SURF CITY

NORTH CAROLINA

RESOLUTION No. 2015-18

RESOLUTION SUPPORTING THE TOPSAIL ISLAND SHORELINE PROTECTION COMMITTEE COMMENTS SUBMITTED TO THE NORTH CAROLINA DIVISION OF COASTAL MANAGMENT

Whereas, Topsail Island, a barrier island located at the coast of North Carolina in Pender and Onslow Counties is the home of Surf City, Topsail Beach and North Topsail Beach municipalities, and

Whereas, These coastal municipalities and counties formed the Topsail Island Shoreline Protection Commission in 2004 with a mission to actively support and promote plans and programs to restore and maintain wide sandy beaches and storm protection dunes through beach nourishment for all of Topsail Island's oceanfront, and to support and promote development and execution of the NC Beach and Inlet Management Plan, and

Whereas, The North Carolina General Assembly has directed the Department of Environmental Quality's Division of Coastal Management to study and develop a proposed strategy for preventing, mitigating and remediating the effects of beach erosion, and

Whereas, the Division of Coastal Management is seeking public input to be included as part of the study and recommendations that will be provided to the General Assembly, and

Whereas, The Topsail Island Shoreline Protection Commission has developed and approved at its regular November 2015 meeting, a letter documenting several specific recommendations to be considered and included in the public comments,

Now, therefore, be it resolved that the Surf City Town Council hereby supports and endorses the Topsail Island Shoreline Protections Commissions letter to the Division of Coastal Management detailing recommendations as part of the beach erosion study and public comments, and

Be it further resolved that the Surf City Town Council encourages Governor McCrory, NC Representative Chris Millis, Senator Bill Rabon and the rest of the North Carolina General Assembly to consider these recommendations and the Division of Coastal Management's report as a means to protecting and improving our shoreline.

Adopted this the 1st day of December, 2015.

A.D. (Zander) Guy, ~~Mayor~~

Attest: Stephanie Hobbs, Town Clerk

RECEIVED

DEC 14 2015

DCM- MHD CITY

PO Box 2475
Surf City, NC 28445

Phone: (910) 328-4131
Fax: (910) 328-1746

Town of North Topsail Beach

Fred J. Burns, Mayor
Richard Macartney, Mayor Pro Tem
Aldermen:
Don Harte
Joann M. McDermon
Richard Peters
Walter Yurek

Stuart Turille
Town Manager

Carin Z. Faulkner, MPA
Asst. Town Manager/Town Clerk

Nature's Tranquil Beauty

RESOLUTION NO. 2015-30

RESOLUTION IN SUPPORT OF THE TOPSAIL ISLAND SHORELINE PROTECTION COMMISSION'S RESPONSE TO NC DIVISION OF COASTAL MANAGEMENT'S REQUEST FOR COMMENTS ON BEACH EROSION

WHEREAS, the 2015 Appropriations Act (S.L. 2015-241) directed the NC Division of Coastal Management to prepare a beach erosion study; and

WHEREAS, the law states that the Division of Coastal Management shall study and develop a proposed strategy for preventing, mitigating, and remediating the effects of beach erosion and in doing so consider efforts by other states and countries to prevent beach erosion and ocean over wash and to renourish and sustain beaches and coastlines and incorporate best practices into the strategy; and

WHEREAS, the study is due by February 15, 2016 and the short study period does not allow enough time to make the draft report available to the public review and comment; and

WHEREAS, the Division of Coastal Management has invited the public to submit written comments to be included as an appendix to the report; and

WHEREAS, the Constitution of the State of North Carolina Article XIV Section 5 states, "it shall be the policy of this State to conserve and protect its lands and waters for the benefit of all its citizenry, and to this end it shall be a proper function of the State of North Carolina and its political subdivisions to acquire and preserve park, recreational, and scenic areas, to control and limit the pollution of our air and water, to control excessive noise, and in every other appropriate way to preserve as a part of the common heritage of this State its forests, wetlands, estuaries, beaches, historical sites, open lands, and places of beauty;" and

WHEREAS, the Town of North Topsail Beach, the Town of Surf City, and the Town of Topsail Beach created the Topsail Island Shoreline Protection Commission with goals that are consistent with the State Constitution and S.L. 2015-241 which are: to deal with the adverse effects of beach erosion; promote the restoration, maintenance and enjoyment of Topsail Island beaches for the general public and property owners; improve the quality of recreational public beaches for families to enjoy; and restore and maintain habitat essential to the survival of sea turtles, shorebirds and native dune plants.

NOW THEREFORE BE IT RESOLVED that the North Topsail Beach Board of Aldermen hereby supports and endorses the Topsail Island Shoreline Protections Commissions letter to the Division of Coastal Management detailing recommendations as part of the beach erosion study and public comments, and

BE IT FURTHER RESOLVED that the North Topsail Beach Board of Aldermen encourages Governor McCrory, NC Representative Chris Millis, Senator Bill Rabon and the rest of the North Carolina General Assembly to consider these recommendations and the Division of Coastal Management's report as a means to protecting and improving our shoreline.

Adopted this the 3rd day of December, 2015.

Fred J. Burns
Mayor

(Seal)

RECEIVED

DEC 14 2015

DCM- MHD CITY

ATTEST:

Carin Z. Faulkner
Asst. Town Manager/Town Clerk

2008 Loggerhead Court
North Topsail Beach, NC 28460

ntbnc.org

Phone (910) 328-1349
Toll Free: (800) 687-7092
Fax (910) 328-4508

TOWN OF TOPSAIL BEACH NORTH CAROLINA

INCORPORATED 1963

RESOLUTION NO. 4-12-9a-15

RESOLUTION SUPPORTING THE TOPSAIL ISLAND SHORELINE PROTECTION COMMITTEE COMMENTS SUBMITTED TO THE NORTH CAROLINA DIVISION OF COASTAL MANAGMENT

Whereas, Topsail Island, a barrier island located at the coast of North Carolina in Pender and Onslow Counties is the home of Surf City, Topsail Beach and North Topsail Beach municipalities, and

Whereas, These coastal municipalities and counties formed the Topsail Island Shoreline Protection Commission in 2004 with a mission to actively support and promote plans and programs to restore and maintain wide sandy beaches and storm protection dunes through beach nourishment for all of Topsail Island's oceanfront, and to support and promote development and execution of the NC Beach and Inlet Management Plan, and

Whereas, The North Carolina General Assembly has directed the Department of Environmental Quality's Division of Coastal Management to study and develop a proposed strategy for preventing, mitigating and remediating the effects of beach erosion, and

Whereas, the Division of Coastal Management is seeking public input to be included as part of the study and recommendations that will be provided to the General Assembly, and

Whereas, The Topsail Island Shoreline Protection Commission has developed and approved at its regular November 2015 meeting, a letter documenting several specific recommendations to be considered and included in the public comments,

Now, therefore, be it resolved that the Commissioners of Topsail Beach hereby supports and endorses the Topsail Island Shoreline Protections Commissions letter to the Division of Coastal Management detailing recommendations as part of the beach erosion study and public comments, and

Be it further resolved that the Topsail Beach Commissioners encourages Governor McCrory, NC Representative Chris Millis, Senator Bill Rabon and the rest of the North Carolina General Assembly to consider these recommendations and the Division of Coastal Management's report as a means to protecting and improving our shoreline.

Adopted this the 9th day of December, 2015.

Howard M. Braxton Jr., Mayor

ATTEST:

Christina Watkins, Town Clerk

RECEIVED
DEC 1 4 2015
DCM-MHD CITY

Miller, Tancred

From:	Theresa Cullen <tac_fauxpas.1@verizon.net>
Sent:	Monday, November 02, 2015 6:37 PM
To:	Miller, Tancred
Subject:	beach nourishment plans
Follow Up Flag:	Follow up
Flag Status:	Flagged

I grew up in NJ where the beaches have eroded, where the Army Corps of Engineers has unsuccessfully tried to hold back the water and where engineering "marvels" allowing more wet lands to be used for buildings failed. I don't believe in beach restoration…do not believe in spending public funds on saving properties…I bought, put a lot of money into a restoration, and live on the beach… I know what a risk it is and do not expect anyone or any agency to save my home. And I don't think the loss of tax revenue from properties that are being saved is worth the great expense of restoration and the follow up procedures needed to keep the sand in the restoration area.

Thank you for your attention to this.
Theresa Cullen
122 Martin Lane
Duck, NC 27949

Miller, Tancred

From: GBD1414@aol.com
Sent: Wednesday, November 04, 2015 10:19 AM
To: Miller, Tancred
Subject: Beach erosion

Follow Up Flag: Follow up
Flag Status: Flagged

To Whom it May Concern,

I understand from an article in the Raleigh News and Observer that a study is being undertaken to "develop a proposed strategy for preventing, mitigating and remediating the effects of beach erosion". As a simple man I would like to provide my input on this issue. I do not understand how a government agency, or any human, can propose to overwhelm nature and prevent beach erosion. It has been an ongoing process for thousands of years and I do not think taxpayer money should be spent trying to stop the ocean. It defies the little intelligence I do have. I also feel the same way about mitigating the effects of erosion. I recently walked along a stretch of "our" beach where sandbags had been placed in an attempt at such mitigation. At high tide there was no beach present as the waves washed against the sandbags. At low tide, when the beach could be walked, and enjoyed by others, we all had the lovely sight of beige bags to enjoy. We could also enjoy the view of the house that were under washed and that eventually fall into the ocean, along with the pilings in the surf from other houses that had fallen. As far as remediation, are we to assume that pumping sand onto an eroding beach will forever create a useable beach? I think not. Where has this effort ever been successful? Would the state spend money to place sandbags on a mountain side that had suffered a mudslide and backfill with hole with dirt so the property owner could save his house and continue to rent it? I think not. It is arrogant to think we can defeat the ocean in order to save the homes of a few well off people. The homes were built in a bad location with a known risk of erosion and storm damage from high surfs. I don't feel the taxpayers should fund the poor decision and bad investments of the few. I am aware of the tourist dollar/tax income argument concerning these rental houses: however, the average North Carolinian will suffer absolutely no ill effects from allowing nature to take its course along the coast. There will always be a beach there if humans do not interfere with natural processes. In short, as you can see, I am totally opposed to any attempts at "preventing, mitigating and remediating the effects of beach erosion". As a side note, I have enjoyed visiting the beaches of North Carolina for many years and have family and friends that own beach properties. I do not wish ill toward anyone, but I do feel the ocean can't be stopped by human intervention.

Thanks for your time,

Gregg Dixon

Miller, Tancred

From: Dixon, John E
Sent: Monday, November 02, 2015 10:02 AM
To: Miller, Tancred
Cc: justin@capitolstrategies.com
Subject: Shoreline erosion on south end of Hatteras Island
Attachments: Hatteras Shoreline.jpg; Malcom's slide.pptx

Follow Up Flag: Follow up
Flag Status: Flagged

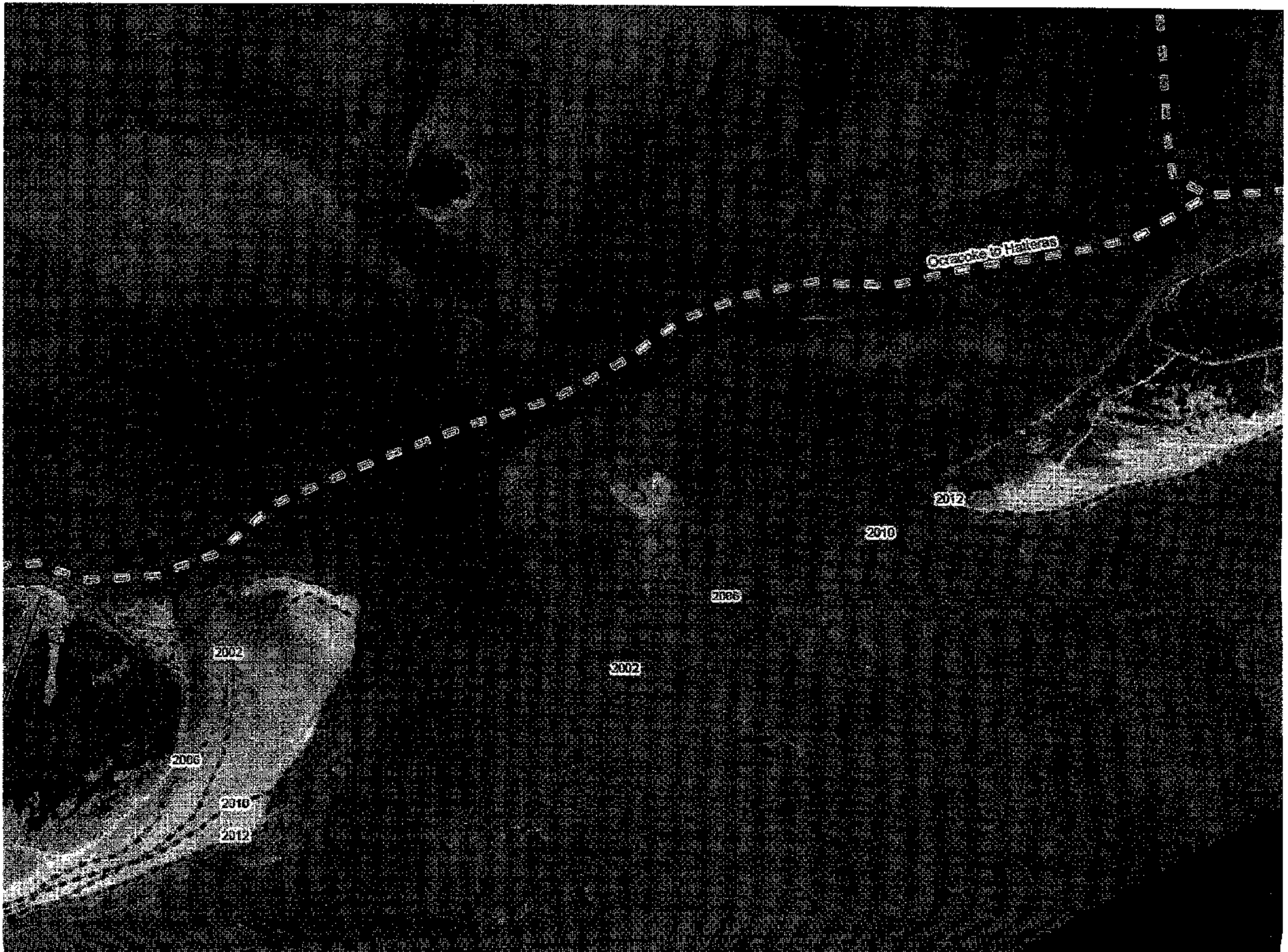
Good Morning,

My name is Jed Dixon and I am the Deputy Director for the NC Ferry Division. I would like to comment on the shoreline erosion on the south end of Hatteras Island. Since 2013 the North Carolina Ferry Division has had to run a different route on our Hatteras to Ocracoke route. This change was due to wide spread shoaling in our channel that we were running. This shoaling is a direct impact from the shoreline erosion on the south end of Hatteras Island. This map that I have attached shows the staggering loss of shoreline over the last 10 years. If this trend continues it could impact our operations even further. Running this new route has affected our level service causing longer waits and more cost associated with our operations. We estimate the additional cost with running the longer route to cost be around $200,000 per month. I have attached two images. The first is a topographic map that shows the shoreline that has been lost over the last several years in Hatteras Inlet the second is a map of the channels that we use to run and the alternate channel that we are having to run now.

Please let me know if you have any questions.

Regards

Jed Dixon
Deputy Director
NC Ferry Division



Ocracoke to Hatteras
2012
2010
2006
2002
2002
2006
2010
2012

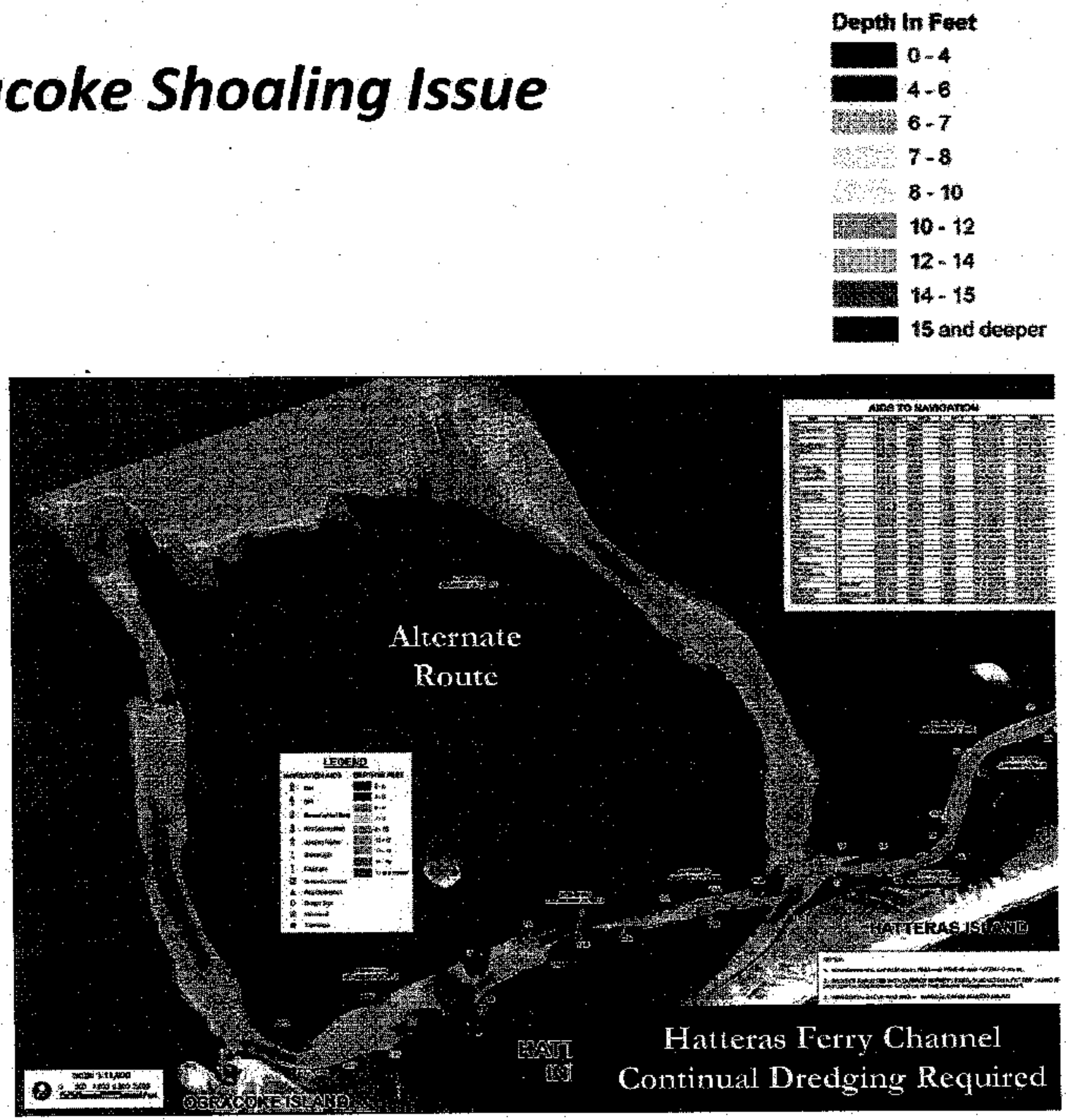
Hatteras-Ocracoke Shoaling Issue

Hatteras Ferry Channel – 4.3-miles

- Emergency Area Federally Maintained
- Constant Dredging
- Up to 52 departures/day

Alternate Route – 9.5 miles

- Natural Deep Water Chanel
- Cost Up to $250,000 more per month in labor/fuel
- Up to 42 departures/day



Tancred Miller, NC Division of Coastal Management
400 Commerce Ave
Morehead City, NC 28557
Tancred.Miller@ncdenr.gov
RE: Beach Erosion Study Public Comments

Mr. Miller,

The Town of Oak Island respectfully requests that you add the following recommendations to the comments you are gathering for the Division of Coastal Management's beach erosion study:

1. Update and implement the recommendations of the NC Division of Coastal Management BIMP Report. http://portal.ncdenr.org/web/cm/bimp-final-report1
   a) Regionalize the coastline for efficiency of scale. Regional groups that include elected and appointed components, including dedicated staffing, can coordinate things like coastal projects, accommodations tax uses, and reporting, as examples.
   b) Ensure long-term funding of the shoreline with a stable and predictable financial foundation by creating a dedicated Beach and Inlet Management Fund.
   c) Strategy development – make certain all beach-compatible dredged material ends up on the NC shoreline, ensure Federal reimbursement is maximized, and support the development of innovative dredging technologies.
   d) Data collection and monitoring – identify data gaps and partner with various State and Federal agencies, local governments and academia to assess data needs and acquire coastal datasets relevant to Beach and Inlet Management regions, standardize data collection formats among the regional authorities to improve data sharing across BIMP regional boundaries, and establish a framework for multiple permanent monitoring stations within the N.C. coastal zone, such as a system of estuarine, ocean and river stations, to measure absolute changes in sea-level rise, characterize the dynamics of storm surges and tides, and monitor water quality. Explore the current National Estuarine Research Reserve sites as "sentinel sites" for location of some of this equipment where possible.
   e) Update the economic data of the original report and include information on the combined value of occupancy taxes statewide in relation to occupancy taxes from coastal communities. Evaluate and report on the collective costs of local governments to protect shorelines.

2. Immediately implement "State Managed" Terminal Groin Projects for inlets having CAMA authorized private and public development with demonstrated serious erosion

4601 E. Oak Island Drive • Oak Island, North Carolina 28465
Phone: (910) 278-5011 • Fax: (910) 278-3400 • Website: www.oakislandnc.com

problems. Ideally such projects would not fall on the local government but rather be a state responsibility and/or an equal partnership with the local government.

3. Authorize alternate lower-cost erosion control devices in addition to sand bags. Research other devices or methods which are effectively being used by the U.S. Army Corps of Engineers, other States, and internationally for erosion control, allow for pilot projects using these devices, and if successful, authorize use. Such devices may include but are not limited to geo-tubes, SandSaver blocks, offshore structures, porous hardened structures, terminal jetties, and similar technologies that would become choices from a "tool box" of authorized erosion control options during the permitting process.

4. Adopt and implement the recommendations of the Washington D.C. Headquarters Army Corps of Engineers for making the nation's coastline and sound side more resilient for Hurricane Sandy-type storm events and sea-level rise. Specifically, deploy and maintain oceanfront buried seawalls and/or other alternatives from a wider array of options and construct sound side flood control revetments. Use documentation of how protected beaches fared much better than unprotected beaches using the Hurricane Sandy event historical data.

5. Modify and streamline procedures and permitting to allow coastal regulatory agencies, including CAMA officials, to be more proactive, aggressive and timely responses to all requests for services, especially emergency needs. Create more opportunities for streamlining of ongoing or repeated projects after initial permitting is completed.

6. Modify the role of CAMA from regulator to defender of the State's coastline and require that CAMA officials monitor and respond to present and future erosion threats and problems. Let that role become part of state level, multi-agency, regionalized effort that can save money and respond more quickly to coastal needs.

7. Adopt as a common goal and commitment of the entire State of North Carolina to protect its coastline as a means to protect economic interests of the entire State in addition to local impacts. Let the Division of Coastal Management act as an advocate along with other state agencies that educate the public and elected officials about the various types and amounts of revenues generated along the coast, what the impacts are if coastal resources are lost or diminished, and how other business and educational growth are related.

8. Provide additional revenue options and tools to entities at the local, county and state level in the form of special taxes, fees, or changes to accommodations taxes to ensure funding sources for shoreline protection.

9. Revisit the concept and possibility of a statewide dredging program.

Sincerely,

Tim Holloman, Manager
The Town of Oak Island

Topsail Island
Shoreline Protection Commission

December 15, 2015

Tancred Miller, NC Division of Coastal Management
400 Commerce Ave
Morehead City, NC 28557
Tancred.Miller@ncdenr.gov

RE: Beach Erosion Study Public Comments

Mr. Miller,

The Topsail Island Shoreline Protection Commission (TISPC) consisting of representation from North Topsail Beach, Surf City and Topsail Beach municipalities and the counties of Pender and Onslow, respectfully requests that you add the following recommendations to the comments you are gathering for the Division of Coastal Management's beach erosion study:

1. Update and implement the recommendations of the NC Division of Coastal Management BIMP Report. http://portal.ncdenr.org/web/cm/bimp-final-report1

    a) Regionalize the coastline for efficiency of scale. Regional groups, such as the Topsail Island Shoreline Protection Commission, that include elected and appointed components, including dedicated staffing can coordinate things like coastal projects, accommodations tax uses, and reporting, as examples.
    b) Ensure long-term funding of the shoreline with a stable and predictable financial foundation by creating a dedicated Beach and Inlet Management Fund.
    c) Strategy development – make certain all beach compatible dredged material ends up on the NC shoreline, ensure Federal reimbursement is maximized, and support the development of innovative dredging technologies.
    d) Data collection and monitoring – identify data gaps and partner with various State and Federal agencies, local governments and academia to assess data needs and acquire coastal datasets relevant to Beach and Inlet Management regions, standardize data collection formats among the regional authorities to improve data sharing across BIMP regional boundaries, establish a framework for multiple permanent monitoring stations within the N.C. coastal zone, such as a system of estuarine, ocean and river stations, to measure absolute changes in sea-level rise, characterize the dynamics of storm surges and tides, and monitor water quality. Explore the current National Estuarine Research Reserve sites as "sentinel sites" for location of some of this equipment where possible.
    e) Update the economic data of the original report and include information on the combined value of occupancy taxes statewide in relation to occupancy taxes from coastal communities. Evaluate and report on the collective costs of local governments to protect shorelines.

214 N New River Dr · Surf City, NC 28445 · Phone: 910-328-4131 · Fax: 910-328-1476 · Email: shobbs@townofsurfcity.com

2. Immediately implement "State Managed" Terminal Groin Projects for inlets having CAMA authorized private and public development with demonstrated serious erosion problems. Ideally such projects would not fall on the local government but rather be a state responsibility and/or an equal partner with the local government.

