cessation of dredging and fill placement in that locality.

It has been shown that dredging practices play a role in the offshore rate recovery. In general, when the post-dredging physical conditions resemble the pre-dredging conditions, repopulation of biota can be expected. Potential long-term physical and biological impacts could occur if dredging significantly changes the physiography of the shoals. Sediment removal has the potential to alter seabed topography, particularly if sediment removal in the borrow area results in a deep hole. Numerical modeling of morphological changes associated with sand mining has been used to show borrow area location can drive whether infilling of an excavated area will occur (CSA International *et al.* 2009). A borrow area located in an active shoal area will likely be in-filled, while an inactive area will not. In instances where in-filling does not occur, the hydrology and hydrodynamics that drive benthic recolonization and recovery can subsequently be affected. Therefore, when dredging from an offshore shoal formation, targeting the portion of the shoal facing the predominant current (i.e. the leading edge of the shoal) will facilitate a relatively rapid recovery of the physical condition of the shoal feature, thereby increasing the rate of recovery of the benthic infaunal community (CSA 2009). This is due primarily to the physical conditions that would lead to a net long-term deposition and faster infilling rates of these dredged areas. The second most desirable location for dredging would be the shoal crest, followed by the trailing edge where finer sediments trapped by depressions created by sand extraction would be expected (Johnson and Nelson 1985). In terms of the dredging removal method, dredging in a relatively shallow striped pattern has also shown to contribute to a more rapid infilling rate (CSA 2009). Another factor to consider is that the potential for creation of deeper holes is higher with a cutterhead than a hopper dredge.

Wilber *et al* (2009) developed a comprehensive list of lessons learned from biological monitoring of beach nourishment projects from 1996 to 2008. Using the result of this paper and other meta-analyses of dredge and fill project impacts to benthic infaunal communities, the coastal management community including regulatory agencies, coastal engineers, environmental consultants and the dredging industry have adopted several best management practices to reduce and avoid biological impacts resulting from beach nourishment activities. Many of these best management practices have become standard over the years. The ASBPA Science and Technology Committee recognize these best management practices were developed in order to promote a relatively rapid recovery of the benthic infaunal community and recommends implementing these practices in dredge and fill projects when and where feasible. These best management practices, or "lessons learned" as recommended by Wilber *et al* (2009), CSA (2009), and others are as follows:

- When possible, avoid beach nourishment activities during seasons of peak larval recruitment to the benthos (e.g. the spring/summer for the eastern U.S.);
- Complete projects prior to the natural seasonal decline in infaunal abundances to allow recolonization to occur;
- Use sediments that are compatible between the native beach and the borrow source to minimize recovery times and retain similar benthic infaunal community composition;
- Locate borrow sites in areas that are likely to refill rapidly with beach compatible sediments while not disrupting cross-shore transport;
- Utilize specific dredging methodology including:
- Utilize shallow cuts and leave furrows between cuts ("striped dredging") to promote recolonization from un-impacted refuge areas;
- Avoid creating deep pits with steep side-slopes at borrow areas such that water quality conditions are substantially altered;
- When dredging from within an offshore shoal, selectively dredge from the leading edge to allow for the net long-term deposition and faster infilling rates.

The above Best Management Practices, of course, have their caveats. For example, spring/summer dredging may be necessary in some settings because of unsafe conditions during winter months. Further, organisms living in these "high energy" beaches may be better adapted to large-scale changes in the profile, often associated with storms (e.g. CZR Incorporated and CSE Inc. 2014).

RECOMMENDATIONS FROM THE ASBPA SCIENCE & TECHNOLOGY COMMITTEE

As beach nourishment continues to be one of the primary strategies used to protect developed shorelines in the wake of increased rates of storms, rising sea levels, and chronic erosion, it is imperative that project design considers the welfare of the various biological resources they may impact. The intention of this white paper is to provide information pertaining to benthic infaunal community response to disturbances caused by dredge and fill operations and how to minimize the effects. It is presumed that this paper may be utilized by project applicants, their consultants, and regulatory agencies to ensure that the best available science, data, and knowledge is utilized in state and federal permit applications and their associated NEPA documents.

The following recommendations have been identified as next steps:

Develop a comprehensive annotated bibliography of benthic infaunal research studies organized by region, as they relate to dredge and fill activities. ASBPA should host this bibliography on its website and updated annually.

Facilitate one-on-one discussions with natural resource managers and regulatory agencies to gain additional insight on residual concerns which may lead to the continuation of future monitoring efforts.

REFERENCES

Botton, M.L., R.E. Loveland, and T.R. Jacobsen, 1994. "Site selection by migratory shorebirds in Delaware Bay, and its relationship to beach characteristics and abundance of horseshoe crab eggs Limulus polyphemus eggs." *Auk* 111: 605-616.

Burlas, M., G.L. Ray, and D.G. Clarke, 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.

