BEACH NOURISHMENT: Global Perspectives and Local Applications to the North Carolina Coastline

Bryant C. Cooney
Kari D. Forrest
Juliana R. Miller
Florian U. Moeller
Jennifer K. Parker

Fall 2003

Carolina Environmental Program Capstone Experience conducted at the UNC Chapel Hill Institute of Marine Sciences in Morehead City, North Carolina

Field Site Director: Rachel T. Noble

TABLE OF CONTENTS

I. INTRODUCTION

A. What is beach nourishment?

Beach erosion has become a major problem for many coastlines around the world. Scientists and coastal managers have been working on ways to solve the problem of coastal erosion, and these solutions involve both hard structures such as groins and jetties and soft solutions like beach nourishment – projects comprised of borrowing sand and re-depositing it on the beach. Beach nourishment has recently become a more popular solution to the problem of erosion; however it has been around for many decades. It is important to realize that erosion is only a problem because people care a great deal about their beaches.

There are many reasons why people care about preserving beaches and thus are interested in perfecting the beach nourishment process. Beaches are great sources of recreation. Swimming, surfing, sunbathing, playing beach volleyball, walking, running, kite-surfing, and building sand castles are only a few of the activities people do on beaches for exercise or clearing the mind and soothing the soul. Douglass (2002) refers to America's beaches as "America's longest playgrounds." Approximately half of the world's population lives within 100 km of an ocean and 51% of the United States' population lives in a coastal county. In addition to the permanent residents, roughly 180 million people will visit coastal communities annually (ORCA, 2003). It is easy to see that beaches are very important to a very large proportion of the world's population.

Because of their recreational value, beaches are very large tourism industries, generating large amounts money for local economies. There are many regions that are famous for their beaches and it is these areas that are the main attraction to several parts of Spain, Italy, Australia, Florida, California, Florida, North Carolina, and the Caribbean. Beaches are valuable pieces of land that people love to be around and are "economic engines" (Douglass, 2002) that keep some local communities running. Some of the jobs beaches produce include lifeguards, surf shops and lessons, beach merchandise, hotels, seafood and restaurants, fishing, and boardwalks. The loss of beaches would result in a vast decrease in the job market. One specific example of how important the beaches are to jobs is California: 800,000 jobs contribute $14 billion in wages (Douglass, 2002). According to the tourism council, in North Carolina, over $10 billion comes in annually into the economy due to tourism and over 180,000 jobs are generated (NCSBPA, date not given).

Furthermore, high value can be, and is, placed on wanting to live within a view of the water. This prime real estate on the water can be fleeting, however, as it can quickly be lost as the shoreline disappears due to beach erosion. According to Douglass, "Anything that hurts the beach also hurts the economy" and it is more true today than it has ever been. However, development along the shoreline of the world's oceans is a controversial matter. There are opposing opinions. Some believe that development along the shoreline should always be possible, and that it should be possible to continually conduct beach nourishment to save homes even in areas that are considered high erosion areas. Others believe that either development should be prohibited, or that the buildings should simply be allowed to be reclaimed by the sea and not rebuilt after beach erosion takes place, because it was unintelligent to build on such a dynamic piece of land in the first place (UNCTV, date not given).

The biology of beaches is also important. People enjoy whale and dolphin watching, bird watching, shell examining, snorkeling and scuba diving along coastal areas, and many communities will take pride in certain animals that take advantage of local beaches. Sea lions, for example, that bask in the sun on beaches can be a source of local pride in California (Douglass, 2002). Some North Carolina locals also take pride in having sea turtles use their beaches to lay their eggs. Sea birds and fiddler crabs will also use the beach as their home and a source of food. Harming the beaches, as well as the process of beach nourishment, has the potential to impact specific species, and might deprive us of important biodiversity. There are some people who hold the opinion that nourishing the beaches will help keep the animals around by increasing their habitat size. There are others that believe nourishment ruins their natural habitats because nourishment projects can cause dramatic changes in sediment sizes along the beach, and beach structure and hydrology. It is apparent that before nourishment can occur, it is important to understand how beach erosion occurs.

B. What causes beach erosion?

Beach sands, firstly, are the result of the physical and chemical weathering of continental rocks. The sediments are deposited from land sources; however, once settled on the beach they are not dormant but are constantly changing (OUCT, 1999). There are several major regions of the beach starting from the upper berm down to below the sea level (Diagram I-1). An eroding beach is shown on the left, while an example of a nourished beach can be seen on the right.

Worldwide erosion of coastal regions causes major changes in beach profiles. Coastal erosion contributes approximately 0.25×10^9 tons per year of sediment to the oceans. Two of the largest factors involved in the transport of sediments are grain size and composition. Clay materials are usually small and flakey and will increase the cohesiveness of the sediment making the shear stress necessary to put the sediments in motion greater. Non-cohesive sediments, however, are easier to move and are made up of larger grains. Larger sediments will remain in place while finer grain size is more easily lifted into the water column and can, therefore, be more easily carried out to sea. Sediments of average grain size are the easiest to erode and require slower current speeds to be lifted into suspension. Another important thing to note is that because it is harder to lift fine muds and clays into the water column, they are usually lifted in clumps. This can be a big factor in increasing the rate of erosion (OUCT, 1999).

Turbulence is another important factor affecting the movement of sediments. When turbulence increases, there are more frictional interactions among the sediments to lift them and carry them to sea. Flow is not always turbulent, however. It is sometimes laminar (more or less straight) in even sea beds with slow current velocities. However, if the current speed picks up, the flow will become more turbulent right down to the sea bed. When grain size gets to the point where the sediments stick out into the lower sub layer of the water column, eddies begin to form. Eddies have the ability to reach in between the grains and pick them up and cause more movement. At high shear velocities, non-cohesive sediment grains are lifted permanently into suspension and carried off as suspended load for as long as the upward velocity of the sediment is greater than the settlement velocity (OUCT, 1999).

Wave energy also has an impact on beach erosion. The profiles of beaches can change quickly in response to the energy of the waves hitting the shore. Most of the wave's energy is transferred into the movement of sediments when they break upon the shore (OUCT, 1999). Wind and tide conditions have a huge effect on wave energy: the stronger the winds, the larger the waves (Douglass, 2002). Storm waves are much stronger than everyday waves and can cause greater amounts of erosion in a shorter period of time. The seasons also have an effect on the amount of energy waves have: summer is dominated by beach-building low-amplitude swell and winter is composed mostly of steep beach-eroding waves. When normal waves break on the shore, there is a net movement of sand onto the beach because the backwash, which erodes the beach away, is weaker than the swash, which moves sand onto the shore. However, steep storm waves have greater energy dissipated over a smaller area and the swash is generally weaker than the backwash causing a net movement of sediments to sea. There is also a net offshore movement of finer materials and a net onshore movement of coarse sand grains. Besides natural wave creation from storms and winds, waves can be generated by man. Boats and large ships generate wakes when they disturb the water. The waves they produce, like natural waves, can travel for a long time until they hit land where they contribute to erosion of beaches (OUCT, 1999).

Other factors that affect sediment transport on and off the beach are height and speed of waves, water depth, beach slope, settling velocity of sediments, magnitude and direction of currents, residential and industrial development, hardened structures up shore, and long shore transport. Waves in shallower water become taller and their orbital velocity increases and this can lead to higher sediment movement (OUCT, 1999). Longshore currents move sediments along or parallel to the shore. This is caused when a wave approaches an even shoreline at an angle. Longshore transport is part of nature's recycling process; sands are constantly moved between beaches and are shared all up and down the coast. Hard structures, however, disrupt longshore transport by causing sediment build up on one side and erosion on the other. The erosion can be seen miles downdrift of the hard structure (Douglass, 2002). They interrupt the movement of sand down the coast. Once waves lift the sediments into suspension, the currents carry them either down the shore or off to sea. An increase in development also contributes to higher rates of beach erosion. It can cause increased runoff, and with the runoff materials are carried away from the beach. The works of man like jetties and groins are also included in development as are seawalls, damns, dredging ship channels and sand mining. "The long-term monitoring of coastal changes around [hard engineering] frequently shows adverse environmental effects" (Hamm *et al.*, 2002). Over one billion cubic yards of sand have been removed from beaches because of these structures (Douglass, 2002). There are other problems with canals besides just their use of rock jetties. When ship channels are dredged the sand is dumped offshore instead of being placed back on beaches where they belong, so the sand is wasted and lost from the onshore recycling system.

Beaches are home to many people, and a vacation spot to even more. Their erosion due to physical processes is natural; however the accelerated rates are not. The most popular solution at this time is beach nourishment. Many countries have been implementing beach nourishment including the United States, Spain, the United Kingdom, Denmark, Germany, and The Netherlands to name a few. New Jersey, Florida, and North Carolina are just a few examples of some coastal states in the US that commonly implement beach nourishment as a method of coastal protection. This document will first provide a general overview of beach nourishment practices in several countries in Europe, as well as the east coast States of the United States. This document then moves on to address the needs of beach nourishment in North Carolina on a more thorough level; including the history of beach development, regulations and legislations, monitoring, specific cases of beach nourishment, and local biological impacts of beach nourishment. The document will continue to summarize a United States Army Corps of Engineers biological program monitoring (USACE-BMP) report that covers beach nourishment in detail about the New Jersey area. Shortcomings of the USACE-BMP report will be covered as well as its applicability to other states' nourishment programs, in particular North Carolina's. Finally, it will introduce some overall recommendations for future beach nourishment projects in North Carolina. This document has been created by a team of students as part of a Carolina Environmental Program's Capstone Project. The goal of the students was to conduct a semester work of team-based research in order to identify some of the key issues related to beach nourishment on a global scale. Also, the students aimed to identify the physical, biological, and environmental processes specific to North Carolina that make the biological impacts of beach nourishment different in comparison to other locations, and its beach nourishment needs different from other places in the world. Finally, the document addresses the shortcomings associated with other beach nourishment and biological beach monitoring projects, the lack of applicability of beach nourishment guidelines from one geographical location to the next, and identifies a set of recommendations for future beach nourishment practices along the dynamic coast of North Carolina.

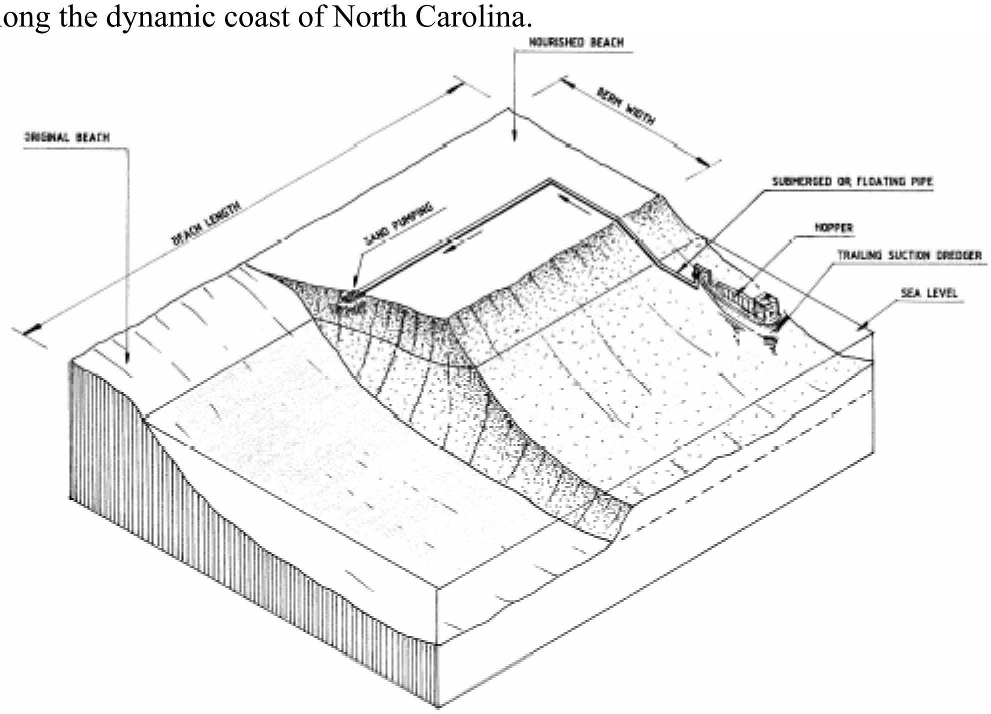

Diagram I-1. Beach Nourishment diagram with some basic concepts on it.
(Adapted from Muñoz-Perez *et. al.*, 2001)

II. BEACH NOURISHMENT AROUND THE GLOBE

A. Introduction

Coastal protection can involve the replacement of lost sediment in order to "stop or reduce the general retreat of the coastal profile" (Hanson *et. al.*, 2002). Beach nourishment has become one of the most popular methods of coastal protection to solve the problem of beach erosion in both the United States and Europe. However, there are big differences in beach characteristics between the two regions. Not only are the characteristics of the beaches different, but their recreational benefits are also different. In the US there is more activity occurring at beaches such as more surfing, sailing, and swimming. European beaches are more relaxed, with people spending more time simply sunbathing and tanning. There is also a lack of heavy wave action, or good "surfing" waves in Europe, that limits some of the activities that can go on. That does not mean, however, that there is no beach erosion. It just means that the waves are not conducive to the same kind of beach activities that can be found in the US. There are therefore different draws to different beaches around the world. With these different characteristics to the beach, there are also changes to what contributes to the economy at that location.

There are a few key things to recognize when beach nourishment is observed globally. The many facets of beach nourishment include management, economics, modeling and engineering, and monitoring. They differ not only between countries or continents, but also between states within the US. Funding, as well as monitoring, for beach nourishment can differ regionally within states. The key aspects of beach nourishment project design are project analysis, nourishment design, implementation, monitoring, and environmental impact and design (Hamm *et. al.*, 2002). There are many different reasons why a beach nourishment project would be put into effect. Some examples are for improving coastal stability (from erosion), improving coastal protection (for flooding), and for increasing beach width (for recreation). There are no specific monitoring programs required for beach nourishment projects. No two projects are the same; therefore, the effectiveness and performance of one project put in place to prevent flooding cannot be compared to a project that has been executed to increase the berm of the beach for recreational purposes. A lot of emphasis is placed on performance evaluations in the US especially (Hamm *et. al.*, 2002).

Not only are there differences in the types of beaches between the US and Europe, there are differences in the way beach nourishment is managed, paid for, maintained and monitored. An important point that should be stressed is how both of them feel about the process of beach nourishment. "Whereas in the USA, a debate on recognizing beach nourishment as a sound engineering response to coastal erosion is ongoing, in Europe, confidence has been established in shore nourishment as a central technique in the soft engineering strategy" (Hamm *et. al.*, 2002). This is an interesting comment because it openly states that Europeans approve of beach nourishment even though scientists in the US have found many problems with it, including negative biological and economic impacts. The monitoring programs associated with European beach nourishment projects are very good, both before and after, the nourishment project is conducted. They observe the profiles of the beaches to see if the erosion rate is increasing or decreasing to determine the success of the project. One important aspect that has been left out, it seems, is biological monitoring. Articles in the US abound about the effects of the different sediments on benthic invertebrates and how those effects move through the food chain up to the fish that live in the surf zone. There are articles on problems encountered in the borrow site, the nourished site, the increased turbidity, and the decrease or complete disappearance of animals at nourished sites. Literary searches have come up short for biological effects of beach nourishment in European countries. Maybe it is not a top priority or maybe the cost is too high for them to put the time and workers into determining the biological effects. This document has chosen to focus on two areas of the world that have conducted extensive beach nourishment projects: Western Europe and the East Coast of the United States.

B. Western Europe

According to Hamm, *et. al*. (2002), shore nourishment has become the preferred method for short term emergencies and long term issues for European countries. What they call "soft-engineering" has become more important as people want to develop more on the coast. However, beach nourishment is fairly young in Europe because they have a larger history of using hard engineering. According to Hamm's European views, "the philosophy behind beach nourishment is based on the consideration that when a stretch of coast is sediment starved, it could be more appropriate to import sediment and let nature do its job, rather than desperately try to counteract natural forcing factors to keep the remaining sediment" (Hamm, *et. al.*, 2002).

There are various attitudes about beach nourishment within the different coastal European countries. Some countries, such as France and Italy, try to avoid doing it all together so that no maintenance is necessary such as upkeep or monitoring. Other countries will only carry out beach nourishment when their beaches have already started to visually show major problems of erosion, such as Spain. They have more of a 'fix it only when it is broken' philosophy. Other countries like the United Kingdom, the Netherlands, Germany, and Denmark attempt to treat the problem before it starts using a more pro-active approach. These five countries' coastal protection programs have a strong link to flood protection, which is why it is important to prevent erosion before it starts. They use "long-term intervention strategies, which are implemented through follow-up programs" (Hamm *et. al.*, 2002) and are constantly monitoring changes in their shoreline over the long-term so they can see when problems will arise before they actually do arise. This is in contrast to countries like Spain, France, and Italy which only do their nourishment projects when a local coastal development project has caused destabilization of the beaches. Some countries do not want to acknowledge the problem of beach erosion unless they have to, and even then they will not admit that the problem was caused by their own mistakes, such as groins and seawalls.

Europeans put a strong emphasis on the public's perception of the projects: "Experience teaches us that while economic and ecological considerations are important, the combination of effectiveness and the public perception of this effectiveness is often the most important issue" (Hamm *et. al.*, 2002). It is not the safety of the biota living on the beach, but whether or not the public likes the new beaches that concerns the people in charge of beach nourishment in Europe. Perhaps the opinion of the public is what helps fund the projects. They believe it is important to know what the expected changes of shore nourishment are based on the given design objectives. This is because they are concerned about the public opinions and perceptions of what is going on and it is why post-nourishment monitoring has become practically routine. It seems very self-conscious to worry about what others think before worrying about the safety and the cost, both economically and biologically, of the project.

Europeans plan their beach nourishment projects with great detail and are very aware of coastal processes when considering the timing of the projects. They may leave out biological monitoring, but otherwise they have a strong sense of longshore transport, wave action, and the North Atlantic Oscillation and how all these processes affect sediment movement. They believe that if the reasons behind the variability of beach profiles over long periods of time are understood, they can work with nature instead of against it when planning their nourishment projects. Nature would then be helping in the success of the nourishment instead counter-acting all the work that was done. Despite all the planning that goes into their nourishment projects, only a few evaluations have been done in Europe. "The Netherlands and Denmark are the [two] countries where a serious overall performance evaluation program has been integrated into their legal framework" (Hamm *et. al.*, 2002). Of these evaluations programs, however, none of them involve biological indicators.

Table II-1 is a summary of beach nourishment in European countries that have coastal management programs as well as some information on the US. This table was adapted from Hamm *et. al.* (2002).

Table II-1. Summary of beach nourishment in European Countries (Adapted from Hamm *et. al.*, 2002)

Country	**Date of 1st recorded nourishment project**	**Number of nourished sites**	**Total fill volume (millions of m^3)**	**Mean annual rate of projects**	**Long-term strategy**	**Origin of funding**
France	1962	26	12	< 1	No	Local
Italy	1969	36	15	1	No	National/Regional
Germany	1951	60	50	3	Yes	Federal/National
The Netherlands	1970	30	110	6	Yes	National
Spain	1985	400	110	10	No	National
Denmark	1974	13	31	3	Yes	National/Local
United Kingdom	1950s	32	20	4	No	National/Local
Total Europe				27.5		
USA	1922			30	No	Federal/Local

There is variety in all the different facets of beach nourishment between the individual countries within Europe. The United States has 2.5 more projects per year than all of the European countries put together. Germany, The Netherlands, and Denmark all have long-term strategies whereas the US does not have any. The US, however, was the first to start doing beach nourishment in the 1920s, whereas Europe's earliest project was in 1951.

Two types of nourishment have been done in Europe: beach nourishment and shoreface nourishment. Beach nourishment is when the sand is put directly on the beach. Shoreface nourishment is when the sand is placed offshore and the movements of the ocean are taken advantage of to help bring the sand onshore naturally (Hamm *et. al.*, 2002). Most cases are regular beach nourishments with the sand placed directly on the beach. An extensive study of Spain as well as summaries of nourishment procedure of the Netherlands, Germany, Denmark, the United Kingdom, France, and Italy follows.