3. Authorize alternate lower cost erosion control devices in addition to sand bags. Research other devices or methods which are effectively being used by the U.S. Army Corps of Engineers, and other States, and internationally for erosion control, allow for pilot projects using these devices, and if successful, authorize use. Such devices may include but are not limited to geo-tubes, SandSaver blocks, offshore structures, porous hardened structures, terminal jetties, and similar technologies that would become choices from a "tool box" of authorized erosion control options during the permitting process.

4. Adopt and implement the recommendations of the Washington D.C. Headquarters Army Corps of Engineers for making the nation's coastline and sound side more resilient for Hurricane Fran and Sandy type storm events and sea-level rise. Specifically, deploy and maintain ocean front buried seawalls and/or other alternatives from a wider array of options and construct sound side flood control revetments. Use documentation of how protected beaches fared much better than unprotected beaches using the Hurricane Fran and Hurricane Sandy events historical data.

5. Support engineered beaches and beach nourishment projects as a proven shoreline protection method to mitigate and prevent damage to natural as well as manmade resources from the impacts of beach erosion through funding and streamlined permitting.

6. Modify and streamline procedures and permitting to allow coastal regulatory agencies, including CAMA officials more proactive, aggressive and timely responses to all requests for services, especially emergency needs. Create more opportunities for streamlining of ongoing or repeated projects after initial permitting is completed. Strive for more state and federal coordination of permitting and regulations as it relates to shoreline protection projects and emergency needs.

7. Modify the role of CAMA from regulator to defender of the State's coastline and require that they monitor and respond to present and future erosion threats and problems. Let that role become part of state level, multi-agency, regionalized effort that can save money and respond more quickly to coastal needs.

8. Adopt as a common goal and commitment of the entire State of North Carolina to protect its coastline as a means to protect economic interests of the entire State in addition to local impacts. Let the Division of Coastal Management act as an advocate along with other state agencies that educates the public and elected officials about the various types and amounts of revenues generated along the coast, what the impacts

are if coastal resources are lost or diminished, and how other business and educational growth is related.

9. Provide additional revenue options and tools to entities at the local, county and state level in the form of special taxes, fees, or changes to accommodations taxes to insure funding sources for shoreline protection.

10. Revisit the concept and possibility of a statewide dredging program.

Sincerely,

Michael H. Curley, Chairman
Topsail Island Shoreline Protection Committee

PINE ISLAND
OUTER BANKS, NC

Pine Island Property Owners Association, Inc.
PO Box 1465
Kitty Hawk, NC 27949

26 December 2015

Tancred Miller - N.C. Division of Coastal Management
400 Commerce Ave
Morehead City, NC 28557

Dear Tancred,

In response to the request from the State of North Carolina seeking public input on the study mandated by the North Carolina General Assembly on methods to prevent erosion and to restore beaches, please find below a submission from the Pine Island Property Owners Association (PIPOA), a North Carolina organization.

PIPOA represents Pine Island, an ocean side community (a PUD) that exists east of Highway 12 in Currituck County. Pine Island consists of 274 homes, most of which are used for rental purposes. The southernmost end of the development is the Currituck-Dare County line. The northernmost end is approximately 3.5 miles north of the County line. Approximately 140 of the homes in Pine Island are beachfront.

PIPOA has actively studied the dynamics of their beach and dune system for many years and has taken aggressive measures to protect against and mitigate the effects of natural forces which influence it. We know that beaches and dunes are in fact, a dynamic system that should be evaluated and treated in totality. In 2004, after a series of storms seriously eroded our dunes and beaches, PIPOA formed a special Dune Committee which, with the guidance of professional coastal engineers, created standards and initiated actions to strengthen our dunes. For more than ten years, dunes have been regularly measured and classified as to whether they adhered to those standards and the Association has trucked in sand to ensure a robust and vital dune system protecting our community. In addition, we regularly install sand fencing, plant dune grasses and fertilize the vegetation at our own cost to protect and to further enhance the dunes.

A six step process could be considered:

1. Understand the case for action
2. Engage experts

3. Educate stakeholders
4. Establish a proactive beach sustainment action plan
5. Establish consistent funding approaches across all shoreline Counties in the State
6. Leverage other States experience and already established programs

Further detailed explanation of these steps is included below.

(A) Suggestions for methods/approaches to prevent shoreline erosion

- Understand the case for action
    - Studies by experts indicate that beach erosion rates along the North Carolina coast can range between 2ft/yr up to 15ft/year.
    - Recent events have shown that specific communities (homes and businesses) along the North Carolina coast have been significantly impacted by ocean overwash and beach/dune barriers have been significantly eroded.
    - The tourism industry in 2014 in North Carolina had an all time high $21.3 billion in direct spending, a 5.5 percent increase over 2013. Spending by travelers directly supported 204,909 jobs for North Carolinians with a payroll of more than $4.9 billion and generated more than one billion dollars in State and local tax revenues for reinvestment in communities all across North Carolina. In addition to topping the 200,000 mark for the first time, the 3.3 percent growth in tourism jobs was the largest increase in 14 years. This needs to be sustained and the healthy sustainable beaches along the Outer Banks are a key component of the tourism industry. Losing a significant number of tourists due to shoreline breach would have a significant impact on the economic ecosystem of restaurants and other small businesses that in turn generate income taxes to the benefit of the North Carolina.
    - Development of strategies and associated actions for the long term stability of the beaches is required to protect properties, businesses and the tax base that helps sustain the health and prosperity of counties in North Carolina.
    - Linking back to the communities on the Outer Banks, they represent a significant source of revenue for Currituck County. They generate over $14M of annual property tax for Currituck County and this is close to 60% of the total real estate tax for the County (specifically our Pine Island community generates over $2M in annual property taxes for the County). If properties are impacted by a breach of our shoreline due to lack of suitable protection the consequential drop in property values for the Outer Banks area of Currituck County, and other shorelines of North Carolina would have a significant impact on the tax revenue for the County.
    - Pine Island, along with numerous other rental and vacation communities on the Northern Outer Banks, supports the livelihood of numerous full time residents of both Currituck and Dare counties, generating, undoubtedly, a significant amount of income tax revenue for the State of North Carolina. This income for the State

needs to be adequately supported through proper and timely shoreline protection plans.
  - This source of revenue is threatened by continued loss of beaches and potential erosion that could result in the loss of beachfront property. It should be noted, furthermore, that the loss of beachfront property reduces the tax value of homes within an area that are not on the beachfront. Such losses will also result in loss of renters venturing into the area from out of State with the subsequent loss of revenue to local businesses.
  - Doing nothing to prevent shoreline erosion is really not a viable option for North Carolina and it's Counties.
- Engage experts
  - Data must be gathered and benchmarks established to aid in the development of a comprehensive beach management plan that will sustain the beaches along the Currituck Outer Banks into the future thus supporting the North Carolina economy.
  - Professional consulting companies such as CSE and CPE have already completed studies of some of the beach systems in North Carolina and have significant proven experience in this geography.
  - Learn from other States (i.e New Jersey, South Carolina, Florida and Texas) on how they approached the challenges.
  - Conducting an integrated beach profile survey along the entire coast will be a valuable piece of information on which decisions and subsequent actions can be based.
  - PIPOA commissioned a study by a highly qualified firm to create a baseline of data, at a high level of detail, of the status of the beach and dune system the entire length of Pine Island, including the aforementioned area that is not within the Pine Island community per se.
  - The expert companies who have completed research along the North Carolina (and other) coasts would indicate
    - We need consistent wider beaches to break the waves further out.
    - We need dunes that have sufficient sand in the foredune to reduce the possibility of overwash during a storm event and thus provide protection to personal property, continue to provide a recreational beach for tourists and reduce any consequential impact on local businesses.
  - Understand and acknowledge that there is a problem of wind erosion where hardened structures (i.e. dune decks and beach access stairs) are built in the dunes.
  - Statewide standards should be developed by the governing bodies/codes to help reduce the "blowout" effect under dune decks due to a lack of vegetation. This would be accomplished by limiting the number of such structures, controlling their size and adhering to professional design standards which consider the effects of aerodynamics and hydraulics. These guidelines must be strictly and uniformly enforced.

RECEIVED

DEC 31 2015

DCM- MHD CITY

(B) Suggestion for methods/approaches to restore shorelines

- Establish beach restoration/sustainment programs leveraging examples that other States have already established.
- Consider the health, safety and evacuation issues associated with barrier island dune breaches. For example, at the Dare and Currituck County line on the Outer Banks the distance between ocean and sound is less than a quarter-mile. The evacuation route is south on Route 12 and across the Wright Memorial Bridge. If there were to be a dune breach at that point any residents or vacationers north of that point would be stranded. This is not necessarily an argument for another bridge but rather for the integrity of the dune protecting travel south on Route 12.
- The ongoing cost of restoration will be reduced if the shoreline has a proactive beach erosion management plan in place and those actions have been already implemented.

In summary, we urge the State to undertake the following at a minimum:

- North Carolina should recognize that a valuable economic asset of the State (tourism and vacation revenue streams) may be in jeopardy due to shoreline erosion.
- North Carolina should have consistent integrated engineering surveys and analysis of the health of the beaches along the coast and be willing to share in the cost of any local communities/counties coastal engineering studies. Such surveys are indispensable to determining the health of a beach. Once a baseline is established, they should be undertaken at regular time intervals. In essence, the beach survey is similar to someone taking his blood pressure on a regular basis. A base line is established, changes can be noted and corrective action taken as needed.
- North Carolina should recognize that many communities, such as our own Pine Island Home Owners Association, have been very active and proactive for over 10 years in taking action to help maintain the recreational beach, but more is needed.
- Propose cost sharing methods to be used consistently across the North Carolina's counties. Financing opportunities that would spread costs over a reasonable horizon, with help from the State/Counties could be helpful as well.
- Consider the merits of doing extensive beach nourishment consistently throughout the length of the Northern Outer Banks. Act now to preserve and enhance this vital source of revenue to the counties and the State.

Submitted by Pine Island Property Owners Association (PIPOA) located in Currituck County, NC.
Contact: Jeff Shields, Manager PIPOA, 252-261-1200

Miller, Tancred

From: tony patrick <patrick85ed@yahoo.com>
Sent: Wednesday, October 14, 2015 3:55 PM
To: Miller, Tancred
Subject: Ways to slow beach erosion

Follow Up Flag: Follow up
Flag Status: Flagged

Terminal groins are effective if properly situated and constructed or another idea is to do what some Island nations in the Caribbean do and create artificial reefs offshore up to within approximately 10 feet of the water surface which will take storm driven waves and cause them to crest and break thus loosing most of their destructive energy before breaking again on shore, they would need to be built probably 1/2 to 1 mile off shore to be effective, it also creates some great habitat for marine animals. The former is a lot easier and more cost effective to build but the latter seems to offer more protection. You have to treat it like an elephant you are about to eat, just take one bite at a time.

Miller, Tancred

From:	R. Bryan Harrell <rbryanharrell@yahoo.com>
Sent:	Tuesday, October 20, 2015 11:23 AM
To:	Miller, Tancred
Subject:	Beach nourishment
Follow Up Flag:	Follow up
Flag Status:	Flagged

The outer banks is NC's biggest tourist attraction that brings in millions of dollars in revenue to the state. Also, the damage to property is costing millions. It makes sense to spend the money on restoring our beaches. We spend a lot of time in Rodanthe and the amount of beach there now is wonderful. It keeps us from even thinking about going to Myrtle Beach.

Sent from Yahoo Mail for iPhone

Miller, Tancred

From: floundering1001 <floundering1001@hotmail.com>
Sent: Tuesday, October 20, 2015 12:54 PM
To: Miller, Tancred
Subject: Beach Erosion

Follow Up Flag: Follow up
Flag Status: Flagged

For the first thing, everyone is worrying about beach erosion. Though it is a problem, we have potentially worse problem inland that noone is addressing. It is the problem of projected ocean rise. It will affect the shoreline, of course, but has anyone studied the effects on properties and roads on the sound and inland waterway? I have not seen any study on this and it will be affected by ocean rise.
Secondly, the effects of storms causing beach erosion, has been going on ever since I can remember and especially along highway 12. Year after year we spend money on dumping more sand, creating dunes etc. Again with ocean rise, it will get worse. So right now we should be planning on elevating highway 12, say about 6 feet. Similar to highway 64 between New Bern and little Washington. This has also been done on highway 95 in South Carolina. There could be "off ramps" along highway 12 for the communities or for beach access for fishing etc.

Sent from my Verizon Wireless 4G LTE smartphone

Miller, Tancred

From: Tom Wiltrout <choppin330@gmail.com>
Sent: Saturday, October 24, 2015 8:54 AM
To: Miller, Tancred
Subject: Obx beach nourishment

Follow Up Flag: Follow up
Flag Status: Flagged

The outer banks is truly a amazing band of communities like no other place in America. Whatever the cost is obx holds my heart and I expect to relocate very soon. I would expect that these communities are preserved and protected for decades to come I couldn't imagine any other outcome this place has more history than my home town it was a big part in building today's America. at all cost save this amazing place I love!

Miller, Tancred

From: Dillard Horton <papadhh@gmail.com>
Sent: Friday, October 30, 2015 8:56 AM
To: Miller, Tancred
Subject: Comments on Beach Nourishment

Follow Up Flag: Follow up
Flag Status: Flagged

Tancred Miller: This email is being sent to you to inform you of the importance of beach nourishment on the beaches comprising the Outer Banks of North Carolina. My wife and I have owned our cottage in South Nags Head at Mile[Post 20 since 1977. We have watched an entire row of cottages wash into the ocean and the adjoining city street wash away. The beach nourishment project in Nags Head a few years ago stabilized the erosion situation and saved millions of dollars in potential damage to structures caused by subsequent storms. I would greatly encourage the adjoining towns to nourish their beaches as quickly as possible. There will be a need for follow-up beach nourishment projects to protect the beaches, but I consider that cost as part of the price of living along the coast. The Weather Channel staff in reporting storms along the Outer Banks have been very critical of the State of North Carolina in not protecting their beaches. The time is now to make a difference. Thanks! Dillard and Judy Horton

Miller, Tancred

From: Fred Brinkley <dewey35@cox.net>
Sent: Monday, November 09, 2015 11:54 AM
To: Miller, Tancred
Subject: beach erosion

Follow Up Flag: Follow up
Flag Status: Flagged

after reading the article on beach erosion, something came to mind that may or may not mean anything. in 1982 and 83 I was having a cottage built in avon. back then it wasn't unusual for overwash to occur in the area we now call Canadian Hole and just north of buxton. one day when talking with a man by the name of clarence winslow from frisco about this ,he said that the county was afraid that future overwash at the canadian hole area would take out the electricity line poles in that area and there was plans to relocate them westward.but then he added that it had been determined that there was a slew running perpendicular to the beach and that he worked for a dredging company that had been hired by the county to pump sand from the sound , under route 12 to the slew. I cant remember how long this lasted, but it must have helped because the poles are still standing. just a thought to kick around or maybe laugh about.

KARL BRINKLEY

Miller, Tancred

From: colleen@sunandsea.com
Sent: Thursday, November 19, 2015 8:11 AM
To: Miller, Tancred
Subject: Beach Erosion Study

Follow Up Flag: Follow up
Flag Status: Flagged

Thank you for continuing to find ways to protect our shorelines.

The State of Florida understood the importance of Tourism to their economy. They also realized that their citizens prefer to live close to the beaches so they can enjoy the coastal way of life. They have been very pro-active in building their beaches.

I believe that hardened structures is the last resort but it should not be banned as an option. Keeping inlets and waterways open is also a plus! We have areas where ports are the heart of the economy and their need is different. Again Florida is a State that has set the standard.

Having a comprehensive and long term plan to nourish our beaches regularly I believe is the best plan. You are replenishing the sand that went back to the sea. If the State, with the Federal Government, would look at the funding needed I believe you would find public support.

Communication is key. Bring the documentation and show what the people of other areas were willing to do to support what was necessary to protect infrastructure and keep the economy of their communities alive.

Thank you for your time.

Colleen

Colleen R. Shriver, REALTOR, ABR, e-Pro, GREEN, RSPS, SRES
2015 President of the Outer Banks Association of REALTORS
2013 REALTOR Of The Year at Outer Banks Association of REALTORS 252-305-4585 cell; 252-261-6400 office; 207-433-6468 e-fax
The Sun and Sea Team, Helping You Reach Your OBX Real Estate Goals.
CENTURY 21 Nachman Realty
4628 N. Croatan Highway
Kitty Hawk, NC 27949
www.sunandsea.com / www.century21nachman.com
BULLETIN: WORKING WITH REAL ESTATE AGENTS
http://www.ncrec.gov/publications-bulletins/WorkingWith.mht

This is a historical summary of public input regarding beach erosion and management options. These are provided to demonstrate comments that are still expressed by communities today. It is important to note that these may not represent concerns for the same community today, but interesting to read.

Joan Altman, Mayor of Oak Island 2001

Form Oak Island Mayor, Joan Altman speaking at "Save Our State Report on Dredging, Dunes and Development Meeting Human and Ecological Needs in Coastal North Carolina." 2001 (p. 55-57)

"Beach Erosion is a reality in North Carolina and it is frightening because it threatens residences and infrastructure. Loss of these structures means a loss of tax base, loss of business revenue, and loss of an attractive beach. But most importantly, loss of the beach means loss of the best, cheapest storm protection for the town." Speaking from personal experience, Mayor Altman said, "Loss of beach is loss of identity and lifeblood of a beach community."

"Now I know many people look at this situation and say, too bad, these people should not have built on the beach, but again, I have to remind you to look at 'what is.' The beach development occurred over decades and the construction has complied with improved building codes and the various state and local setback regulations. The development on these beaches is what the local populace approved and encouraged through their zoning ordinances. The fact that you may not like the development is as pertinent as the fact that I do not like some of the development in your community. This development has occurred on privately owned property and has all the legal strings and attachments called property rights that apply anywhere else in the state.

"People like to talk about the waste of federal money to protect private beachfront property. The coastal local governments seeking beach nourishment must find a way to fund their share of the cost and it is very significant bite for a small community. I firmly believe in state and federal government participation in beach preservation and restoration because in North Carolina beaches are public. You own the beach and you ought to contribute to its upkeep just as we (oceanfront property owners) contribute to the upkeep of other state parks."

"As an elected official, I understand regionalism and I deplore the absolute waste of public money and talent which occurs when we squabble over and scramble for federal and state dollars. Watching very complex beach restoration issues be reduced to 'My money is not going to be thrown in the ocean at your beack,' is heartbreaking and puzzling. Especially when I pay for roads, parks, housing, and many other publicly funded improvements throughout the state that I will never see and cannot use."

Miller, Tancred

From:	Lee Atwood <leeatwood24@yahoo.com>
Sent:	Tuesday, October 20, 2015 4:04 PM
To:	Miller, Tancred
Subject:	OBX Erosion
Follow Up Flag:	Follow up
Flag Status:	Flagged

Tancred Miller:

The ocean coast of the Outer Banks is, and will remain, in a losing battle with rising sea levels and coastal storms as long as the mindset is one of protecting the coast against such onslaughts. The presence
of fixed location real estate, businesses and roads which must be protected against nature's dynamic coast
line is destined to be a recurring losing battle. As long as man insists on denying the dynamic nature of the
coastal shoreline, he will lose this fight. As long as real estate consists of fixed plats on a moving substrate,
this will never result in a sustainable situation. The remnant pilings of former houses on the barrier Cedar Island, VA, now well out in the surf, are testament to this. Developer Benson had to move his house three times before
other owners finally abandoned the idea of trying to sustain homes on the back of this migrating sea turtle of an island. Money literally thrown into the sea out of ignorance.

Just prior to the passage of Hurricane Erika, I recall a Kitty Hawk Public Works manager on TV in proudly pointing out
large sandbags placed just seaward of the highway, and proclaiming how they would direct wave energy down away from the road. Of course, this was just the problem. If wave energy is directed downward, it carries away the sand
foundation under the bags allowing them to collapse. If Erika had passed a little closer, all the expensive repairs to
Hwy 12 would have been erased just weeks after they were completed.

The only thing I can think of that will slow this process is a series of (expensive) Tombolos, 40-50 meter long piles
of large stone (4-5 ton) blocks parallel to and just off the beach such as those built in the 1990s at Fort Story on Cape Henry. Tombolos are named after the town in Italy where they were first tried.

This would obviously change the esthetics of the beach and would likely be criticized by residents. However they do seem to disrupt the erosive action of winter storms and allow accretion to occur as longshore currents are disrupted, allowing particulates to settle out rather than be carried along the shore and swept away.

We have not begun to learn to accept (much less live with) the coast as a dynamic environment. It changes just a bit too slow for us to learn to adapt to it. We don't know how to live in a way in which we adapt to the coast; we always expect to be able to adapt the coast to our whims, and whims they are indeed.

I don't envy you. You are tasked with guarding a very flimsy door against a very powerful wolf.

Bob Anderson
Norfolk

October 23, 2015

Kimberly Hernandez
1030 Spa Road Apt. K
Annapolis, MD 21403
kimh06@gmail.com

Mr. Tancred Miller
Coastal and Ocean Policy Manager
NC Division of Coastal Management
400 Commerce Avenue
Morehead City, NC 28557

Submitted electronically

Re: <u>State coastal agency seeking public comments on beach erosion study</u>

Dear Mr. Miller:

This letter is in response to the 2015 Appropriations Act, Session Law 2015-241 call for the study and development of a proposed strategy for preventing, mitigating and remediating the effects of beach erosion in North Carolina. As the Division of Coastal Management considers options to prevent beach erosion and ocean overwash and to renourish and sustain beaches and coastlines, I hope that you consider the extensive research I conducted at Duke University between 2012-2014 that focused on beach nourishment and sea turtle nesting.

The following comments are my own and are not intended to reflect the views or opinions of any of my current or previous affiliations, including: Duke University; North Carolina Sea Grant; North Carolina Coastal Resources Law, Planning, and Policy Center; or the Maryland Department of Natural Resources.

Accompanying this letter is the final report of research that I conducted in partial fulfillment of the requirements of Master of Environmental Management degree in the Nicholas School of the Environment at Duke University and an accompanying Coastal Policy Fellowship with North Carolina Sea Grant and the North Carolina Coastal Resources Law, Planning, and Policy Center. I believe this report contains critical information that should be considered in the beach erosion study.

Without being able to read a draft report, I offer my entire report with the hope that you find the data, research, and references contained therein valuable to inform your study. To summarize my conclusions in a few sentences, I offer the following comments for your consideration based on two years of in-depth research and discussions with biologists, shoreline managers, and policy experts.

1. It is irresponsible to generate a long-term plan to tackle shoreline erosion without the consideration of how climate change, particularly sea level rise, will increase the need for

shoreline stability measures as sea level rise and increased storm activity erodes shorelines quicker.

2. If beach nourishment continues to be a preferred method of shoreline erosion control, then there must be a predominantly locally-funded mechanism to ensure long-term financial sustainability of the projects, instead of the heavy reliance on federal disaster relief funding.
3. I urge this study to recommend maintaining the limit of 4 terminal groins to be considered for construction. Any leverage to increase that number I fear will open the floodgates to hardened shoreline structures along the entire North Carolina coastline.

Even though I am no longer a resident of the state, North Carolina continues to hold a special place in my heart. The largely undeveloped barrier islands with abundant wildlife and scenic beauty should be protected from any measures that will harm their long-term viability. While I recognize the importance of economic drivers and constraints, I hope the Division of Coastal Management also considers the many species that also depend on these barrier island and beach ecosystems. I look forward to your final study and hope that my comments prove useful.

Sincerely,

Kimberly Hernandez
Mater of Environmental Management, Duke University

Attachment (1)

Protecting Beaches and Sea Turtles: An Analysis of Beach Nourishment, Loggerhead Sea Turtles, and Sea Level Rise in North Carolina

Prepared by Kimberly Hernandez | Duke University | July 2014

With funding support from North Carolina Sea Grant and North Carolina Coastal Resources Law, Planning, and Policy Center's Coastal Policy Fellowship

Sea Grant North Carolina
North Carolina Coastal Resources Law, Planning, and Policy Center
Duke NICHOLAS SCHOOL OF THE ENVIRONMENT

Abstract

Federally protected loggerhead sea turtles rely on wide sandy beaches for their terrestrial reproductive phase. Accustomed to hurricanes and erosion, North Carolina has taken to extensive beach nourishment efforts for shoreline protection. The majority of these efforts have been to benefit interests other than sea turtles, but given the July 2014 critical habitat designation for the Northwest Atlantic Ocean Distinct Population Segment of the Loggerhead Sea Turtle (*Caretta caretta*) by the US Fish and Wildlife Service and the National Marine Fisheries Service, their consideration warrants further attention.

Each beach selected for my study: 1) is a known loggerhead sea turtle nesting beach; 2) is within the final terrestrial critical habitat designation; 3) has a "High" to "Extremely High" vulnerability to sea level rise based on the US Geological Survey Coastal Vulnerability Index; and 4) is a developed barrier island. The final economic analysis was on Bogue Banks (Carteret County), Pleasure Island (New Hanover County), Bald Head Island, Oak Island, and Holden Beach (Brunswick County). In this project, I explored historic nourishment data to understand the full costs of beach protection, hypothesizing that sea level rise will exacerbate that cost in the future.

Through my research, I unveiled how nourishment efforts potentially both help and hinder the state and sea turtles. My analysis uncovered ways North Carolina can responsibly move forward with beach protection while taking both sea turtles and sea level rise into account. First, there must be state-level support for sea level rise planning – the Coastal Resources Commission should move forward with sea level rise discussions and define a rate of sea level change for planning purposes. This rate, and associated increased need for sand, should be incorporated into future nourishment projects so the US Army Corps of Engineers and the North Carolina Division of Coastal Management do not underestimate costs and how much sand will be needed over the lifetime of each project. County and municipal governments should also devise local tax plans to finance future nourishment projects. Finally, the US Army Corps of Engineers, the state Wildlife Resource Commission, and local sea turtle volunteer groups must continue monitoring nesting beaches for any changes post-nourishment to further understand how modified beaches impact loggerhead sea turtles.