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

CSA International Inc., Applied Coastal Research and Engineering Inc., Barry A. Vittor & Associates Inc., C.F. Bean LLC., and Florida Institute of Technology, 2009. "Analysis of Potential Biological and Physical Impacts of Dredging on Offshore Ridge and Shoal Features." Prepared by CSA International Inc. in cooperation with Applied Coastal Research and Engineering Inc., Barry A. Vittor & Associates Inc., C.F. Bean LLC, and the Florida Institute of Technology for the U.S. Department of the Interior, Minerals Management Service, Leasing Division, Marine Minerals Branch, Herndon, VA. OCS Study MMS 2010-010. 160 pp. + apps.

CZR Incorporated and CSE Inc., 2013. "Nags Head Beach 2011 Nourishment Project: Post-Year 1 Report." Town of Nags Head, Dare County, NC. 45 pp.

CZR Incorporated and CSE Inc., 2014. "Nags Head Beach 2011 Nourishment Project: Post-Year 2 Report." Town of Nags Head, Dare County, NC. 40 pp. + Appendices.

Day, J.H., J.G. Field, and M.P. Montgomery, 1971. "The use of numerical methods to determine the distribution of the benthic fauna across the continental shelf of North Carolina." *J. Animal Ecology,* 40:93-125.

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

Gorzelany, J.F., and W.G. Nelson, 1987. "The effects of beach replenishment on the benthos of a subtropical Florida beach." *Marine Environment Resources,* 21: 75-94.

Grantham, B.A., G.L. Eckert, and A.L. Shanks, 2003. "Dispersal potential of marine invertebrates in diverse habitats." *Ecological Applications,* 13 (Supplement):108-116.

Greene, K., 2002. "Beach nourishment: A review of the biological and physical impacts." Washington D.C.: Atlantic States Marine Fisheries Commission. ASFMC Habitat Management Series no. 7.

Hayden, B., and R. Dolan, 1974. "Impact of beach nourishment on distribution of *Emerita talpoida*, the common mole crab." *J. Waterways, Harbors, and Coastal Engineering Division*, 100: 123-132.

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

Jones A.R., A. Murray, T. Lasiak, and R.E. Marsh, 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*. 29:28-36.

Jutte, P.C., R.F. Van Dolah, and P.T. Gayes, 2002. "Recovery of benthic communities following offshore dredging, Myrtle Beach, South Carolina." *Shore and Beach*, 70:25-30.

Leewis, L., P.M. van Bodegom, J. Rozeman, and G.M. Janssen, 2012. "Does beach nourishment have long-term effects on intertidal macroinvertebrate species abundance?" *Estuarine Coastal and Shelf Science,* 113:172-181.

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

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

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

Newell, R.C., L.J. Seiderer, and D.R. Hitchcock, 1998. "The impact of dredging works in coastal waters: A review of the sensitivity to disturbance and subsequent recovery of biological resources on the seabed." *Oceanographic and Marine Biology, An Annual Review,* 36:127-178.

Oliver, J., P. Slattery, L. Hulberg, and J. Nybakken, 1977. "Patterns of Succession in Benthic Infaunal Communities Following Dredging and Dredged Material Disposal in Monterey Bay." Technical Report D-77-27, October 1977. U.S. Army Corps of Engineers Waterways Experiment Station.

Posey, M., and T. Alphin, 2002. "Resilience and stability in an offshore benthic community; responses to sediment borrow activities and hurricane disturbance." *J. of Coastal Res.,* 16:368-378.

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

Peterson, C.H., M.J. Bishop, G.A. Johnson, L.M. D'Anna, and L.M. Manning, 2006. "Exploiting beach fill as an unaffordable experiment: benthic intertidal impacts propagating upwards to shorebirds." *J. Experimental Biology and Ecology,* 338:205-221.

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

Pratt, S., 1973. "Benthic fauna." In: *Coastal and offshore environmental inventory, Cape Hatteras to Nantucket Shoals. University of Rhode Island,* Marine Publication Series, 2:5-1-5-70.

Rakocinski, C., R. Heard, S. LeCroy, J. McLelland, and T. Simons, 1996. "Responses by Macrobenthic Assemblages to Extensive Beach Restoration at Perdido Key, FL. USA." *J. Coastal Res.,* 12.1.326-353.

Saloman, C.H., 1974. "Physical, Chemical and Biological Characteristics of Nearshore Zone of Sand Key, Florida, Prior to beach restoration." Vols. I and II. National Marine Fisheries Service, Gulf Coast Fisheries Center, Panama City, FL.

Schlacher, T.A., R. Noriega, A. Jones, and T. Dye, 2012. "The effects of beach nourishment on benthic invertebrates in eastern Australia: impacts and variable recovery."

U.S. Army Corps of Engineers, 2001. "The New York Districts' Biological Monitoring Program for the Atlantic Coast of New Jersey, Asbury Park to Manasquan Section Beach Erosion Control Project." Final report. Waterways Experiment Station, Vicksburg, MS.

Wilber, D., D. Clarke, G. Ray, and R.V. Dolah, 2009. "Lessons learned from biological monitoring of beach nourishment projects." In Fortieth Texas A&M Dredging Seminar. Tempe, Arizona.

Wooldridge, T., H.J. Henter, and J.R. Kohn, 2016. "Effects of beach replenishment on intertidal invertebrates: A 15-month, eight beach study." *Estuarine Coastal, and Shelf Science*. 175: 24-33.