<u>Spain:</u>

Spain has the highest number of nourished sites out of all of Europe; however, its total fill volume is equivalent to that of the Netherlands, and they only have 30 nourished sites compared to Spain's 400 (Table II-1). There have been many repeated nourishment projects in Spain where beaches that have been nourished are starting to erode again, and therefore more sand needs to be added continuously. In the 400 sites that have been filled, there have been over 600 fills and refills (Hanson *et. al.*, 2002) with the total fill volume of 110 million m^3. Spain has the highest annual rate of projects at 10 per year. This is very high, especially when compared to France which has less than 1 nourishment project per year. It is no surprise that we are seeing so many nourishment projects in this country considering that Spain has no long-term strategy when it comes to its beach nourishment projects. Spain was the last country in Europe to enter into the soft substrate method; therefore, they have been rapidly jumping into the nourishment groove. Spain's first beach nourishment project was in 1985 which means in only the last 18 years, it has done 400 nourishment projects and counting. That shows that something is wrong with Spain's management program. However, it is important to realize that out of all the countries in Europe with a coastline, Spain's is among the biggest and will therefore require much more work to maintain as long as it is continuing to be developed.

Figure II-1. Beach Nourishment in Spain adapted from Hanson *et. al.*, 2002

All of the beaches on the Spanish Mediterranean coast are sandy, and it is the Mediterranean coast that has most of the beach nourishments. The northwestern and northern coasts have much fewer nourishment sites (Figure II-1). The biggest cause for beach erosion in Spain is harbor installations interrupting the sediment transport along the coast. During the nourishment projects, they try to avoid using hard structures in combination with the soft engineering. All Spanish beaches are state-owned and therefore the projects are well funded mostly by the central (or national) government. The government is working on an "integrated coastal zone management process" which would combine central and regional and local governmental funding for projects. Most of the beach fill projects are done with recreational uses in mind because tourism is a big industry in the Mediterranean region of Spain. Because the government wants the beach to be wider to accommodate more people, they are not concerned about the accuracy of where the shoreline should be. Only the Spanish government does follow up studies and monitoring for major projects (Hanson *et. al.*, 2002). Hanson *et. al.* (2002) mentions one thing about environmental interests when designing the projects: "In the design process, environmental concerns seem more important than the engineering aspects." Environmental issues, however, are not mentioned again in the document. Plus, if environmental concerns were important at all, there would not be as many nourishment projects as there are and the designers would have come up with a better design method to reduce the amount of dredging and bulldozing that would be going on because of their adverse effects on the environment.

Figure II-2. A before and after shot of the Maresme Coast in Barcelona, Spain. (Adapted from Hamm *et. al.*, 2002)

A nourishment project carried out in Barcelona at the Maresme Coast was assessed by Lechuga (2003). A photograph of what the coastline looked like before and after the nourishment has been provided (Figure II-2). Lechuga classified the reasons for erosion as mostly due to human impacts such as increased marina construction, harbors blocking longshore currents, and reduced sediment supply from rivers. The nourishment project in Barcelona was the first of its kind in Spain. Hard structures such as groins had been previously used to attempt to decrease erosion as well as preserve a railroad that was built right on the coast. The people involved in the project knew when entering that there would need to be several renourishments since the causes for the erosion would not be going away (Lechuga, 2003). It is not necessarily the best idea to go into the project knowing that it would not work in the long-term. Had the officials in charge given more thought to the planning of the project they could have determined the best way to make the sand last longer as well as be more economic. Determining when, where, and how many times the beaches will be renourished depends on the morphology of the beach. The objectives of the beach nourishment on the Maresme Coast were two-fold. One was to widen the beach for tourist use, and the second was to defend the railway. The study that Lechuga works with involves only 7 km of the 44 km stretch that was nourished. It was referred to as "comparatively in better condition than the rest" so the study may be skewed because it did not look at the whole beach, but simply the part that was holding up the best against erosion. The sand used was classified as "relatively coarse" and came from a borrow site not too far off shore. The sand was put onto the beach and was slightly compacted with the idea that the wave action would help to shape the beach. Extensive beach nourishment in this region has been occurring since the first project was carried out. Surveys began in 1987 and were carried out two times a year for the initial part of the monitoring and then once a year after that until 1994. Shoreline evolution and sand volume differences were examined to help determine when renourishment projects would need to occur. The study concluded that the nourishment was successful and that coarser sand in comparison to the native sand should be used because sand loss is less than expected. There was more beach area for recreation and the railroad seemed to be better protected with the nourishment in place (Lechuga, 2003). It is interesting that the monitoring the study carried out was only concerned with beach erosion, but not with how the sand effected the beach biota. Knowing that the sand was more compacted than normal should have biologists worried about the benthic infauna, creating a possible conflict of interest as to what constitutes successful beach nourishment.

Muñoz-Perez *et. al.* (2001) studied beach maintenance in the southwest coast of Spain in an area known as the Gulf of Cadiz (Figure II-3). The main aim of the study was to "describe a morphological and economical evaluation of the beach nourishment maintenance strategy carried out in the Gulf of Cadiz during the 1990s." The sand in this region is composed mainly of quartz and the tidal range is mesotidal. The beaches intersect submerged reefs close to shore which can cause wave decay, which would help decrease coastal erosion. Monitoring methods involved using wave rider buoys to collect data on waves and climate. Sediment samples via Shipek grabs and "sounding of the sea bottom" were taken to extensively study the borrow sites. They also conducted aerial topographic surveys of the beach and developed mathematical models using current measurements. The data collected from the surveys and the mathematical models will be used to help study the evolution of the coastline. The surveys were done for two years performing 1 per year. This helped researchers have a good comparison for before and after beach properties to help establish the importance of the nourishment. Thirty-

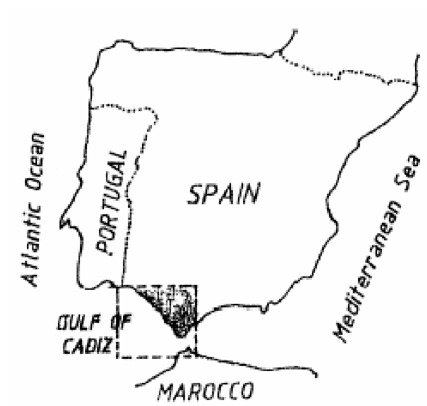

Figure II-3. Gulf of Cadiz adapted from Muñoz-Perez *et. al.*, 2001 eight beach nourishment projects have been done in this area in the last 10 years over twenty-eight different sites. Information was collected on sand volume, budget, sediment characteristics of borrowed sand (size, percent shell, etc.), borrow sites, beach profile (sand rich or reef supported), and erosion rates to name a few. The sediments can be separated into three categories along the coast: medium, fine, and coarse grains. The cost is best looked at in cost per unit of beach length: US$/yr/m. The average cost of beach nourishment for the 400 km of coastline monitored in this study was US $\$3.75 \times 10^6$ a year for an average volume of 1.2×10^6 m^3 of sand per year. It was found that transporting sand via truck is cheaper than dredging and using tubes to transport the sand; however very few projects were conducted using the cheaper method. The range of costs of beach nourishment per length of beach can be as low as US $7/year/m to as high as US $350/year/m. It was also found to be more economically favorable to do more small re-nourishment projects yearly than to do larger nourishment projects repeated less often but with a lot more sand. Not only is it better economically, but it is also better in using the resources that are available (Muñoz-Perez *et. al.*, 2001). The study, however, should go further to investigate whether it is more environmentally favorable to do mutliple small nourishments or a few big ones.

<u>The Netherlands:</u>

The Netherlands started their beach nourishment in 1970 and they have the same total fill volume as Spain, but it is spread out over a longer period of time and over a smaller number of projects. Their funding comes from the national level, and they integrate long-term planning with their beach nourishments. They have done approximately 200 different fills over the 30-35 sites that have been nourished (Table II-1, Figure II-4). Recent policy states that the shoreline should not be more landward than it was in 1990. Some sites, however, have defined the 1990 site to be more seaward as a "just in case" protection of the coast (Hanson *et. al.*, 2002). Verhagen (1990) states "Because of the increased importance of dune areas, official Dutch policy is that the coastline will be maintained at its present location but not at any cost." Legal safety standards must be followed when doing nourishment projects. National and regional government levels are responsible for coastal protection (Hanson *et. al.*, 2002).

Figure II-4. The Netherlands beach nourishment sites. (adapted from Hanson *et. al.*, 2002)

Previously beach nourishment was used to reinforce dunes to assist in flood prevention. Sea defense is very important because many of the main cities in the Netherlands are below sea level, so flooding is an important issue. Coastal erosion was mostly prevented by groins and other hard structures in the past (Verhagen, 1990). The country gradually turned to dune reinforcement first to try and protect the dunes; however, beach nourishment became possible because of its cheap price tag. Dunes still play a big part in sea defense, however. It is possible that beach nourishment is a "byproduct of the dredging industry" because of the excess sand from the channels being dredged coupled with the continuing beach erosion helped to bring beach nourishment to the forefront of coastal protection (Verhagen, 1990).

The main authorities that control coastal erosion are the Polder Boards that raise their own taxes and have parliaments chosen for their specific region of land. Polder Boards are known to finance some of their own management such as dike construction. They receive subsidies from the central government as part of the national interest for protecting the coast, for example if a railway is near the coast like the one mentioned above in Spain. The remaining costs of coastal management are paid for by the people who directly benefit from the nourishment. Larger scales of coastal management are handled at the national level because the scale may too big for the Polder Boards (Verhagen, 1990). Based on Verhagen's description, the Polder Boards are more decision makers than they are main funders. Rijkswaterstaat bodies are the national authorities for coastal protection. They plan all the nourishment projects and design all the beach profiles. There is little variation between beach sites. The main factors considered are beach volume and the erosion rate of the nourished sand (Hanson *et. al.*, 2002).

The polder, or town, is how most of the decisions are made in reference to beach nourishment. If the polder is not endangered when the coast is eroding, no action may be taken in trying to stop the erosion. The key point to all decision making with beach nourishment in the Netherlands is safety for the people who live on the coast. If a dune cannot protect a village, it has to be improved. The preferred solution is beach nourishment. The law is only to protect polders. If a coastal village (not the same as a polder) is at risk, then the Polder Board is not required to protect it. Erosion will be controlled, or should be controlled, in situations were the coastal villages instead of the polders are at risk, but the dunes are not required to be strengthened. Integration and coastal regression is calculated to predict future beach profiles to determine the amount of coastal erosion that is expected and how much it will cost to stop the erosion and protect the towns (Verhagen, 1990).

Verhagen states in his article that "Beaches are generally not affected by coastal erosion. In principle coastal erosion only causes beach problems if a fixed structure such as a seawall lies behind the beach" (Verhagen, 1990). He makes no mention of physical oceanic processes such as waves, turbulence, and longshore transport. Beaches are one of the most affected coastal features to see problems of erosion. Large boulders are harder to be lifted into sea. Verhagen does not acknowledge natural processes of erosion, but places all the blame on human impacts.

Monitoring of nourished areas is typically a collaborative effort between the different levels of authority including the Polder Boards and the Rijkswaterstaat. As part of the monitoring program, the dunes are measured regularly to ensure standards are met (Hanson *et. al.*, 2002). Performance indicators used in the Netherlands are (underlined letters are the abbreviations used for the indicators): <u>E</u>ffectiveness factor of nourished sand, preservation of adopted boundary <u>C</u>oastline, ratio of width of beach before and after nourishment for <u>R</u>ecreation, <u>N</u>atural values, and <u>F</u>lood protection (Hamm *et. al.*, 2002).

An experimental shoreface nourishment was performed at Terschelling, an island belonging to the Netherlands that is exposed to the swell of the North Atlantic and other large wind waves coming from the northwest (Figure II-5). A shoreface nourishment is when the sand is placed offshore underwater to let the currents naturally bring the sand to shore. This particular project was designed to make up for the occurring natural erosion over the course of eight years. The designers expected about half the sand to end up in the berm with high rates of gain early on but tapering off in the later stages. This site was chosen because the dunes are not protective on this island so there would be no major consequences if the shoreface technique did not work out because it was new. There was a more extensive monitoring program with this particular nourishment project to determine if the goal was met and the technique was successful. The goal was to have more sand on the beach then there was in 1990, as was stated earlier. The monitoring was also done to gain more baseline data about coastal processes. The officials checked the beach and dune profiles 3-4 times per year to record tides, measure currents, measure suspended sediments, and analyze sediments and grain size. The designers of the project purposefully chose coarser sand from the borrowed areas (Hamm *et. al.*, 2002). Coarser sediment will erode more slowly than finer sized grains. Many projects will use coarse sediments even if they do not match the natural characteristics of the beach (Peterson, 2003). The nourishment was considered successful in that the erosion rate decreased. Because the success was much better than expected, it was "further investigated with GIS tools" (Hamm *et. al.*, 2002). Again, there was no mention of studying biota and the effects of the biology when monitoring.

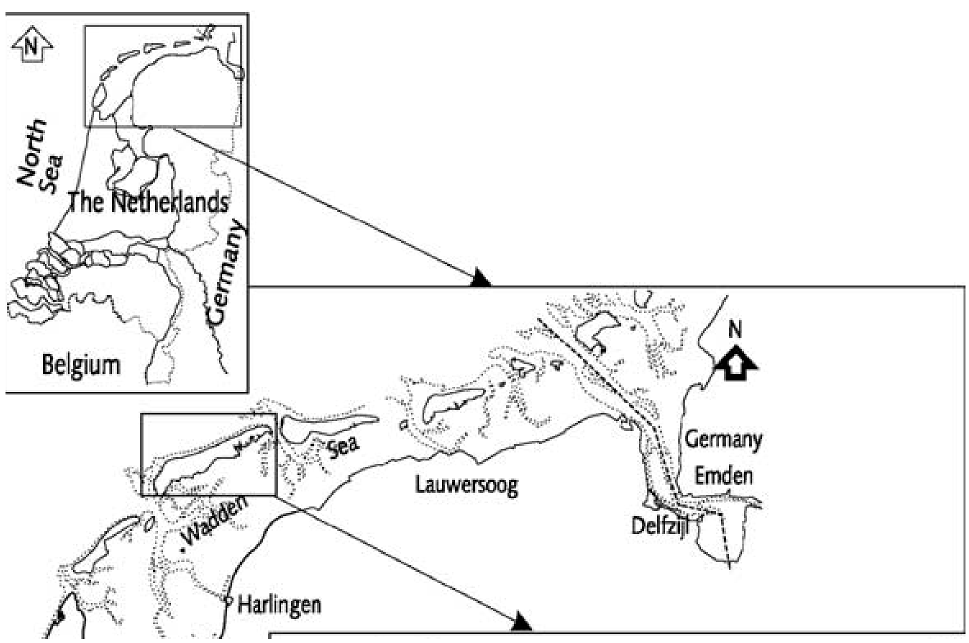

Figure II-5. Terschelling, The Netherlands. (adapted from Hamm, *et. al.*, 2002)

<u>Germany:</u>

Germany started their beach nourishment program in 1951 and they have performed projects on 60 sites since then with more than 130 fills over those sites (Table II-1, Figure II-6). They use long-term strategies and their funding comes from federal and national sources. Germany's main beach protection up until the 1950s consisted mostly of hard structures. The protection of the Northfrisian and the Eastfrisian Islands is considered high priority because they are thought to protect the mainland from erosion and high wave action. There is an attempt to keep the shorelines at their 1992 positions, a regulation similar to the Netherlands 1990 regulation. Dunes and landward extensions are used to help prevent flooding in some areas and erosion in others. Local communities in Germany will also take their own initiative to try and improve their beaches for recreational purposes (Hanson *et. al.*, 2002). Germany's master plan states that if at least 100 m of consecutive coastline is kept free of development then the number of replenishments would decrease (Hamm, *et. al.*, 2002).

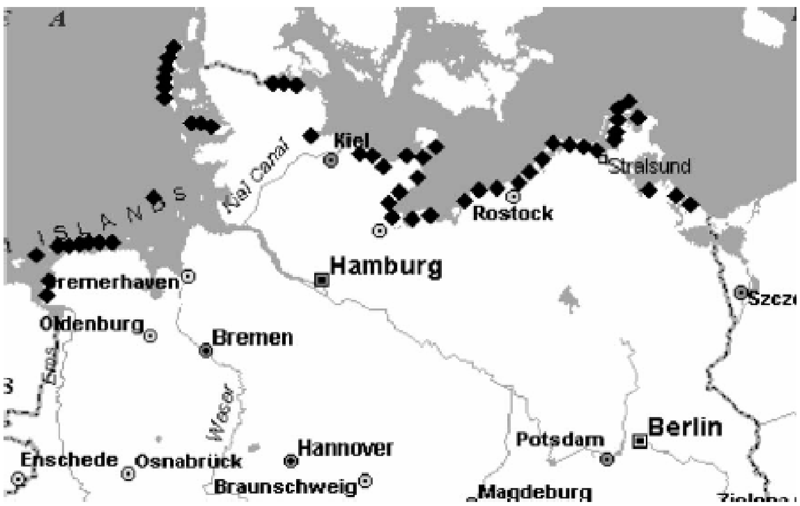

Figure II-6. Beach nourishment sites in Germany. (adapted from Hanson *et. al.*, 2002)

When a project is being designed, the main factors taken into account are the longshore transport rates and the maximum storm surge level. Environmental concerns are not an important issue and the main concern taken into account when it comes to timing the nourishment is tourist season. They plan the projects so as not to interfere with recreation during the summer months. When it comes to choosing a grain size, it is preferred to use a coarser grain size as in the Netherlands and Spain. No hard structures are used in conjunction with the soft nourishment, but it has been considered. Unlike in the Netherlands, Germany has not done any offshore fills, but mainly keeps their fill sites onshore and they are expected to last 5 – 7 years. Deep offshore dredging is used to collect the sand from the borrow site because it is believed to be the most effective. No extensive performance evaluations have been done for any beach nourishment project (Hanson *et. al.*, 2002).

There are five coastal federal states that have their own regulations for coastal protection. The regulations may differ slightly between the states; however there are no cases where conflicting legislation has had to be used. Funds given from the national level must be matched by funds from the federal level, therefore the national funds are only supplementary to the federal ones. A legal cooperation was made between the federal and national level in 1969 by means of "joint tasks." According to Hanson *et. al.* (2002), "Such tasks have to be classified as being of national importance and as being necessary for improving the standard of living." Approximately 5 % of the fill projects done in Germany were funded by local authorities because they were done mainly for recreational purposes in their own interest (Hanson *et. al.*, 2002).