Acknowledgements

This report is the final product of the 2014 North Carolina Sea Grant and the North Carolina Coastal Resources Law, Planning, and Policy Center's Coastal Policy Fellowship. In addition to this fellowship support, this report would not have been possible without the guidance of several individuals:

Dr. Andy Read, for providing constructive edits and comments and always challenging me to think critically and thoroughly, and Dr. Mike Orbach, for asking the hard questions, believing in me, and providing assistance during project conception.

Dr. Betsy Von Holle, for conceptualizing this project and encouraging me throughout, and Tom Holmes, for enthusiastically contributing to the economic analysis.

Dr. Matthew Godfrey, for supplying the sea turtle data and several biological references, and for inspiring me to follow my passion.

Greg "Rudi" Rudolph, for many explanations about beach nourishment laws, policies, and practices in Carteret County, and Layton Bedsole and Doug Piatowkski, for our conversations about beach nourishment in New Hanover County.

Dr. Andy Colburn, for supplying the PSDS beach nourishment database, and Matthew Slagel and Jonathan Howell, for sitting down with me to explain coastal laws and policies, and for cross-referencing nourishment projects.

> "When we try to pick out anything by itself,
> we find it hitched to everything else in the Universe."
>
> - John Muir, *My First Summer in the Sierra* (1911)

Table of Contents

Introduction

Climate change and sea level rise occur globally, but efforts to deter the rising seas will first occur at the state and local level (Karetinkov et al. 2008). North Carolina's iconic sandy beaches draw thousands of tourists annually, generating millions in economic revenue (Department of Commerce 2013), but are threatened by future sea level change. Wide, stable beaches provide protective benefits to coastal property owners, renters, and businesses, as well as to developers interested in capitalizing on the picturesque coastline. Given that beaches are dynamic and naturally erode and accrete over time, a challenge for coastal managers is how to protect investments while maintaining the ecological integrity of the system. One key component of this system often overlooked is the federally threatened loggerhead sea turtle (*Caretta caretta*). This final report explores how beach preservation and sea level rise adaptation efforts in North Carolina may come into repeated conflict with loggerhead nesting as the climate changes and sea levels rise.

Sea turtles spend most of their life at sea, but the critical female reproductive stage takes place on sandy beaches worldwide (Dodd 1988). About 330 miles of the North Carolina coastline is suitable nesting habitat for sea turtles (WRC 2013), but much of this coast is developed. The demand for limited beach space will only continue as sea levels rise and beaches are wedged between the rising oceans and coastal development (Fish et al. 2005; Mazaris et al. 2009). Accelerated rates of erosion due to sea level rise will both exacerbate the need to actively protect the shoreline, and at the same time limit the availability of suitable nesting sites for female sea turtles (Fish et al. 2005; Mazaris et al. 2009).

In September 2011, under the Endangered Species Act (ESA), the National Marine Fisheries Service (NMFS) and the US Fish and Wildlife Service (USFWS) jointly issued a rule listing nine Distinct Population Segments (DPS) of loggerhead sea turtles (76 FR 58868). This action labeled each DPS as either threatened or endangered and allowed for more focused critical habitat designations and conservation efforts (NOAA 2011). Loggerhead sea turtles in North Carolina were determined to be part of the Northwest Atlantic DPS and designated as threatened (76 FR 58868). In March 2013, the USFWS submitted for public comment the "Proposed Designation of Terrestrial Critical Habitat for the Northwest Atlantic Ocean Distinct Population Segment of the Loggerhead Sea Turtle" (*78 FR 18000*). Included in the final July 2014 critical habitat ruling are 96.1 miles of North Carolina ocean-side beaches, including Bogue Banks, Bear Island, Topsail Island, Lea-Hutaff Island, Pleasure Island, Bald Head Island, Oak Island, and Holden Beach (*79 FR 39755*).

Fuentes et al. (2011) outlined sixteen adaptation strategies coastal areas can employ to mitigate the impacts of sea level rise on the terrestrial reproductive phase of sea turtles (Appendix A). Using specific criteria for choosing the most feasible strategies, Fuentes et al. (2011) suggested identifying and protecting areas that may be suitable nesting sites in the future. Investing in policies and legislation designed to protect beaches will not only have positive benefits for sea turtles and other beach-dwelling biota, but also for the North Carolina tourism industry, coastal landowners, and the general public. The original intent of this report was to analyze all sixteen strategies, but as my research and conversations with stakeholders progressed I quickly realized one strategy stood out among the rest: beach nourishment.

Beach nourishment – also called beach replenishment, renourishment, or beach fill – is the process of placing sand onto an eroded beach in order to widen the beach. Due to the economic value of coastal property and the ban on hard engineering structures on North Carolina beaches, beach nourishment is seen as an accepted engineering solution to combat shoreline erosion and is the favored erosion control strategy in North Carolina (Brock et al. 2009). Beach nourishment is a "soft" approach to erosion control and does not use "hard" engineering structures such as breakwaters or groins. Soft alternatives are preferred for North Carolina shoreline management because they do not severely alter the natural geomorphic and hydraulic processes in the littoral zone. The three main types of nourishment projects in North Carolina include: dredged material disposal; storm protection; and habitat restoration (Limber and Warren 2006).

Most of North Carolina's barrier islands were developed in the 1960s to 1980s during a 30-year lull in major hurricane activity (GL Rudolph, personal communication, November 6, 2013). When Hurricanes Bertha, Fran, Bonnie, Dennis, and Floyd hit in the 1990s, nourishment activity was swift, responsive, and haphazard. At the time, these mostly federally-funded nourishment projects were town-specific, with little consideration of the long-term or ecosystem-wide impacts. With advances in engineering and research on the impacts of nourishment, coastal managers are now trying to streamline the process and account for more variables, including sea level rise and sea turtle nesting.

Nourishment can have many recreational and economic benefits, but also carries several costs to both humans and sea turtles (Steinitz et al. 1998). The Program for the Study of Developed Shorelines estimates a total $617,223,415 has been spent to date on beach nourishment in North Carolina (PSDS 2013). Despite the lofty price, nourishment is favored by influential beachfront property owners and by coastal counties and municipalities who depend on tax revenues from tourists and coastal property owners who value a wide, sandy beach.

Using hedonic property value models to estimate the loss of property value in Carteret and New Hanover Counties under different sea level rise scenarios, Bin et al. (2007) estimated a loss of $30-$170 million if sea levels rise 0.52 feet (0.16m) by 2030, and $110-$650 million if levels rise 1.51 feet (0.45m) by 2080. For the entire state, the North Carolina Beach and Inlet Management Plan (BIMP) Section IV analysis estimated a total economic loss of $408 million if there were a 50 percent loss of all state beaches (2011, pg. IV-49). This scenario is not likely to happen, given the enormous investments by government and private entities to protect beachfront property and recreational beaches, but the enormous incentive to protect the beach (and the property behind it) is worth noting. With the state prioritizing nourishment as a viable and effective option to protect beaches, it is important that care be taken during the permitting process. Given the series of safeguards in place in North Carolina to help avoid negative impacts on the biota, nourishment should not be viewed as a beach protection strategy necessarily unfavorable for sea turtles (Crain et al. 1995). Even with these safeguards, however, there is still ample room for improvement.

In 2000, the United States Geological Survey (USGS) released the Coastal Vulnerability Index (CVI) – a national assessment of coastal vulnerability to sea level rise[1]. In an effort to help policy makers and managers prioritize areas that will need the greatest conservation attention, Von Holle et al. (2014, in progress) investigated the effects of sea level rise on nesting sea turtles from North Carolina to Florida. Mapping the CVI alongside known nesting distributions in the South Atlantic, Von Holle et al. (2014, in progress) created habitat suitability maps for nesting sea turtles, including the loggerheads that nest on North Carolina beaches. This information is not yet published, but the Principal Investigator on this project granted me permission to use the unpublished maps to determine where to focus my research (see Appendix B).

In this final report, I first summarize the known loggerhead sea turtle nesting biology, and then discuss sea turtle management in North Carolina and why the species is a factor in beach protection projects. Next, I give a brief outline of all the federal, state, and local government agencies involved in beach protection across the state, and explain the nourishment permitting process. I then explain several recent changes to North Carolina legislation that inhibit long-term sea level rise planning, and discuss all of the stakeholders who may be impacted by the findings in this report. I then present my analysis and literature review findings.

For my analysis, I chose to focus on beaches in Carteret, New Hanover, and Brunswick Counties in the southern half of North Carolina. These counties were chosen for four reasons: 1) high human population density in the developed beach areas; 2) vulnerability to sea level rise based on the USGS CVI (see Appendix B); 3) the existence of nesting loggerhead sea turtles (see Appendix C); and 4) each county contains designated terrestrial critical habitat (see Appendix D). The beaches under the jurisdiction of Marine Corps Base Camp Lejeune from Bear Inlet to New River Inlet were not included (Onslow County). Also omitted were Figure Eight Island, Wrightsville Beach, and Masonboro Island, because these areas were not designated critical habitat for loggerhead sea turtles. Given the relatively low CVI ranking of Bear Island, Topsail Island, and Lea-Hutaff Island, I chose to also exclude these areas from the analysis. In my final analysis, I focus exclusively on Bogue Banks (Carteret County), Pleasure Island (New Hanover County), and Bald Head Island, Oak Island, and Holden Beach (Brunswick County). In 2013 there were a reported 1,246 loggerhead nests in the state, with 456 (36.6%) of those occurring in these five areas (WRC 2013).

The literature review yielded persistent negative associations between beach nourishment and loggerhead sea turtles in the first year after nourishment but showed nesting to rebound in the second year. I also discovered that the true costs of historic beach nourishment projects are not accurately reflected in neither the Program for the Study of Developed Shorelines database, nor the North Carolina Division of Coastal Management

[1] A detailed discussion of climate change, historic sea level change, current sea level rise trends, and future rate predictions, is beyond the scope of this report. See Bin et al. (2007), Kartinkov et al. (2008), and the 2011 North Carolina Beach and Inlet Management Plan Final Report (BIMP) for further discussion on the economic impact of sea level rise on North Carolina.

database, as half to a third of all projects listed in the databases do not list project cost. My economic analysis revealed that approximately $535,148,645 has been spent on beach nourishment in Carteret, New Hanover, and Brunswick Counties between 1939 and 2013.

Finally, I conclude this report by presenting my recommendations, which grew as a result of thorough research, analysis, and conversations with relevant stakeholders about feasibility and logistics. In brief, my recommendations include: continuing to ban hard-engineering structures on North Carolina beaches; building state-level support for sea level rise planning at the local level; accounting for the increased need for sand as a result of sea level rise into future nourishment projects; designing local-level tax plans to finance future nourishment projects; incorporating sand color into the Sediment Criteria Rules; and continuing to monitor nesting beaches for any changes in loggerhead nesting post-nourishment. These final recommendations are ambitious, and there is much information still unknown about the impacts of nourishment on loggerhead sea turtles, but long-term planning is essential to ensure a vibrant North Carolina economy and ecologically sustainable coastline.

Background

Loggerhead Nesting Biology

There are seven species of sea turtles worldwide. Four species – loggerhead, green, leatherback, and Kemp's ridley – are commonly seen in the waters of North Carolina. This final report focuses exclusively on the loggerhead sea turtle (*Caretta caretta*), the species most likely to be seen nesting on North Carolina beaches. To gain a thorough understanding of loggerhead nesting biology and historical nesting patterns I worked with Matthew Godfrey, the state sea turtle biologist with the North Carolina Wildlife Resources Commission (WRC). I also conducted a literature search to gauge the previous work done to understand loggerhead nesting.

In North Carolina, nesting occurs in the summer months, generally between May and October. These months coincide with peak tourism season, increased boating and beach activity, and hurricanes.

Female loggerhead turtles nest on average every 2.5 to 3.7 years (Richardson et al. 1978; Bjorndal et al. 1983) and tend to lay 3-6 clutches of eggs per season (Frazer and Richardson 1985; Hawkes et al. 2005), depositing an average of 100 to 126 eggs in each nest (Dodd 1988). However, hatchling sea turtles have very high mortality rates (Crowder et al. 1994). Threats to hatchling survival include, but are not limited to predation, marine debris ingestion and entanglement, illegal harvest of eggs, and human impacts on sea turtle nesting sites (STC 2013). Sea level rise "may cause loss and/or alteration of nesting beaches and egg mortality" (Fuentes et al. 2010, pg. 140).

Loggerheads in North Carolina generally show high nest site fidelity (Miller et al. 2003) but it is unknown why a female chooses a particular nesting site over another. "False crawls" occur when a female leaves the water, begins to crawl onto the beach – presumably to select a nesting site – but, perhaps due to unfavorable nesting conditions or disturbance, she returns to the water without nesting. Factors possibly affecting nest site selection include beach length, width, height, slope, orientation, and/or vegetation (Mortimer 1990). Given that females tend to return to the same nesting area in which they hatched, loss and/or modification of these nesting beaches due to sea level rise and/or human disturbance may have an impact on future loggerhead demography.

Sea turtles exhibit temperature-dependent sex determination (TSD), with cooler sand tending to yield males and warmer sand tending to yield females (Yntema & Mrosovsky 1980; Wibbels 2003). Sex is determined by sand temperature during the middle third of the incubation period (Mrosovsky & Pieau 1991). Many studies (Hawkes et al. 2007; Mrosovsky & Godfrey 2010; Fuentes and Cinner 2010; Fuentes et al. 2010) cite increasing temperature – and the correlating skewed sex ratio of females to males – as the most detrimental aspect of climate change to sea turtles. However, Fuentes et al. (2012) points out that in areas with cooler nest depth temperatures, and therefore areas likely to produce more male hatchlings, mitigating the impacts of sea level rise is "of greater relative importance than mitigating the impacts of increases in temperature on nesting grounds" (Fuentes et al. 2012, pg. 59). North Carolina is one of those areas, as it is at the northern limit of nesting for the Northwest Atlantic Ocean Loggerhead Sea Turtle distinct population segment.

Sea level rise is a concern for sea turtle survival because of the possible loss of nesting habitat (Fish et al. 2005; Hawkes et al. 2007; Fish et al. 2008). Sea turtles have survived climatic variations in the past (Hamann et al. 2007) but the rate at which sea levels are rising, coupled with pressures from coastal development, beachfront structures, beach driving, and coastal construction, is a challenge that they have not yet faced. The ability of sea turtles to adapt will depend, in part, on effective conservation and management strategies (Hamann et al. 2010).

Sea Turtle Management in North Carolina

Sea turtle management in North Carolina is complex and involves several federal and state agencies that differ in their management jurisdiction and philosophy (McClellan et al. 2011). Further complicating management and volunteer conservation efforts are the recent listing of critical habitats under the federal Endangered Species Act (ESA). It remains unclear how these new critical habitat designations will impact state, county, and municipal projects that impact sea turtles.

Sea turtles have been listed as threatened throughout their range under the ESA since 1978 (*43 FR 32800*). Under the ESA, the NMFS and the USFWS were assigned joint jurisdiction over the threatened and endangered species at the federal level. Pursuant to a joint memorandum of understanding, the NMFS has responsibility to manage sea turtles in the marine environment while the USFWS is responsible for the protection of sea turtles on land – during nesting, incubation, and hatching. Both the USFWS and NMFS are responsible for protecting sea turtles from anthropogenic stressors, such as dredging, nourishment projects, shoreline armoring, artificial lighting, fishing, and other threats (McClellan et al. 2011).

Despite being given the authority and responsibility to protect loggerheads under the ESA, critical habitats were not established upon their initial listing in 1978 (*43 FR 32800*). Decades later, in 2007, the Center for Biological Diversity, the Turtle Island Restoration Network, and Oceana petitioned requests for the loggerhead to be reclassified into distinct population segments (DPSs) and for critical habitats to be designated (NOAA 2011; NMFS 2013). The NMFS and USFWS created a Recovery Team charged with drafting a Recovery Plan for the Northwest Atlantic DPS (NMFS and USFWS 2008). In this Recovery Plan, the loggerhead sea turtles in Virginia, North Carolina, South Carolina, and Georgia were identified as part of the Northern Recovery Unit. Then, in September 2011, the NMFS and USFWS jointly issued a rule that modified the ESA listing from one global population to nine DPSs of loggerhead sea turtles (*76 FR 58868*). Loggerhead sea turtles in North Carolina are part of the Northwest Atlantic Ocean DPS and designated as threatened (*76 FR 58868*).

The Northern Recovery Unit of loggerheads is particularly important to conservation efforts because these loggerheads are genetically distinct from other Recovery Units in the southeast United States (NMFS and USFWS 2008). Additionally, because sand temperatures are inherently cooler in North Carolina, South Carolina, and Georgia than in Florida, this northern subpopulation produces a greater number of males that then are able to interbreed with the females from the other populations (Hawkes et al. 2007). Based on 26 years of data, Hawkes et al. (2007) found that North Carolina beaches produce 42% male hatchlings, whereas beaches in Florida only produce around 10% males.

As per the ESA, recovery plans and critical habitat must be designated and implemented by the NMFS and the USFWS within one year of listing. The USFWS and the NMFS submitted separate proposals for critical habitats (terrestrial environment and marine environment) in March 2013 and July 2013, respectively (*78 FR 18000; 78 FR 43005*). The final terrestrial and in-water critical habitats were designated in July 2014, with the terrestrial habitat covering 96.1 miles of North Carolina nesting beaches and the marine habitat encompassing migratory, wintering, and nearshore reproductive habitat in North Carolina waters (*79 FR 39755; 79 FR 39855; see Appendix D*). These critical habitat designations are relevant to this study, as they may impact the ability of coastal communities to obtain federal permits for beach protection projects. The designations mean that any federally funded, managed, or permitted projects or activities within these areas will have to undergo additional consideration before a federal permit is granted. This includes any federally funded dredging or beach nourishment projects (Shutak, 2014).

Under Section 6 of the ESA, the NMFS and the USFWS have the opportunity to create cooperative agreements ("Section 6 agreements") with state agencies to protect listed species such as sea turtles (McClellan et al. 2011). These cooperative agreements are an avenue by which funding is allocated to states for endangered and threatened species protection. In North Carolina, the state agency with Section 6 agreements for sea turtles with the NMFS and the USFWS is the Wildlife Resources Commission (WRC). As per the Agreements, the WRC has the responsibility to comply with the ESA and support the recovery plans for sea turtles in North Carolina. As a result, the WRC has authority to manage nesting females, incubating eggs, and hatchlings (McClellan et al. 2011). While the WRC is critical for the management of sea turtles on land, the relationship between the NMFS, which holds authority over sea turtles in the water, and the state of North Carolina, is different. The cooperative agreement between the NMFS and the WRC is for the management of sick, injured, or dead sea turtles that strand on the ocean or estuarine coastline in North Carolina. All other in-water management falls completely within the jurisdiction of the NMFS. The North Carolina Division of Marine Fisheries (DMF) holds ESA Section 10 permits with the NMFS to allow the incidental capture and mortality of sea turtles in state-managed fisheries (McClellan et al. 2011).

At the local level, volunteer groups are authorized by the WRC to conduct management activities with the sea turtles, such as protecting nests and assisting with inventories after nest emergence, in accordance with the ESA and recovery plan guidelines (MH Godfrey, personal communication, November 23, 2013). All activities at the state and local level are overseen by the USFWS. Nearly all coastal municipalities are recognized as sea turtle sanctuaries, meaning they will uphold the state laws that protect sea turtles. As such, they are bound to reduce all activities that negatively impact or disturb sea turtles. This includes minimizing artificial lighting during nesting season, which has an impact on both nesting females and emerging hatchlings as beach lighting can misorient sea turtles.

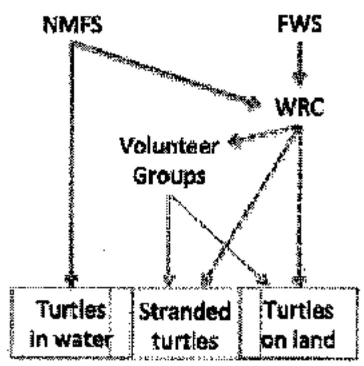


Figure 1. Sea turtle management structure in North Carolina. Flow chart of federal (bold solid line), state (dashed lines), and local (thin line) management entities and their management jurisdiction (boxes).

Management of North Carolina Beaches

Similar to the management network for sea turtles, the management of beach protection projects in North Carolina follows a complex structure, with several federal, state, and local government stakeholders. At the federal level, a multitude of agencies have the responsibility to protect areas from shoreline erosion and flooding, including: the U.S. Army Corps of Engineers (USACE), the Federal Emergency Management Agency (FEMA), the National Oceanic and Atmospheric Administration (NOAA), and agencies within the Department of Interior, including the United States Geological Survey and the Bureau of Ocean Energy Management.

The legal mandates that influence management of shoreline erosion are the various Water Resources Development Acts (WRDA), the Coastal Zone Management Act (CZMA), and Section 111 of the River and Harbor Act of 1968 (NOAA Coastal Services Center 2013). The

WRDA gives the USACE authority to administer any water resource development project – which includes nourishment projects – while the River and Harbor Act of 1968 authorizes the USACE to participate in cost-sharing and construction of shoreline protection projects.

In addition to these legal mandates, there are laws regulating construction projects themselves. The USACE has the authority to construct, operate, and maintain projects, but also has the responsibility to comply with Section 404 of the Clean Water Act (CWA) and the National Environmental Policy Act (NEPA) water quality guidelines. NEPA requires an Environmental Impact Statement (EIS) or Environmental Assessment (EA) for all major construction projects, which include beach nourishment and terminal groin construction. This environmental assessment is integrated into the USACE 6-step planning processes before construction begins. As per the CWA, Section 404 permits for coastal construction projects are coordinated through the USACE district office in Wilmington, North Carolina (USACE 2013).

The CZMA requires all federal projects to be consistent with the approved state coastal zone management program's enforceable policies, or the North Carolina Coastal Area Management Act (CAMA). When CAMA was adopted in 1974, the North Carolina General Assembly gave the Coastal Resources Commission (CRC) the authority to create rules for both CAMA and the North Carolina Dredge and Fill Act (DCM 2013), another law regulating beach fill projects in the state. In addition to rule-making, the CRC granted beach nourishment permitting authority to the Division of Coastal Management (DCM). DCM has the responsibility to coordinate with local and county governments, the state WRC, Division of Marine Fisheries, and Division of Water Resources, and the federal USFWS, NOAA, and USACE, in order to minimize adverse environmental impacts and impacts to wildlife. The fact that sea turtles are a threatened species under the ESA increases the difficulty in obtaining permits, because many agencies must coordinate to ensure the protection of critical habitat. The designations of marine and terrestrial loggerhead critical habitat further complicate the process because it remains unclear what additional considerations county and municipal governments will have to undergo in order to receive a federal permit for any activity that may impact sea turtles. Recent changes in North Carolina legislation, such as the reconfiguration of the CRC, add yet another layer of complexity to an already multipart management structure, as seen in Figure 2.

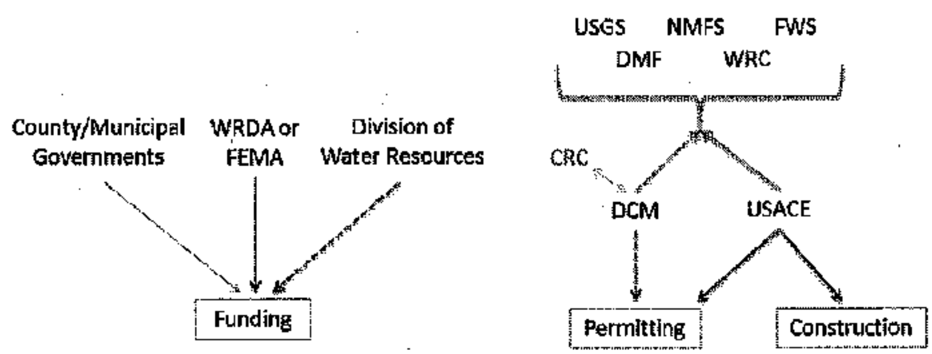


Figure 2. Beach protection management structure in North Carolina. Flow chart of federal (bold solid blue line), state (dashed blue lines), and local (thin blue line) management entities and their management jurisdiction (boxes). Grey lines represent coordination efforts between the listed agencies.

Sea Level Rise Planning in North Carolina

Currently, factoring in future sea level rise is not required when planning beach nourishment projects. Beginning in the 2011-2012 Session, the North Carolina General Assembly began making changes to state legislation that facilitate coastal development and shoreline protection and make conservation and sea-level rise planning more challenging. Contention has been brewing in the state over the rate at which sea-levels are rising ever since the 2010 CRC Science Panel released the "North Carolina Sea-Level Rise Assessment Report", which recommended planning for 1 meter of sea-level rise (pg. 12). As a result of this controversy, House Bill 819/ Session Law 2012-202 prohibited any "rule, policy, or planning guideline that defines a rate of sea-level change" (HB 819 Section 2(a)). Additionally, HB 819 states that "the General Assembly does not intend to mandate the development of sea-level policy" and that "the Commission shall be the only State agency authorized to define rates of sea-level change for regulatory purposes" (HB 819 Section 2(a)). Therefore, at the state-level, sea-level rise planning is neither required nor allowed. Finally, HB 819 Section 2(b) mandates that the State cannot define rates of sea-level rise until July 1, 2016. Section 2(c) of HB 819 mandates that the CRC Science Panel should create a follow-up "North Carolina Sea Level Rise Assessment Report" by March 31, 2015.