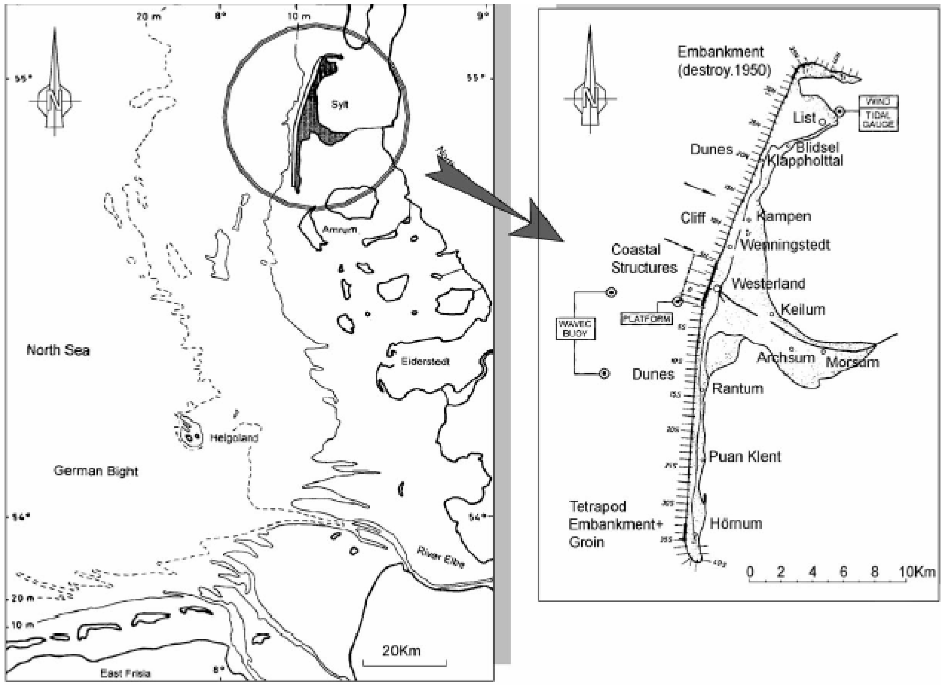

Figure II-7. The Island of Sylt, Germany. (adapted from Hamm, *et. al.*, 2002)

Any well-documented cases of beach nourishment in Germany are located on the Island of Sylt (Hanson *et. al.*, 2002). The Island of Sylt (Figure II-7) is the northernmost island in Germany and the study discussed here is a classic beach nourishment. Thirty-six kilometers of sandy coast is exposed to North Sea waves and tides that can get up to 2 m high and storm tides that reach 3.5 m. Over a period of 7000 years the coast of this island has receded approximately 13 km. Sand is eroded away and carried off by the tidal currents and therefore it is never recycled back to the island. Beach nourishments on the island have been occurring since 1972. The increase in storm surges lately has caused the erosion rates to increase. Germany created a coastal protection plan to last for 35 years which involves "repeated replenishments in the form of deposits on the beach and shoreface nourishments" (Hamm, *et. al.*, 2002). This exhibits somewhat how Germany uses long-term planning with their nourishment projects, although 35 years is not "long-term" it is better than most other European countries. They use dune erosion models to determine the order and degree to which various areas have to be nourished (Hamm, *et. al.*, 2002). Dune erosion may not be the same as beach erosion, and this could be a problem with their planning. Detailed land and sea surveys are done before, during, and after each nourishment on the island. Officials perform regular monitoring of dune, cliff, and dry beach positions with profile surveys done two times a year. Monitoring also involved taking wave measurements via wave rider buoys as well as collecting data on water levels, currents, and wind speed direction (Hamm, *et. al.*, 2002).

<u>Denmark:</u>

Denmark had their first nourishment in 1974. They have had 13 nourishment sites (Figure II-8) with over 115 fills, and they also have a long-term strategy for their projects. Their funding comes from either national or local funding (Table I). The national government usually covers between 50 – 70 % of the cost of the project in most cases, while in others it can pay the full 100 % of the cost (Hanson *et. al.*, 2002). The projects have the opportunity to get free sand from channel dredging projects that can be trucked to the beaches, and any extra sand that is needed is dredged from offshore then pumped over the bow of the boat (Thyme, 1990). Danish coastlines can be classified into three categories: (1) protected by dykes, (2) very exposed to the North Sea, and (3) not as exposed on the Baltic Sea. As can be seen by looking at the map, most of the nourishments have been done on the coast facing the North Sea, or the western coast of Denmark. A large cause of the increased coastal erosion in Denmark was due to harbors and groins being built and preventing longshore transport. Before beach nourishment was implemented, dune reinforcement was used to protect the coast along with building hard structures like sea walls (Hanson *et. al.*, 2002). However, storms over the last few years have caused extra erosion and hard structures previously used for protection are causing problems (Thyme, 1990).

Figure II-8. Beach nourishment in Denmark. (adapted from Hanson *et. al.*, 2002)

Predictions of future erosions have been mapped and sites of particularly high erosion rates can be seen in areas where fixed structures are upwind of the beaches. Denmark began using more stone breakwaters in 1 m deep water because of their decreasing leeside effects. Beach nourishment is said to be necessary to "maintain equilibrium" (Thyme, 1990). This is an ironic statement, because it is the structures put up my man that disrupted the equilibrium of sediment transport in the first place and now it is as if people are taking credit for learning how to create and maintain the equilibrium that nature had already set up.

The Danish Coastal Authority is responsible for maintaining and improving coastal protection on the North Sea coast of Denmark. It "investigates, plans, and designs" all the projects (Thyme, 1990). The coastal authority is also responsible for safety assessments and other post nourishment monitoring activities. It is estimated that 97% of the sand used in nourishment projects in Denmark was put on the North Sea coast. Policy from 1982 has set objectives for Danish nourishment projects: "(1) to reestablish and maintain a safety level against flooding of a minimum 100-year return period, (2) to stop the erosion where towns are situated close to the beach, and (3) to reduce erosion on parts of the coast where erosion in the near future would reduce the safety against flooding to less than 100 years" (Hanson *et. al.*, 2002). Denmark does not use beach nourishment to improve beaches for recreational purposes, but simply to protect the beaches and dunes from erosion. Their policy is to renourish beaches once a year because they believe putting too much sand on the beach at one time will harm the beach unnecessarily. Nourishment surveys are carried out once a year while dune safety is checked one time every five years through aerial photography (Hanson *et. al.*, 2002).

In Lønstrup, a 1.1 km stretch of land needed to be nourished after a storm in 1981 because erosion was putting a nearby village at risk. The objective for the project at this location was to stop erosion immediately as well as try to solve the erosion problems so that in the future there will be less to worry about. The initial beach nourishment was very large compared to the follow-up nourishments that continued to occur yearly after it. The project was successful because the beach height today is that same as it was in the beginning of the project; therefore, the amount of sand leaving the site is the same as what is being put back on through nourishment projects annually. Pre-fill monitoring occurred as well as post-fill monitoring that is ongoing at 4 times per year including bathymetric surveys (Hanson *et. al.*, 2002).

Another Danish beach fill was performed at Fjaltring-Torsminde. This site is located on the lee side of a groin and therefore it will be experiencing beach erosion rates higher than would naturally be there. Houses and farms were at risk due to an erosion rate of approximately 10 m/year. The main objective here was simply to "stop coastal retreat." This project was done by shoreface nourishment where the sand was dumped offshore in about 5-6 m depth. This area of land has been studied for a long time before the nourishment project began so bathymetric surveys go back to 1938. This will help to give a good picture of development of the shore over time from before and after the nourishment. Post-fill monitoring and sediment sampling continues to go on (Hanson *et. al.*, 2002).

United Kingdom:

The United Kingdom (UK) started their beach nourishment program in the 1950s. They have only performed approximately 35 fills over 32 sites (Figure II-9). These numbers show their high success rate of beach fill projects. They have no long-term strategies with their projects. Funding comes from the national and local level (Table II-1); however it must be applied for. The coastal department for each region gives the ultimate approval for projects after a lot of consultation has gone on. The UK uses beach nourishment in combination with "traditional forms of coastal defense," most likely hard structures. Sand dredging allowed an increase in recreational usage as well as protecting seawalls that were already in place for coastal protection. The biggest nourishment project to occur in the UK was on the Lincolnshire coast. The main objective of most beach nourishment projects in this country are to protect against flooding and erosion (Hanson *et. al.*, 2002). Since flooding is a problem, it would make more sense if they implemented long-term planning so the flooding would not be as big of a worry.

In addition to using beach nourishment as a method to stop erosion, offshore breakwaters are also being implemented in areas like the East Anglia coastline. They have experienced a high rate of erosion throughout history. Beach width is decreasing and flooding is increasing and it is predicted that storm frequencies will increase in the future causing greater coastal erosion problems in this region (Thomalla and Vincent, 2001).

The UK has performed “experimental ‘beach fill’ schemes” in order to use material from dredge sites in the best way possible. They are trying to increase their efficiency of dredging, and one way they are doing so is by using the excess sand to protect their salt marshes (Hanson *et. al.*, 2002). The UK’s management plan seems to be one of the best and most organized in Europe. The beaches are broken into “cells” and for each cell a management plan is drawn up taking into account information on that part of the coastline so appropriate recommendations can be made. There are 4 factors involved in deciding the best beach management strategy: (1) the benefit/cost ratio, (2) the feasibility and likely effective lifetime, (3) the standard of defense that is appropriate, and (4) the environmental impacts of the scheme both locally and at a distance. When project ideas are proposed in the beginning stages, the officials look at the economics, engineering, environmental design, cost, and performance. They also begin looking for suitable fill material and using number models and calculating drift. The beaches that are adjacent to the ones to be nourished are also considered (Hanson *et. al.*, 2002).

Figure II-9. Beach nourishment in the United Kingdom. (adapted from Hanson *et. al.*, 2002)

After the nourishment has been completed, the biggest loss of material is due to the tides. Because of this concern, most projects are accompanied with hard structures to reduce the loss. Extensive monitoring occurs after the nourishment. Most of the beaches in England – where a majority of the nourishment has taken place – are made of shingle and not sand, which is a very important difference in beach nourishment in the UK. Shingle is easier to work with than sand because it will erode less quickly. Those who maintain the beaches after the nourishment are responsible for regularly recycling the shingle by bringing it back from the down-drift end to the up-drift part of the beach (Hanson *et. al.*, 2002).

<u>France:</u>

France’s first beach nourishment project was in 1962. There have been 115 beach fills over the course of 26 different beach sites (Table II-1, Figure II-10). This is a very small number compared to other European countries. There are 3 beaches that contain 82% of all the material used to nourish beaches in France. Most of France’s coastal protection comes from hard substrates such as groins, seawalls, and breakwaters. France’s coastline extends from the Atlantic Ocean with lots of tidal activity to the Mediterranean Sea with very little to no tidal activity (Hanson *et. al.*, 2002).

Funding for French nourishment projects comes from the local government. The landowners whose best interest it is to replenish the beach will be responsible for most of the cost, unless of course the federal government sees it fit to subsidize federal funds for the project. Even when federal funds are distributed, they are not very large. The local communities are in charge of coastal defenses and it is because of this reason that there is no homogeneity in coastal management in France. There are, however, changing views and the move to think regionally as opposed to locally is growing (Hanson *et. al.*, 2002).

Figure II-10. Beach nourishment in France.
(adapted from Hanson *et. al.*, 2002)

Since most of the coastal protection in France is hard structures, it is not much of a surprise to find out that most of its nourishment projects are coupled with hard methods of beach protection. Many nourishment projects are also only carried out because there is excess sand available from a nearby dredging of a canal or other navigational area. One or more of several possible objectives could be reasoning for beach nourishment in France. They include making recreational beaches, helping in coastal defense, restoring the dunes, and putting to use dredged sand from other projects. Beaches that are nourished for recreational purposes are sometimes nourished to points that were never seen naturally. The berms are much wider than the beaches have ever been. France is like Italy in that it does not perform nourishment to prevent, but to restore what has already been lost. Most nourished beaches have been sand, but one beach in particular at Les Bas-Champs is made of shingle and is nourished often to prevent flooding of the low lying region. Other flood controls involve nourishing dunes (Hanson *et. al.*, 2002).

France has done some very thorough designs for their nourishment episodes. They determine the water levels and wave climates of the area and perform field studies to get information about the beach profiles at each location. The officials also look at the sediments in the area. Since the sand is mostly taken from dredge sites, there is not usually much control over grain size. It is only after the designing and field studies when the fill is actually planned and executed along with the accompanying hard structures. Environmental considerations are also taken into account when designing the project (Hanson *et. al.*, 2002).

An attempt at post-nourishment monitoring is carried out. They evaluate the changes in the morphology of the beach using various models including numerical and "mobile-bed scale" models. However, the monitoring programs are not planned nor are they systematic or complete. The main measurement used to determine performance of the nourishment is sand loss from the beach. The Law of 1977 is trying to increase the implementation of environmental impact assessments when budgets exceed a certain price. The government is also trying to protect "the natural state of the coastline" by preventing artificial nourishments of beaches extending them further out to sea than they have ever been naturally (Hanson *et. al.*, 2002).

<u>Italy:</u>

Italy started its nourishment program with its first project in 1969. Approximately half of Italy's 7,500 km of beach are characterized as "low lying alluvial beds, particularly exposed to coastal erosion" (Hanson *et. al.*, 2002). There have been approximately 50 fills at 36 different beach locations over the past 34 years (Figure II-11). Funding for the projects comes from national and regional sources for the most part (Table II-1). Italy will usually combine sand nourishment with hard structures, but no long term planning is implemented – just quick solutions (Hanson *et. al.*, 2002).

According to Hanson *et. al.*, most of Italy's beach fill projects have been small scale besides 4 exceptions which include: Cavallino, a barrier beach in front of Venice; Ravenna, near the Po River Delta; Ostia, near Rome; and Bergeggi in the Italian Riviera. Most of the project objectives are to restrict local erosion, increase beach recreation, or save coastal railways. There are two types of coastal defenses as defined by the Law of 1907: methods to protect built up and developed areas and methods simply to stop beach erosion. All the small scale projects, which are most of them, have only crude evaluations of erosions rates and equilibrium slopes. The larger projects are much better monitored and managed. They evaluate "longshore sediment transport rate combined with detailed computations of the volume budget" (Hanson *et. al.*, 2002). However, neither large nor small scale projects will use numerical models or post-project monitoring. There is no "established methodology for maintenance schemes, and no actual performance evaluation is made for the projects" (Hanson *et. al.*, 2002). This lack of monitoring and evaluations could be due to economics. Doing thorough follow-ups of beach nourishment projects can get to be very expensive, and if funding is regional there may not be enough funds to cover it. However, this is not a valid reason because financial support can be applied for from the Ministry of Public Works (Hanson *et. al.*, 2002).

Figure II-11. Beach nourishment in Italy.
(adapted from Hanson *et. al.*, 2002)

C. East Coast of the United States

The United States places a high value on its beaches because of their popularity as tourist spots and their ability to produce economic gains. The condition of the beaches plays a large part in how they are used and who wants to visit them. Nobody wants to spend his or her vacation at a beach that is in poor condition. Because Mother Nature is constantly shifting the beaches, beach nourishment has become a popular method to respond to shoreline erosion. In fact, beach nourishment has become the most popular method in the U.S., and probably worldwide to respond to these changes. Beach nourishment practices are not new ideas, on the East Coast of the U.S. beach nourishment practices date back to the early 1920's, when Coney Island New York was nourished. Since then beach nourishment has become an increasingly popular practice. In the 1970's we experienced a remarkable increase in nourishment projects, according to Valverde *et. al.* (1999), "This can be attributed in part to three factors: 1) legislation adopted around the 1970s, which increased the federal role in beach nourishment; 2) an increasing trend for federal navigation projects with beach disposal of dredged material, beginning in the 1970s; and 3) a shift in shore protection expenditures from hard stabilization to soft stabilization." Since we experienced these changes in the 1970s we have seen nourishment increase in both the 1980s and 1990s. In the 1990s, an estimated $68 million a year was spent on beach nourishment, compared to only an estimated $42 million a year in the 1980s. This rise in the amount spent on beach nourishment is also consistent with the rise in the amount of sand placed on beaches each decade. Funding for projects in the United States can come from any one of the six types of funding. Funding types are as follows: 1) Federal storm and erosion; this type of funding is up to 65% federal and is used for shore protection, hurricane protection, and erosion control. 2) Federal navigation; nourishment that involves taking sand from federal navigation maintenance and placing it on the beach, though if beach disposal of this sand is not the most cost efficient method than the local community will have to pay. 3) Federal Emergency; federally funded projects that occur in response to storm events. 4) State; projects funded by the state. 5) State/local; projects in which the state and local government share costs. 6) Local/private; funded by local or private parties (Valverde *et. al*, 1999). Despite this drastic rise in the occurrence of beach nourishment monitoring and design practices are still incomplete.

Florida:

Beach nourishment has been occurring in Florida since 1944, when the Lake Worth Inlet area and Palm Beach both received nourishment. From 1944 through 1996, Florida experienced 143 nourishment episodes (Valverde *et. al.,* 1999). The state of Florida has held several workshops in which it has developed recommended beach nourishment guidelines. Roughly, these guidelines include recommended design guidelines and courses of action to improve design methodology. Within the recommended design guidelines five design issues were considered: 1) background erosion, 2) sediment sizes, 3) volume densities, 4) project monitoring, and 5) end losses (Dean and Campbell, 1999). These five design issues are often some of the most problematic areas when a beach nourishment project is proposed.

A brief summary of how Florida sees fit to handle each design issue is below. In discussion of background erosion there are several factors to consider. Historical background erosion rates are considered to apply after project completion and therefore these rates should be a factor when considering project volume. It is acknowledged that historical rates would underestimate post-project rates "since the shoreline alignment after construction would induce greater transport gradients and thus erosion rates" (Dean and Campbell, 1999). It is also established that obstructions such as jetties, inlets, shoreline armoring, etc. play a role in erosion rates. Sediment size of the pre-existing beach and of the new sand used for nourishment often do not match. This causes problems for the design and limits what sands can be used for nourishment. Sand sizes different from native sand sizes will erode differently and cause changes in the beach profile. As stated in the workshop, “If sands smaller or larger than the native are used, greater and less volume densities will be required, respectively to achieve the design objectives” (Dean and Campbell, 1999). Fill needs, or volume density will be increased by erosion hot spots, and should also be taken into consideration along with historical background erosion rates. Volume density is considered one of the most important aspects of the design variables. Beach nourishment projects in Florida have ranged in volume densities from 40 yd^3/ft to 100+yd^3/ft.

Monitoring in the State of Florida is done for two purposes, to document project performance and to improve design capabilities. The state of Florida sees it necessary to have a network of extensive monitoring in place for each nourishment project. It recommends monitoring prior to the project, immediately after, at one year, two years, and three years after construction and biennially after the three-year period. Recommendations by the state of Florida for monitoring seem to be very well thought out. Monitoring of both topographic and bathymetric profiles is given consideration. It is recommended in the report to monitor using aerial photography along with sediment sampling and extensively recording physical data of the project. The workshop also calls for end losses to be accounted for, generally through a numerical model (Dean and Campbell, 1999). Florida has taken steps in the right direction by setting up workshops in which leading scientists in each respected field come together and construct guidelines for beach nourishment projects.

Besides just recommendations Florida has many laws in place that deal with beach restoration and nourishment. Chapter 161 of the Florida Beach and Shore Preservation Act states that beach erosion is a major threat to the economy of the state and that it is in the best interest of the public to finance beach nourishment and erosion control. The legislature calls for beaches with the greatest needs to receive funding priority for restoration (Florida’s Beach and Shore Preservation Program). The state of Florida only allows shore armoring as a last restore to a problem, and in legislation states armoring is only allowed when “The structure to be protected is vulnerable to erosion from a five year return interval storm event as determined by the department based on an analysis of general and site specific physiographic features or conditions such as: storm surge hydrograph and duration, bathymetry and topography, sediment and wave characteristics, and manmade and natural structures; All other alternatives, including dune enhancement, beach restoration, structure relocation, and modification of the structure’s foundation to make it no longer vulnerable to the erosion impacts of at least a five year return interval storm event, are determined not to be economically and physically feasible; It is demonstrated that there will be no significant adverse impact” (Florida State General Assembly, Florida Statutes of Strategic Beach Management Plan, Chapter 62b-41). This kind of legislation shows Florida’s preference to not use methods such as sea walls, bulkheads and other armoring techniques. In this same legislation it is required that any permitted construction that will cause an adverse impact shall have monitoring in place. It calls for monitoring for pre-construction, during construction, and after construction of topographic, hydrographic, and biological data. This data is to be analyzed by an engineer or geologist registered with the state of Florida, and for any biological data to be analyzed by a qualified biologist. Within this legislation there is an emphasis to have sufficient pre-construction data for comparison after project completion. State law also calls for only beach compatible sand to be placed on the beach or dunes, sands are to have the general characteristics of already existing sand and to be classified as sands by either the Unified Soils or Wentworth classification, with no greater than 5% by weight, silts, clays, or fine gravels. If rocks or other similar materials were to appear on the beach with greater than 50% of background in a 10,000 square foot area, then rocks are to be removed. Florida has also written in legislation for experimental coastal construction, and calls for scientific monitoring along with control sites for comparison (Florida State General Assembly, Florida Statutes of Strategic Beach Management Plan Chapter 62b-41). By allowing experimental construction the state is encouraging new ideas and hopefully advances in shore protection methods and technologies.

Under the Office of Beaches and Coast Systems in Florida a monitoring system has been set up to keep tabs on the conditions of state beaches. The statewide coastal monitoring system is used for measurement and analysis of coastal projects, mainly beach nourishment. The Florida Statewide Coastal Monitoring Program calls for monitoring of bathymetry, topographic, and aerial photography of one quarter of the state every year, or in other words, the entire state is monitored on a four year cycle. The state has been divided into four regions for monitoring purposes and monitoring of each region cycles on a yearly basis. The data components of the plan are to include: topographic and bathymetric surveys, digital photography and videography, laser technologies, and wave and weather information (Leadon, 2002). Technical specifications are provided for all aspects of the monitoring, as well as for analysis. The program also calls for an annual reevaluation of the monitoring specifics to accommodate new technologies, needs or budget changes (Coastal Monitoring Program, 2001).