The 2011-2012 Session also saw a change to the thirty-year ban on hardened structures on the North Carolina shoreline. Senate Bill 110, passed in 2011, allowed for up to four trial terminal groins to be considered for construction. Four permit applications have been submitted to the USACE for terminal groin construction projects at Holden Beach, Ocean Isle Beach, and Bald Head Island in Brunswick County, and Figure Eight Island in New Hanover County (NCCF 2013). Before any of these structures will be constructed, they must go through a series of environmental reviews, including a formal Environmental Impact Statement (EIS). None of the areas have completed this review process or applied for state permits yet. It should be noted that during the 2013-2014 Session, Senate Bill 151/Session Law 2013-384 (SB 151) was passed into law, which explicitly stated that plans for terminal groins are *not* required to address sea-level rise.

Also in the 2013-2014 Session, Senate Bill 402 – the 2013 Budget – replaced all but four of the fifteen CRC, decreased the number of seats from fifteen to thirteen, and removed the dedicated conservation seat. This sweeping change is relevant because the CRC maintains the authority to create rules about sea-level rise planning in North Carolina (per HB 819). It is too early to know how the new members will prioritize sea-level rise planning, but much of the institutional knowledge about the 2010 CRC Science Panel's North Carolina Sea-Level Rise Assessment Report has been lost with the reorganization of the CRC.

After years of no public discussion, the updated Sea Level rise Assessment Report was finally on the agenda[2] during the May 2014 CRC meeting in Atlantic Beach. DCM staff and CRC commissioners discussed the rules imposed by HB819 and the timeline for new ad hoc appointments the Science Panel. On June 11, 2014, CRC Chairman Frank Gorham appointed Gregory "Rudi" Rudolph to fill one of four vacancies on the Science Panel. The Chairman

[2] May 2014 CRC Meeting Agenda can be found at: http://portal.ncdenr.org/web/cm/may-2014-agenda.

chose not to appoint any additional scientists to the panel, stating "I believe with pretty good certainty that we have all the expertise we need on the panel to produce a good report" (Tursi 2014b). As per HB819, an updated draft report is still due by March 31, 2015. A major discrepancy between this study and the 2010 report is that this 2015 study will be limited to only a 30-year forecast of sea level rise to remain consistent with the 30-year erosion rate for oceanfront setbacks and the 30-year mortgage plans for homes (Tursi 2014a). Therefore, the new analysis will only estimate how much the oceans may rise between now and 2045. The previous study projected sea level rise out to 2100. This shorter timeline undermines the long-term beach nourishment planning horizons usually done by North Carolina counties and municipalities. Many historic nourishment projects were permitted for 50 years, and areas like Carteret County seek to create the Bogue Banks Beach Master Nourishment Plan for up to 50 years into the future.

Other Relevant Stakeholders

In addition to all of the federal, state, and local government stakeholders mentioned in the previous sections, other key stakeholders are coastal residents, property owners, and tourists, as well as development interests, coastal business owners, and municipalities. Oceanfront property owners tend to have the most interest in beach protection, because their property is directly impacted by beachfront erosion and nourishment projects. Additionally, many oceanfront property owners pay increased property taxes; of which a portion goes toward financing these beach protection projects (GL Rudolph, personal communication, November 6, 2013). The local town governments and county commissions are instrumental to the process if local residents push for a nourishment project or engineered structure to protect their beachfront property (Annabelle 2010a).

NC-20, a partnership that supports economic development in the 20 North Carolina coastal counties and whose leaders have publically denounced the validity of sea level rise, is another major stakeholder. This organization was the driving force encouraging the watering-down of language in the 2010 Sea-Level Rise Assessment Report and was instrumental to the final passage of HB 819. NC-20 will almost certainly continue to lead lobbying efforts against adopting a rate of accelerated sea level rise, as suggested by the first Sea-Level Rise Assessment Report.

Other major stakeholders include the Carteret County and New Hanover County Shore Protection Managers, Greg (Rudi) Rudolph and Layton Bedsole, respectively. Organizations like the Carteret County Shore Protection Office play a key role lobbying legislatures, taxpayers, and county and municipal governments to secure funding for nourishment projects (Annabelle 2010a).

Matthew Godfrey, the Wildlife Resources Commission sea turtle biologist, is also a key stakeholder, as his work focuses on sea turtle protection within the state. Additionally, there are 21 sea turtle volunteer groups across the state (NC Sea Turtle Project 2013), contributing the annual equivalent of approximately $630,000 in volunteer labor to monitor and protect nesting beaches and hatchlings (MH Godfrey, personal communication, December 4, 2013). These volunteer groups have been given the authority to manage nesting sea turtles and hatchlings under the WRC, and they have had a tremendous impact on both the protection and the public perception of the species.

Public perception of sea turtles, beach nourishment, and sea level rise are central factors influencing this issue. Tourists, for example, are major players on the coast – the domestic tourism industry in Carteret, New Hanover, and Brunswick counties generated $1.187 billion in revenue in 2012 (Department of Commerce 2013). Undoubtedly, tourists visit the North Carolina coast mostly for the beaches. If beaches erode, then tourism, and its associated revenue, suffers. Beach protection itself stems from the desire of individuals or municipalities to protect the beach. The public's willingness or desire to protect sea turtles should also be considered, as some tourists come to North Carolina specifically with the hope of seeing a nesting loggerhead sea turtle. Delgadillo (2012) conducted public interviews during the summer of 2012 and estimated that the presence of sea turtles on Bald Head Island resulted in a total value of $49 million, and that turtle eco-tourism could generate $33 million for Bald Head Island annually.

Summary of Findings

Historical North Carolina Nourishment Projects

Beach protection projects in North Carolina consistently begin at the local level. Each project is initiated by the desire of a coastal county or municipality to protect their beaches. Once an area decides to pursue a nourishment project, cost-sharing is almost always required between federal, state, and local governments. The local governments play an instrumental role in acquiring funding for these projects via bonds and taxation. While the issuance of bonds is the main local funding source, each county and some municipalities have an occupancy tax that generates a portion of local funding, in addition to taxation revenues from oceanfront private property (GL Rudolph, personal communication, November 6, 2013).

Bin et al. (2007) estimated the loss of property value in Carteret and New Hanover Counties under different sea level rise scenarios. According to this study, Carteret County could see losses from 1% to 3% depending on the amount sea levels rise (0.36 feet to 2.66 feet, respectively). New Hanover County is estimated to lose about one percent of its total coastal property value to sea level rise by 2080 (BIMP 2011, pg. IV-4).

From 1950-1993 annual renourishment project costs across the state averaged $3.4 million, but since the mid-1990s, as demand for nourishment projects grew, costs increased up to $100 million annually (BIMP 2011, pg. IV-7). More recently, due to federal budget cuts, there is a shift away from relying on federal funding and towards entirely locally-funded projects. Carteret County in particular is looking at ways they can secure long-term local funding for beach nourishment (GL Rudolph, personal communication, November 6, 2013).

For my analysis, I obtained historic beach nourishment data from both the North Carolina Division of Coastal Management (DCM) and the Program for the Study of Developed Shorelines at Western Carolina University (PSDS). I cross-checked the databases to eliminate discrepancies and, after speaking with the database managers at both organizations, determined that the PSDS database is the most up-to-date and complete dataset to use for my analysis.

I first sorted the.nourishment data by county and beach. The database had nourishment information through 2013, but costs were in 2012 dollars. However, for Carteret County only 64% (28/44) of the projects listed in the database listed total project costs. In New Hanover County only 63% (26/41) listed costs, and in Brunswick County 68% (42/62) listed costs. Unable to do a complete analysis with about 40% of the data missing, I chose to estimate total project costs in 2014 dollars ($) by using the Consumer Price Index (CPI) conversion factors and a series of interpolations.

For each project that already listed cost, I estimated the cost of each project in 2014$ using the CPI conversion factor for that year. Once I had a total cost estimate for each project in 2014$, I calculated the 2014$ cost per cubic yard of sand. Next, I found the average cost per cubic yard for all the beaches within each county using the volume of sand placed as the denominator. Using this average cost per cubic yard, I was able to then interpolate the cost of projects that did not originally have a cost listed. For example, given that the average cost per cubic yard in New Hanover County is $6.11, I used that average to estimate the total cost of each project of which there is a record of the cubic yardage but not of cost (91% of the projects in New Hanover County had volume listed but only 63% listed project cost). As an example, the PSDS database showed that in 1996, 3,500,000 cubic yards of sand were placed on Carolina Beach and Kure Beach in New Hanover County, but there is no record of the cost of that project. If the average cost per cubic yard is $6.11 (2014$), then I estimated the total cost of that rather large project to be $21,385,000 (2014$).

To the best of my knowledge, Table 1 represents the most comprehensive estimate of the total cost of beach nourishment in Carteret, New Hanover, and Brunswick Counties to date. The PSDS "Beach Nourishment Viewer"[3] unfortunately underestimates total costs across the state since only 34% of the 274 projects between 1939 and 2013 actually list project cost. These three counties alone have spent the equivalent of $535 million on beach nourishment since 1955.

[3] Program for the Study of Development Shorelines North Carolina beach nourishment database: http://beachnourishment.psds-wcu.org/results.php?state=NC

County	Years	Total Volume Placed (cy)	Previously Estimated Total Cost	My Estimated Total Cost to Date	Average Cost per Cubic Yard	Average Cost per Project
Carteret	1958-2013	27,346,801	$186,258,631	$200,385,767	$13.25	$4,554,222
New Hanover	1955-2013	26,903,664	$129,212,589	$159,281,036	$6.11	$3,792,406
Brunswick	1971-2013	23,321,059	$129,688,491	$175,481,842	$6.91	$2,830,352

Table 1. This table summarizes all of the completed beach nourishment projects on Carteret, New Hanover, and Brunswick counties to date. All costs are in 2014 USD. There have been a total of 148 projects in these three counties, with an estimated total cost of $535,148,645. The Previously Estimated Total Costs are the original estimated costs of nourishment as listed in the PSDS Beach Nourishment Viewer, but did not take into account 66% of the projects since cost was not listed in the PSDS database. Areas included in the Carteret County analysis: Fort Macon State Park, Atlantic Beach, Pine Knoll Shores, Indian Beach/Salter Path, Emerald Isle. Areas included in the New Hanover analysis: Carolina Beach, Kure Beach. Areas included in the Brunswick County analysis: Bald Head Island, Caswell Beach, Oak Island, Holden Beach. Fort Fisher State Recreation Area (New Hanover County) was excluded from this analysis as there is no record of beach nourishment within the SRA boundaries. Figure Eight Island, Wrightsville Beach, and Masonboro Island (New Hanover County), and Ocean Isle Beach (Brunswick County) were also excluded since they were not designated critical habitat for nesting loggerhead sea turtles.

Historical Loggerhead Nesting in North Carolina

Since 2000, there have been 10,882 loggerhead sea turtle nests laid on North Carolina beaches. 7,106 (65.3%) of those nests were laid between Bogue Banks and the South Carolina border – the southern beaches identified in the critical habitat designations. 4,082 (37.5% of the total) nests occurred on the beaches within my study area (see Table 2). Fort Fisher State Recreation Area, Bald Head Island, and Caswell Beach support the three highest nesting densities in the state (See Appendix B) with Caswell Beach far exceeding others with an average 10.49 nests per kilometer. Atlantic Beach, Fort Fisher SRA, and Bald Head Island average more false crawls than confirmed nests (0.87; 0.85; 0.79:1, respectively) while Emerald Isle, Carolina Beach, and Kure Beach averaged almost two confirmed nests to one false crawl from the years 2000-2013 (1.54; 1.91; 1.63:1, respectively).

Beach	Length (km)	Avg Nests per Year	Nest Density	Avg False Crawls per Year	False Crawl Density	Nest to False Crawl Ratio
Fort Macon State Park	1.70	3.00	1.76	1.00	0.59	3 : 1
Atlantic Beach	8.10	3.64	0.45	4.18	0.52	0.87 : 1
Pine Knoll Shores	7.50	5.62	0.75	6.08	0.81	1 : 1
Indian Beach/Salter Path	3.90	4.00	1.03	2.08	0.53	1.92 : 1
Emerald Isle	18.00	16.86	0.94	10.93	0.61	1.54 : 1
Carolina Beach	6.44	7.79	1.21	4.07	0.63	1.91 : 1
Kure Beach	4.83	9.21	1.91	5.64	1.17	1.63 : 1
Fort Fisher SRA	4.83	24.07	4.99	28.43	5.89	0.85 : 1
Bald Head Island	14.48	70.00	4.83	94.85	6.55	0.79 : 1
Caswell Beach	4.83	50.64	10.49	44.00	9.11	1.15 : 1
Oak Island	16.09	63.93	3.97	43.29	2.69	1.47 : 1
Holden Beach	11.27	34.57	3.07	30.43	2.70	1.14 : 1

Table 2. Beaches listed were designated critical nesting habitat for loggerhead sea turtles in July 2014. Thick blue lines separate beaches by county, with beaches listed north to south in Carteret County, then New Hanover County, then Brunswick County.

In the entire state, nesting is gradually increasing (see Figure 3 – see Appendix E for regressions of individual beaches). One caveat to this assertion is that the amount of volunteer effort spent searching for loggerhead nests and false crawls has also increased. If more volunteers are scouring the beaches searching for turtle tracks, it is likely that more tracks are being counted. For example, Atlantic Beach has only had a consistent volunteer nest-monitoring group since 2003, the Atlantic Beach Sea Turtle Patrol. Other beaches in the state, such as Masonboro and Lea-Huttaf Islands, have had intermittent monitoring effort. Future studies should attempt to control for changes in monitoring effort, as it may bias estimates of the number of loggerhead sea turtle nests. It is also entirely plausible, however, that the population is, in fact, recovering – the ultimate aim of the ESA. Because of these unknowns, and because this is an ESA listed species, it is vital to understand how beach construction, manipulation, and other aspects of nourishment impact loggerhead sea turtle nesting.

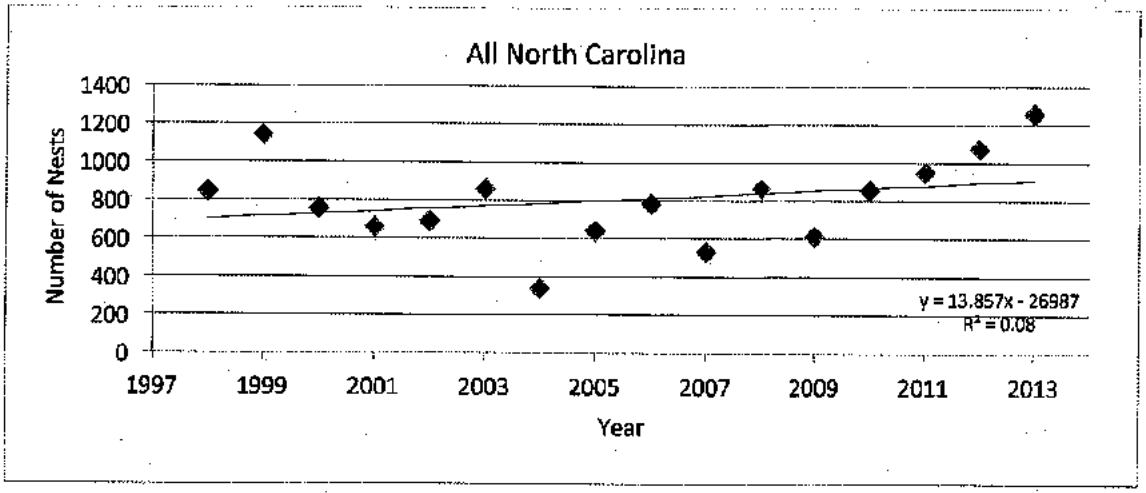


Figure 3. Number of nests occurring within the entire state of North Carolina from 1998 to 2013. See Appendix E for individual beach regressions. Nesting data obtained through the North Carolina WRC.

Impacts of Nourishment on Nesting

The Economic Analysis for Loggerhead Proposed Terrestrial Critical Habitat produced by Industrial Economics, Inc. (2013) includes "in-water and coastal construction" and "sand placement" as key activities that may have an impact on loggerhead critical habitat. The use of heavy construction equipment – such as bulldozers and pipelines – can compact the placed sediments, making conditions unsuitable for nest digging. Additionally, dredge equipment in the water can accidentally kill or injure sea turtles. Under Section 3(19) of the ESA, any dredge action that would "harass, harm, pursue, hunt, shoot, wound, kill, trap, capture, or collect, or to attempt to engage in any such conduct" is considered a "take". In North Carolina, the USACE administered a National Marine Fisheries Biological Opinion in 2007 that all civil works and regulatory projects must operate under (GL Rudolph, personal communication March 10, 2014). The Biological Opinion sets incidental take limits and provides suggestions for environmental windows during which construction projects may occur. In North Carolina, either hopper dredging or pipeline dredging may be used to transport borrow sand onto the receiving beach. For hopper dredges, the environmental window is January 1 to March 31 of every year; for pipeline dredges, the window is November 16 to April 30 (GL Rudolph, personal communication March 10, 2014). From 1992 to 2006, only one sea turtle was killed in the Morehead City vicinity while dredging within the January 1 to March 31 window, while 20 sea turtles were taken while dredging outside of this window (GL Rudolph, personal communication May 22, 2014). Under certain situations, these windows are sometimes not adhered to and construction continues into loggerhead nesting season, which is generally May to October. It is important to note that there is currently a movement among dredging contractors and consultants to extend the environmental windows in North Carolina beyond these guidelines (M Slagel, personal communication May 19, 2014). Their argument is that by allowing projects to occur for an extra couple of months, it allows applicants more flexibility with planning and scheduling, drives down costs, and increases competition among dredging companies. This, of course, incurs a cost of potentially more sea turtle takes.

A Web of Science and Google Scholar literature review revealed there are no published studies of the impacts of beach nourishment specifically on North Carolina loggerhead sea turtle nesting. Most studies to date have focused on Florida or South Carolina and draw negative correlations between nesting success and nourished beaches (Steinitz et al. 1998; Rumbold et al. 2001; Dean 2002; Byrd 2004; Brock et al. 2009; Long et al. 2011). However, others point out that nourishment may create beach nesting habitat that would otherwise be unavailable (Crain et al. 1995).

During a seven-year study on Jupiter Island, Florida, Steinitz et al. (1998) found sea turtle nesting decreased in the nesting seasons immediately following beach nourishment. Their analysis also revealed a greater frequency of false crawls in the year after nourishment, perhaps due to overly compacted sand and construction berms that make it difficult for a female to dig or to navigate the nesting beach. They found that it took two years – the third nesting season – for nesting success on the nourished beach to be statistically the same as the control beach (without nourishment), although it took only one year for the beach profile to stabilize. Lund (1986) was the first to capture the idea that it takes one to two years for a beach profile to stabilize. There seems to be a lag of approximately one year between when a profile equilibrates and when nesting success rebounds.

Rumbold et al. (2001) also found that loggerhead nesting success decreased in the first year after nourishment on Jupiter Island, Florida, but then bounced back the second year. Likewise, false crawls increased on the nourished beach the first year after nourishment, but remained at approximately a 1:1 ratio on the unnourished control beach. The decreased nesting success and increased false crawl-to-nest ratio suggests a negative impact on loggerhead nesting the season immediately following beach nourishment.

Byrd (2004) conducted an analysis in South Carolina and found that "beach nourishment has the potential to significantly affect loggerhead sea turtle nesting" (pg. 45), but that the effects varied among different beaches in her study site. Brock et al. (2009) also found a decreased loggerhead nesting in the first year immediately following nourishment and that an altered beach profile in Florida was the likely cause. Physical attributes of the nourishment material did not seem to hinder nesting. Their conclusion came as a result of the increase in loggerhead nesting two seasons post-nourishment.

The greatest concern regarding the effects of beach nourishment stem from an altered shoreline profile; particularly from the existence of a scarp that can hinder the ability of nesting females to move into areas of preferred nesting conditions (Dean 2002). Long et al. (2011) used LiDAR imaging to study a hurricane-impacted Florida beach and subsequent restoration to see how sea turtle nesting success was impacted before and after alteration. Their multiple regression models revealed that slope, volume, and beach profile may be the most significant variables prompting loggerheads to select a certain nesting site. Their most notable finding was that a change in the beach profile was negatively correlated with loggerhead nesting success, suggesting that beach profile is a key driver in nest site selection.

When the USACE nourishes a beach, they build a "constructed berm" that extends the shoreline profile seaward (see Figure 4), but they do not manipulate the new profile to recreate the original profile. The "design profile" is what the constructed berm is supposed to equilibrate to. It is assumed that over time – usually 1 year – the profile will adjust naturally to look more like the design profile. The studies in Florida suggest the lag between completed construction and corrected profile may be negatively influencing loggerhead sea turtle nesting (Brock et al. 2002). Depending on how close the end of the construction is to nesting season, this lag may delay or deter some nesting approaches. If a female does successfully nest close to the shoreline on the newly constructed berm, there is a risk of the nest washing out as the profile equilibrates.

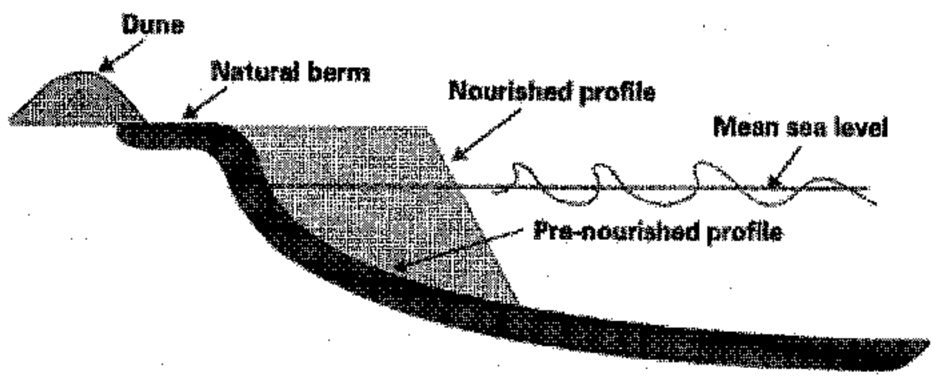


Figure 4. Taken from ASBPA Shore Protection Assessment on Beach Nourishment: How Beach Nourishment Works (2007). This image shows the typical post-construction nourished profile in relation to the pre-nourished profile. The nourished profile is much more abruptly sloped and may deter nesting female loggerhead sea turtles.

Other concerns for the impacts of nourishment on sea turtle nesting include the quality of sand placed on the beach. DCM addressed most of these issues in February 2007 with the adoption of 15A NCAC 07H .0312 Technical Standards for Beach Fill Projects[4], also known as "Sediment Criteria Rules." These rules mostly focus on sediment size, to avoid placing overly course or fine sand onto the recipient beach. To determine compatibility, the rule requires at least five transects to occur along the native beach, with at least thirteen sediment samples taken along each transect. Almost all of North Carolina sand today is taken from federally or state maintained navigation channels. When dredging for sand within the boundaries of these channels, five cores are required and the sediment must be less than 10% fine-grain – less than 0.0625 millimeters. It is critical to note that sediment borrowed from these regularly maintained navigation channels may not require repeated sampling. After the navigation channel has been sampled twice, with one dredge event in between, and both samples were compatible, then that sampling data may be used to show compatibility for future projects within the immediate area (M Slagel, personal communication May 19, 2014). Other rules for sampling the borrow

[4] The North Carolina Technical Standards for Beach Fill Projects, or Sediment Criteria Rules, can be seen here: http://dcm2.enr.state.nc.us/rules/07H%20.0312%20-final.pdf

sediment include sonar and bathymetric imaging and evenly-spaced core sampling (Limber and Warren 2006). Again, the exception to this rule is sand borrowed from navigation channels, where fewer cores must be taken and no imaging is necessary due to technical and safety limitations.

Through my research I developed concems about the toxicity, color, and quality of sand that has been dredged from harbors and inlets since these areas are often the source of material for the majority of North Carolina's nourishment projects and are sinks for contaminants and toxins. Placing this material on the beach can, over time, have an effect on sea turtle survival (Crain et al. 1995). Originally this sand may have been on a beach and washed out into the harbor or inlet, but after continued exposure to boat traffic and runoff pollution there is a chance that this sand is of poorer quality than that which originated on the beach. Both the USACE and the Sediment Criteria Rules limit the amount of fine-grain sediment allowed to be placed on the beach to less than 10%. Typically, it is the fine silt or muddy material that is at greater risk of holding higher toxin levels and this material is not placed on the beach (M Slagel, personal communication May 19, 2014). However, given the ability to avoid re-sampling of regularly maintained navigation channels discussed above, the state may run the risk of allowing lesser quality (more contaminated) sand onto the beach over time.

It is also important to note that the Sediment Criteria Rules do not specify sediment color as a criterion. This may be a critical neglect on the part of the state, especially with water and air temperatures already increasing as a result of climate change. As mentioned before, loggerhead sea turtles exhibit TDS, meaning their sex is determined in the middle third of the incubation period (Mrosovsky & Pieau 1991). It has been found that nests incubated on darker (warmer) beaches will produce almost exclusively females, while nests incubated on lighter beaches tend to have a mix of males and females (Yntema & Mrosovsky 1980; Wibbels 2003). The USACE also does not use a color chart or specific rules to define sediment compatibility, but they do attempt to match new sediment to the native beach (Limber and Warren 2006). See Figure 5 for a comparison between the USACE Federal Standards and the North Carolina Sediment Criteria Rules.

		USACE	North Carolina
Native Beach	Characterization required?	YES	YES
	Beach transect spacing	5,000 ft	5,000 ft
	Beach profile sampling	Active beach profile sampled from dune toe to offshore bar; more offshore samples than onshore	≥13 samples along active beach profile at specific morphodynamic zones; half offshore and half inshore
Borrow Site	Bathymetric imaging	YES; variable coverage	YES; 100% coverage
	Subsurface seismic profiling	YES; variable line spacing	YES; 1,000 ft line spacing
	Core density	1,000 ft grid spacing	1,000 ft grid spacing; 2,000 ft grid spacing if Offshore Dredge Material Disposal Site (ODMDS)
Sediment Compatibility	Determination of sediment compatibility	Overfill factors; fine sediment may not exceed 10%	Grain size thresholds ("Fine", "Granular", and "Gravel") tied to native beach
	Carbonate content allowable	Unspecified	≤15% above native content

Figure 5. Adapted from Limber and Warren (2006). Comparison of North Carolina Sediment Criteria Rules and the USACE Federal Standards for beach fill sediment.