Florida has seen beach nourishment projects within a wide range of both size and cost. The largest and most expensive project ever undertaken in the state was in Miami Beach and began in 1978. The project placed 12,000,000 cu. yards of sand on the beach at a cost of $55,000,000. The smallest documented project was in Ft. Pierce and only placed 7,190 cu. yards of sand on the beach, unfortunately the cost was not documented; the least costly nourishment project in the state of Florida that was documented was in Pompano Beach at a cost of only $3,677. The state of Florida is about par with entire East Coast with its funding classifications, through 1996 the state had only seen two federally-funded beach emergency nourishment projects, which accounts for only 1% of their total nourishment projects, compared to 6% total on the entire East Coast (Valverde *et. al*., 1999).

Many problems that occur with beach nourishment are being addressed by the State of Florida and their use of workshops and other research invested into beach nourishment hints at their reliance on nourishment as a tool for handling problems with beach erosion. Florida has begun to tackle such as problems as poorly sorted sediments and mismatched sand color (though it is stated that the state of Florida will select its sands to be used for beach nourishment projects based on grain size and economics (Dean and Campbell, 1999).) Florida's willingness to address such problems and to begin looking for answers is a step in the right direction for nourishment practices.

New Jersey:

Beach nourishment is not a new practice to New Jersey (NJ); its first beach nourishment episode was in 1936 when an Atlantic City beach was nourished. From 1936 till 1996, NJ experienced 121 beach nourishment episodes (Valverde *et. al.,* 1999). New Jersey also has claim to some of the largest beach nourishment projects, with one project 25 miles in length and 25 million cubic yards of sand being placed back on the beach (US Dept. of Interior, 2003). Many of these massive nourishment projects have plans for the beaches to be re-nourished every eight years or as needed in order to maintain a 100ft beach berm width, and this cycle will be in place for the next 50 years (Shore Protection, NJDEP 2003). New Jersey does place the maintenance of their beaches as a high priority. Since 1992, the State of NJ has been collecting money for a Shore Protection Fund. The legislature in place provides $25 million dollars annually towards beach restoration. This $25 million dollars is coming from realty transfer fees and was increased in 1998 from $15 million. This law states that money must be used for "shore protection projects associated with the protection, stabilization, restoration, or maintenance of the shore, including monitoring studies, and land acquisition…" (New Jersey Senate Budget and Appropriations Committee Statement, 1998). Currently, every beach in NJ is under some phase of beach restoration or nourishment. The state has seen both large and small-scale nourishment projects, ranging from only 15,000 cu. yards to the massive 25 million cu. yards mentioned earlier (Valverde *et. al.,* 1999).

In an attempt to assess the success of nourishment episodes the state has funded, a monitoring program to record geophysical aspects of the beaches was implemented. This monitoring program records real time observations of shallow water wave characteristics, water temperature, water level, wind speed and direction, temperature, and barometric pressure for the three sites chosen for monitoring. The sites are also fitted with a camera that takes pictures of the beach every five minutes. The state has taken up partnership with the Richard J. Stockton College of New Jersey's Coastal Research Center, and Stevens Institute of Technology's Davidson Laboratory of Marine Hydrodynamics and Coastal Engineering to handle this monitoring. With this data available NJ believes it will be able to effectively measure success or lack thereof of nourishment projects. This type of data allows an analysis of how a particular beach nourishment project will hold up to the storm events they are designed to protect against (Bruno *et. al*., 2002).

The trends developed by the beach nourishment projects in NJ seem to vary greatly from the rest of the East Coast. The majority of funding sources (which can also be an indication for the reasons behind a nourishment event) for NJ's beach nourishment projects show a distinct departure from other locations. New Jersey, which up to 1996 experienced 121 nourishment episodes, received funding for 44 of those episodes by state/local cost sharing; while receiving funding for Federal storm and erosion control for 24 of those episodes, and federal emergency funding for 25 episodes. That calculates into 36%, 20%, and 21% of the total respectively, while the totals for the entire East Coast are 18%, 43%, and 6% respectively. These seemingly high amounts of state and local projects would lead one to believe NJ is trying to be proactive with its beach nourishment, though the state still seems to be in need of considerably high amounts of nourishment projects to respond to storms, thus the high amounts of federal emergency nourishment events. Though NJ's many small-scale state and local nourishment episodes may be the reason they are seeing much less federal storm and erosion control nourishment events than the rest of the East Coast (Valverde *et. al*., 1999).

One NJ project that has received a lot of attention is the Sea Bright to Manasquan Inlet nourishment project. This project will provide protection to several highly populated communities on the NJ shoreline with the construction of a 100 ft. beach berm. This area previously had protection provided by a highly eroded section of beach or a seawall. This project is broken down into two sections, section one running from Sea Bright to Ocean, which is 12 miles of beach, and section two running from Asbury Park to Manasquan Inlet, which is 9 miles of beach. Each section will also have groins implemented for trapping sand, and section one will be re-nourished every six years with 3.5 million cubic yards of sand, while section two will be re-nourished every six years with 2.6 million cubic yards of sand. Sixty-five percent of the project is federally funded and the other 35% will come from the NJ Dept. of Environmental Protection; the total estimated cost of the project is $210,000,000 (Ciorra).

<u>North Carolina:</u>

Beach erosion is not a new process for NC's Outer Bank islands. According to Orrin Pilkey's theory about life on the barrier islands of NC, "the only thing constant here is change" (UNCTV, date not given). The beaches and dunes will grow and shrink with the movement of sediment on the barrier islands using the transport methods described earlier in the document. NC's beaches are defined to be approximately one mile out to sea. Most of NC's Outer Banks are classified as low vegetated islands bordered by salt marsh with approximately a 4,000 year cycle of island movement (UNCTV). This history of living on the coast in NC dates back hundreds of years.

It was in the middle of the 18th century that year-round settlements became established on Okracoke Island and other barrier islands in NC. Before that only seasonal settlements could be found on the Outer Banks. Even though the colonies were settling on the island for a year-round life, they still knew that they had to live *with* the islands and not *on* the island and, therefore, they stayed on the sound side and away from the ocean side. It was unthinkable at the time to live on the ocean because of the high amount of damage coming from storms as well as the continued movement of the water line. It was the aristocracy that began to build their vacation cottages on the beach to have a view of the sea. Even then, however, they knew the cottages were not permanent, and they were constantly being moved back with the receding shoreline. After World War II, more inappropriate building sites were chosen and bulldozing of the beaches and dunes began in order to level out the land for construction. The attempts to move the beach to keep up with the high demands for coastal property increased, especially in Nags Head (UNCTV, date not given). Now, however, many of these post-war practices are illegal, but people are still choosing unintelligent sites for building.

The early settlements overgrazed the islands and stripped the land of timber (UNCTV, date not given). The loss of vegetation created a huge impact on later erosion rates. The trees, marshes, and maritime forests all played a part in holding the sediments in place and slowing the rates of erosion on the outer bank islands and protecting them from storm, wind, and waves. Marshes were a huge natural barrier for erosion that were disappearing with increased development. The inflexibility towards nature in the settlements began to threaten the islands. The islands were seeing high density development with non-movable buildings in areas of sand-shifting environments (UNCTV, date not given).

Today's Outer Banks in NC are even more developed and are continuing to grow. The increased development causes coastal erosion rates much higher than what was once seen naturally. With eroding coastlines comes the desire to protect the property that is built on or near them and the economy that has risen. Early beach nourishment protection involved using seawalls to stop the waves from taking the sand. However, protecting buildings with seawalls comes with a bad environmental price. Using a seawall can eventually lead to the complete loss of a beach. Examples of this destruction can be seen up and down the NJ beaches. NC leads the way in preventing armored shorelines. Regulations mentioned later in the document are in place to prevent seawalls, however there is increasing pressure to overturn these rules (UNCTV, date not given). Without seawalls as a possibility of coastal protection, NC turns to beach nourishment. It has been used extensively in many of the state's beaches and can be successful.

North Carolina is part of the most nourished coastline in the United States. Up until 1996, the East Coast of the US had 573 different nourishment projects that used 350 million cubic yards of sand. NC is the third biggest state on the east coast in terms of nourishment projects implemented (Valverde *et. al.*, 1999). Of the 5 fastest growing counties in this state, 4 of them are on the water (UNCTV, date not given); so a lot of money needs to go into maintaining the beaches for public use in order to keep the coastal economy going.

The first nourishment project in NC was in 1939 at Wrightsville Beach. The project was just over 3 miles and cost approximately $100,000. Up until 1996, NC had a total of 102 beach nourishment projects and that number continues to climb. Wrightsville Beach and Carolina Beach have been the two locations that have experienced the most nourishment activity. There have been nineteen nourishment episodes at Wrightsville Beach up until 1996. Carolina Beach has had 26 (Valverde *et. al.*, 1999). A majority of the nourishments were by-products of navigational projects. Channels were being dredged and the excess sand was dumped on nearby beaches instead of being wasted offshore and lost from the beaches forever (Valverde *et. al.*, 1999). Most of the funding for NC's beach nourishments has come from federal sources for either navigation or storm and erosion. Only some projects were funded by the state or locally and even fewer from private sources.

There has been a lot of legislation and regulation passed in the past several years involving beach preservation and replenishment as development continues on the coast and as the process of beach nourishment has gained popularity. The NC Department of Environmental and Natural Resources' (NCDENR) Division of Coastal Management (DCM) put together a Coastal Areas Management Act (CAMA) Handbook for Development in Coastal NC. Section 4 of the CAMA Handbook refers to various types of projects and the rules that apply to them. The coastal counties of NC are depicted in Figure II-12. Beach nourishment is mentioned in a brief section that covers several rules and requirements to be followed when instituting a project. The first of the rules is in regards to sediments. The grain size and quality must be similar to the natural sediments found on the beach being replenished. When nourished, the beach slope must also remain close to the beach's natural profile. There are also restrictions involving borrow sites. Sand may not be taken from a sensitive area where increased levels of environmental impacts could occur. No beach nourishment projects may occur between May 1 and November 15 due to sea turtle nesting during this time period. However, it does say that permission to carry out projects in this date range can be granted (NCDENR, 2003).

NCDENR defines development as "activities such as dredging or filling coastal wetlands or waters, and construction of marinas, piers, docks, bulkheads, oceanfront structures and roads". Development along the coastline is regulated in order to prevent more problems with coastal erosion. All structures must be built back 30 times the erosion rate away from the first line of vegetation on the beach. Before development can even occur, a CAMA permit must be obtained if the area to be developed is within a county covered by CAMA. Most coastal counties in NC are covered by this act and therefore special permits are required for all coastal development. Appropriate measures must also be taken to protect the structure from environmental hazards (NCDENR, 2003).

As mentioned earlier, permanent stabilization of beaches in prohibited in NC. This regulation was set by the Coastal Resources Commission (CRC). House Bill 1028 states that "no person shall construct a permanent erosion control structure in an ocean shoreline" (NC General Assembly Bill 1028, 2003). That same bill gives the CRC permission to distribute permits to make offshore erosion control structures. There are, however, regulations on the permits they are allowed to give. All other methods for beach stabilization besides permanent structures are available options to slow beach erosion. The following list has been adapted from the CAMA Handbook off the NCDENR website. It provides the specific regulations that must be abided by when considering erosion protection projects such as beach nourishment. They include the following:

- Permanent erosion-control structures, such as seawalls, groins and revetments, are prohibited.
- Building relocation and beach nourishment are preferred responses to erosion.
- Comprehensive shoreline management is preferred over small-scale projects. Erosion management measures are more successful when coordinated over a large stretch of shoreline rather than at scattered, individual sites.
- Rules governing erosion response apply to all oceanfront property.
- Erosion-control measures that interfere with public beach access are prohibited.
- All erosion-response projects must demonstrate sound engineering practices.
- Unless appropriate mitigation is incorporated into your project plan, erosion-response projects will not be permitted in areas that provide substantial habitat for important wildlife.
- Your project must be timed to cause the least possible damage to biological processes. Certain times of year and day are important for breeding, spawning, nesting and feeding cycles of shorebirds, sea turtles and other species. Your project must accommodate these cycles in order to protect NC's wildlife.
- You must notify all adjacent property owners of your proposed project. No permit will be issued until the property owners have signed the notice form or until a reasonable effort has been made to contact them by certified mail.
- All exposed remnants and debris from failed erosion-control structures must be removed before beginning any erosion-response project.

The CRC also has specific criteria for sediment size on beach erosion. As mentioned earlier it should try to match the natural grain size and sediment quality of the area, but it must also be pollutant free and if not the same size than larger than the original grain size. When removing sand from the source it must not cause environmental harm in the process. Before removing the sand from the borrow site, certain assessments must take place in order to ensure the quality of the sediment at the site and its similarity to the nourishment site. Seismic surveys and sediment sampling must get all the stratifications of sediment types at the site to ensure that only the required size is present. There are specific limits for fine silts and heavy gravel. Silts can make up no more than 8% of the weight of the material being used and the coarser sand cannot exceed 17% by weight. North Carolina's sediments are not like Florida's or other tropical beaches, therefore calcium carbonate is not abundant naturally and should not be more than 25% of the weight of nourishment material. When sediment comes from a dredging project as excess sand, it may be used if it has no more than 12% silts or clays present; the same standards are used in Florida.

North Carolina has recognized the importance of its coastal region to the public and economy. The recreational use of the beaches is of great importance and in order to protect it there should be a coordinated effort to minimize the damage to the area from "recognized coastal hazards". The draft says nourishment should "provide storm protection and a viable alternative to allowing the ocean shoreline to migrate landward threatening to degrade public beaches and cause the loss of public facilities and private property". It is decidedly a better alternative to relocation of buildings. According to the CRC, nourishment is allowed if erosion is presenting a clear danger to public beaches and private property and if it seems to be economically feasible with no environmental impacts.

The NC State General Assembly put forth a recent bill in April 2003 giving the Legislative Research Commission permission to analyze all the regulations and laws in the state on "beach preservation, restoration, and public access and the role of citizen and advisory input into these policies and programs" (NCGA, House Bill 1165). This bill helps exhibit the continued interest at the state government level to keep up to date on beach nourishment legislation. The commission will be able to make recommendations to the General Assembly regarding their studies. Besides House Bill 1165, the General Assembly has completed several bills regulating beach erosion protection at more specific levels such as Topsail Island, Ocean Isle Beach, Carolina Beach, and Kure Beach to name a few.

A look at the Bogue Banks beach nourishment project, which is still in progress, reveals much about the steps of a given nourishment project. This particular nourishment project, the Beach Preservation Plan, is broken up into two tiers and three phases, and involves 16.8 miles of beach from Atlantic Beach to Emerald Isle. Tier I involves a strategic 50-year beach nourishment plan under the supervision of the United States Army Corps of Engineers, and is referred to as the Carteret County Beach Preservation Plan. This plan would involve re-nourishment of beaches every eight to ten years as needed, and is still in the early stages of the planning process. At the earliest, the first nourishment episode would not take place until 2008 under this plan, and 2010 is estimated to be the latest projected project starting date. Tier II, the Bogue Banks Restoration Project, has already begun and is currently in phase two of the project (Rudolph, date not given).

The first nourishment episode, phase one; of tier II began construction during the winter of 2001. This phase involved nourishment of the beach from the boundary line of Atlantic Beach/Pine Knoll Shores westward to Indian Beach, the project was 39,202 feet in distance. Looking at and analyzing historical erosion data for the area developed fill rates, and the project was engineered to provide ten years of protection. The total cost of the project, $12,585,000, was divided up among Pine Knoll Shore, Indian Beach, and the state. Pine Knoll Shores paid out $7,549,999.38, while Indian Beach paid $4,135,000, and the state paid $900,000. Pine Knoll Shores and Indian Beach both developed oceanfront and non-oceanfront tax districts to fund the project. Payment was divided up based on the amount of beach to be nourished for each of the three players in the project, with the state paying because a section of the beach to be nourished was the Roosevelt State Park. This phase of the project used only hopper dredges to remove sand from borrow areas, and borrow areas were determined by extensive coring of the sediments off Bogue Banks. Once sand reached the beach it was bulldozed into place and the new beach was shaped. Several problems arose during this phase. Early in this phase dredges experienced problems with up taking tires that broke free from a nearby artificial reef, with near 100 tires a day being sucked up by the dredges. These tires were missed in initial reconnaissance because they were covered in sand, and a scallop boat was finally contracted to sweep the area to remove any remaining tires. On December 15, 2001 this phase came to a halt as four turtles (two Kemp's Ridley and two Loggerheads) were taken up by the dredges. A biological assessment modification was made and dredging continued on December 21, 2001. These delays caused for an extension of this phase to be applied for, and was granted. The project was allowed to continue until April 30, 2002, though the project came to an end on April 11, 2002 when the fifth turtle (Kemp's Ridley) was taken up during the dredge process. This resulted in a reduction in the actual amounts of sand placed on the beach, and in Indian Beach some areas received no nourishment because of this stoppage (Rudolph, date not given)

Phase II of the project involved beach nourishment of Eastern Emerald Isle, and is one of the three projects involving nourishment before the United States Army Core of Engineers begin their Beach Preservation Plan. Phase two took place from January 13-March 27, 2003. The cost of phase two was $11,711,630; the town of Emerald Isle funded this with a bond referendum imposing oceanfront and non-oceanfront tax districts as a money source. Phase two involved a 39,111-foot/5.9 mile stretch of beach. The volume of the project was developed in the same matter as in phase one, and also accounted for ten years of erosion protection, and 1,810,000 cubic yards of sand were to be placed on the 5.9-mile stretch of the beach. Areas were to receive anywhere from 35cy/ft to 83cy/ft, depending on need. Nourishment during phase two used both hopper and cutterhead-suction dredge techniques; the cutterhead-suction dredge was brought in in hopes of reducing turtle take and to because of its ability to work faster. This phase called for dune construction for the last three miles of the beach. On March 13, 2003 the town of Emerald Isle received a violation from the NC DCM for the placement of materials on the beach that were deemed unacceptable. Sediment being placed on the beach reached as high as 87% calcium carbonate, while the target level was 42%, littering the beach with shells and rocks. One dredge was forced to relocate as a result and rocks were to be manually removed. With this violation also came increased monitoring of the area (Rudolph).

Phase III of the project calls for nourishment of the beaches of Western Emerald Isle, and possibly the realignment of Bogue Inlet. This portion of the project is to be funded in the same matter as phase two, and is scheduled to take place the end of 2004-beginning of 2005 (Rudolph, date not given).

The monitoring of this program, as with most NC nourishment projects, involves the use of several types of monitoring, including monitoring of physical parameters along the beach, monitoring of biota and biological diversity, and monitoring of endangered species such as sea turtles. Prior to 2002, monitoring of physical parameters such as beach slope was accomplished using the classic rod and level mapping. This involved walking the beach with a rod and level and only allowed for monitoring of the beach between the water in wading deep depths and up to the dune, and involved stopping and having one person operate each rod and level. This type of monitoring was very time consuming. With this method, transects were taken every 1000 ft of the entire project length. In May of 2002, Bogue Banks became the first area in NC to utilize Real-Time Kinematic-Global Positioning Device (RTK-GPS). This type of technology provides an increased number of data points of pre-monitored beach and also expands the monitoring area farther offshore. The RTK-GPS takes signals from a nearby base station to either an all terrain vehicle equipped with sonar or boat with an echosounder, and maps the physical data of the beach. The technology is so advanced that it is capable of compensating for tide, pitch, roll, and heave of the boat. The RTK-GPS provides a 3-D map of the beach terrain and allows for volume changes and sediment transport to be mapped with extreme accuracy (Rudolph, date not given).

Many other cases of beach nourishment in NC exist. A majority of the projects in NC have been undertaken to improve navigation of high-use areas, but many have also been implemented for restoration of the beaches. Below are some summarized specifics of various NC nourishment projects.

- Beach being developed near Tubbs Inlet was relocated and has since caused many problems for the town of Ocean Isle.
- Shallot Inlet has been dredged and dredged materials totaling approximately 1.7 million cu/yards of sand were placed on the beach.
- Carolina Beach Inlet contains a sediment trap, which is dredged every three years, and an average of 1,000,000 cu./yards of sand are placed over 14,000 feet of beach.
- Wrightsville Beach is under a nourishment project similar to that of Bogue Banks in that it calls for continual re-nourishment over the years.
- A northern beach of the Cape Hatteras National Seashore has been proposed for nourishment as part of a 50-year erosion program.
- New River Inlet has been dredged with approximately 710,000 cu/yards of sand being placed on Onslow Beach.
- Wrightsville Beach is one of NC's oldest beach nourishment projects and began in 1965. Since this time nearly 10.2 million cu/yards of sand have been placed back on the beach.
- Bald Head Island received sand from Wilmington Harbor in December of 1991.
- In 1996 Brunswick County beaches received 5.6 million cu/yards of sand from the Cape Fear River.
- NC Highway 12 on Hattaras Island saw 56 miles of dunes constructed, with completion in December of 2001. These dunes run the length of the highway in hopes of offering protection from erosion.

Figure II-12. All coastal North Carolina counties covered by the Coastal Area Management Act. (Adapted from NCDENR)

III. SUMMARY OF NORTH CAROLINA PHYSICAL AND BIOLOGICAL CHARACTERISTICS PERTINENT TO BEACH NOURISHMENT

Many specific attributes of the NC coast, as with any individual location, make it unique in terms of its needs during the process of beach nourishment. Any examination of the biological and physical processes will reveal differences from other locations, and even differences within NC, which must be taken into account when designing a nourishment project for the NC coastline. Therefore, while it can be useful to incorporate studies which have been conducted in other locations, specific knowledge from NC must be utilized as a starting point in order to best determine whether other information is applicable or not. The following is a brief summary of basic knowledge that has been acquired about both the biological and physical characteristics of NC and the manner in which NC biota has previously responded to beach nourishment under the constraints inherent to the NC coastal system.

A. Physical Characteristics of the NC Coast

Knowledge of the physical characteristics of the NC coast is needed to provide a basic understanding of the oceanographic processes that shape the coast to connect this with the need for erosion-control and the manner in which nourishment projects will affect biology.

NC has 301 miles of coastline and 3,375 miles of shoreline (including all offshore barrier islands). The barrier islands which border the coast play a major role in hydrological and biological processes (Mallin et al. 2000), as they provide a breaker for many physical forces (e.g. wind, currents). From the barrier islands, the continental shelf gradually deepens to about 50-60 m at the shelf break, which is roughly marked by the position of the Gulf Stream (Mallin et al. 2000). Upwelled nutrients are a significant portion of total new nutrients entering the shelf ecosystem; winds also drive significant flows shoreward (Mallin et al. 2000).

Cape Lookout separates the coastal system into northern and southern provinces, each with a unique geologic framework that results in uniquely different barrier islands and estuaries: south of Cape Lookout are sand-starved, ancient hard bottoms, while the area north of the cape is underlain by younger sediments, comprised of muds, muddy sands, sand, and peat deposited during sea-level fluctuations.

Sedimentology is a crucial factor in the beach nourishment process, as there are options as to what type of sediment can be used for fill material. Beaches of NC vary in sedimentary characteristics, and beaches along one part of the coastline often look distinctly different from beaches in another part (Rice 2003). A U.S. Fish and Wildlife Service study on NC native sediment characteristics analyzed oceanfront beach sediment data from various sources and found some important average characteristics (Rice 2003). The average NC beach sediment is predominantly medium to fine sand with 2.89% gravel (>2 mm; by weight), 2.05% fines (silt and clay), and 5.79% shell material. Carbonate content is highly variable, ranging from 0 to 99.00%, with a mean of 5.79% and a median of 2.00%. The beaches of the northern Outer Banks (north of Cape Hatteras) are slightly coarser than average, Brunswick County beaches are finer grained than average, and beaches of Onslow Bay and the southern Outer Banks (Cape Hatteras to Cape Lookout) are similar to the average. For the study's fill recommendations based on percentiles of native sedimentology, see Table III-1. In areas where sufficient data is available, site specific sedimentary characteristics can be used to choose fill material to further minimize impacts to biology.

Table III-1: Recommended Fill Material Composition Based on Native Sedimentology

Material	**95th percentile**	**90th percentile**
Gravel (>2 mm)	≤ 16.84%	≤ 5.89%
Fines (silt and clay)	≤ 7.72%	≤ 4.00%
Carbonate	≤ 25.00%	≤ 15.00%

B. Biological Characteristics of the NC Coast

North Carolina has a high level of biological diversity which stands to be impacted by beach nourishment operations. Just in terms of fish species, over 730 marine species have been documented from the estuarine interface to the 200 m isobath offshore, which is more than any other East/Gulf coast state except Florida (Ross and Bichy 2002). The level of diversity is explained by: 1) NC's location at a moderate (temperate) latitude, 2) NC straddles a major zoogeographic boundary (Cape Hatteras), 3) Gulf Stream influence facilitates an extensive tropical/sub-tropical marine community, 4) extensive habitat diversity that supports faunal diversity (Ross and Bichy 2002). Therefore, much stands to be lost if biological impacts from beach nourishment are not minimized.

Although there are differences in the biological assemblages along the 301 miles of NC coastline (this is a fairly large north-south gradient), it will be assumed that the biology present is similar enough within this span to make some reasonable generalizations as to the characteristics of the assemblages and the manner in which they are affected by nourishment. It must be noted, however, that, due to the physical characteristics as discussed above, there is a zoogeographic divide that occurs at Cape Hatteras. Also, Cape Lookout serves as another physical divide which influences biological variation, with areas north of Cape Lookout generally eastward facing and areas south of Cape Lookout generally southward facing. This alters ocean flow in such a way that biology is slightly different above and below this divide. When possible and/or necessary, the attempt will be made to differentiate between circumstances above and below these areas, though, in general, the biological nature of the NC coast is reasonably similar.

Characteristics of NC Plankton, Nekton, and Seagrass Assemblages:

Since the marine waters are relatively oligotrophic, there is low phytoplankton abundance except in a narrow inshore zone, which is dominated by small centric diatoms and flagellates, along with occasional blooms of larger centric diatoms (Mallin et al. 2000). Dinoflagellates and coccolithophorids tend to dominate farther from the coast (Mallin et al. 2000). Southern species of phytoplankton enter marine waters in subsurface intrusions, eddies, and occasional Gulf Stream rings, while cool water species enter with the flow of the Labrador Current to the Cape Hatteras region (Mallin et al. 2000). Species diversity can be high at the transition area of Cape Hatteras, which is the southernmost extension for some cold-adapted species and the northernmost extension of warm-adapted species (Mallin et al. 2000).

Marine zooplankton community composition is heavily influenced by mixing of inshore waters with Gulf Stream waters (Mallin et al. 2000). Inshore, the community is dominated by small copepods, chaetognaths, ctenophores, and larval fishes with estuarine affinities, while offshore communities include many species of both large and small copepods, gelatinous forms of several taxa, and larval fishes advected by the Gulf Stream with more tropical affinities (Mallin et al. 2000).

The dominant seagrass, *Zostera marina*, lies at the southernmost extension of NC, with *Halodule wrightii* at the northernmost extent. (Mallin et al. 2000).

The USACE Wilmington nourishment project (2001-2002) showed no significant differences in nekton abundances and diversities between disturbed, undisturbed, and reference sites during any season, however it was noted that the highly mobile nature of the community made detection of variation difficult (Burton et al. 2003).

<u>Characteristics of NC Benthic Macroinvertebrate Assemblages:</u>

A study conducted by USACE Wilmington in southern NC found benthic macroinvertebrate assemblages were dominated by *Donax variabilis*, *Emerita talpoida*, the polychaete worm *Scolelepsis squamata*, and amphipods in the Haustoridae family, which is typical of the East Coast, and specifically the South Atlantic Bight (Burton et al. 2003). Pre-Dredge studies for Bogue Banks showed that benthic populations were generally diverse with high numbers of species, diversity, and evenness in the spring, showing a decline in number of organisms and diversity in the fall/winter with the greatest decline at the onshore areas (Coastal Science Associates, Inc. 2002). This decrease is attributed to cooler water temperatures, stronger wave and current conditions, and seasonal habitat variations which occur during fall/winter (Coastal Science Associates, Inc. 2002). Ghost crab activity seemed to increase somewhat in the fall/winter, which is associated with season and decline of human activity along the beach (Coastal Science Associates, Inc. 2002).

Abundances of *Donax* and *Emerita*, which have the highest intertidal biomass, increase greatly in spring, most likely because of spring migration of adults from the subtidal bottom to the intertidal beach and spring recruitment of planktonic larvae (Peterson, Duvall, and Laney unpublished).

When discussing impacts of beach nourishment to benthos, it is relatively well understood that the actual dumping of sand on the beach kills everything that lives there, but the ability of benthic organisms to reproduce and recolonize quickly determines the actual recovery (starting from essentially zero population, Tursi 2002). Therefore, post-nourishment populations of benthos are ideally to be replenished by recolonization based on the suitability of the nourished environment for benthic habitat. Impacts to benthos, then, are constituted by an inability to re-achieve the original population in a timely manner. Basic monitoring projects have shown that there are clear impacts to benthos in both the borrow area and the nourishment area.

Nourishment of the Bogue Banks area in 2002 showed a general decline in number of organisms, species diversity, and evenness of macrobenthos, with the largest decline being in onshore populations such as *Donax variabilis* and *Emerita talpoida*, which is typical of date collected in previous studies on the Southeast Atlantic coast – see Table III-2 (Coastal Science Associates, Inc. 2002).

Table III-2: Decline in Organims Following Nourishment on Bogue Banks, NC

Beach	% Change in Mollusca	% Change in Annelida	% Change in Arthropoda
Nourished	-87 %	+181 %	-98 %
Controls	-78 %	+265 %	-78 %
Normalized Nourished	-9 %	-84 %	-20 %

This study also showed that offshore macrobenthic populations had a small shift in number of organisms to a greater number of annelid worms in the spring, which are opportunistic species that take advantage of new habitat provided by the dredging of borrow areas. This trend continued after the fall nourishment event, when apparent declines in Phylum Mollusca (*Donax variabilis*) and Arthropoda (*Emerita talpoida* and *Amphiporeia virginiana*) were offset by an increase in Annelida (polychaete worms).

The USACE Wilmington project which took place from 2001-2002 also has some initial monitoring results on benthos. Impacts from sand placement were clear for all of the nourished sample sites (Burton et al. 2003). Benthos of the swash area appeared most directly impacted, which was true for all sampling seasons and when all samples were combined. Seasonal impacts were more prominent for certain areas: impacts for the shallow subtidal habitat were greatest in spring and summer and impacts for the deep habitat were greatest in spring since which is the period of major recruitment for benthic macroinvertebrates.

Of the benthic invertebrates which can be affected by sand placement, only the larger, mobile organisms can leave the area to avoid smothering (Seymour et al. 1995). Reilly and Bellis (1978) observed that densities of the mobile ghost crab decreased following nourishment of Bogue Beach and they suggested that the crabs had moved away due to physical disruption or loss of suitable food resources (Seymour et al. 1995).

While many studies taking place in NC have focused on the aftereffects of nourishment simply based on whether or not nourishment has occurred and what the results have been, some studies note the characteristics of the nourishment event and describe how this is potentially reflected in the impact on the biota. Variables such as sand grain size, mud content, time of year the operation is conducted, and manner in which the operation is conducted can greatly impact the success of the nourishment operation in terms of minimizing impacts to biota. A study was done on the placement of sediments dredged from a channel in Bogue Sound onto the beach face (Peterson 2000). From June to early July (5-10 weeks after nourishment) there was 86-99% less *Emerita talipoida* and *Donax* spp. Though recovery from other similar projects had been apparent by mid-July, there were no signs of recovery in this project, and Peterson notes that it may be a result of the poor match in sediment grade. The dredged sand was very fine and poorly matched existing sediment on the beach. The U.S. Fish and Wildlife Service sedimentology study notes the macroinvertebrate benthic community of sandy beach ecosystems is sensitive to grain size and other sedimentary parameters and that adverse impacts can be minimized by using fill material that is compatible with the native sedimentary characteristics of the project beach (Rice 2003). This study also comments about the timing of nourishment events. It is stated that future nourishment projects should be timed to end before the onset of the warm season (April or May in NC) to see how this affects the rate and timing of recovery. Overall, this study showed consequences of large short-term effects on dominant species of beach macro-invertebrates.

Characteristics of NC Finfish Assemblages:

In the Pre-dredge monitoring studies done for Bogue Banks in 2001, the predominant nearshore demersal fish species found in spring were *Trachinotus carolinus* (Florida Pompano – the most abundant overall, juvenile form), *Menticirrhus littoralis* (Gulf Kingfish), *Leiostomus zanthurus* (Spot), *Menidia menidia* (Atlantic Silverside), *Lagodon rhomboids* (Pinfish), *Paralichthys dentatus* (Summer Flounder), and *Dasyatis americana* (Southern Stingray) (Coastal Science Associates, Inc. 2002). In the fall, the predominant species changed to *Trachinotus carolinus*, *Menidia menidia* (the most abundant overall), *Paralichthys dentatus*, and *Mugil cephalus* (Striped Mullet) (Coastal Science Associates, Inc. 2002). The majority of gut contents of fish from both seasons are Donax shells with an occasional mole crab (Coastal Science Associates, Inc. 2002). In the USACE Wilmington nourishment project, pre-monitoring showed that fish assemblages were similar to other findings for the South Atlantic Bight (Burton et al. 2003). Counts of ichthyofauna around Zeke's Island and Masonboro Island revealed species of the families Clupeidae, Engraulidae, Cyprinodontidae, Sciaenidae, and Bothidae were ubiquitously present in large numbers, typical of southeastern U.S. estuaries (Ross and Bichy 2002), and it can be assumed that many of these fish species are the same ones that spend part of their lives offshore.

Fish can be found at different locations in the ocean depending on the season, and this also varies by species. Overall, the dominant life history is one where adults spawn offshore during late fall through early spring, larvae migrate into estuaries and as juveniles settle into shallow bays and creeks to reside spring/summer, and leave for deeper waters in fall (Ross and Bichy 2002). The bottom of the nearshore continental shelf is known to be used in late fall and winter for spawning and overwintering for striped bass and dogfish sharks (northern beaches off Dare and Hyde County), scianids (Cape Lookout south), flounders (entire coast, fall until spring), bluefin tuna (Dare County through Cape Lookout) (Peterson, Duvall, and Laney unpublished).

The Bogue Banks nourishment project Post-dredge monitoring revealed a decline in numbers and in species (from 8 to7) of demersal fish for the June nourishment event, which could be associated with netting that takes place off the beach in spring and summer (Coastal Science Associates, Inc. 2002). Numbers also declined for the November nourishment event, but species increased (from 4 to 5).

In the USACE Wilmington project, there was a trend of fewer Gulf Kingfish at disturbed stations, which may be related to prey decreases (their prey of choice are crustaceans and some benthic organisms, which did experience a seasonal impact). The schooling nature of a number of dominant species (e.g. Bay anchovy) constrained the ability to determine differences among the three groups of sampling stations. Changes among surf zone fish were said to be similar to the results found for the USACE Biological Monitoring Program (which will be discussed later in detail) which mostly found no impacts on surf zone fish.

Sampling done on North Topsail Beach nourishment in 1998 showed that elevated turbidity resulted in a 40.5% decrease in predation on coquina clams by Florida pompano, which forage visually (Lindquist and Manning 2001). A different experiment showed a 30% decrease in feeding on mole crabs by pompano when turbidity was high (Lindquist and Manning 2001).

Characteristics of NC Megafauna:

Shorebirds utilize the coastline of NC for a variety of purposes. The beach is used for summer breeding sites, foraging grounds during spring and fall migration, and overwintering sites, and offshore waters are used by rafts of overwintering seaducks, cormorants, and other seabirds (Peterson, Duvall, and Laney unpublished). The federally listed piping plover and Audubon's petrel utilize the area for wintering/breeding and foraging respectively, and birds such as wading birds, ospreys, neotropical migrant species, and raptors utilize the resources of the area, even if only for part of the year in the case of migratory species (Peterson, Duvall, and Laney unpublished).

Beaches and coastal shelf waters are also used by five different species of sea turtles (all endangered or threatened), of which primarily loggerheads, but also green and Kemp's ridley, nest May-August and eggs hatch July-October (Peterson, Duvall, and Laney unpublished). The rest of the year, these turtles forage offshore, and autumn/early winter finds them in waters of the continental shelf from Dare County to the South Carolina line (Peterson, Duvall, and Laney unpublished).

Not as much research has been done on the effects of nourishment on NC megafauna as for benthos and fish. But, considering that effects are seen in these communities occupying a lower trophic level, repercussions of nourishment to larger organisms are highly probable based on their dependence on affected communities. The loss of prey animals due to nourishment could effect growth and reproduction of shorebirds (Peterson, Duvall, and Laney unpublished), and other megafauna. The number and condition of bird young is known to be dependent on lack of disturbance during nesting and abundant supplies of prey, and some species require generally undisturbed conditions (Peterson, Duvall, and Laney unpublished), all of which could be affected by nourishment operations.

Sea turtles can be greatly impacted by nourishment operations. Nourishment can affect nesting, hatching success, and the general survival of sea turtles. Studies have shown that the number of turtle nests decrease on a nourished beach, which can be caused by inability to crawl up the beach because of steep cliffs formed from pumped sand, too great a composition of silt, shell, or rock fragments that harden and make digging difficult, or alteration of nesting behavior (e.g. failure to nest, abandonment of eggs in the ocean, nesting in an unsuitable area) due to beach activity, construction lights, or other causes (Tursi 2002). Hatching success can be affected if the sand is not the right size, color, and consistency for turtle eggs to hatch successfully, the material is incompatible so as to prevent escape from the nest, the nests are covered up or destroyed, or hatchlings become disoriented by artificial light from the construction zone or run over as they try to make it to the ocean (Tursi 2002). Adult turtles can be killed by being sucked up by a dredge, as happened to four turtles in one day during a project in Carteret County (Tursi 2002).

IV. SUMMARY OF UNITED STATES ARMY CORPS OF ENGINEERS (USACE) BIOLOGICAL MONITORING PROGRAM REPORT ON BIOLOGICAL MONITORING PROGRAM FOR NEW JERSEY EROSION CONTROL PROJECT

A. *USACE Biological Monitoring Program Overview*

The Final Report of *The New York District's Biological Monitoring Program for the Atlantic Coast of New Jersey, Asbury Park to Manasquan Section Beach Erosion Control Project* was issued in 2001. This document was compiled through work conducted by the USACE, and includes information regarding the process of beach nourishment in northern NJ, created with the intention of analyzing the biological impacts of the most recent erosion control project undertaking, as well as determining the implications for future projects in the NJ area.

The specific project which was assessed involved the placement of one of the largest volumes of sand ever used in a nourishment project. However, there are other characteristics of the project and its subsequent biological impact assessment which lend a wider appeal to this particular document than solely in the scope of NJ erosion control. The report provides one of the most comprehensive views available of a beach nourishment project, from start to finish, including several years of baseline data to establish knowledge of biological conditions in the absence of nourishment. Planning is one of the key factors which separates this biological assessment of nourishment from many others. It was determined well in advance of the project commencement that a Biological Monitoring Plan (BMP) was to be put into place and that an overarching report would be generated from the findings. Also, beach nourishment is a fairly recent concept, and it is unusual to have a document which analyzes information accumulated over such a long period of time from an early date (1993-2001). The applicability of the document, then, extends beyond that to NJ beaches alone. Both the manner in which the report was done as well as the information contained within it provides a promising model for nourishment projects in other areas, specifically along the NC coast. Certainly, there are shortcomings to the document and aspects of the monitoring project which can be improved upon. Enough useful information, though, is contained in the document to make it a worthwhile tool for use in designing beach nourishment projects taking place on the coast of NC.