The 2013 Review of Biological and Biophysical Impacts from Dredging and Handling of Offshore Sand produced by the Bureau of Ocean Energy Management (Michel et al. 2013) reported that impacts from dredge activities in the water that could potentially affect loggerheads include: sound, increased sedimentation and turbidity, water quality, changes to the borrow site, and direct interactions with the dredge vessel. The report estimates that the sea turtle "take" rate is one turtle per 3.8 million cubic yards of dredged sand. To mitigate a "take", the USACE implemented national protection methods in 1992 that include: adhering to dredging windows for certain dredge types and locations; requiring dredges to have drag head turtle deflectors; and observer efforts to capture and relocate any sea turtles seen in the vicinity. However, the USACE South Atlantic Division Regional Biological Opinion did not set environmental window restrictions on the use of hopper dredges in North Carolina (Michel et al. 2013, pg 4-121). While the USACE does not set restrictions, permits for dredging and nourishment must still be obtained from the state Division of Coastal Management, which requires that:

> In order to protect threatened or endangered species and to minimize adverse impacts to offshore, nearshore, intertidal and beach resources, no excavation or beach nourishment activities shall occur from April 1 to November 15 of any year without prior approval from the Division of Coastal Management in consultation with the Division of Marine Fisheries, the North Carolina Wildlife Resources Commission, and the US Army Corps of Engineers (Permit Number 86-12 for dredging and nourishment of Emerald Isle to Pine Knoll Shores, pg. 1).

Additionally, the state permit requires the dredge operator to immediately cease operation for any of the following scenarios: 1) if the sand is deemed non-compatible; 2) if a turtle crawl or nest is identified within the nourishment area; 3) if there is an incidental take of a sea turtle by the dredge. State permits also require monitoring of beach compaction and escarpments for the next three nesting seasons immediately following completion of the nourishment project.

Discussion and Recommendations

The North Carolina BIMP Final Report calculated the socio-economic value of North Carolina beaches and inlets to recreationists (2011, IV-13). These "Beach Recreation Annual Direct Expenditures" estimate the total amount spent by visitors within each county/beach. Table 3 summarizes both the 2011 BIMP data and my 2014 beach nourishment cost analysis. If the average cost of a project in Carteret County is $4,544,222, one project costs about 2% of the annual revenue brought into the county by way of beach recreation. Of course not all of the annual direct expenditures are retained by the county/beach, and only a small portion of tax revenues (a mere 3.6% of the Tourism Occupancy Tax) goes directly to funding beach nourishment. However, given that wide, sandy, stable beaches are a prerequisite for the beach recreation and tourism industries, there are clear economic incentives for protecting North Carolina beaches.

Orrin Pilkey suggests that the only long-term solution to sea level rise and shoreline change is strategic retreat (Pilkey 2012). Immediate retreat is unfortunately not seen as a viable option for many wealthy and influential beachfront property owners and municipalities. Allowing the system to migrate landward naturally with sea level rise is only an alternative in undeveloped barrier islands, such as Shackleford Banks, Bear Island, and Masonboro Island, where the lack of permanent structures allows sand to overwash and redeposit on the backside of the barrier island. In developed areas, permanent structures – private homes, businesses, roadways – obstruct the natural sand flow. In these areas, we will likely see increased coastal squeeze as barrier islands are unable to be replenished and migrate landward (Fish et al. 2005). Of the sixteen strategies offered in Fuentes et al. (2011) to mitigate the impact of sea level rise on nesting sea turtles, I have found that only four are politically, economically, and logistically feasible in North Carolina: beach nourishment, using groins and jetties, banning permanent hard-engineering structures, and planning for sea level rise.

County	Beach	Beach Recreation Annual Direct Expenditures	Average Cost Per Nourishment Project
Carteret		**$238,730,493**	**$4,554,222**
	Fort Macon SP	$5,154,950	
	Atlantic Beach	$49,558,267	
	Pine Knoll Shores	$18,836,295	
	Indian Beach/Salter Path	$11,010,834	
	Emerald Isle	$128,693,187	
New Hanover		**$169,813,929**	**$3,792,406**
	Figure Eight Island*	No Data	
	Wrightsville Beach*	$104,128,871	
	Masonboro Island*	No Data	
	Carolina Beach	$50,602,615	
	Kure Beach	$15,082,444	
	Fort Fisher SRA	Included in Kure Beach	
Brunswick		**$203,546,079**	**$2,830,352**
	Bald Head Island	$18,064,623	
	Oak Island (Includes Caswell Beach)	$38,546,230	
	Holden Beach	$55,990,520	
	Ocean Isle*	$55,622,777	
	Sunset Beach/Bird Island*	$35,133,558	

Table 3. Summarizes the annual direct expenditures on beach recreation for each county and beach and compares these values to the average cost of a beach nourishment project. All data is in 2014$. Items followed by an * are not included in my study area and therefore do not contribute to the average cost of beach nourishment figures. I included these beaches only to show where each of the total counties' expenditures are generated.

Recommendations

1. Continue to ban hard structures on beaches.

North Carolina's nearly thirty-year ban of permanent hard structures on beaches is commendable and should be noted. In 1985, the CRC concluded that hard structures may cause irreversible damage to the state's beaches and adopted a resolution banning oceanfront shoreline hardening. This regulatory ban was in place until 2003 when the North Carolina General Assembly adopted a rule banning the construction of permanent hard-engineering structures on beaches, with an exception for immoveable historic buildings or for maintaining vital waterways (NCCF 2013).

However, pressure to allow for hard structures materialized in 2011 when Senate Bill 110 was signed into law and let up to four trial terminal groins to be considered for construction, one each at Holden Beach, Ocean Isle Beach, Bald Head Island, and Figure Eight Island. Experts caution against advocating for other hard-engineering structures, such as terminal groins and jetties, because they can act as barriers to females approaching the area to nest. Adult females may attempt to crawl around them, move to another area of the beach – provided another area is available – or abort nesting entirely. Additionally, construction during nesting season may destroy nests, disturb nesting females, or harm emerging hatchlings (NMFS and USFWS 2008). While beneficial in the short-term for mitigating the effects of beach loss and sea level rise, terminal groins may actually hinder the ability of beaches to rejuvenate over time (Fish et al. 2008). Holden Beach, Ocean Isle Beach, Bald Head Island and Figure Eight Island, along with the USACE should not only include sea level rise in the four terminal groin project plans, but I also highly recommend that groin construction, if permitted, avoid sea turtle nesting season.

2. Garner state-level support for sea level rise planning.

The North Carolina Sea Grant Strategic Plan for 2014-2017 calls for incorporating the prospect of rising sea levels in new coastal investment plans and policies. Mentioned in the 2012 "Addendum to the North Carolina Sea Level Rise Assessment Report of 2010," several other states and agencies are prioritizing sea level rise planning, including: Maine, Delaware, Louisiana, California, Florida, and the USACE (Addendum 2012, pg. 5). However, House Bill 819/Session Law 2012-202 mandated that the State cannot define rates of sea level rise for policy or planning purposes until July 1, 2016, but it instructs the CRC Science Panel to create a follow-up "North Carolina Sea Level Rise Assessment Report" by March 31, 2015. The ruling requires the CRC Science Panel to include a comprehensive review of the best scientific literature available, hopefully minimizing bias and sparking an honest conversation about the threat of sea level rise in North Carolina.

The panel met for the first time to discuss the new report in July 2014 and a draft is expected on time. This draft should include the Intergovernmental Panel on Climate Change 5th Assessment Report, as well as North Carolina-specific peer-reviewed sea level rise projections, and associated economic and ecological analyses. One such analysis and interactive map may be the "North Carolina and the Surging Sea" report released in late July 2014 by Climate Central. This nonprofit, non-partisan research group predicted intermediate flooding level of 4 feet above the high tide line, which would put 2,045 square miles of land and $8.8 billion in property value at risk of inundation in North Carolina.

The CRC directive approved on May 15, 2014 limits the Science Panel to only project sea level rise for the next 30 years, with an update every five years. This short-term horizon will make it difficult for county and municipal governments to develop long-term economically and ecologically responsible policies. While I recommend the CRC adhere to Section 2(c) of HB 819 and adopt a 30-year projection of sea level rise for which county and municipal governments can plan for immediately, it is also important that the state consider planning for a longer time horizon.

3. Account for the increased need for sand in future projects.

The level of sea level rise agreed upon by the CRC should be incorporated into the nourishment permitting process. Furthermore, the DCM should require shoreline protection managers and the USACE to incorporate the increased need for sand into future nourishment projects to avoid underestimating how much sand will be needed and the total lifetime cost of each project. The shoreline protection offices would have to account for an additional volume of sand needed for each project, and increase that amount for future maintenance projects as sea levels rose. Both the Bogue Banks Master Beach Nourishment Plan (Moffatt & Nichol, et al. 2014) and the BIMP Draft Report (NCDENR 2009) discussed the additional volumes of sand needed to adapt to relative sea level rise change scenarios. However, it should be noted that as a result of controversy over HB 819, the calculations to incorporate additional volumes of sand were removed from the BIMP Final Report (NCDENR 2011). Originally, the BIMP Draft Report assumed that 1 foot of sea level rise would require an additional 1.3 cubic yards of sand volume to be placed throughout the entire shoreline profile – or an additional 10-20% of sand needed. A more in-depth engineering study for the Bogue Banks Master Beach Nourishment Plan calculated the additional volume of sand needed for three different design scenarios – one accounting for 0.57 feet of rise (low), one accounting for 1.01 feet of rise (intermediate), and one accounting for 2.39 feet of rise (high). The report states that "based on USACE guidance provided at the PRT meetings, the intermediate should be used for planning purposes. Therefore, the additional need to account for potential sea level change would be 1,825,000 [cubic yards], equating to a total need 46.8 to 51.6 [million cubic yards over a 50-year time frame]" (Moffatt & Nichol, et al. 2014, pg. 171). With a historic average cost of $13.25 per cubic yard of sand in Carteret County, this would equate to an additional $24,181,250 in total costs over the lifetime of the project.

Given that local counties and municipalities are already grappling with securing funding for current projects, adding in the additional sand required (and therefore money required) to construct the same beach profile after seas have risen by 1-3 feet is simply not feasible in the eyes of coastal managers. In the 2011 BIMP, sea level rise was mentioned as a long-term threat to beach and inlet management (BIMP 2011, pg. IV-1); but it was determined that there was not enough information to officially plan for that threat. As a result, beach and inlet management projects (such as nourishment and terminal groin construction) are moving forward and being permitted without consideration for how sea level rise will impact the total lifetime cost. Not accounting for this additional amount of sand needed is economically irresponsible.

4. Design local-level tax plans to finance future nourishment projects.

Historically, 50-year nourishment projects were funded 65% from federal funding, 26.25% state funding, and 8.75% local funding (Annabelle 2010a). However, given the current economic downturn and federal cutbacks, federal funding for nourishment is minimal except in emergency situations, such as after major storms as part of the FEMA's Public Assistance

Program (Annabelle 2010a). This has prompted county and municipal governments to look for new ways to secure nourishment funding.

In 2000, the Carteret County Shore Protection Office began the 100% locally-funded Bogue Banks Restoration Project and in 2010 began putting together plans for a 50-year Master Nourishment Project. Initial funding for the Restoration Project came via bonds backed by the US Department of Agriculture. Since a county-wide bond referendum failed in 2000, Carteret County towns are taxed varying rates as a result of municipal bond referendums passed (Annabelle 2010a). Half of the Bogue Banks projects are paid for via the Carteret County Room Occupancy and Tourism (ROT) tax (6%). Enacted in 2001 (SL 2001-381) and codified in 2013 as SL 2013-223, 3% of this tax is remitted to a fund that is to be used exclusively for beach nourishment projects (GL Rudolph, personal communication, November 6, 2013). The Carteret County Beach Commission is an 11-member group that makes decisions concerning the fund. Carteret County could be a model for how other North Carolina counties can generate enough local support and funding for beach protection projects.

New Hanover County has collected ROT tax since 1983 – the current rate is 6% on area hotel stays and short-term rentals. Sixty percent of the first 3% goes directly into a fund for beach nourishment projects while the other 40% goes towards the Tourism Development Authority and Visitors Bureau. Fifty percent of the second 3% goes toward tourism marketing while the other 50% varies uses but must be spent on activities that enhance tourism (*GS 153A-155* and *GS 160A-215*). On March 26, 2014, the New Hanover County Tourism Development Authority denied a request to use a portion of tourism-marketing funds on beach nourishment in the county (Stansell 2014). After the denial for funds, New Hanover County beach town leaders met to discuss other potential permanent funding sources for nourishment projects on Carolina, Kure, and Wrightsville Beaches. One option discussed was a new tax on prepared food and beverages to help fund future beach nourishment projects in the county (Queram 2014). Another alternative is to further increase the ROT tax. For either to happen, the town leaders will have to gather unanimous support from county commissioners and majority support from local voters. With the Tourism Development Authority declining their request to free-up some of the occupancy tax funds, plus the prospect of increased taxes unfavorable among citizens, such support may be challenging.

Dissimilar from Carteret County or New Hanover County, Brunswick County has collected only a 1% Room Occupancy Tax since January 1998. In April 2014, Brunswick County officials proposed a sales tax increase to help fund both shoreline protection projects and public school improvements (Gonzales 2014), but this sales tax hike was shot down in the May 2014 vote leaving Brunswick County still unclear how to fund future nourishment projects (Brown 2014). Brunswick County also does not have an organized Shore Protection Office/Manager like Carteret and New Hanover Counties. I recommend the county create a designated Brunswick County Shore Protection Office that can act as a mechanism by which to lobby for shoreline protection funding in the future, and to ensure a county-wide approach to beach nourishment.

5. Incorporate color into the Sediment Criteria Rules.

Peterson & Bishop (2005) found that 84% of (39/46) beach nourishment biological monitoring efforts failed to statistically test associations between physical habitat and biological responses. I first recommend that the CRC maintain the Sediment Criteria Rules and impose firmer regulations during permitting so that coastal construction projects must adhere to the environmental windows (Arnold 1992). I also recommend the CRC take steps to incorporate sand color into the guidelines. Sand color can dictate sand temperature, with darker sand trapping more heat than lighter colored sand. Given that sex is determined in sea turtles during incubation, with cooler temperatures tending to yield males and warmer temperatures tending to yield females, artificially altering the sand color by placing different color sand than what is native to a beach might skew sex ratios.

6. Continue monitoring nesting beaches for any changes post-nourishment.

The Recovery Plan for the Northwest Atlantic Population of the Loggerhead Sea Turtle identifies 34 priority actions "that must be taken to prevent the extinction or to prevent the species from declining irreversibly in the foreseeable future... [which include] monitoring trends on nesting beaches and at in-water sites; minimizing the effect of coastal armoring; maintaining the current length and quality of nesting beach; [and] acquiring and protecting additional properties on key nesting beaches" (NMFS and USFWS 2008, pg. xii). Historically, sea turtle nesting conservation efforts in North Carolina have been from the ground up, with local volunteer groups coordinating nesting management with the guidelines of the USFWS and the state WRC. Now that the critical habitats have become codified, the USFWS and NMFS must continue to coordinate with the WRC and these local volunteer groups. From 2011-2012, volunteers contributed 40,660 hours to monitor nesting beaches. This is equivalent to $626,589 in volunteer labor that is at no cost to the state or federal governments. These efforts are crucial for the effective management of the loggerhead sea turtle.

Data Gaps and Suggestions for Future Studies

One of the greatest challenges for sea turtle management in North Carolina is a lack of data. Unlike Florida, which has been monitoring loggerhead nesting for years, many North Carolina beaches have only recently begun citizen-led monitoring efforts, some as recently as the late 2000s. Data gaps for loggerhead nesting across the state makes it challenging to quantitatively assess the impacts of beach nourishment, or other, projects on nesting success. The mechanisms by which a female sea turtle chooses an area to dig and lay her nest remain a mystery. Until this critical information gap is resolved, it will be impossible to determine if a recently nourished beach deters nest site selection.

In Florida, a collaborative effort to create a turtle friendly beach design is underway. Led by R.G. Ernest and R.E. Martin at Ecological Associates, Inc., this effort would shape the nourished beach profile to something more alike a typical beach profile (see Figure 6). A pilot project is currently underway in Martin County, Florida, with construction ending winter 2013.

The 2014 nesting season will be the first documentation of how this adjusted profile influences nest site selection and nesting success. Depending on the outcome of the project, the USACE may consider constructing the initial profile more like that of the "profile design" instead of leaving it to equilibrate itself. It will be worthwhile to follow-up on the results of the "Turtle Friendly Beach Design" in Florida to see if the new beach profile design is increasing nesting success relative to the typical profile design standards.

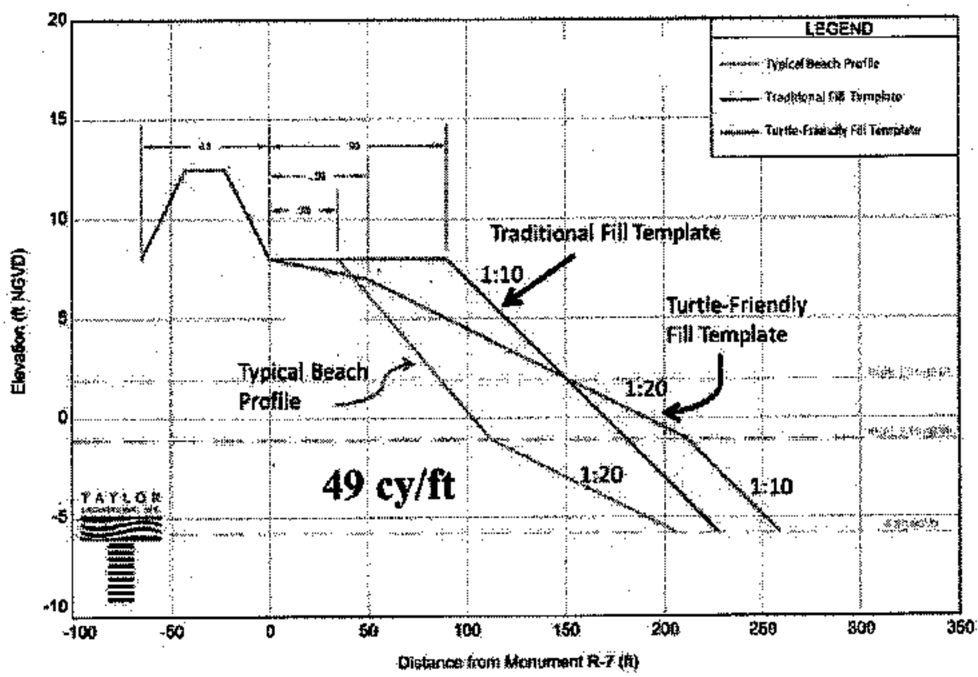


Figure 6. Taken from Ernest et al. (2012) showing the profile differences between a typical beach profile, a traditional profile after beach nourishment, and the proposed turtle-friendly construction profile.

Other future studies should assess the feasibility of the other thirteen adaptation strategies outlined by Fuentes et al. (2012), listed in Appendix A. Given the current political and economic climate in North Carolina, only continued beach nourishment, consideration of terminal groin structures, and incorporating sea rise into future planning and policies, are currently feasible. Once the CRC Science Panel completes the updated Sea Level Rise Assessment Report in 2015, and once the current legislative session is complete, perhaps other strategies will become viable.

Conclusions

With an increasing rate of sea level rise and enhanced storm activity, many state and local governments are turning toward engineered solutions to combat erosion (Barth & Titus 1984). Current management strategies in North Carolina fail to take into account the effect of sea-level rise on sea turtle populations. Sea turtle survival will depend, at least in part, on the effectiveness of future conservation strategies and management plans that take projected sea-level rise into account (Fuentes et al. 2012). It is critical that North Carolina's barrier island beaches are maintained and protected in a sustainable way to ensure both the endurance of loggerhead sea turtles and the beaches themselves. Investing in policies and legislation designed to protect beaches (and turtles) will not only yield positive ecological advantages, but will also benefit the tourism industry, coastal landowners, and the general public. Strong collaboration between coastal managers, conservation teams, and researchers is necessary.

As proven by the controversial HB 819 sea level rise legislation in 2012, there is much political hesitation in the current North Carolina legislature about planning for future sea level rise scenarios. Projects today are already costly and incur a significant strain on local and state governments. This hesitation is enhanced by the fact that the election cycle is every 2-4 years. Legislators tend to not be focused on what *may* happen 20, 50, 100 years from now – they are concentrated on what is best for their constituents right *now*. However, it is important that governments take steps today to account for sea level rise, especially when managing protected species. There will be impacts to loggerhead sea turtles with each beach protection project, but the ultimate goal of this research was to suggest ways in which these impacts may be minimized over the long term.

Due to the regulatory restrictions imposed by HB 819, plans *cannot* take sea-level rise into account at this time, but again, I recommend the state make sea-level rise planning a priority after the release of the updated "North Carolina Sea-Level Rise Assessment Report" in 2015 and that the state require all new 50-year nourishment plans and Beach and Inlet Management Plans to factor in sea-level rise. All beach protection management agencies must also continue to work with the NMFS, USFWS, WRC, and sea turtle volunteer groups to ensure sea turtle safeguards during construction. Solutions to protected species management in the face of sea-level rise will be politically and publically challenging and involve a wide range of stakeholders, but cooperative planning is necessary to ensure a vibrant economy and ecologically sustainable North Carolina coastline.

References

43 Federal Register 32800, Marine Turtle Endangered Species Act Listing, July 28, 1978.

76 Federal Register 58868, Nine Distinct Population Segments, September 22, 2011.

78 Federal Register 18000, USFWS Proposed Terrestrial Critical Habitat Rule, March 25, 2013.

78 Federal Register 43005, NMFS Proposed Marine Critical Habitat Rule, July 18, 2013.

78 Federal Register 42921, USFWS Proposed Rule: Reopening of Comment Period, July 18, 2013.

79 Federal Register 39755, USFWS Designation of Critical Habitat for the Northwest Atlantic Ocean Distinct Population Segment of the Loggerhead Sea Turtle, July 10, 2014.

79 Federal Register 39855, NMFS Critical Habitat for the Northwest Atlantic Ocean Loggerhead Sea Turtle Distinct Population Segment (DPS) and Determination Regarding Critical Habitat for the North Pacific Ocean Loggerhead DPS, July 10, 2014.

"Addendum to the North Carolina Sea Level Rise Assessment Report of 2010" (2012). Retrieved March 2014 from: http://dcm2.enr.state.nc.us/Hazards/Addendum%20to%20the%20NC%20SLR%20Assessment%20Report_April%202012.pdf.

Annabelle, N.G. (2010a) The social and political process behind beach nourishment in Carteret County, NC, working paper. NSF-sponsored biocomplexity project, "Coupling Human and Natural Influences on Coastline Evolution as Climate Changes", Principal Investigators Brad Murray, Martin Smith, Mike Orbach and Joe Ramus. Durham: Nicholas School of the Environment, Duke University.

Annabelle, N.G. (2010b) Beach Nourishment in New Hanover County, working paper. NSF-sponsored biocomplexity project, "Coupling Human and Natural Influences on Coastline Evolution as Climate Changes", Principal Investigators Brad Murray, Martin Smith, Mike Orbach and Joe Ramus. Durham: Nicholas School of the Environment, Duke University.

ASBPA – American Shore and Beach Preservation Association. (2007). Shore Protection Assessment on Beach Nourishment: How Beach Nourishment Works. Retrieved March 2014 from: http://www.asbpa.org/publications/fact_sheets/HowBeachNourishmentWorksPrimerASBPA.pdf.

Arnold, D.W. (1992). The scientific rationale for restricting coastal construction activities during the marine turtle nesting season. New Directions in Beach Management: Proceedings of the 5th Annual National Conference on Beach Preservation Technology. Tallahassee, Florida: The Florida Shore & Beach Preservation, pg. 374-380.

Barth, M.C., Titus, J.G. (1984). Greenhouse effect and sea level rise: A challenge for this generation. New York: Van Nostrand Reinhold.

Bin, O., Dumas, C., Poulter, B., Whitehead, J. (2007). Measuring the impacts of climate change on North Carolina coastal resources. Final report prepared for National Commission on Energy Policy. Retrieved February 2014 from: http://econ.appstate.edu/climate/NC-NCEP%20final%20report.031507.pdf.

Brock, K.A., Reece, J.S., Ehrhart, L.M. (2009). The effects of artificial beach nourishment on marine turtles: Differences between loggerhead and green turtles. *Restoration Ecology*, 17:2, 297-307.

Bjorndal, K.A., Meylan, A.B., Turner, B.J. (1983). Sea turtles nesting at Melbourne Beach, Florida I. Size, Growth, and Reproductive Biology. *Biological Conservation*, 26, 65-77.

Brown, B. (2014, May 6). Brunswick votes down sales tax increase; BHI passes $18M bonds for erosion control. *Port City Daily.* Retrieved May 2014 from: http://portcitydaily.com/2014/05/06/brunswick-votes-down-sales-tax-increase-bhi-voters-pass-18m-bond-for-erosion-control/.

Byrd, J.I. (2004). The effect of beach nourishment on loggerhead sea turtle (Caretta caretta) nesting in South Carolina. Master's Thesis, College of Charleston, Charleston, SC. Retrieved March 2014 from: http://www.dnr.sc.gov/seaturtle/Literature/byrd-thesis.pdf.

Crowder, L.B., Crouse, D.T., Heppell, S.S., Martin, T.H. (1994) Predicting the impact of turtle excluder devices on loggerhead sea turtle populations. *Ecological Applications*, 4, 437-445.