Beginning in 1997, an erosion control project was initiated jointly by the U.S. Army Corps of Engineers (USACE, New York District) and the State of NJ (under the NJ Department of Environmental Protection, NJDEP) to combat the loss of beaches by erosion of the northern NJ shoreline. Prior to the beginning of this project, the need for an assessment of potential impacts of the project on local biota was realized, and a BMP was designed by USACE, which we will refer to as the USACE-BMP. The goal of this plan was to determine biological impacts, specifically as indicated by change in population levels and diversity, of both the borrow areas, from which sand was dredged, and of the nourishment areas, where dredged material was added. While the total project area contained the areas from Manasquan Inlet northward to Highland Beach, the USACE-BMP was designed to specifically focus on the stretch from Manasquan Inlet northward to Asbury Park for the indication of biological change.

From 1994 until 1996, baseline data was collected to characterize the nature of the beach and its ecological conditions prior to nourishment. In 1997, the southernmost reach, from Manasquan Inlet to Shark River, was nourished, while in 1999 the remaining area included in the USACE-BMP, from Shark River to Asbury Park, was nourished. Monitoring took place both during and post-construction for these two areas. During the initial nourishment in 1997, the remaining unnourished area (Shark River to Asbury Park) served as a reference area, so it was monitored as well. In this way, both prior baseline data and control data coincident to nourishment were made available for comparative purposes. For reference purposes, the site of the USACE-BMP was divided into three areas: the South Area (Manasquan to Shark River Inlet), the Middle Area (Shark River Inlet to Asbury Park), and the North Area (Asbury Park to Deal Lake).

B. Sampling design and methods

Biological sampling was conducted to identify specific population levels and characteristics for both the nourishment area and the borrow area. Data sampled for in the nourishment area included: intertidal and nearshore benthos, surf zone and nearshore ichthyoplankton, potential fish food items present in ichthyoplankton samples and on rock groins, beach seine data, food habits of surf zone fishes, turbidity and suspended sediment characterizations, and recreational fishing information. In the borrow area, sampling was conducted for benthos, finfish, and fish food habitats located where sand was borrowed.

Sampling of intertidal benthos consisted of collecting sediment cores and passing them through a sieve to separate infauna from sediment. Sediment samples from cores were also used to determine grain size distribution. The nourished South Area was compared with the reference Middle Area initially, and these roles were switched when the Middle Area was nourished, as the South Area by then had been deemed sufficiently recovered to serve as a reference. Sampling for nearshore benthos was conducted by taking single grab samples at various sampling stations. Sampling times were standardized to reduce variability. Organisms were hand-picked, identified, counted, and weighed. Sediment was separated by diameter with sieves and weighed to determine mean and median grain size. Offshore borrow area benthos was sampled for in a very similar way by taking grab samples in that location.

For surfzone and nearshore ichthyoplankton, plankton nets were deployed at sampling stations in both the surfzone and nearshore areas. Larvae were separated by species and counted. Some of each larvae type were also measured.

To determine potential fish food item availability, the previously collected ichthyoplankton samples were examined. Netted samples from both intertidal and nearshore zones were viewed under a microscope and potential fish food items were identified and counted. An average fish food item concentration was determined for each given date. For the rock groins, scrape samples were taken from the groins and relative abundances of potential fish food were qualitatively determined.

To obtain seining data, fish were collected with a beach seine in a nourished location (South Area) and a reference location (North and Middle Areas). Fish were identified and counted. Standard length was found for each species.

The fish collected by seine were then used to determine the food habits of surf zone fish. The fish were dissected, and the stomach contents were removed and pooled together within each species by standard length then date and location the fish was collected at. Stomach contents were sorted taxonomically and weighed.

Determination of turbidity and characterization of suspended sediment were done by wide area surveys and site intensive surveys. The wide area surveys were done by deploying a Hydrolab water quality meter set to record turbidity at frequent time intervals at the beach seine stations. Site intensive surveys were conducted during fill operations at sites near the discharge and in reference areas. Water samples were collected at different depths and locations and TSS was measured for each sample. Samples were also taken from the discharge effluent running down the face of the beach.

The offshore borrow area finfish collection was sampled for by trawling at the borrow areas. Bottom-feeding species were separated, measured, and weighed. The same was done with the rest of the catch by species, or with a subsample of the catch. Stomachs were removed from target species for diet analysis.

Offshore borrow area fish food habits were determined by analyzing the stomach contents collected from trawling for the finfish collection. Contents were pooled by size class of the predator finfish species. The contents were then analyzed similarly to those of the surfzone fish.

Recreational fishing surveys were conducted among anglers located at nearshore groins, inlet jetties, and beach areas located along the USACE-BMP shoreline to cover both nourished and reference areas. Questions were asked about fishing success and related parameters to gauge potential differences in fishing in the years of the USACE-BMP.

C. Nourishment area assessment

<u>Intertidal and nearshore benthos:</u>

Two types of infaunal organisms are dominant in high-energy, sandy beaches – small interstitial forms (rhynchocoels, oligochaetes, hesionid and protodile polychaetes) and large mobile forms (mole crabs – *Emerita talpoida*, wedge clams – *Donax variabilis*, polychaete – *Scolelepsis squamata*). This infauna is roughly assembled into several zones based on the physical characteristics of each zone. Wave energy and tidal range combine to produce different beach zone types that are conducive to the habitation of different assemblages. Sediment texture was also found to have an effect on the type of species assemblage. Beaches of large grain size are known to have different dominant species than beaches composed of small-sized grains. Generally, species composition was found to be similar to other NJ and Atlantic Coast beaches.

Interstitial organisms are more abundant, while larger, mobile organisms compose more of the biomass. Distribution of infauna, however, can be patchy, especially considering the redistribution of interstitial organisms that occurs with wave action. Abundance and biomass have seasonal peaks in summer and fall, with the lowest values occurring in mid-winter.

Few to no deleterious effects were detectable in benthic assemblages following the 1997 nourishment operation. The 1999 nourishment operation, however, had clear, although short-lived, effects on the benthos. Changes were seen in abundance, biomass, and taxa richness. Lower abundance and biomass were still detectable in May 2000, but it was estimated that 80% recovery had been completed based on an estimated recovery time of 6.5 months. Impacts were seen to be more severe for small, relatively immobile species, but typically high reproduction and dispersal capabilities allow these organisms to rebound quickly. Overall recovery time was found to take about 2-6.5 months. Similarity between dredged fill materials and natural beach sediment was one of the most important aspects in shortening recovery time. Also, concluding fill operations before seasonal decline of infauna begins (in this case around November) significantly effects recovery in that it allows for colonization of disturbed sediments before the population is too small. This seems to explain the slower recovery rate for the 1999 operation, as it was not completed until mid-December.

Surfzone and Nearshore Ichthyoplankton:

Analysis was made of larval fish distributions and larval fish response to beach nourishment. Larvae were more abundant in nearshore than surfzone samples. Of the larvae present, sciaenids, gadids, engraulids, scombrids, and bothids were the most speciose. Direct comparisons between beaches were not possible since nourishment timing interfered with the summer sampling season, so general comparisons were made of the nourished (South Area) versus reference (North and Middle Areas). Based on physical parameters, surfzone ichthyoplankton abundance, size, and species composition, there were no clear differences between ichthyoplankton assemblages in the nourished and reference areas. However, the process of sampling ichthyoplankton and interpreting the data is difficult due to the variability of spatial and temporal distributions of larvae as well as the physical aspects of the coastal ocean. This could lead to the lack of distinct spatial patterns that was found among all species.

Potential Fish Food Items Present in Ichthyoplankton Samples and on Rock Groins:

Surf zone plankton was dominated by three invertebrate taxa: copepods, the amphipod *Gammarus annulatus*, and megalops stage crab larvae. Important fish food species such as *Emerita talpoida* and *Scolelepsis squamata* were present, but in small numbers. A similar assemblage was found for nearshore plankton, though with decreased abundances. Rock groin epifauna was dominated by barnacles, the blue mussel *Mytilus edulis*, and the green alga *Ulva*. Though these species specifically are not really food items, food item organisms such as amphipods and chironomids had close associations with these assemblages. Generally, it was found that almost all types of common surf zone fish food items are present in surf zone plankton. Wave action, organismal residence time (temporary or permanent,) and other aspects affect larval distribution, making this a complex part of the food web.

Analysis of Beach Seine Data:

Baseline sampling showed that fish assemblages were fairly uniform in both the nourishment and reference areas, indicating that habitat type was probably fairly similar. The surfzone finfish community was dominated by silversides, and it was found to be of higher diversity and abundance nearer to the groins.

After the 1997 nourishment, bluefish abundances increased greatly in all locations, though they were higher in the nourishment area. Abundances of other species also increased. However, it was determined that the increase in bluefish abundance in the year of nourishment was only coincidence. Differences in post-nourishment assemblages were attributed to natural variation, which tends to be high for surf zone finfish. Though no deleterious impacts to finfish were found, some impacts appeared to be present: low bluefish abundances in the immediate location of the fill operation in 1997 and possible attraction of benthic feeders to suspended sediments or other characteristics of the nourishment condition at the nourished areas. The 1999 nourishment operation yielded similar results to sampling from the baseline years. There was, overall, no clear indicator of differences in fish abundance or distribution between the nourished and reference areas.

Food Habits of Surf Zone Fishes:

No negative impacts were seen for kingfish or silversides based on potential consumption of less beneficial prey or decrease in filled stomachs or biomass. Foraging success was comparable at nourishment and reference sites and across species. Kingfish in 1997 nourished areas contained less mysids and more annelids than those at reference areas, but it is thought that this can be attributed to localized differences in prey abundances. Silverside prey biomass increased at beach nourishment stations during the first nourishment phase. It was hypothesized that this was a result of increase in suspended prey from wave action on newly deposited sediments, which silversides can capitalize on due to their upturned mouths. Late in the 1997 sampling period, fish appeared in the diets of silversides, particularly at beach nourishment stations. Ingestion of fish may have been incidental while searching for other prey. It is also noted that the diets of surf zone fishes shift according to prey availability. Strong shifts in kingfish diets did not occur except for some understandable temporal shifts. There were no distinguishable differences in the food habits of fish in 1998 and 1999. Overall, food habits were changed only minimally related to nourishment projects, and these changes were short in duration, both temporally and geographically.

Turbidity and Suspended Sediment Characterization:

Effects of beach fill operations tended to raise turbidity levels significantly only in a narrow swath of beach front. Suspended sediments disperse primarily in the immediate vicinity of the fill location and traces are found in the nearshore bottom waters. The surf zone had the effect of rapidly lowering sediment concentrations by mixing from surf and turbulence. Since low amounts of silts and clays were present in borrowed sediment, this probably aided in dispersal. TSS was strongly correlated with turbulent resuspension dependent on present turbulence conditions. The specifics of ocean circulation patterns had great effects on sediment movement and dispersal, so patterns can be highly variable based on the conditions at a given time. Except for swash zone samples, the elevation of turbidity above ambient levels was negligible. Strong storms appear to produce elevated swash zone turbidities similar to those from the nourishment project.

D. Borrow area assessment

<u>Offshore Borrow Area Benthos:</u>

Offshore borrow area benthos was characterized by a single assemblage primarily composed, in terms of numbers, of the archiannelid *Protodrilus*, the amphipod *P. obliquua*, and the tanaid *T. psammophilus* and dominated in terms of biomass by the sand dollar *Echinarachnius parma* and to a lesser extent the bivalves *Spisula solidissima* and *Tellina agilis*. This assemblage is similar to others in medium sand habitats along the NJ and New York coastlines.

The water quality and the suspension of sediments in the borrow area appeared to change little. The actual dredging operation, though, had clear impacts on the benthos. Abundance, biomass, taxa richness, and average size for *E. parma* declined following the dredging operation. Abundance, biomass, and taxa richness recovered fairly quickly (typically by the following spring) after both dredging operations, though there were still some lingering effects in the spring after the 1999 operation. It took 1.5 to 2.5 years for the change in biomass composition to return to the previous levels. Other parameters were essentially back to normal within one year of dredging operations.

<u>Offshore Borrow Area Finfish Collection:</u>

Finfish composition was very similar to those found in a previous study of the area between Delaware Bay and Martha's Vineyard. In that study, spring finfish collection was primarily composed of, in order of frequency of occurrence, windowpane and winter flounder, silver hake, skate, hake, ocean pout, yellowtail flounder, sculpin, and summer flounder. Autumn collections were composed of butterfish, smooth dogfish, searobins, summer and windowpane flounder, and silver hake. These findings are similar in terms of species present, relative prevalence, and seasonal periodicity. There was no strong evidence that any change occurred in the finfish composition or in catch-per-unit-effort after dredging in either 1997 or 1999.

<u>Offshore Borrow Area Fish Food Habits:</u>

Winter flounder, summer flounder, and scup were the most common fish for which potential food habits could be easily assessed. Winter flounder fed mostly upon polychaetes, anthozoans, and bivalve siphons. Summer flounder fed upon amphipods, squid, fishes, and several large crustaceans. Scup consumed polychaetes, anthozoans, amphipods, isopods, and crangonid shrimp parts. Stomach contents from both types of flounder were mostly the same over the course of dredging. A study of potential trophic support for winter flounder, which consumes prey in all size classes, showed that winter flounder continue to consume anemones as the primary part of their diet, even though the anemones are not common at areas after borrowing has occurred (as shown by data on borrow area benthos).

<u>Recreational Fishing Survey:</u>

Anglers primarily fished at the jetties for greatest ease of access, followed by groins and then beaches, which were the least utilized areas. Targets species were striped bass, flounder, and bluefish, but a fair percentage of anglers were fishing for "anything that bites." The most common fish caught were flounder, bluefish, black seabass, kingfish, and cunner. There were no dramatic shifts in overall angler utilization, recreational species preference, or angler fishing success for the period in which the surveys were conducted. A larger percentage of anglers believed that fishing was worse during construction surveys than in surveys taken after construction.

V. SHORTCOMINGS OF THE USACE-BMP DOCUMENT

The USACE-BMP lacked the appropriate design to adequately monitor the system or to draw convincing conclusions regarding the impacts of a large-scale beach nourishment program. Additional errors in the analysis of the data only served to amplify these inherent flaws. The conclusions reached in the document were often based on this flawed design or overlooked important ecological concepts. This analysis of the NJ BMP attempts to outline the overarching flaws and oversights of the document to address the need for additional research on the topic of beach nourishment on the east coast. Examples of specific points will be provided as appropriate in tables referenced in the text, but it is assumed that the reader is familiar with the BMP document.

A. Clarity

The USACE-BMP document consistently lacked clarity and did not adequately fulfill the purpose of monitoring the specific effects of beach nourishment. The monitoring program was designed to produce data based on a Before, After, Control and Impact Approach (BACI) to determine if beach nourishment was affecting the biota on NJ beaches. This design involves two main variables: space and time. A BACI design controls for space by monitoring the area before an impact occurs to determine baseline measurements for the area. This allows the study to compare the area to itself, to prevent spatial variation that a simple control and impact design could overlook. Monitoring occurs again after the impact to determine if the area was affected. The BACI design also monitors for temporal variation by monitoring a similar area over the same period to ensure that a seasonal or environmental change is not confounding the results of the study. The design can be expanded into a BACI Paired Series by monitoring at several times before and after to determine change over time. By utilizing the BACI Paired Series, the ACE monitoring project should have been able to control for temporal and spatial variation. In addition, it should have been able to monitor the area for recovery over time, using seasonal data gathered at both sites. The document however, does not focus on the treatment and effects monitored by the design of the project. The BMP repeatedly addresses change due to seasonality, but rarely uses the text to explain the presence of a significant change due specifically to the nourishment treatment. The goal of the BMP was not to monitor for seasonal trends, but to create a document that assesses biological impacts on the beaches caused by the nourishment project. By listing environmental variations over time, the document downplays these impacts.

One of the persistent problems with the document is the amount of data given to the reader. The data are often presented in raw or unprocessed form, lacking appropriate statistical manipulation. Since the document was not written to distinguish treatment from effect, the reader has to sort through the data given to determine any significant differences. Individual chapters do not consistently provide necessary information about which sites were nourished, un-nourished, or previously nourished. The treatment and control areas are different in some chapters, but are not always delineated in the text; allowing readers to examine pages of information without knowing which sites are the reference and which are the control. In the text, the maps are referred to for clarification of the sites, but the maps do not succinctly show and label the treatment and control areas for individual studies (See Figures 2-1 and 2-2 below, adapted from the USACE report).

The study treats the sites in the North area as an un-treated control area, while the Middle and South areas were nourished in 1997 and 1999. Insets of the individual sampling locations are provided, but it also lacks an explanation of treated versus un-treated areas. This could have easily been marked on the map or in the caption, providing a concise explanation of the study area. The purpose of the document should be to interpret data by showing significant results and important relationships, not to list unnecessary and unprocessed data.

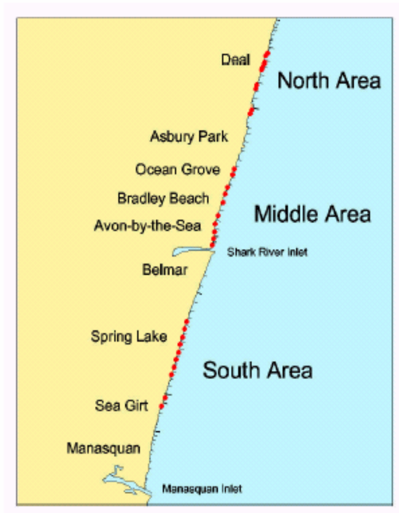

Figure 2-1. Intertidal and Nearshore benthos sampling locations.

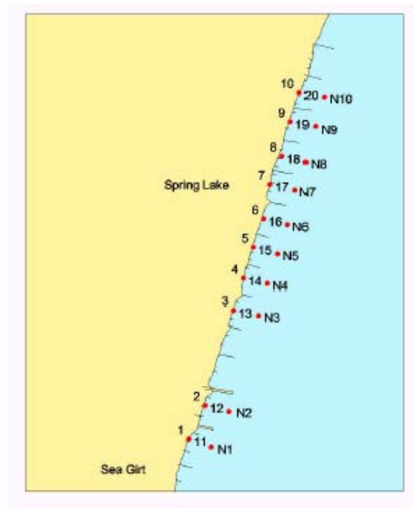

Figure 2-2. Intertidal and Nearshore benthos sampling locations in the South Area.

The figures and tables included in the report also pose problems to interpretation. Charts do not clearly illustrate possible relationships between two factors; the choice of data presentation often obscures rather than illustrates any trends. The charts tend to break down information into a visual representation of data points, showing all trends over the sampling periods, rather than focusing on the changes caused by the studied treatment. The data in many cases is raw. In one instance (Figures 5-11 and 5-12 below, adapted from the ACE INC report), the reader is presented with 376 data points on the number of silversides caught between August 9th and October 23rd, 1999. The data was not processed to show significant interactions within and between sites or across dates. Some graphs combine information, creating lengthy datasets with high variability, diluting potentially important factors. Naturally, any environment will show change over time and this natural variation creates unnecessary noise on the charts. In other datasets, charts separate information into individual years or months, spreading possible effects across several pages and separate graphs, making it difficult to find any correlations at all.

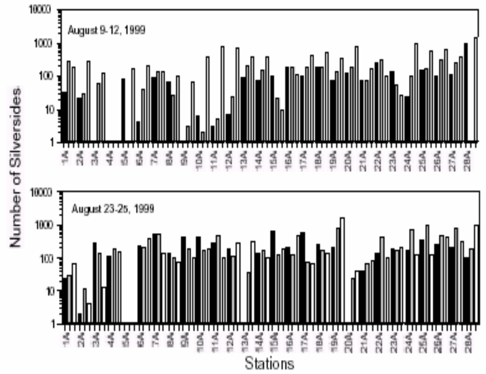

Figure 5-11. Number of silversides captured at each substation (A- black bars, B - gray bars, C - white bars).

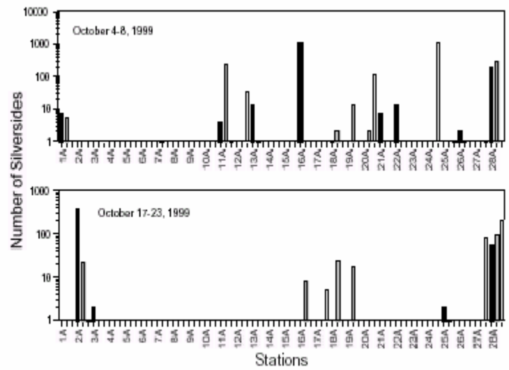

Figure 5-12. Number of silversides captured at each substation (A- black bars, B - gray bars, C - white bars).