Crain, D.A., Bolten, A.B., Bjorndal, K.A. (1995). Effects of beach nourishment on sea turtles: Review and research initiatives. *Restoration Ecology*, 3:2, 95-104.

Delgadillo, G.M. (2012). A case study on the value of having sea turtles nest on Bald Head Island, NC in 2012. Stanford University undergraduate research at Bald Head Island Conservancy. Retrieved April 2014 from: www.bhic.org/media/pdf/DelgadilloInternshipPaper.docx.

Dodd, C.K. Jr. (1988) Synopsis of the biological data on the loggerhead sea turtle *Caretta caretta* (Linnaeus 1758). U.S. Fish and Wildlife Service, Biological Report 88(14).

"Economic Analysis for Loggerhead Proposed Terrestrial Critical Habitat" produced by Industrial Economics, Inc. (2013) . Retrieved March 2014 from: http://www.fws.gov/northflorida/seaturtles/2013_NWA_Loggerhead_CH/20130717_Draft_Economic_Analysis_for_Loggerhead_Proposed_Terrestrial_Critical_Habitat_Revised_06-03-13.pdf.

Ernest, R.G., Martin, R.E., Stites, D., Fitzpatrick, K. (2012). "Testing an alternative template to improve the performance of built beaches for sea turtles" presentation by Ecological Associates, Inc., Taylor Engineering, Inc., and Martin County, Florida. Retrieved February 2014 from: http://fsbpa.com/2012TechPresentations/BobErnest.pdf.

Dean, R. (2002). *Beach Nourishment: Theory and Practice.* Singapore Uto-Print: World Scientific Publishing Co. Pte. Ltd.

Department of Commerce, North Carolina Tourism. (2013). Travel Economic Impact Model (TEIM): 2012 data. Retrieved March 2014 from: http://www.nccommerce.com/tourism/research/economic-impact/teim.

DCM - Division of Coastal Management. (2008). Unpublished Beach Nourishment Database. Accessed through personal communication with Matthew Slagel, Shoreline Management Specialist. Last updated 29 May 2008.

DCM – Division of Coastal Management. (2013). "CAMA Rules & Policies." Retrieved January 2014 from DCM website: http://dcm2.enr.state.nc.us/rules/rules.htm

Fish, M.R., Côté, I.M., Gill, J.A., Jones, A.P., Renshoff, S., Watkinson, A.R. (2005). Predicting the impact of sea-level rise on Caribbean sea turtle nesting habitat. *Conservation Biology, 19*(2): 482-491.

Fish, M.R., Côté, I.M., Horrocks, J.A., Mulligan, B., Watkinson, A.R., Jones, A.P. (2008). Construction setback regulations and sea-level rise: Mitigating sea turtle nesting beach loss. *Ocean & Coastal Management, 51*(4): 330-341.

Frazer, N.B., Richardson, J.I. (1985). Annual variation in clutch size and frequency for loggerhead turtles, *Caretta-caretta*, nesting at Little Cumberland Island, Georgia, USA. *Herpetologica 41*(3): 246–251.

Fuentes, M.M.P.B., Limpus, C.J., Hamann, M., and Dawson, J. (2009). Potential impacts of projected sea level rise to sea turtle rookeries. Aquatic Conservation: Marine and Freshwater Ecosystems, 20,132-139.

Fuentes, M.M.P.B., Cinner, J.E. (2010). Using expert opinion to prioritize impacts of climate change on sea turtels' nesting grounds. *Journal of Environmental Management*, 91, 2511-2518.

Fuentes, M.M.P.B., Limpus, C.J., Hamann, M. (2011). Vulnerability of sea turtle nesting grounds to climate change. *Global Change Biology*, 17, 140-153.

Fuentes, M.M.P.B., Fish, M.R., Maynard, J. (2012). Management strategies to mitigate the impacts of climate change on sea turtle's terrestrial reproductive phase. *Mitigation and Adaptation Strategies for Global Change, 17*(1): 51-63.

Gonzales, J. (2014, April 27). Proposed sales tax could be useful for Brunswick beaches. *Star News Online*. Retrieved May 2014 from: http://www.starnewsonline.com/article/20140427/ARTICLES/140429695.

Hamann, M., Limpus, C.J., Read, M. (2007). Vulnerability of marine reptiles in the Great Barrier Reef to climate change. In Johnson J. Marshall P. (eds) Climate Change and the Great Barrier Reef: a vulnerability assessment. Great Barrier Reef Marine Park Authority and Australian Government Greenhouse Office. Townsville, pp 466-496.

Hamann H., Godfrey, M.H., Seminoff, J.A., et al. (2010). Global research proprieties for sea turtles, informing management and conservation in the 21st century. Endangered Species Research, 11, 245-269.

Hawkes, L.A., Broderick, A.C., Godfrey, M.H., and Godley, B.J. (2005). Status of nesting loggerhead turtles at Bald Head Island (North Carolina, USA) after 24 years of intensive monitoring and conservation. *Oryx*, 38, 65-72.

Hawkes, L.A., Broderick, A.C., Godfrey, M.H., and Godley, B.J. (2007). Investigating the potential impacts of climate change on a marine turtle population. *Global Change Biology, 13*: 923-932.

House Bill 819. General Assembly of North Carolina, Session 2011, Session Law 2012-202.

House Bill 1011. General Assembly of North Carolina, Session 2013.

Irish, J.L., and Taylor, N. (2013) Predictions of Future Coastal Vulnerability Along the U.S. East Coast Using the U.S. Geological Survey Coastal Vulnerability Index Framework. Department of Civil and Environmental Engineering, Virginia Tech.

Karetinkov, D., Lakhey, S., Horin, C., Bell, B., Ruth, M., Ross, I., Irani, D. (2008). Economic impacts of climate change on North Carolina. A review and assessment conducted by The Center for Integrative Environmental Research, University of Maryland. Retrieved February 2014 from: http://www.cier.umd.edu/climateadaptation/North%20Carolina%20Economic%20Impacts%20of%20Climate%20Change%20Full%20Report.pdf.

Limber, P., Warren, J. (2006). Development of sediment criteria regulations for beach fill projects along North Carolina's Atlantic Coast. North Carolina Division of Coastal Management CRC 06-01.

Long, T.M., Angelo, J., Weishampel, J.F. (2011). LiDAR-derived measures of hurricane- and restoration-generated beach nourishment morphodynamics in relation to sea turtle nesting behavior. *International Journal of Remote Sensing*, 32:1, 231-241.

Mazaris, A.D., Matsinos, G., Pantis, J.D. (2009). Evaluating the impacts of coastal squeeze on sea turtle nesting. *Ocean & Coastal Management, 52*: 139-145.

McClellan, C.M., Read, A.J., Cluse, W.M., Godfrey, M.H. (2011). Conservation in a complex management environment: The by-catch of sea turtles in North Carolina's commercial fisheries. *Marine Policy, 35*: 241-248.

Michel, J., Bejarano, A.C., Peterson, C.H., Voss, C. (2013) Review of Biological and Biophysical Impacts from Dredging and Handling of Offshore Sand. U.S. Department of the Interior, Bureau of Ocean Energy Management, Herndon, VA.

Miller, J.D., Limpus, C.L., Godfrey, M.H. (2003) Nest site selection, oviposition, eggs, development, hatching, and emergence of loggerhead sea turtles. In: Bolten, A.B., Witherington, B.E. (Eds.), Ecology and Conservation of Loggerhead Sea Turtles. Smithsonian Books, Washington, D.C., 125-143.

Moffatt & Nichol, et al. (2014). Bogue Banks Master Beach Nourishment Plan – Draft Engineering Report. Granted access by Carteret County Shore Protection Office. Retrieved April 2014 from: https://moffattnichol.sharefile.com/download.aspx?id=scf295e17eaa42e79.

Mortimer, J.A. (1990). The influence of beach sand characteristics on nesting behavior and clutch survival of green turtles (*Chelonia mydas*). *Copeia*, 3, 802-817.

Mrosovsky, N. and Yntema, C.L. (1980) Temperature dependence of sexual differentiation in sea turtles: implications for conservation practices. *Biological Conservation, 18*: 271–280.

Mrosovsky, N. and Pieau, C. (1991) Transitional range of temperature, pivotal temperatures and thermosensitive stages for sex determination in reptiles. *Amphibia-Reptilia*, 12, 169-179.

Mrosovsky, N. and Godfrey, M.H. (2010). Editorial: Thoughts on climate change and sex ratios of sea turtles. *Marine Turtle Newsletter*, 128, 7-111.

NCCF - North Carolina Coastal Federation. (2013). "Terminal Groins 101" Retrieved December 2013 from: http://www.nccoast.org/content.aspx?key=79e38ba1-e221-4033-a2b4-86f17b374a7f.

NCDENR – Department of Environment and Natural Resources. (2011). North Carolina Beach and Inlet Management Plan – Final Report. Retrieved February 2014 from: http://dcm2.enr.state.nc.us/BIMP/BIMP%20Final%20Report.html.

NCDENR – Department of Environment and Natural Resources. (2009). North Carolina Beach and Inlet Management Plan – Draft Report. Granted access by Carteret County Shore Protection Office.

NC Sea Turtle Project. (2013) How You Can Help Save Sea Turtles. Retrieved February 2014 from: http://www.seaturtle.org/groups/ncwrc/.

NMFS - National Marine Fisheries Service. (2013). Loggerhead Turtle (Caretta caretta). Retrieved January 2014 from NOAA Fisheries Office of Protected Resources website: http://www.nmfs.noaa.gov/pr/species/turtles/loggerhead.htm.

NMFS and USFWS - National Marine Fisheries Service and U.S. Fish and Wildlife Service. (2008). Recovery Plan for the Northwest Atlantic Population of the Loggerhead Sea Turtle (*Caretta caretta*), Second Revision. National Marine Fisheries Service, Silver Spring, MD.

NOAA – National Ocean and Atmospheric Administration. (2011). NOAA, U.S. Fish and Wildlife Service revise loggerhead sea turtle listing. Retrieved January 2014 from NOAA Fisheries Southeast Regional Office website: http://sero.nmfs.noaa.gov/news_room/press_releases/2011/16_loggerhead.pdf.

NOAA Coastal Services Center. (2013*) Beach Nourishment. *Archived website retrieved from: http://www.csc.noaa.gov/archived/beachnourishment/index.htm.

"North Carolina Sea Level Rise Assessment Report." (March 2010). CRC Science Panel on Coastal Hazards. Retrieved January 2014 from: http://dcm2.enr.state.nc.us/Hazards/slr.html.

Permit Number 86-12 for dredging and nourishment of Emerald Isle to Pine Knoll Shores. (February 2012). Obtained and used with permission from the North Carolina Division of Coastal Management.

Peterson, C.H., Bishop, M.J. (2005). Assessing the environmental impacts of beach nourishment. *Bioscience*, 55:10, 887-896.

Pike, D.A. and Stiner, J.C. (2007). Sea turtle species vary their susceptibility to tropical cycles. Oecologia, 153, 1432-1939.

Pilkey, O.H. (2012, November 14). We need to retreat from the beach. *New York Times*, Opinion Pages. Retrieved April 2014 from: www.nytimes.com/2012/11/15/opinion/a-beachfront-retreat.html?_r=0.

Pippin, J. (2014, July 11). Carteret county officials respond to loggerhead protections. JDNews.com. Retrieved July 2014 from: http://www.jdnews.com/news/local/carteret-officials-respond-to-loggerhead-protections-1.344400?page=0.

PSDS – Program for the Study of Developed Shorelines. (2013). Beach Nourishment Viewer – North Carolina. Western Carolina University. Retrieved March 2014 from: http://beachnourishment.psds-wcu.org/results.php?state=NC.

Queram, K.E. (2014, April 30). Officials consider ways to build up beach renourishment funds. *Star News Online*. Retrieved April 2014 from: http://www.starnewsonline.com/article/20140430/ARTICLES/140439970?p=1&tc=pg&tc=ar.

Richardson, T.H., Richardson, J.I., Ruckdeshel, C., and Dix, M.W. (1978). Remigration patterns of loggerhead sea turtles (*Caretta caretta*) nesting on Little Cumberland Islands, Georgia. Florida Marine Research Publications, 33, 25-30.

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

Rudolph, G.L. (2013) Slide presentation to Chamber of Commerce. Carteret County Shore Protection Office, Emerald Isle, N.C. 13 slides.

Senate Resolution 110. General Assembly of North Carolina, Session 2013.

Senate Bill 402. General Assembly of North Carolina, Session 2013, Session Law 2013-360.

Shutak, M. (2014, July 11). County beaches, waters to be declared critical habitats (updated). *Carteret County News-Times*. Retrieved July 2014 from: http://www.carolinacoastonline.com/news_times/article_925b9d52-079e-11e4-8bb7-0019bb2963f4.html

Stansell, K. (2014, March 27). Beach projects looking for funding, no support from New Hanover County. WECT TV6. Retrieved April 2014 from: www.wect.com/story/25095928/beach-projects-looking-for-funding-no-support-from-new-hanover-county.

Strauss, B., C. Tebaldi, S. Kulp, S. Cutter, C. Emrich, D. Rizza, and D. Yawitz (2014). North Carolina and the Surging Sea: A vulnerability assessment with projections for sea level rise and coastal flood risk. Climate Central Research Report. pp 1-29.

STC – Sea Turtle Conservancy. (2013). Information about sea turtles, their habitats and threats to their survival. Retrieved October 2013 from: http://www.conserveturtles.org/seaturtleinformation.php.

Steinitz, M.J., Salmon, M. and Wyneken, J. (1998). Beach renourishment and loggerhead turtle reproduction: a seven year study at Jupiter Island, Florida. *Journal of Coastal Research*, 14, 1000-1013.

Thieler, E.R. and Hammar-Klose, E.S. (1999). *National Assessment of Coastal Vulnerability to Future Sea-Level Rise: Preliminary Results for the U.S. Atlantic Coast.* U.S. Geological Survey, Open-File Report 99-593. Retrieved March 2014 from: http://pubs.usgs.gov/of/of99-593/.

Tursi, F. (2014a, May 16). CRC limts sea-level rise study to 30 years. *Coastal Review Online*. Retrieved May 2014 from: http://www.nccoast.org/Article.aspx?k=e70f583a-3060-41a8-9f98-55f469cca4aa.

Tursi, F. (2014b, June 12). CRC Chairman avoids climate dust up. *Coastal Review Online*. Retrieved June 2014 from: http://nccoast.org/Article.aspx?k=cc97ef5f-69bb-4870-8fbf-e8fb9027f634.

USACE – US Army Corps of Engineers. (2013) Locations. Retrieved December 2013 from: http://www.usace.army.mil/Locations.aspx.

Von Holle, B., Irish, J., Spivy, A., Weishampel, J., Hagen, S., Dodd, M., Godfrey, M., Griffin, DB., Meylan, A., Ehrhart, L., Stiner, J., Keyes, T., Bimbi, M., Sanders, F., Schweitzer, S., Brush, J., Bard, A., and Stout, I.J. (2014, in progress). The effects of sea level rise on sea turtle, shorebird, seabird, and beach mouse nesting distributions within the South Atlantic Bight.

Yntema, C.L. and Mrosovsky, N. (1980). Sexual differentiation in hatchling loggerheads (*Caretta caretta*) incubated at different controlled temperatures. *Herpetological*, 26, 33-36.

Wibbels, T. (2003). Critical approaches to sex determination in sea turtles. In: *Biology of Sea Turtles*, Vol. 2 (eds Lutz P.L., Musick, J.A., Wyneken, T.), pp. 103-134. CRC Press, Boca Raton.

WRC – Wildlife Resources Commission. (2013) North Carolina Wildlife Resources Commission loggerhead sea turtle unpublished data. Obtained and used with permission from Matthew Godfrey, December 2013.

Appendix A

Fuentes et al. (2012) strategies to mitigate the impacts of sea level rise on the terrestrial reproductive phase of sea turtles

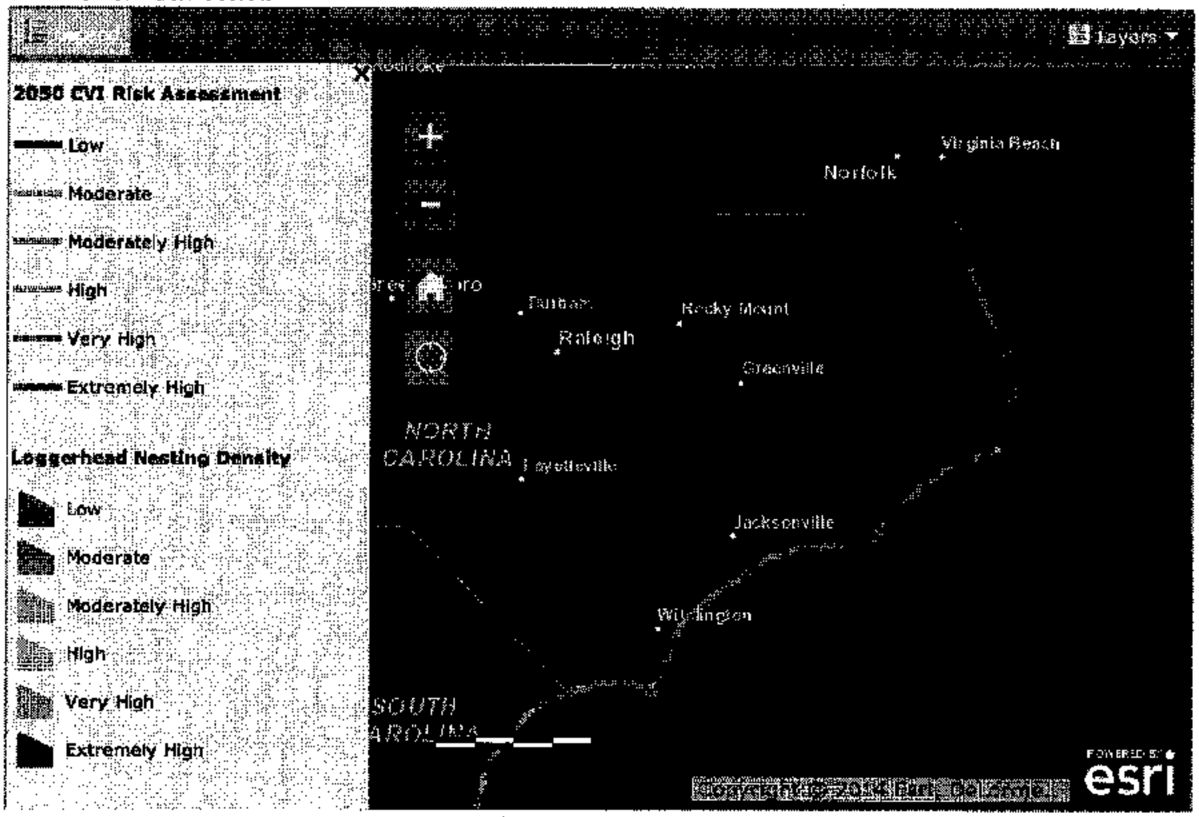
Recommended Strategies	
1	Prevent removal of beach vegetation
2	Re-vegetation or planting native vegetation
3	Identify and legally protect areas that will have suitable nesting environment as climate changes
4	Establish rolling easements
5	Incorporate climate change into land-use planning
6	Establish or enforce existing setback regulations
7	Ban and remove permanent shoreline-hardening structures
8	Plan urban growth to redirect development away from nesting areas
Potential Strategies	
9	Beach replenishment
10	Install offshore breakwaters
11	Use hard engineering structures (e.g. groins)
12	Move nests to areas with suitable incubating environment in the beach (in situ)
13	Move nests to hatcheries
14	Move nests to incubators
15	Move nests to other existing nesting beaches that have more suitable incubating environment
16	Create artificial beaches and move nests to those areas

Recommended strategies are considered best choice while potential strategies should be last resort. For a more detailed discussion of methods, costs, and reasoning, see Fuentes, M.M.P.B., Fish, M.R., and Maynard, J. (2012). Management strategies to mitigate the impacts of climate change on sea turtle's terrestrial reproductive phase. Mitigation and Adaptation Strategies for Global Change, 17(1), 51-63.

Appendix B

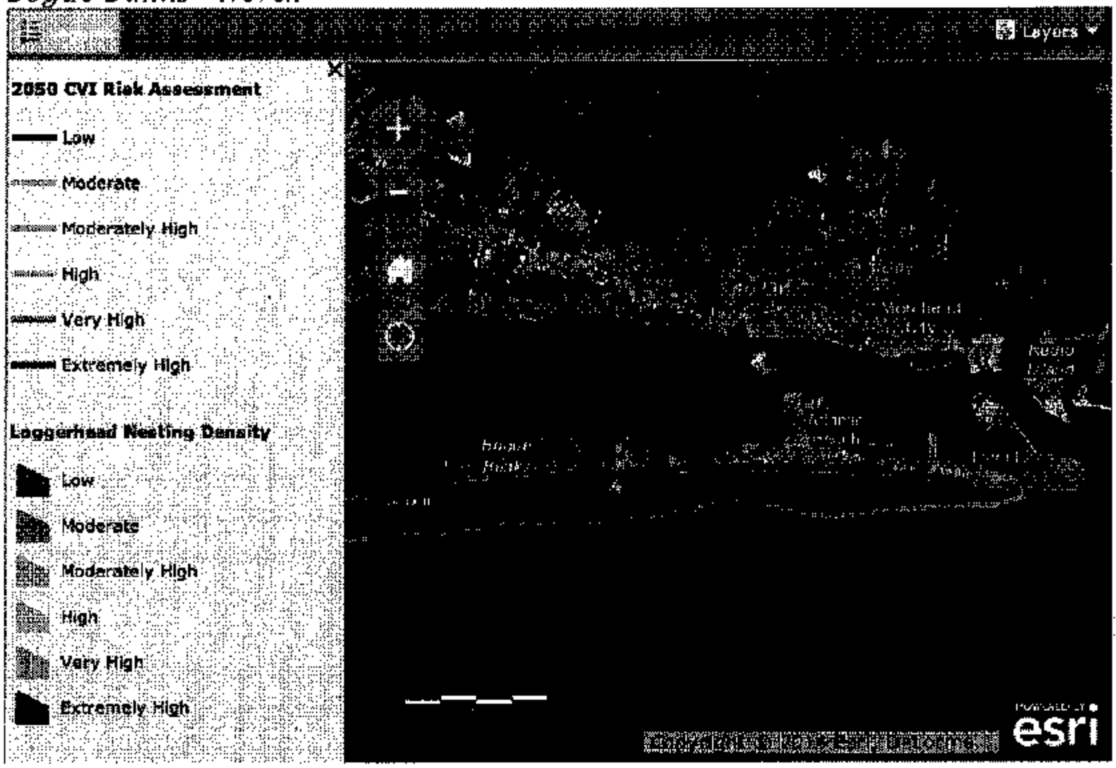
The following maps were developed by Von Holle et al. (2014, in progress) with funding provided by South Atlantic Landscape Conservation Cooperative. Maps were generated on the unpublished Von Holle Lab page and are to be used solely for the purposes of this report. For this study, I was interested in areas with "Moderately High" to "Very High"[5] loggerhead nest density and a "Very High" or "Extremely High" Coastal Vulnerability Index (CVI). The USGS CVI ranking indicates an area's vulnerability to sea level rise.

All North Carolina

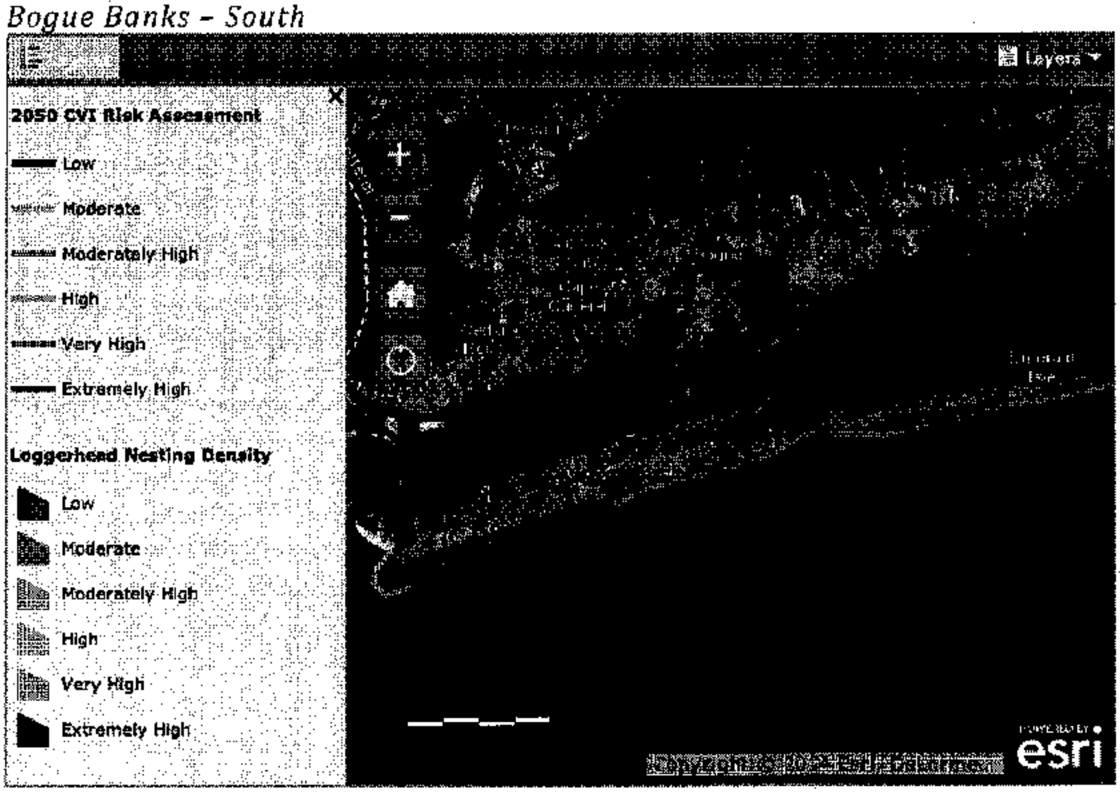


[5] "Extremely High" loggerhead nest density only occurs in Florida and is therefore not relevant to this study.