B. Focus

The US ACE failed to prioritize the scope of their monitoring project. The BMP attempts to monitor biological factors that beach nourishment could affect, but expends too much effort on untested parameters. The document states that most studies in the southeast have focused on effects to lower trophic levels (Nelson, 1993, Peterson *et al*, 2000) and ambitiously aims to document effects on upper trophic levels as well (Ch. 5). It is difficult to effectively interpret these parameters because there is so little available information in peer-reviewed literature. This leads to weakly supported conclusions or precludes any conclusion because there is simply not enough data to determine if a decrease in this factor will affect the larger ecosystem. By widening the focus of the study, the BMP sacrifices thoroughness within any given parameter. ACE fails to maintain the depth of the research by sampling more variables less frequently, allowing ACE to conclude that due to high amounts of error, no conclusions can be drawn or that the monitoring shows no discernable effect. Recent literature on environmental monitoring is increasingly focusing on the likelihood of Type II errors, where the conclusion of no effect is incorrect and an impact is ignored. With high natural variability, sample size needs to be larger to overcome noisy data (Peterson *et al,* 2001). Important effects can be diluted by natural variability. This issue of power was not addressed in the NJ document but should have been included given the broad scope of the study, the length of time, and the number of sampling sites.

C. Oversights

Several seemingly obvious parameters of the monitoring program were ignored in the sampling design, creating flawed data. One of the most obvious biological oversights is the importance of season, time of day, and the tidal cycle in the lives of intertidal and near-shore organisms. Some data were averaged over the entire year, condensing any post-nourishment changes, seasonal highs, or lows into a single point on a graph. This disregard for biological change limits the effectiveness of the study as a whole. Additionally, data were collected only twice a year in several studies, limiting the ability to detect recovery of the system from seasonal changes. Sampling was often conducted once a day, or over a period of several days. For example, the ichthyoplankton study conducted sampling over a period of a week for each sampling event. The sampling has no temporal control in most of these studies, i.e. sampling at low tide. Most plankton has been shown to be photonegative, avoiding predation by visual predators. By sampling only during the day, the study misses many important species. Fish or sharks may use the beach to feed only at night. Another important consideration is consistency in sampling methods. In Ch. 9, the methods of conducting offshore borrow area finfish samples included; a change in trawl size, trawl size mesh, and the presence of a trawl liner. Differences in collection methods prevent analysis between years and sites.

The USACE-BMP also does not appropriately control for physical conditions. The collection of physical data was conducted over a weeklong sampling period. Turbidity can change dramatically over a single tidal cycle or even a few hours; the conditions over the period of a week are drastically different (see Figures 7-4 through 7-9 in the BMP. Figures 7-4 and 7-5 shown below represent two sampling periods over the course of 9 days) and are a presentation of useless information that cannot be compared between sites. The attempt to show wind speed in relation to site, date, and turbidity levels is a completely ineffectual. Factors such as turbidity can change drastically over a short period and should be collected simultaneously at all locations. Changing conditions can also affect biological parameters and should have been controlled by intensifying sampling efforts, collecting all data at the same time. Fewer fish are going to feed in the surfzone if the waves or current is particularly strong; this could bias the entire data set, since these changing physical conditions were not considered when analyzing field data.

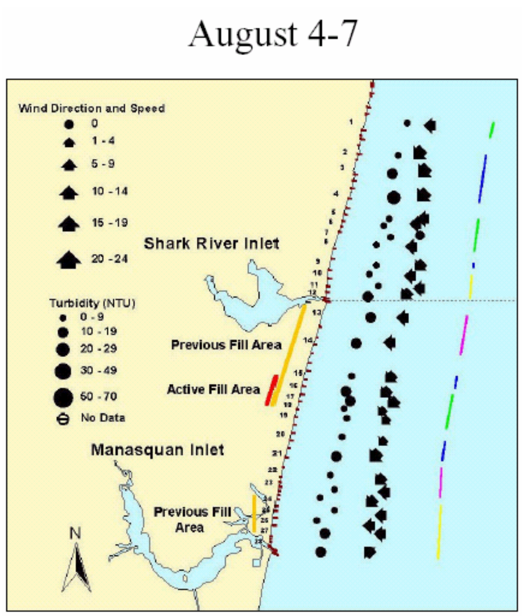

Figure 7-4. Wind direction arrows point in the downwind direction. Lines of the same color indicate stations that were sampled on the same day.

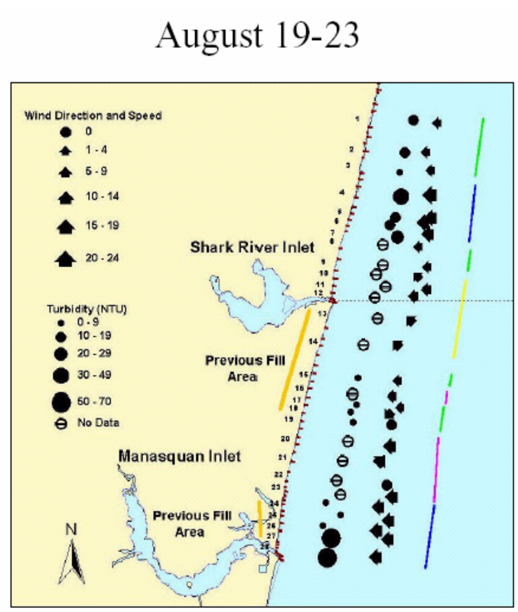

Figure 7-5. Wind direction arrows point in the downwind direction. Lines of the same color indicate stations that were sampled on the same day.

Physical parameters were not given enough consideration in this study. While much effort was put into measuring a variety of biological abundances or biomass, little sampling effort was directed towards physical changes in the beach slope, contour, and elevation. Habitat alteration, such as changing the sediment size or creating a different beach slope could change infaunal assemblages, resulting in trophic cascades.

D. Analysis of Data

Additionally, several design flaws made appropriate analyses impossible. Sampling efforts were not consistent throughout the entire project, creating impractical datasets. (Table V-1.) In addition, the control site had a number of problems the introduced confounding factors (Table V-2.)

Table V-1. Suggested design flaws in the US ACE BMP

Design Oversight	Resulting Factors	Additional Problems
Sampling intensity increases after nourishment. (Ch. 2)	Cannot compare seasonal highs and lows to previous years. Eliminates BA from BACI design. Cannot compare November after nourishment to the previous November at the same site, no baseline data.	Allows for an increase in data for post-nourishment, smoothing the data.
Length of Study (Ch. 2) 1997 monthly sampling only takes place between May and November while the (contd.) 1999 data lasts one year.	Cannot compare the year-long benthos recovery after the nourishment events	Both datasets are too short. A second year would have allowed further monitoring of seasonal variations. Did (contd.) summer season of peak biomass show a full recovery?
Did not control for time of day or tidal cycle.	Cannot conclusively rule out confounding factor of natural variation.	Cannot accurately assess full range of species using the nourishment area and the impacts nourishment.

Table V-2 : Suggested Control Site Issues

Control Site Issue	Result	Additional Problems
Control site was often smaller than the treatment site. (Ch. 5, 7)	Treatment site has benefit of physical variation to smooth the data, *minimizing local effects.*	Greater number of treatment samples minimize any effect by the nourishment.
Control site has different community assemblages from the treatment site. (Ch. 3)	If the two sites are not similar before nourishment, the study cannot assume that the two areas would behave similarly over time.	This artifact is known from the initial sampling of the two areas. By not finding a more suitable control, the study introduced an artifact that prevented analysis of the data.
Control site for turbidity is adjacent to an inlet. (Ch. 7)	Inlet introduces turbidity plume that is not present at treatment site.	This artifact could have been easily controlled.
Control site is not necessarily sampled in the same conditions as the treatment site.	Different conditions (wind speed and direction, surf conditions) can introduce confounding factors.	

Confounding factors previously mentioned preclude analysis of results or limit conclusive evidence. The USACE-BMP project had a significant interaction between area and date that prevented the interpretation of their data. This interaction is more commonly known as seasonal variation and has been documented in temperate zones worldwide. Seasonal variation can affect diversity and abundances of fish, plankton, and benthic organisms. This prevents year-to-year comparisons of the BMP data in no less than twelve of the studied parameters: biannual infaunal abundance, biomass and taxa richness for all three depths and at the borrow area (Ch. 2 and 8). The study should have separated biannual information according to season before analyzing the data. Despite the seasonal interaction, ACE later compares post-nourishment abundances in the spring to pre-nourishment data from the fall, to illustrate that nourishment had not affected species abundance or taxa richness (Ch. 2). ACE also uses the above-mentioned control issues to distort conclusions by comparing dissimilar sites to show that nourishment is not affecting the treatment site.

Ignoring positive change is a serious oversight in the interpretation of data. ACE discarded significant results in Chapter 2 because the results showed an increase in benthic biomass. In Chapter 5, fish distributions change due to turbidity levels. Negative impacts on the environment are not necessarily only indicated by decreases in abundance or biomass. An increase of a certain noxious species or a decrease in a predator species could have lead to this increase in benthic biomass. Mortality or a decline in the total catch is not necessarily the appropriate parameter to monitor. It is unlikely that fish will die from a reduction in prey abundance; more likely, they will show a reduction in health, size, or reproductive output. The only reference to frequency of size or length of fish occurs in Chapter 5, but provides data only from the weeks before nourishment occurred. These factors could be important to consider when measuring biological impacts on fish.

Another important biological consideration that should be considered essential to any biological monitoring program is the impact on endangered or rare species. The USACE-BMP does not mention endangered or rare species. The USACE-BMP instead focuses on the most common species. These are often also the most hardy and generalist species. A more complete analysis would have initially identified sensitive species, rare species, and endangered species. Generalist species are only going to show an effect if the environmental perturbation is severe. A sensitive species might be a better indicator of change, because they are more susceptible to biological or physical changes, indicating more subtle changes in the environment. Rare and endangered species should have been monitored for moral, ethical, and legal reasons (Peterson, Personal Comm.). The Endangered Species Act prevents the destruction of sensitive habitat or of any act that harms endangered species. Another oversight that should have been considered was the impact on commercially and recreationally important species. If blue crab larvae or commercially important juveniles were affected, the study could be overlooking a serious impact that would have repercussions throughout the local economy.

E. Conclusion

The shortcomings of the US ACE-BMP limits its applicability to future beach nourishment projects, especially those in different locations than the NY/NJ coastline area. The document is unclear, making the data inaccessible to resource managers and stakeholders. The design of the study overlooks both important biological and physical factors when testing and analyzing data. The flawed design in many cases results in insignificant relationships and a high probability of Type II errors. It is difficult to draw solid conclusions from the project because monitoring alone cannot determine the importance of interactions. The document does not rely enough on peer-reviewed literature for support and does not involve any scientific testing of proposed hypotheses. The monitoring program has inherent flaws in its design and critical oversights that should preclude its widespread use and citation in beach nourishment projects.

VI. APPLICABILITY OF THE USACE BIOLOGICAL MONITORING PLAN TO NC NOURISHMENT PROJECTS

For a variety of reasons, information gleaned from one location on the biological effects of beach nourishment is not always applicable to another area. Many factors of a given shoreline including the physical characteristics, the typical fauna species and distribution present, and specialized local characteristics have an effect on the manner in which nourishment impacts local biota. Therefore, in order to best assess the needs of NC in terms of beach nourishment, a summary of available information from previous studies located in NC must be compared to data from other locations to facilitate the assessment of the applicability of external information. Once the applicability has been elucidated and, based on the understanding gained from previous NC biological monitoring and the gaps in knowledge determined to be present, applicable information can then be added to the already available body of knowledge from NC. In areas where information for NC is neither available nor can external information be applied, subsequent localized assessments taking place in NC can be conducted in order to present an entire picture of the effects of beach nourishment in NC. In this case, the applicability of the USACE-BMP, information from which is popularly applied to other locations, will be determined for the NC coastline. This will delineate the circumstances in which this document can and cannot be used for nourishment projects in NC, to encourage the use of other paths for selecting appropriate nourishment schemes when necessary.

The socioeconomic conditions under which the USACE-BMP was carried out is particularly relevant in the determination of its applicability to NC nourishment projects. This is because NJ beach nourishment projects are typically federally funded and usually involve large beaches in densely populated areas. This contrasts sharply with nourishment projects in NC which at least in the future will be characterized by local funding and a small-scale focus. Each coastal project must comply with a wide range of federal, state, and local laws and regulations, as well as any associated funding constraints. One of the greatest obstacles that states must overcome with respect to shore protection projects is the location of funding (NOAA Coastal Services Center). States and counties located within states that have densely populated coastal areas, are in a better position to fund these projects due to a larger invested tax base and hence also federal interest. This is because densely populated areas are at greater monetary risk from property loss (e.g., storm induced erosion), since the property value per unit area is higher.

Coastal population densities are a lot higher in NJ than NC. The average coastal county population density per square meter of land area is 3,407.263 in NJ compared to 175.75 for NC. The coastal population density per square meter of land area (using total coastal county populations and land areas) is 1,621.972 for NJ while NC's is 6.04145. The population density analysis for NC coastal counties may be a bit skewed due to some counties having area on the Albermarle-Pamlico Sound side that are particularly sparsely settled. Nevertheless, there is still a significant difference in population densities between the two states. In 2001, Congressional appropriations for beach nourishment projects funded 14 proposed NJ beach control projects while funding only 6 proposed NC projects (FY 2001 Congressional Appropriations for Beach Nourishment, 2000). This difference in federal assistance can perhaps be attributed to the differences between the coastal populations of each state, shown in Tables VI-1 and VI-2. Also shown are the relative levels of federal funding support for beach nourishment projects for both states in Table VI-3

Table VI-1: Distribution of Human Development along Coastal Counties of New Jersey (U.S. Census Bureau, 2000)

New Jersey			
County	Population	Land Area (Square Mile)	Pop. Density/ Sq. Mile of Land Area
Atlantic	252,552	561.07	450.1
Bergen	884,118	234.17	3775.5
Cape May	102,326	255.19	401.0
Hudson	608,975	46.69	13043.6
Middlesex	750,162	309.72	2422.1
Monmouth	615,301	471.94	1303.8
Ocean	510,916	636.28	803.0
Union	522,541	103.29	5059
Total	4,246,891	2,618.35	
Avg. County Pop. Density	3,407.263		
Coastal Pop. Density	1621.972		

Table VI-2. North Carolina Coastal County Populations. (U.S. Census Bureau, 2000)

North Carolina			
County	Population	Land Area (Square Mile)	Pop. Density/ Sq. Mile of Land Area
Brunswick	73,143	85,479	85.6
Carteret	59,383	519.84	114.2
Currituck	18,190	261.7	69.5
Dare	29,967	383.58	78.1
Hyde	5,826	612.8	9.5
New Hanover	160,307	198.93	805.8
Onslow	150,355	766.82	196.1
Pender	41,082	870.67	47.2
Total	538,253	89,093.34	
Avg. County Pop. Density	175.75		
Coastal Pop. Density	6.04145		

Table VI-3. Federal funding for beach nourishment projects according to the American Shore and Beach Preservation Association Newsletter, December 2001. (Sutherland 2003, Surfrider's State of the Beach 2003: New Jersey beach nourishment)

New Jersey	North Carolina
FY '99: $13,425,000	FY '99: $342,000
FY '00: $12,052,000	FY '00: $1,250,00
FY '01: $23,427,000	FY '01: $7,680,000
FY '02: $13,913,000	FY '02: $5,240,000

Since NC beaches get less federal help for beach nourishment projects, the trend in NC has been to extract resources from local communities despite low local population densities. This has been accomplished by nourishing smaller areas of beach and taxing transient tourist populations. In other words, funding sources have come from communities that have the most at stake in reducing erosion of the coastline and, because of this, smaller swaths of beach are usually nourished as compared to the federally funded, larger swaths of beach typically nourished in NJ.

According to shoreline erosion maps of NC released in 2003, 18% of the NC coast is severely eroding at a rate greater than 4.5 feet per year. It is estimated that up to 75% of the NC coastline (240 mi.) is eroding, with the balance accreting (Sutherland 2003). Due to the presence of permanent settlements near beaches, and the economic and intrinsic value derived from these settlements, relocation and disincentives to settlement are unpopular methods of coping with erosion. Instead, management actions have tended to be ones that alter or discourage the natural course of geological processes. These actions include the placement of hard structures such as groins, jetties, and breakwaters which still have caused disputes over the value of beachfront property since they usually cause irregular erosion and deposition patterns that may disproportionally accrete sand on the up-current side while eroding sand on the down-current side. These hard structures have additionally been considered as aesthetically disagreeable and therefore detrimental to the intrinsic value of a beach.

Beach nourishment has, therefore, become the accepted form of erosion control. According to the NC Division of Coastal Management, "beach restoration, nourishment or sand-disposal projects are determined to be socially and economically feasible and cause no significant adverse environmental impacts" (Sutherland 2003). There are numerous problems with this statement, as has been demonstrated, although, under certain conditions, it is valid. For example, as a short-term solution, beach nourishment is a viable economic solution. Also, as long as grain sizes match and projects are done during periods of low biological productivity, beach nourishment causes no significant adverse environmental impacts. There are obvious problems with beach nourishment, one of them being negative environmental impacts. Nevertheless, this form of erosion control has become an acceptable low impact solution that is used quite frequently.

Beach nourishment operations can disrupt the existing biological communities in the subaerial zones (supralittoral and intertidal areas) of beaches, in the borrow sites where dredging occurs and even in the shallow subtidal habitats adjacent to some nourished beaches (Seymour *et al.,* 1995). Negative consequences of beach nourishment on subaerial zones include disturbance of the indigenous biota inhabiting the zones, which may in turn affect the foraging patterns of the species that feed on those organisms and disruption to species that use the zones or adjacent areas for nesting, nursing, and breeding. For the most part, the temporary loss of infaunal communities due to sand burial is expected in a beach nourishment operation. It is, however, more important that these communities recover after the operation since they form the backbone of the sandy shore food web. This usually depends on the sand grain characteristics used in the project and timing of the project in relation to critical periods of biological activity. These considerations may also affect the breeding success of macrofauna such as endangered sea turtles and birds that nest in the supralittoral (dry) zone.

Subtidal beach habitats consisting of either sand-bottom or hard-bottom habitats can be affected by beach nourishment as well. Physical effects may include the burial of bottom habitats in the surf zone as the beach is widened, increased sedimentation in areas seaward of the surf zone as the fill material redistributes to a more stable profile, changes in the nearshore bathymetry and associated changes in wave action, and elevated turbidity levels, particularly in the vicinity of the pipeline effluent (Seymour *et al.,* 1995). Typically, sessile species such as those found in the subtidal hard-bottom reefs or seagrass beds would be the most adversely affected by the high turbidities and silt loads that can smother these organisms, inhibit filter-feeding processes, or significantly decrease photosynthetic activity, potentially resulting in long term damage to these resources (Seymour *et al.,* 1995). Motile invertebrates and fishes found in this zone, however, should be able to avoid most of these direct effects of beach nourishment, although larval forms found in the surf zone could be adversely affected by high turbidity levels (Seymour *et al.,* 1995). Along with decreasing the abundance of potential prey for predators, the turbidity may additionally affect the ability of some vertebrate predators that are visually orienting from locating and capturing their prey (Peterson, Unpublished).

Offshore dredge borrow sites (Figure VI-1) suffer from immediate removal of benthic assemblages inhabiting the surficial sediments which can indirectly affect other species that use the benthos as a major food source (Seymour *et al.,* 1995). Furthermore, dredging activities can result in increased turbidity levels in the vicinity of the borrow area and these conditions may persist afterwards if the site accumulates silts and clays. This potential change in bottom sediment composition may alter benthic species composition for the long-term. Other negative effects from dredging activities include altered water-quality conditions, such as decreased dissolved oxygen levels or increased hydrogen sulfide levels, that can be caused by deep holes and systems with poor circulation; damaged reef habitats in areas adjacent to the borrow area have also been documented

Figure VI-1. Dredging at an offshore borrow site.

(Seymour *et al.,* 1995).