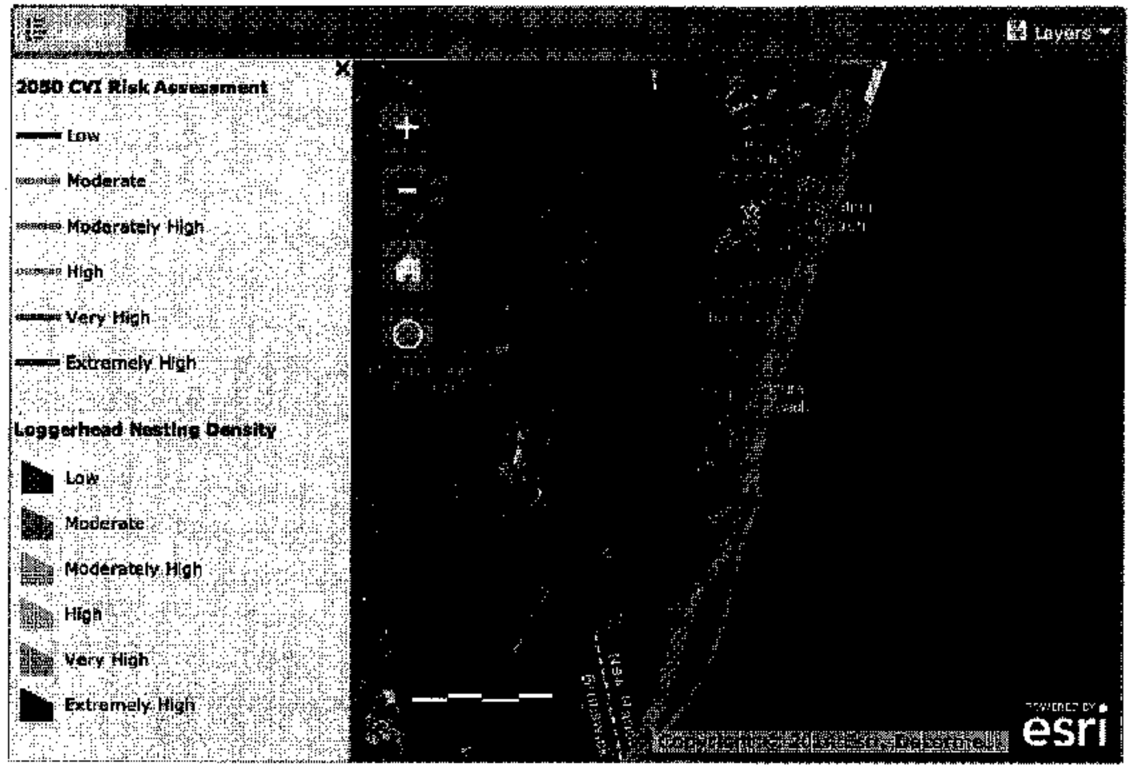
Bogue Banks - North



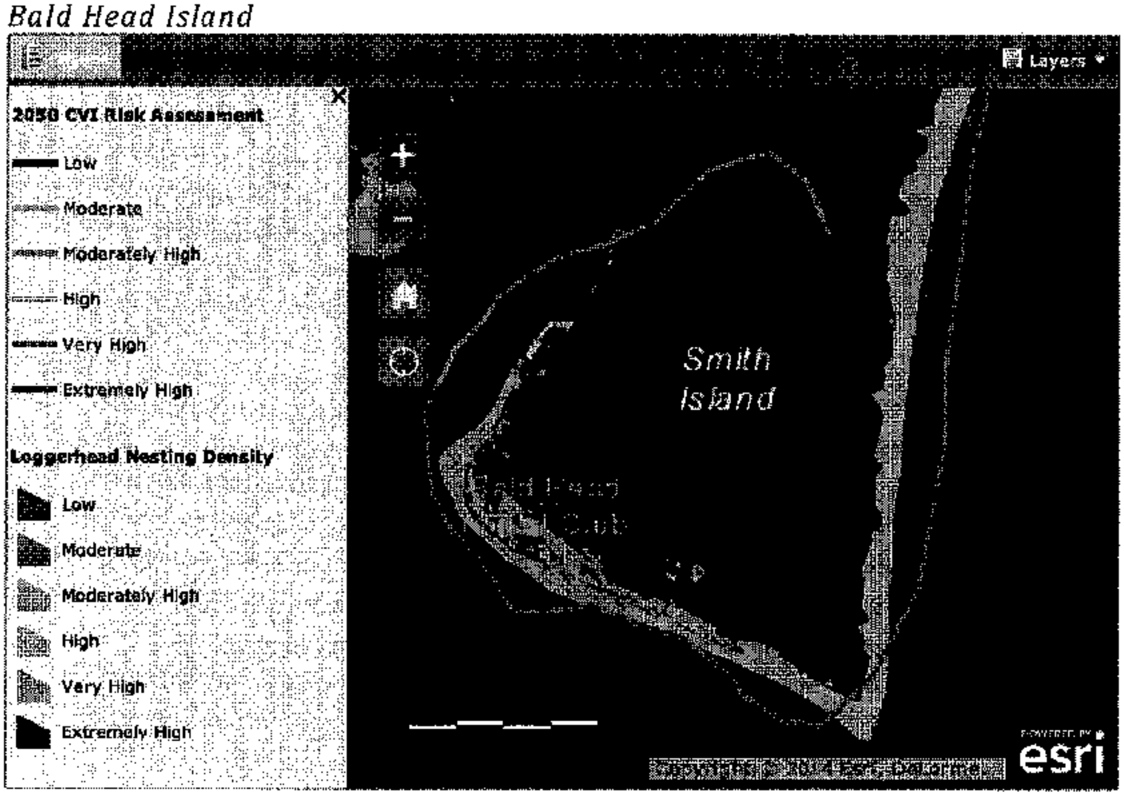
Bogue Banks – South



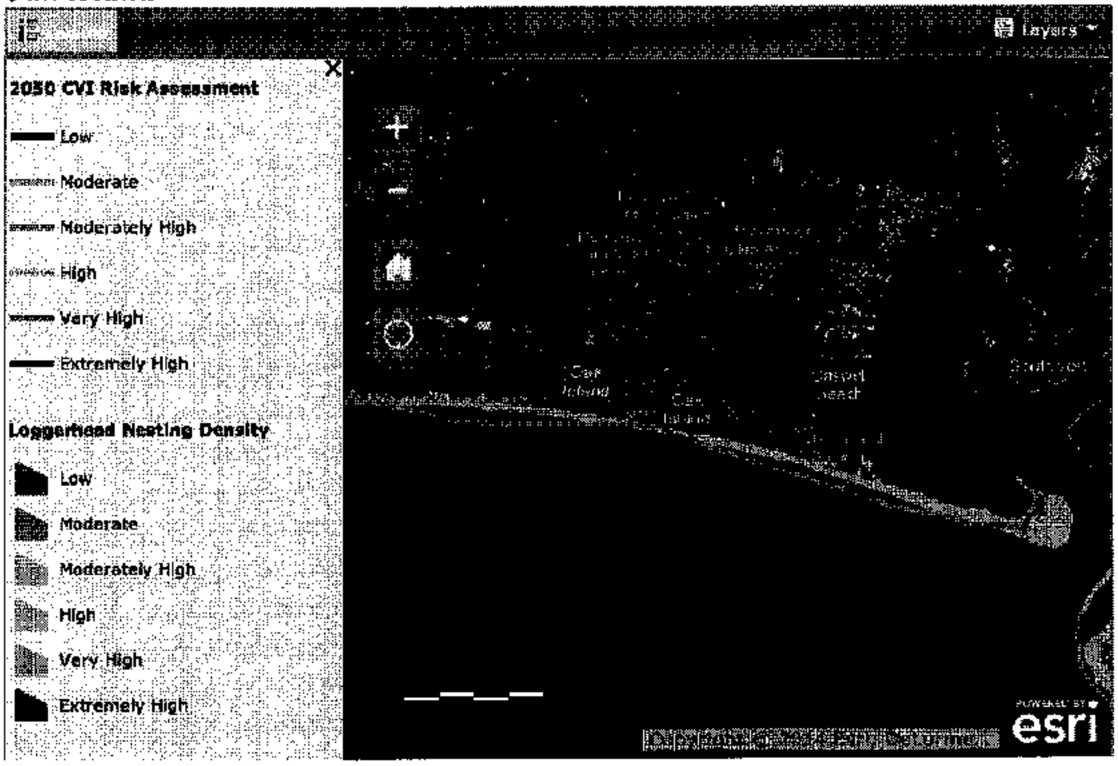
Pleasure Island



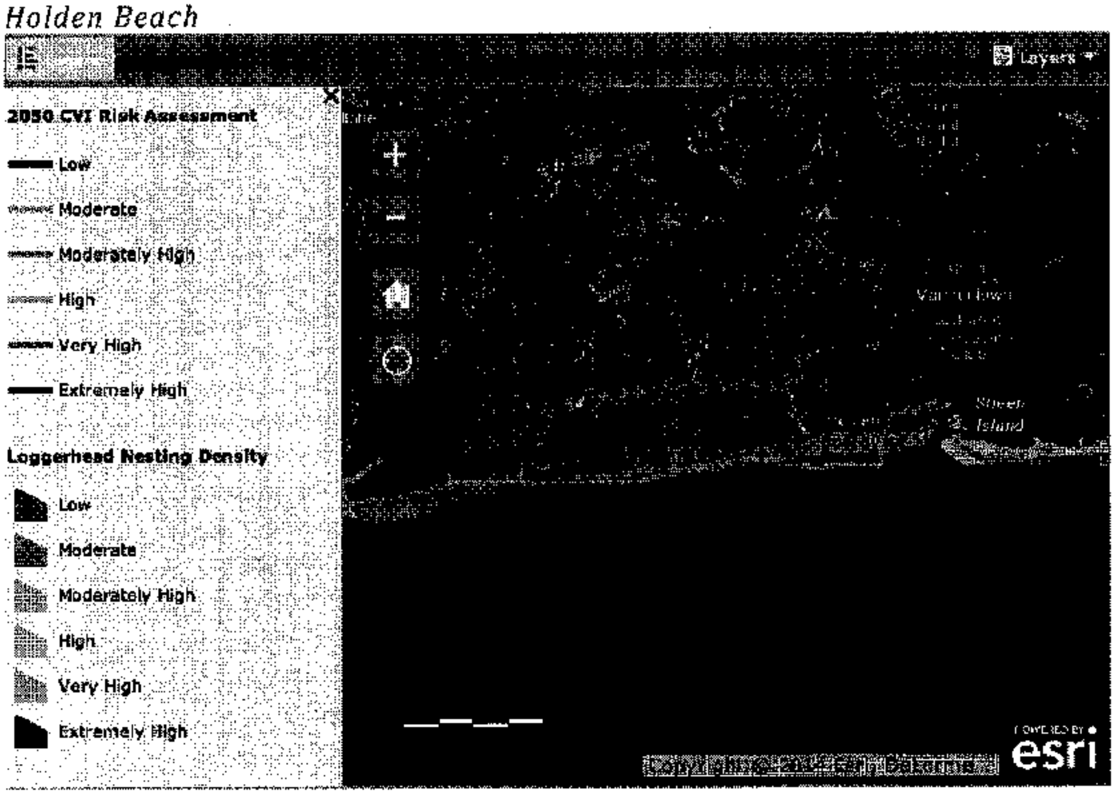
Bald Head Island



Oak Island



Holden Beach



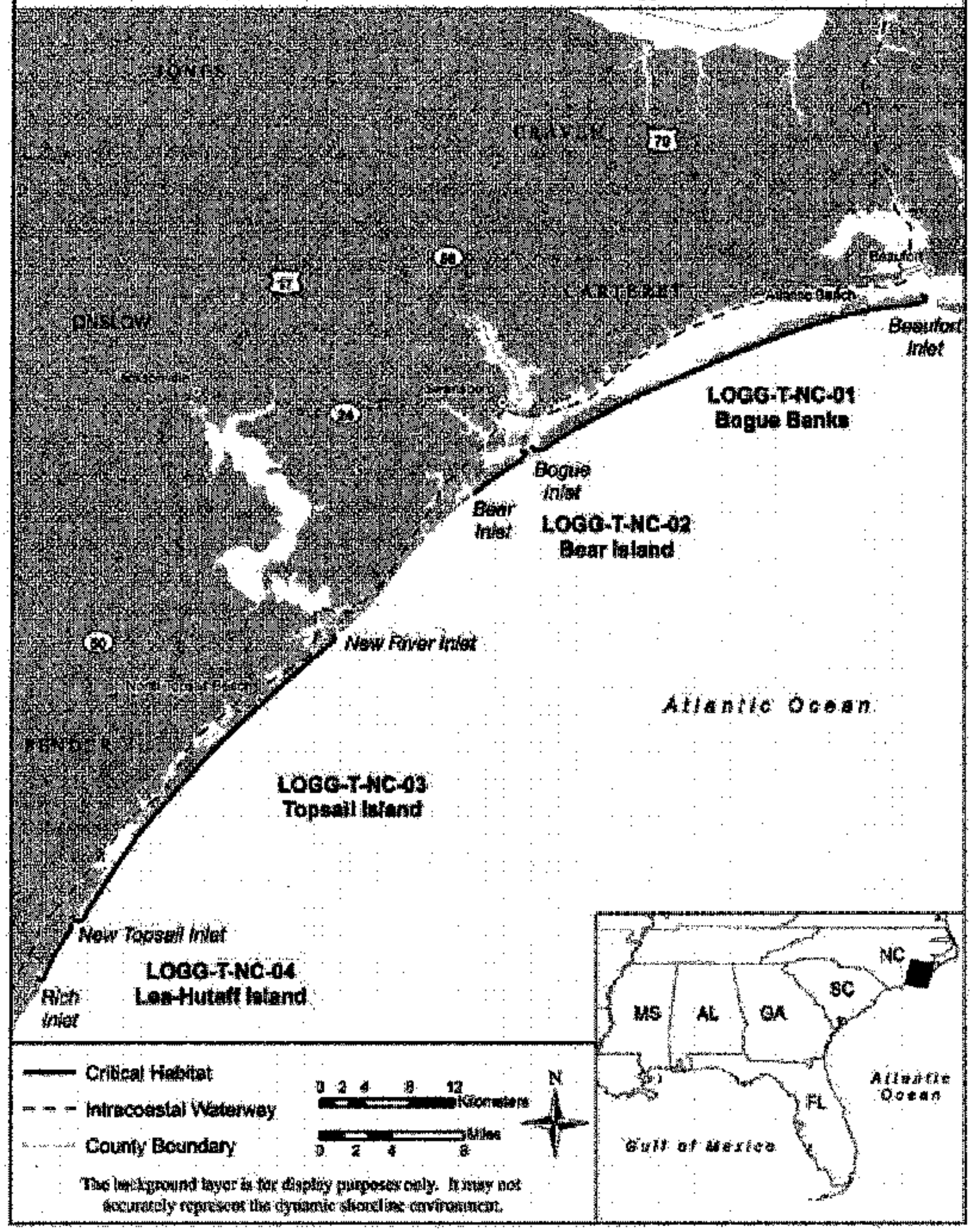
Appendix C

Loggerhead nesting density by beach

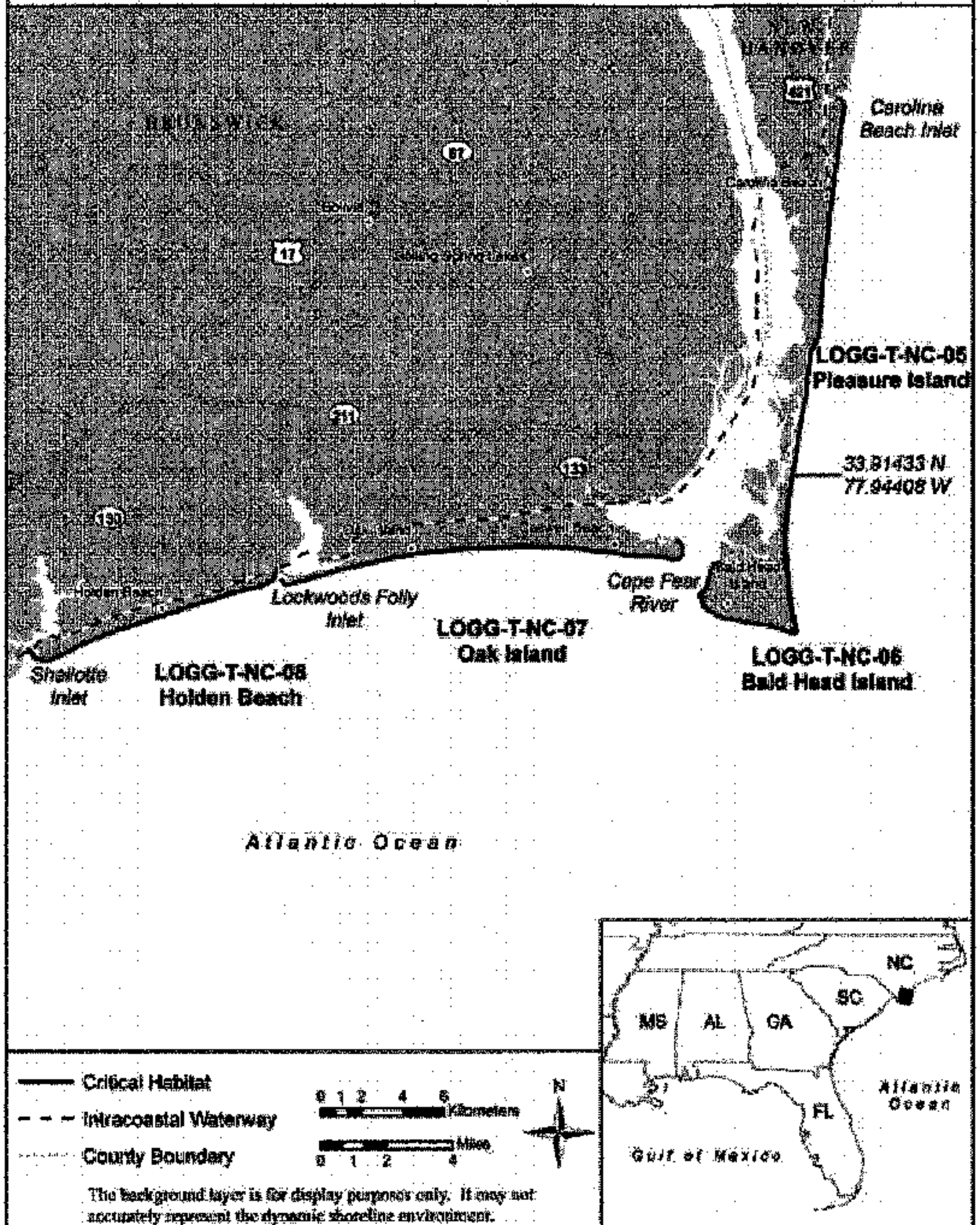
Beach	Length (km)	1998-2013 Total Nests	Average Nests per Year	Nests per km
Virginia border to Nags Head	28.97	159	9.94	0.34
Cape Hatteras National Seashore	62.76	1,706	106.63	1.70
Pea Island Wildlife Refuge	106.22	207	12.94	0.12
Cape Lookout National Seashore	90.12	2,381	148.81	1.65
Fort Macon State Park	4.83	48	3.00	0.62
Bogue Banks	28.97	440	27.50	0.95
Hammocks Beach State Park	6.44	277	17.31	2.69
Onslow Beach	11.27	710	44.38	3.94
Topsail Island	35.41	1,484	92.75	2.62
Lea Island	3.22	65	5.91	1.84
Huttaf Island	4.83	6	2.00	0.41
Figure Eight Island	6.44	214	13.38	2.08
Wrightsville Beach	8.05	74	4.63	0.57
Masonboro Island	12.87	253	19.46	1.51
Carolina Beach	6.44	121	7.56	1.17
Kure Beach	4.83	149	9.31	1.93
Fort Fisher State Recreation Area	4.83	368	23.00	4.76
Bald Head Island	14.48	1,175	73.44	5.07
Caswell Beach	4.83	841	52.56	10.89
Oak Island	16.09	1,060	66.25	4.12
Holden Beach	11.27	608	38.00	3.37
Ocean Isle	8.05	335	20.94	2.60
Sunset Beach/Bird island	4.83	188	11.75	2.43

Source: MH Godfrey, WRC, 2013. Beaches highlighted in blue are within my study area.

Map of Units LOGG-T-NC-01, LOGG-T-NC-02, LOGG-T-NC-03, and LOGG-T-NC-04 of Critical Habitat for the Northwest Atlantic Ocean Loggerhead Sea Turtle DPS

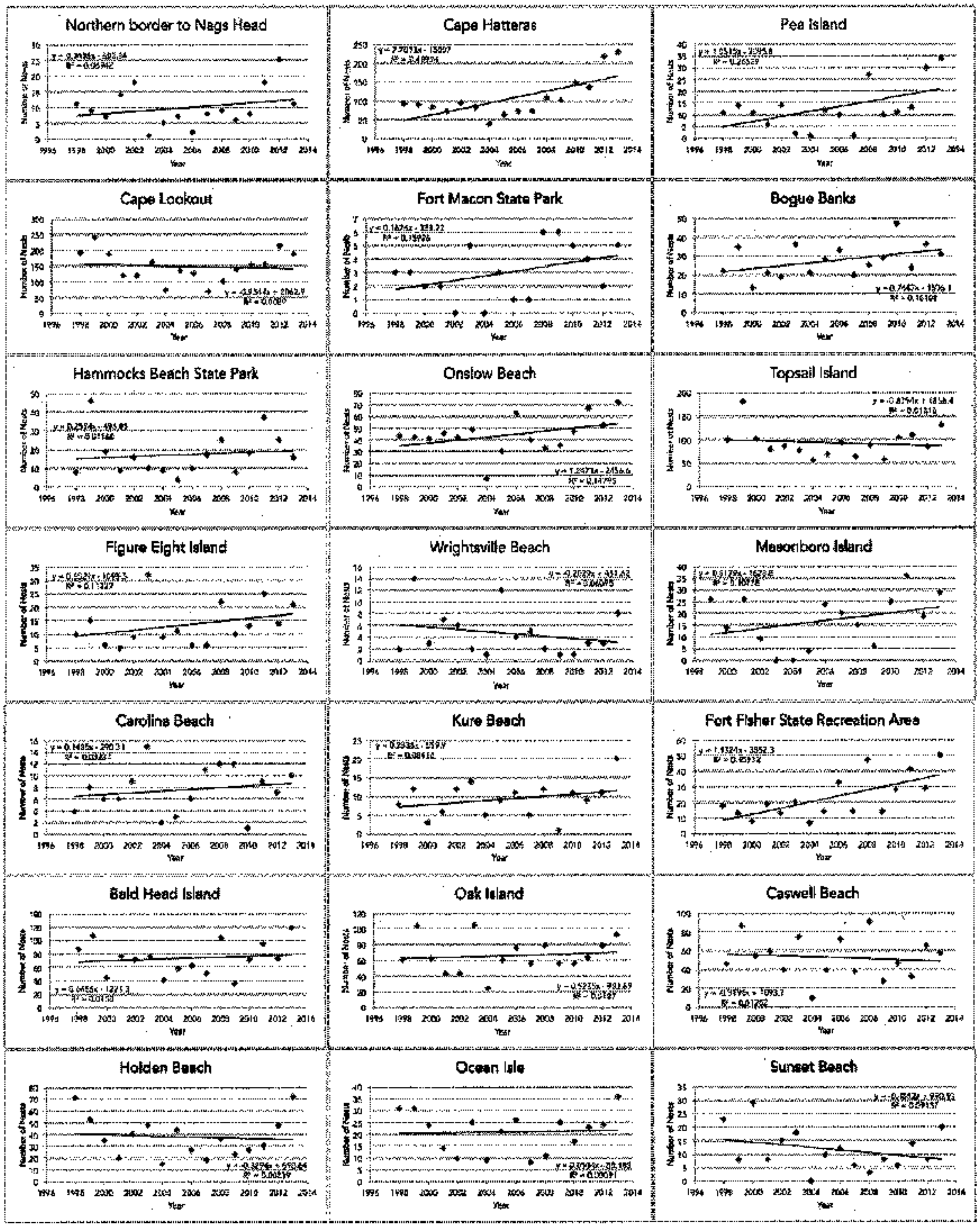


Map of Units LOGG-T-NC-05, LOGG-T-NC-06, LOGG-T-NC-07, and LOGG-T-NC-08 of Critical Habitat for the Northwest Atlantic Ocean Loggerhead Sea Turtle DPS



Appendix E

Regressions of number of nests per year for all North Carolina beaches



Miller, Tancred

From: Anderson CIV Thomas H <thomas.h.anderson1@usmc.mil>
Sent: Tuesday, November 03, 2015 9:37 AM
To: Miller, Tancred
Subject: RE: Beach erosion

I do appreciate the attempt to allow public involvement, but public input and public review are completely different. I also work for the government and understand the challenges associated with limited staff and resources. Often the tasking exceeds the resources provided to complete those tasks. I am however troubled by what seems to be a gov't wide move away from accountability to the public.

Thank you for your response. I hope that the erosion issues can be worked out in a manner acceptable to all.

I also appreciate your kind words in regard to my service. It was my pleasure, and the thanks of others is a blessing I don't take lightly.

R/
Tom

Thomas H. Anderson Jr.
Occupational Safety & Health Specialist (Tactical)
Marine Corps Air Station New River
Station Headquarters - Bldg: AS-211; Room: 217
Jacksonville, NC 28545-1001
Office: (910) 449-5041

-----Original Message-----
From: Miller, Tancred [mailto:tancred.miller@ncdenr.gov]
Sent: Tuesday, November 03, 2015 9:12 AM
To: Anderson CIV Thomas H
Subject: RE: Beach erosion

Dear Mr. Anderson,

Thank you for your comment, it will be included with the final report.