In this context of socioeconomic trends and potential biological impacts, the applicability of the USACE-BMP can be assessed for NC nourishment projects. Due to higher sources of federal funding, a result of higher coastal population densities in NJ, beach nourishment projects in NJ can typically nourish longer sections of beach. The USACE-BMP assessed the potential biological impacts for a beach nourishment project that spanned approximately 9 miles. In terms of volume, the authors claimed that the project was one of the largest nourishment projects of this type ever constructed. Although projects in the past, and even currently in NC, usually range around this length and are repeated at frequent intervals, the future of NC nourishment projects may actually shift to beaches of limited length, such as 1-3 miles that occur on a low frequency (~once per decade) (Peterson, Unpublished). Although the USACE-BMP includes considerations about the fill, dredge and subtidal areas, and environmental and trophic effects, the issue of cumulative impact in time and space is not addressed. A potential concern in NC is the cumulative impact on the intertidal beach and surf zone from nourishment projects since these zones occupy a narrow band along the outer coast (Peterson, Unpublished).

Characteristics of sediment used in nourishment projects can have a variety of effects on the biota. Correlations in grain size, mineralogy, color, compaction, and organic content of the fill material with natural beach sands are important for the minimization of initial impacts and complete recovery and continued usage on the beach by beach infauna, vertebrates dependent on infauna for food, and vertebrates dependent on nesting habitat (Figure VI-2). This was the protocol followed and suggested by the USACE BMP and can partially explain the lack of significant effects observed on benthic invertebrates from that study of beach nourishment. However, numerous projects in NC have frequently ignored this requirement. Enhanced turbidity from resuspended sediments is also a problem. Some effects were found in the ACE study for surf zone fish which may be related to increased turbidity near the discharge of the pipe effluent. There was a negative response for bluefish and positive responses from kingfish and silversides. The bluefish negative response corresponds to observations that they experience reduced foraging success on baitfish prey as a function of increased turbidity (Peterson, Unpublished). The positive responses from kingfish and silversides were speculated to be related to resuspended benthic material or the general nourished condition. However, no study has documented the spatial and temporal scope of turbidity enhancement from beach nourishment at the level required to impact trophic transfers in the surf zone habitat (Peterson, Unpublished).

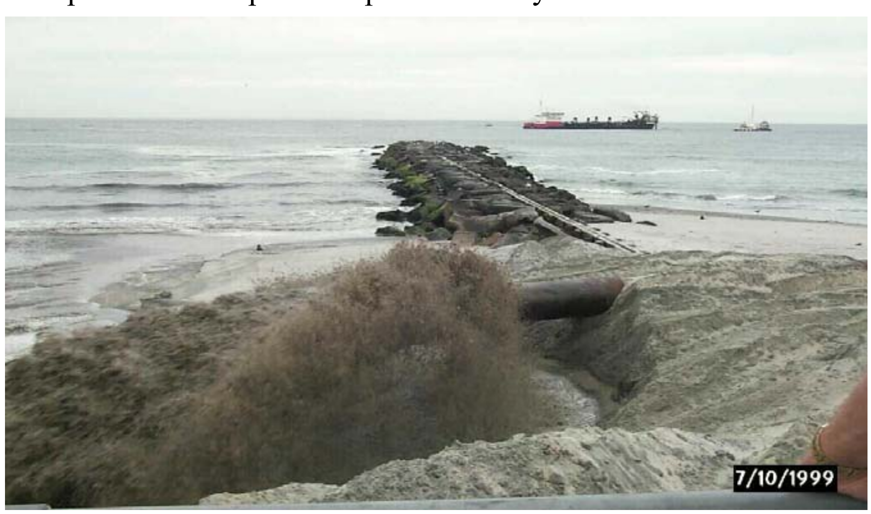

Figure VI- 2: Beach fill operation with discharge from pipe.

The obvious difference in seasonality and overall temperature between NJ and NC, due to differences in latitude and proximity to the Gulf Stream, can have implications on the timing of nourishment projects that are made in order to minimize biological impacts during periods of low biological activity. The temperate sub-tropical biogeographic position of NC also means it is an area of especially high diversity that is a result of Southern species entering in subsurface intrusions, eddies, and occasional Gulf Stream rings, while cool water species enter with the flow of the Labrador Current to the Cape Hatteras region (Mallin *et al.,* 2000). New Jersey surf fish communities lack many of the species that are typically found in NC such as gulf kingfish, Spanish mackerel, and Florida pompano (bluefish being an exception) (Peterson, Unpublished). The Florida pompano, for example, is the dominant predator of the surf zone in NC, yet it is absent from NJ, which may imply differences in impacts and considerations of beach nourishment because of the replacement of species from one locale to another (Peterson, Unpublished). The use of NC beaches for sea turtle nesting is another primary concern NJ nourishment projects do not have to consider, since structural changes caused by beach nourishment like steep berms in the beach can preclude sea turtle nesting (Peterson, Unpublished).

The presence of hard-bottom and reef-type habitats typical of NC means these areas are at risk to sedimentation and other negative consequences discussed above from beach nourishment activities. In the USACE-BMP study, groins were such common and important hard structures that researchers found the highest abundance and species diversity of surf zone fish at substations closest to groins. The resulting beach nourishment however, caused a loss in groin habitat due to sedimentation but did not affect the relative abundance of individuals or diversity of species. Groins are known for their ability to attract epifaunal invertebrates and therefore support other trophic levels. Differences in biogeography dictate that hard-bottom structures in NC should be even more diverse and can therefore be susceptible to large-scale disturbance. This is evidenced by the prevalence of these nearshore hard-bottom habitats in NC being located off the southern stretches of the coast where wave and wind energy are less than east facing stretches of the coast. Also notable, the USACE-BMP document states that the initial high catches off of groins may have been sampling artifacts.

Species richness of sandy beach intertidal macrofauna is mainly controlled by the physical environment on the large scale, such that the interplay of numerous environmental factors like sand, tide, waves, beach face slope, and latitude may determine which species are able to establish permanent populations (McLachlan, Dorvio, Unpublished). Environmental factors, then, can have an effect on the location and distribution of benthic invertebrates. For example, the presence of a low energy regime in NC beaches south of Cape Lookout dictates that *Donax* and *Emerita* are found almost exclusively in the intertidal and swash zones of the beach, while these biomass dominants are found almost exclusively subtidally along the high-energy beaches of NJ (Peterson, Unpublished). This change in distribution means that beach nourishment activities would potentially harm NC *Donax* and *Emerita* populations more than NJ populations due to intertidal beach filling that would directly bury these invertebrates and modify their essential habitat. The importance of different physical settings, therefore, cannot be overlooked.

Beach nourishment has become the predominant and accepted form of erosion control in NC. The effects of beach nourishment however, are unclear due to the numerous socioeconomic, biological and physical factors involved. The USACE-BMP that was conducted in NJ has been widely applied as an indicator of potential environmental effects for beach nourishment activities. In this paper the applicability of the USACE-BMP was assessed for beach nourishment activities in NC. The differences in socioeconomics, biology, and physical environment between NC and NJ suggests that beach nourishment activities in NC must be more closely examined to determine the environmental effects of beach nourishment.

VII. RECOMMENDATIONS

Overall Recommendations

- Design of monitoring program should be appropriately peer-reviewed and approved before project begins.
- Biological impact statements and project reports should be appropriately peer-reviewed.
- Research should be conducted on natural beaches to establish a baseline for biological and physical conditions.
- Additional research should be done on nourished beaches to determine large scale and cumulative impacts in time and space.
- Research on trophic effects of beach nourishment on food web should be better assessed.
- There is a general over-arching need for database development to incorporate economic, biological, physical, and other data generated via beach nourishment projects.
- Current development policy states a "30-year depreciation rate" for the state of NC – this should be re-evaluated.
- Over a certain rate of erosion, development should not be permitted.
- Should look at long term and chronic effects of beach nourishment as opposed to simple initial changes (current trend).

Recommendations Related to Biological Monitoring and Biological Monitoring Programs:

- A third/neutral party should be responsible for the biological monitoring program.
- Choose appropriate indicator species and geographically relevant biota for monitoring programs using species that are sensitive to environmental change.
- Repeated observation of monitoring sites over extended periods of time for gathering of useful temporal, interannual, and seasonal trends.
- Increased replication generates better statistical power for analysis of results
- Monitor until recovery of vital biological parameters is achieved.
- Stratify before sampling of monitored sites for homogeneity of samples: only compare high energy beaches to high energy beaches. This will allow the program to account for anthropogenic and natural variability that can create noise in the data set.
- Focus on any rare or endangered species that inhabit the area. They should receive high priority.
- Null-hypothesis based science should be conducted simultaneous to monitoring programs.
- Final reports of biological monitoring programs should be geared towards resource managers.
- Beach fill material should match natural grain size such that delays in benthos recovery and feeding inhibition of shorebirds and surf fishes are minimized. A percentage value of silt/clay/mud content allowed in a project should be determined in future research and applied in future nourishment projects.
- Mining and filling activities should occur during periods of low productivity (i.e. the cold season) and end before the onset of periods of high productivity (i.e. the warm

season). Therefore, the reproductive dynamics of important benthic invertebrates must be understood.

- Determine the effects of turbidity in time and space due to direct (immediate) and indirect (after completion and chronic) depositional processes on surf zone fishes and nearshore benthic habitat

Policy and Economics-Related Recommendations

- All oceanfront property should be taxed higher than non-oceanfront.
- Future research into economic sustainability and availability of sand deposits should be conducted before continuing with large-scale nourishment projects over the long term.
- There should be a limit of nourishment projects that occur within a length of beach at one time.
- Mitigation: if you are going to nourish one tract of land, you have to purchase another tract of unnourished land or fund local or nearest national park area.
- Permit private conservation associations buy out properties to preserve beach or create conservation easements.
- Realistic education on beach erosion and beach nourishment should be required for all property purchased on oceanfront land.

VIII. REFERENCES CITED

Bruno, S. M.; Herrington, O. T.; and Rankin, L. K. The New Jersey Coastal Monitoring Network. Sea Grant Extension Program Bulletin No. 15. Sept. 2002.

Burton, William H. (Technical Director) et al. 2003. Effects of Dredged Material Beach Disposal on Surf Zone and Nearshore Fish and Benthic Resources on Bald Head Island, Caswell Beach, Oak Island, and Holden Beach, North Carolina: Interim Study Findings. U.S. Army Corps of Engineers, Wilmington District.

Chesnes T. and Montague L. C., Environmental Design of Beach Nourishment Projects in Florida. Prepared March, 14, 2003. Held Nov. 15-16, 2001. Report from Coastal Engineering Technical Advisory Committee. Florida Dept. of Environmental Protection. Tallahassee FL.

Ciorra, A., http://www.nan.usace.army.mil Sandy Hook to Barnegat Inlet. Erosion Control Project. US Army Corps of Engineers. New York district.
FY2001 Congressional Appropriations for Beach Nourishment. September 28, 2000. http://www.coastalcoalition.org/new/Whatsnew/html/shore$$01bb_table092800.htm.

Coastal Science Associates, Inc. 2002. Bogue Banks Beach Nourishment: First Pre-Dredge (June 2001), Second Pre-Dredge (November 2001), First Post-Dredge (June 2002), and Second Post-Dredge (November 2002) Environmental Monitoring Study 2002.

Dean, G. R., and Campbell J. T. Recommended Beach Nourishment Guidelines for the State of Florida and Unresolved Related Issues Environmental Design of Beach Nourishment Projects in Florida. Workshop held by Offices of Beach and Shores. Dept. of Environmental Protection, State of Florida. Atlantic Beach FL. Aug. 3-4, 1999.

Douglass, Scott L., 2002. Saving America's Beaches: The Causes of and Solutions to Beach Erosion. Advanced Series on Ocean Engineering Vol 19.

Florida's Beach and Shore Preservation Program. http://www.dep.state.fl.us/beaches/ Pursuant to Chapter 161, Florida Statutes. Florida Dept. of Environmental Protection. Offices of Beaches and Coastal Systems. 3900 Commonwealth Blvd. Tallahassee, FL. 32399.

Florida State General Assembly. <http://www.dep.state.fl.us/beaches/> Chapter 62B-41 Rules and Procedures for Application for Coastal Construction Permits.

Hamm L, Capobianco M, Dette HH, Lechuga A, Spanhoff R, and Stive MJF, 2002. A Summary of European Experience with shore nourishment. Coastal Engineering 47: 237 – 264.

Hanson H, Brampton A, Capobianco M, Dette HH, Hamm L, Laustrup C, Lechuga A, Spanhoff R, 2002. Beach nourishment projects, practices, and objectives – a European overview. Coastal Engineering 47: 81 – 111.

Leadon, M.E., Development and Implementation of a Regional Coastal Monitoring Program for the State of Florida, Proceedings of the Florida Shore and Beach Preservation Association (FSBPA) National Conference on Beach Preservation Technology, January 23-25, 2002

Lechuga, Antonio, 2003. Assessment of Nourishment Project at the Maresme Coast, Barcelona, Spain. Shore and Beach 71: 3 – 7.

Lindquist, Niels and Manning, Lisa. 2001. Impacts of Beach Nourishment and Beach Scraping on Critical Habitat and Productivity of Surf Fishes. NC Sea Grant.

Mallin, Michael A. et al. 2000. North and South Carolina Coasts. *Marine Pollution Bulletin*, 41(1-6): 56-75.

McFarland, Seth and West Kelley (webmasters). Last updated 2003. http://www.ncga.state.nc.us/homePage.pl . North Carolina General Assembly (NCGA).

McLachlan, A., Dorvio, A. Global Patterns in Sandy Beach Macrobenthic Communities. Unpublished.

Muñoz-Perez, Juan J.; Lopez de San Ramon-Blanco, Belén; Gutierrez-Mas, Jose M.; Moreno, Luis; Cuena, Gabriel J., 2001. Cost of beach maintenance in the Gulf of Cadiz (SW Spain). Coastal Engineering 42: 143 – 153.

Nelson, W. 1993. Beach restoration in the southeastern U. S.: Environmental effects and biological monitoring. Ocean and Coastal Management 19:157-182.

New Jersey Dept. of Environmental Protection., http://www.nj.gov/dep/shoreprotection/nourishment.htm Sept. 25, 2003. Shore Protection. Beach Nourishment.

North Carolina Department of Environment and Natural Resources. Last updated September 2003. http://dcm2.enr.state.nc.us/index.htm .

NOAA Coastal Services Center. http://www.csc.noaa.gov/opis/html/bchleg.htm. Beach Nourishment - Legal and Political Constraints. Charleston, SC.

Open University Course Team. Waves, Tides, and Shallow-water Processes. Butterworth-Heinemann, Oxford. 1999.

Ocean Resources Conservation and Assessment (ORCA). http://search.netscape.com/ns/boomframe.jsp?query=people+coastal+county&page=1&of

fset=1&result_url=redir%3Fsrc%3Dwebsearch%26amp%3BrequestId%3Da849967ba1f47718%26amp%3BclickedItemRank%3D2%26amp%3BuserQuery%3Dpeople%2Bcoastal%2Bcounty%26amp%3BclickedItemURN%3Dhttp%253A%252F%252Fspo.nos.noaa.gov%252Fprojects%252Fpopulation%252Fpopulation.html%26amp%3BinvocationType%3D%26amp%3BfromPage%3DNSCPResults&remove_url=http%3A%2F%2Fspo.nos.noaa.gov%2Fprojects%2Fpopulation%2Fpopulation.html

Peterson, C.H., Duvall, M., and Laney, W. Biology - Project Variables that Influence Biological Impacts. Unpublished.

Peterson, C. H., H. C. Summerson, E. Thomson, H. S. Lenihan, J. Grabowski, L. Manning, F. Micheli, and G. Johnson. 2000. Synthesis of linkages between benthic and fish communities as a key to protecting essential fish habitat. Bulletin of Marine Science 66: 759-774.

Peterson, C. H., McDonald, L., Green, R., Erickson, W. 2001. Sampling design begets conclusions: the statistical basis for detection of injury to and recovery of shore-line communities after the 'Exxon Valdez' oil spill. Marine Ecology Progress Series. 210: 255-283.

Peterson, C.H., Duvall, M., and Laney, W. Biology: Project Variables That Influence Biological Impacts. Unpublished.

Peterson, Charles H. 2000. Short-term Consequences of Nourishment and Bulldozing on the Dominant Large Invertebrates of a Sandy Beach. *Journal of Coastal Research*, 16(2): 368-378.

Peterson, Charles, 2003. Personal Communication.

Rice, Tracy Monegan. 2003. Native Sediment Characteristics of North Carolina Beaches. U.S. Fish and Wildlife Service.

Ross, S.W., and Bichy, J. 2002. Checklist of the Fishes Documented from the Zeke's Island and Masonboro Island Components of the North Carolina National Estuarine Research Reserve. National Estuarine Research Reserve Technical Report Series, 2002:2.

Rudolph G., www.protectthebeach.com Shore Protection Division. Carteret County North Carolina.

"Saving our Beaches." North Carolina Shore and Beach Preservation Association. Video. (No date given)

Senate Budget and Appropriations Committee Statement. Assembly No. 1676. Statement to New Jersey. Dec. 10, 1998.

Seymour, Richard J. et al. 1995. *Beach Nourishment and Protection*. National Academy Press, Washington D.C.

Smith, Pam. 2000. Beach Erosion: Nature's Work-in-Progress. North Carolina Sea Grant. http://www.ncsu.edu/seagrant/coastwatch/ESum00BeachErosion.html

State of Florida. Dept. of Environmental Protection. Office of Beaches and Coastal Systems. Statewide Coastal Monitoring Program. Regional Data Collection and Processing Plan. March 2001.

State of Florida Strategic Beach Management Plan, Certificate of Adoption. Oct. 2, 2000. Signed: Green, B. K.

Surfrider's State of the Beach 2003: New Jersey beach nourishment. http://beach.com/stateofthebeach/6-state/beach_nourishment.asp?state=NJ

Sutherland, J., http://beach.com/stateofthebeach/6-state/beach_erosion.asp?state=NC. Surfrider's State of the Beach 2003: North Carolina beach erosion.

Sutherland, J., http://beach.com/stateofthebeach/6-state/beach_nourishment.asp?state=NC. Surfrider's State of the Beach 2003: North Carolina beach nourishment.

"The Beaches are Moving: The Drowning of America's Shoreline." UNC Public Television. Video. Environmental Media Corporation. (No date given)

Thomalla, F and Vincent, C.E., 2001. Beach response to shore-parallel breakwaters at Sea Palling, Norfolk, UK. Estuarine, Coastal and Shelf Science 56: 203 – 212.

Thyme, Flemming, 1990. Beach nourishment on the west coast of Jutland." Journal of Coastal Research 6: 201 – 209.

Tursi, Frank. 2002. The Risks of Renourishment: How Pumping Sand on North Carolina's Beaches Can Affect Sea Turtles, Mole Crabs, and Other Critters. North Carolina Coastal Federation.

US Army Corp of Engineers New York District. 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. U.S. Army Engineer District, New York and U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.

U.S. Dept. of Interior. New Jersey., http://www.mms.gov/sandandgravel/nj.htm Septemper 30, 2003.Offshore Mineral Management, Sand and Gravel Program.

U.S. Army Corps of Engineers, Wilmington District. http://www.saw.usace.army.mil/WETLANDS/Projects/BogueInlet/App%20F%20CEA/App%20F%20pages%2017-30.pdf

Valverde HR, Trembanis C, and Pilkey OH, 1999. Summary of Beach Nourishment Episodes on the US East Coast Barrier Islands. Journal of Coastal Research 15: 1100 – 1118.

Verhagen, Hendrik J., 1990. Coastal Protection and Dune Management in the Netherlands. Journal of Coastal Research 6: 169 – 179.

Yax, L. K., http://factfinder.census.gov/servlet/GCTTable?ds_name=DEC_2000_SF1_U&geo_id=04000US34&_box_head_nbr=GCT-PH1&format=ST-2. January 25, 2002. New Jersey Census 2000 Demographic Information. U.S. Census Bureau.

Yax, L.K., http://factfinder.census.gov/servlet/GCTTable?ds_name=DEC_2000_SF1_U&geo_id=04000US37&_box_head_nbr=GCT-PH1&format=ST-2. January 25, 2002. North Carolina Census 2000 Demographic Information. U.S. Census Bureau.