I understand your desire to see a draft of the report before it is finalized; that would have been our preference as well. For us it is a resource issue--we were assigned this study with very little time and no additional resources, and are having to divert existing staff from their normal duties in order to complete the study on schedule. I would be happy to speak with you further about this if you would like.

The division's work is always subject to public review and we always welcome public input. We invited public input on this project even though it was not required by the legislation that charged us to do the study, since many people might not have otherwise been aware that a study was being conducted, or been given an opportunity to be heard. We always strive to be transparent.

Thank you again for your comment, and thank you for your service to our country.

Best Regards,
Tancred

Tancred Miller
Coastal & Ocean Policy Manager
Division of Coastal Management
Department of Environmental Quality

(252) 808-2808 ext. 224
Tancred.Miller@ncdenr.gov

400 Commerce Ave
Morehead City, NC 28557

-----Original Message-----
From: Anderson CIV Thomas H [mailto:thomas.h.anderson1@usmc.mil]
Sent: Tuesday, November 03, 2015 8:22 AM
To: Miller, Tancred <tancred.miller@ncdenr.gov>
Subject: Beach erosion

Much is being discussed about the state's role in beach erosion. The bottom line is that shorelines change, always have, always will. It is a farce to think that it is controllable. Millions are spent moving sand around in an effort to appease those who chose to build with sand as a foundation. I believe it is irresponsible for the state to spend money attempting to protect the financial interests of such a small percentage of residents. I understand the need to attempt to protect life and property, but massive beach replenishment projects should be financed by the owners of the property that is being effected and not spread statewide forcing many that live far from the beach to pay for someone else's poor decision to build in an unstable location! Of course, places such as Bald Head Island are occupied by those with the wealth needed to buy an unfair amount of influence on decision makers. Let's stop making it easy for the wealthy to build on the sand and let the government pay for the damages! There are also many businesses effected so politicians bail them out as well....but when they are operating effectively little of the massive profits are returned to be available for use after the next storm. Let's stop being responsible for bailing out people and companies that make poor decisions based only on the fact that they can make a lot of money or enjoy a desired lifestyle knowing that when it all goes bad (yes, when, not if, history shows it will happen again) the state will be there with millions to ease the financial pain of their poor choices.

I also feel that there is no excuse for not allowing time for public review and comment. Time is not that short. Once again a gov agency is choosing a path of least resistance instead of providing transparency in its operations. I'm sure it's much easier to push a report through if you keep what's in it from public sight and review, but it's not the right way to do business.

Respectfully,
Tom Anderson

Thomas H. Anderson Jr.

The Village of Bald Head Island

December 15, 2015

VIA EMAIL

N.C. Division of Coastal Management
ATTENTION: Tancred Miller
400 Commerce Avenue
Morehead City, North Carolina 28557
Email: Tancred.Miller@ncdenr.gov

Re: Public Notice - Beach Erosion Study Public Comments
2015 Appropriations Act, S.L. 2015-241

Dear Tancred:

The Village of Bald Head Island ("the Village") is pleased to submit these comments in response to the public notice for beach erosion study public comments. A more managed approach to beach erosion from the Wilmington Harbor Shipping Channel ("WHSC") and dedicated funding for mitigation are necessary to help the US Army Corps of Engineers ("USACE"), the State, Village and other beach communities, including Caswell and Oak Island, budget and plan necessary actions related to the WHSC and maintenance dredging and the erosion impacting adjacent beaches. This understanding is necessary in order to implement appropriate improvements in Channel design and sand management. It is anticipated that the benefits to regional commerce of an improved shipping channel, avoidance of substantial ongoing environmental harm, secondary benefits of dredged material for coastal storm damage reduction, and dredging cost savings will be of great public benefit. Ultimately, the USACE and State must identify a viable plan of action to control the shoaling and stop the excessive erosion.

Bald Head Island has public beach and environmental resources important to and enjoyed by many persons residing within and outside the State of North Carolina. Moreover, the Island benefits all of Southeast Region of North Carolina with its vibrant environment, its unparalleled recreational opportunities, and its revenue-generating tourism industry. **In short, it is an Island worth saving.**

Bald Head Island has a unique shoreline history, as the entrance to the WHSC lies to the immediate west of the Island. That channel entrance was widened in 2000, bringing the channel much closer to the Island's southwest beaches.[1] As a result, the Island has since struggled to maintain its south and west public beaches, rare habitat, homes, roads and utilities.[2] The dredging practices of the USACE in maintaining the WHSC—North Carolina's most active shipping channel—appear to have intensified the on-going erosion of Bald Head Island into the Cape Fear River.[3] The "Sand Management Plan" agreed to by the Village and the USACE, among others, in 2000 was intended to protect the beaches on both sides of the WHSC from harm caused by the USACE's activities. The SMP has failed to do that.

As a result, Bald Head Island is under constant siege from erosion, resulting in a permanent change in the Island's morphology and loss of sand shoals, which protect the Island from waves and storms. Worse, the erosion is devastating during the four years in which, pursuant to the Sand Management Plan, Bald Head receives no sand placement at all. For example, during the 2009 USACE maintenance dredging sand placement to Caswell Beach and Oak Island—which was part of a four-year hiatus—the Village was forced to organize and fund a beach renourishment project that cost approximately $17.0 million. The Village has since been required to construct a rock terminal groin, completed December 2015, at an $8.0 million project cost.

Although the cost of the Village project was high, the cost of inaction was higher. Bald Head's irreplaceable habitat (including rare sea turtles, Plover birds and SeaBeach Amaranth plant species)[4], homes and public infrastructure[5] were all in jeopardy and remain so. For the time being, the Village dredging project of 2010 and the terminal groin has helped protect these invaluable resources.

The importance of all this is that **Bald Head Island needs immediate action and effective problem-solving.** Otherwise, the battle to save its beaches will wage indefinitely, causing great property, recreational and financial loss, as well as irreversible harm to Bald Head's unique environment. Bald Head Island's beaches, turtles and birds belong to the State and people of North Carolina and are worthy of protection.

RECOMMENDATIONS

1. The State should require the USACE to abide by its erosion monitoring and mitigation obligations made in the environmental review process and incorporated in the State's consistency determination. The USACE Colonel DeLony and NCDENR

[1] See Exhibits A, B and C (attached).
[2] See Exhibits D-H and PowerPoint presentation (attached).
[3] See Exhibit I (attached).
[4] See Bald Head Island Conservancy Report, Exhibit J (attached).
[5] See Map of southwest Bald Head Island, Exhibit K (attached).

Division of Coastal Management Director Donna Moffat letters of 2000 are attached as Exhibit L. [6]

2. The State Division of Coastal Management should work with the USACE to adequately study, scientifically model and modify the Wilmington Harbor Channel 96-Act Project Sand Management Plan, attached as Exhibit M[7] to address adequately erosion impacts at Bald Head Island. The SMP modification should be based on the actual, quantitative impacts to adjacent shorelines at Bald Head Island, Caswell and Oak Island, as shown by the monitoring and studies since the 2000 Channel realignment.

3. The State and USACE should identify a source of dedicated funding for necessary coastal storm damage reduction projects, including at Bald Head Island. Bald Head Island, as shown by fifteen (15) years of survey data, requires 1.2-1.4 million cubic yards of sand placement every two (2) years to meet its sand deficit. That is a $15 million to $17 million project cost every two (2) years.

Thank you for considering this information. Please contact me if any additional information would help you.

Sincerely yours,

J. Andrew Sayre
Mayor

Attachments

pc: Erik Olsen, Coastal Engineer
Calvin R. Peck, Jr., Village Manager
K. Christopher McCall, Assistant Village Manager/Shoreline Protection Manager
Charles S. Baldwin, IV, Esquire

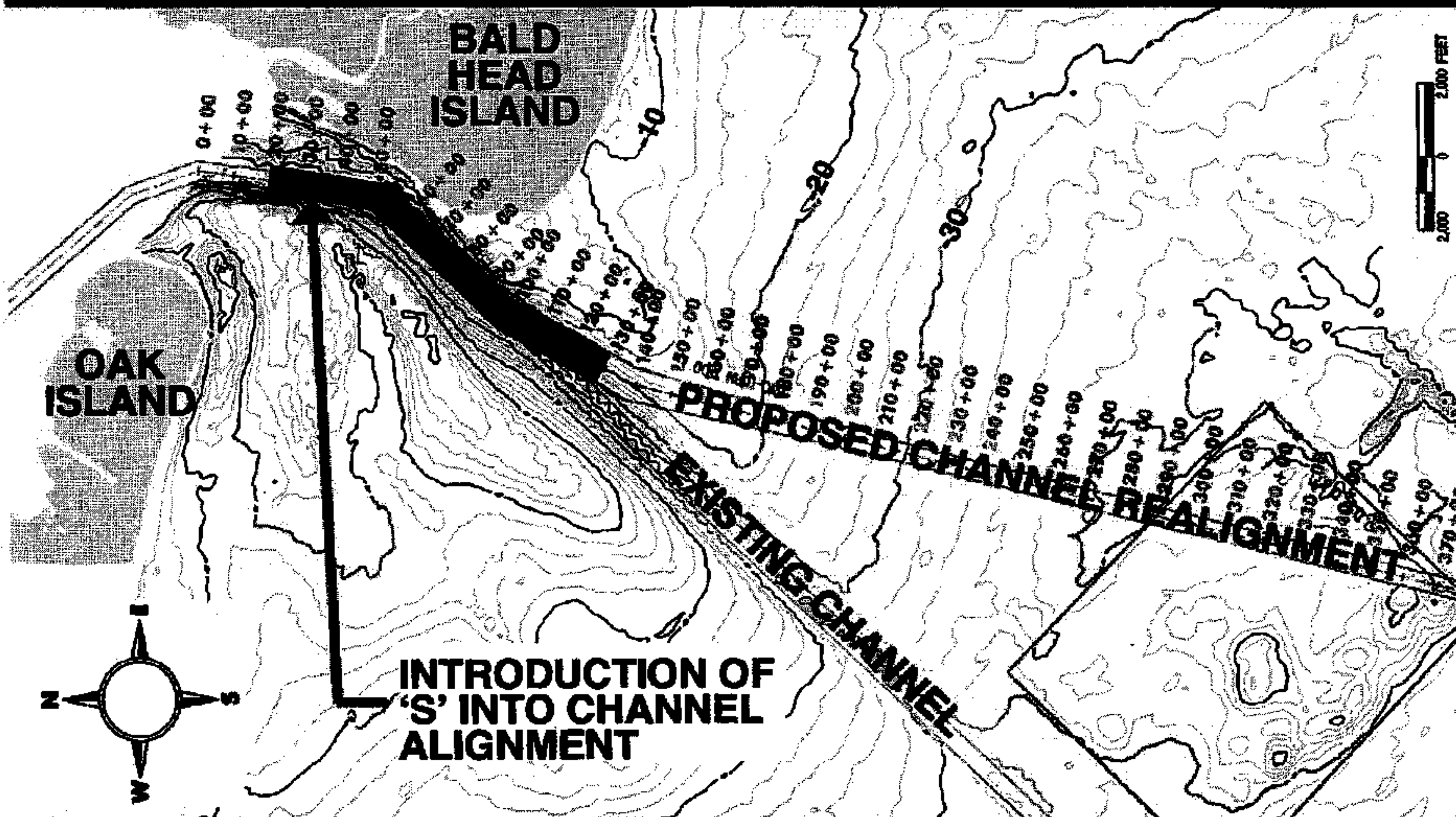
---

[6] See USACE Colonel DeLony and NCDENR Division of Coastal Management Donna Moffatt letters of 2000, Exhibit L (attached).

[7] See Wilmington Harbor Channel 96-Act Project Sand Management Plan, Exhibit M (attached).

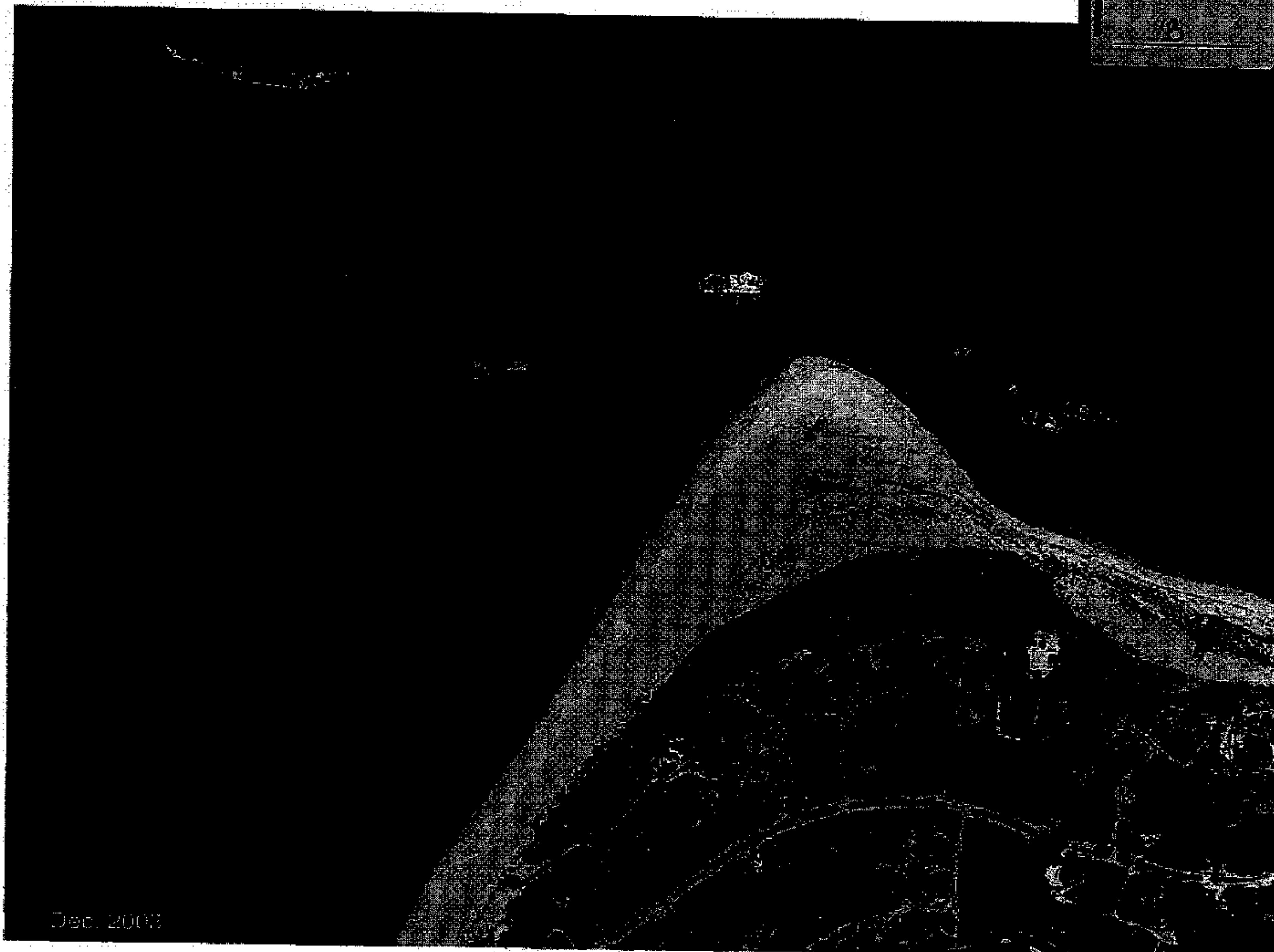
P.O. Box 3009 BALD HEAD ISLAND, NC 28461 (910) 457-9700 FAX (910) 457-6206
E-MAIL: village@villagebhi.org WEBSITE http://www.villagebhi.org

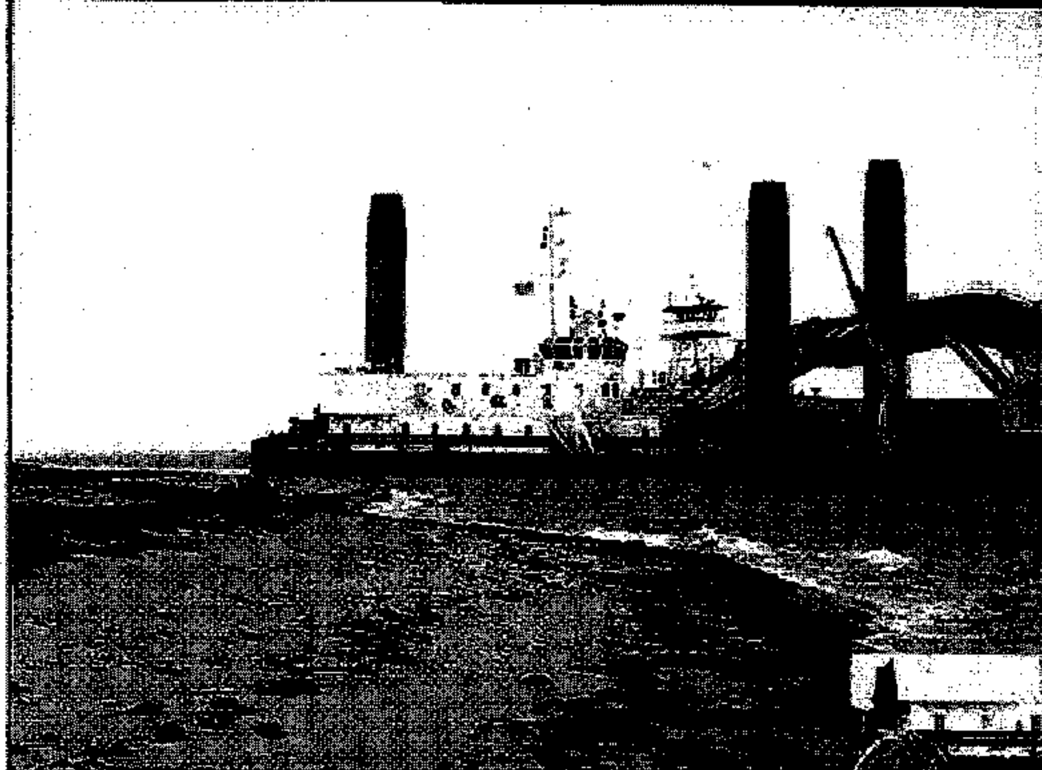
EXHIBIT
A



olsen

EXHIBIT





Dipper dredge Tauracavor excavating channel at "The Point"

EXHIBIT

D

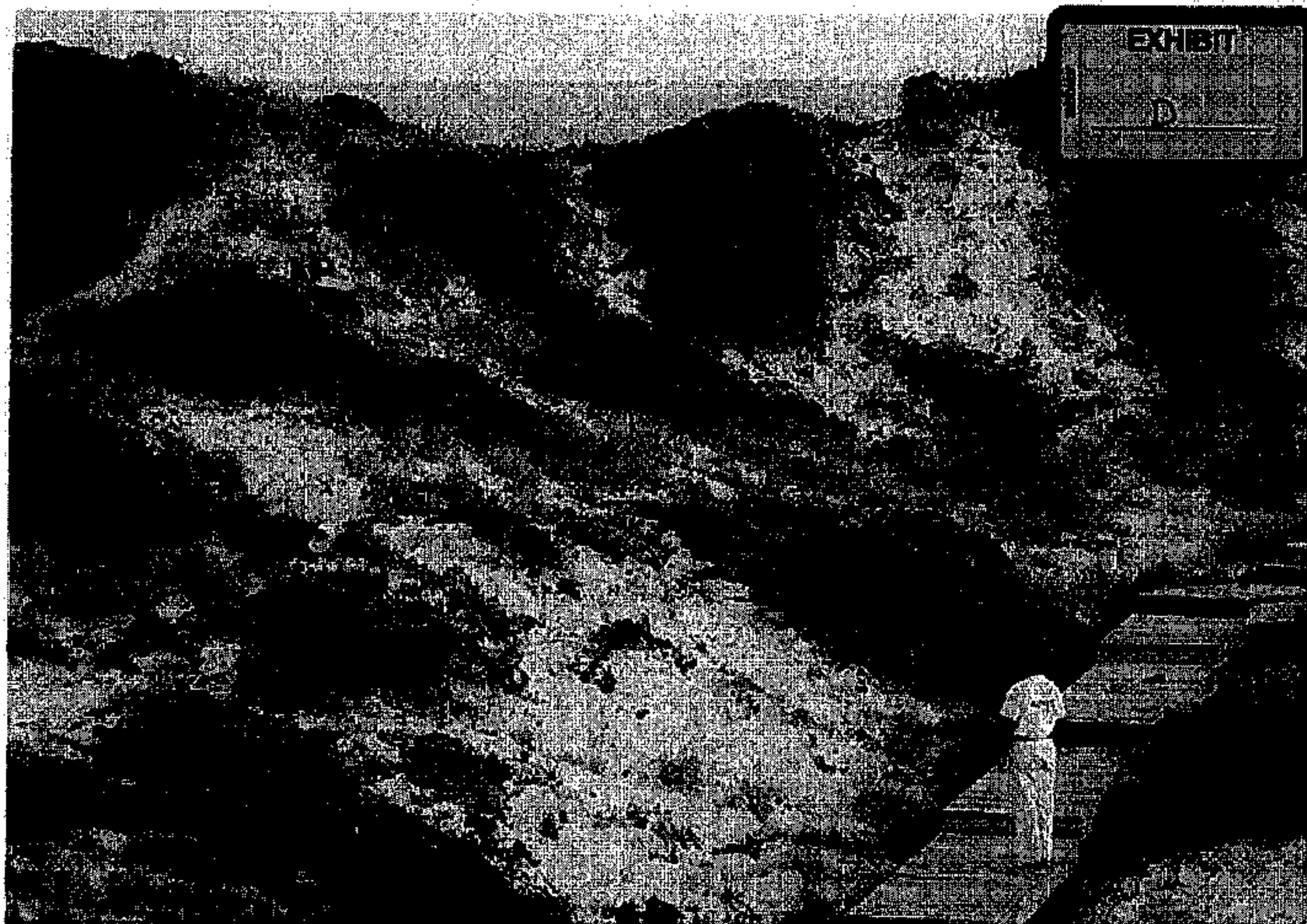
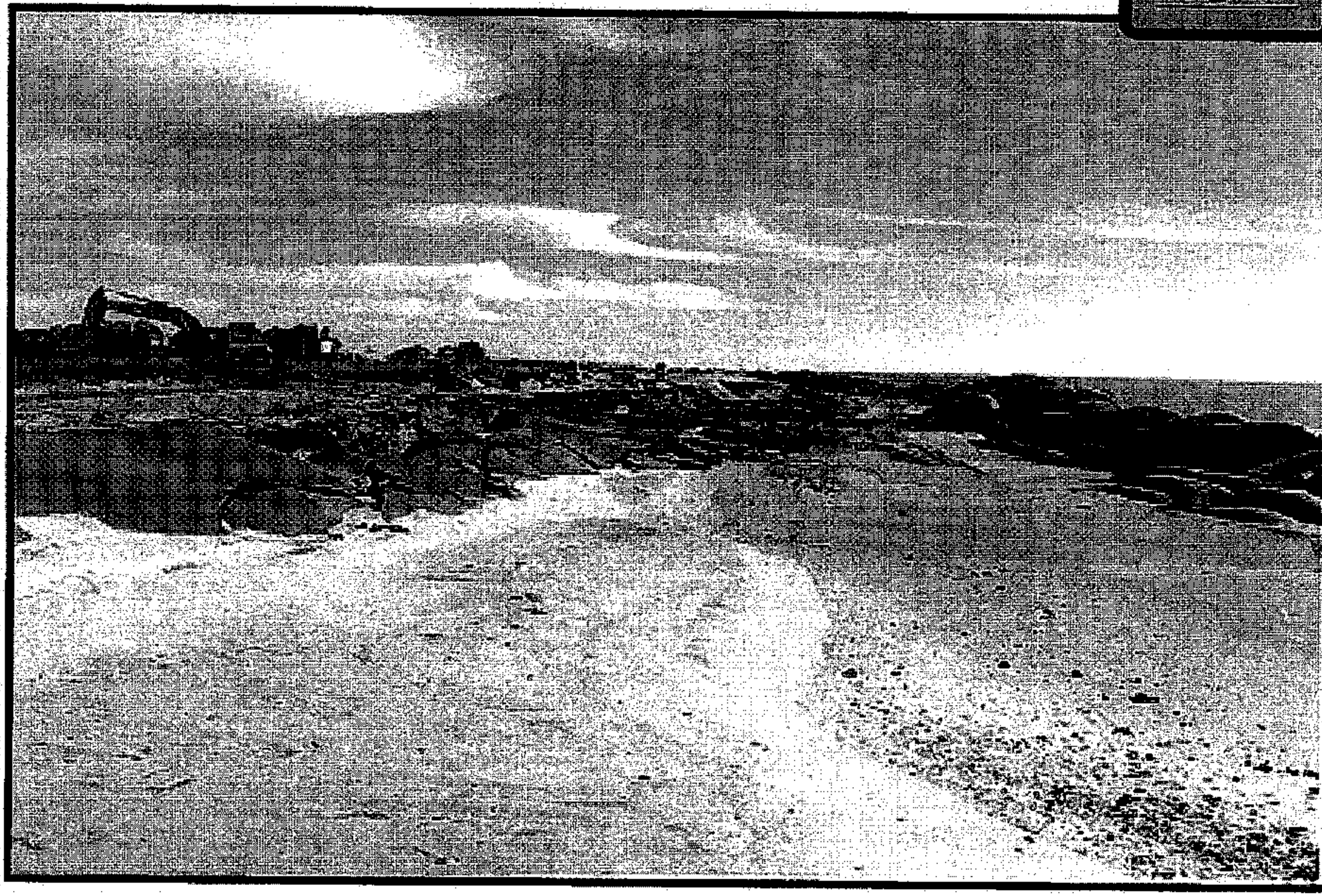
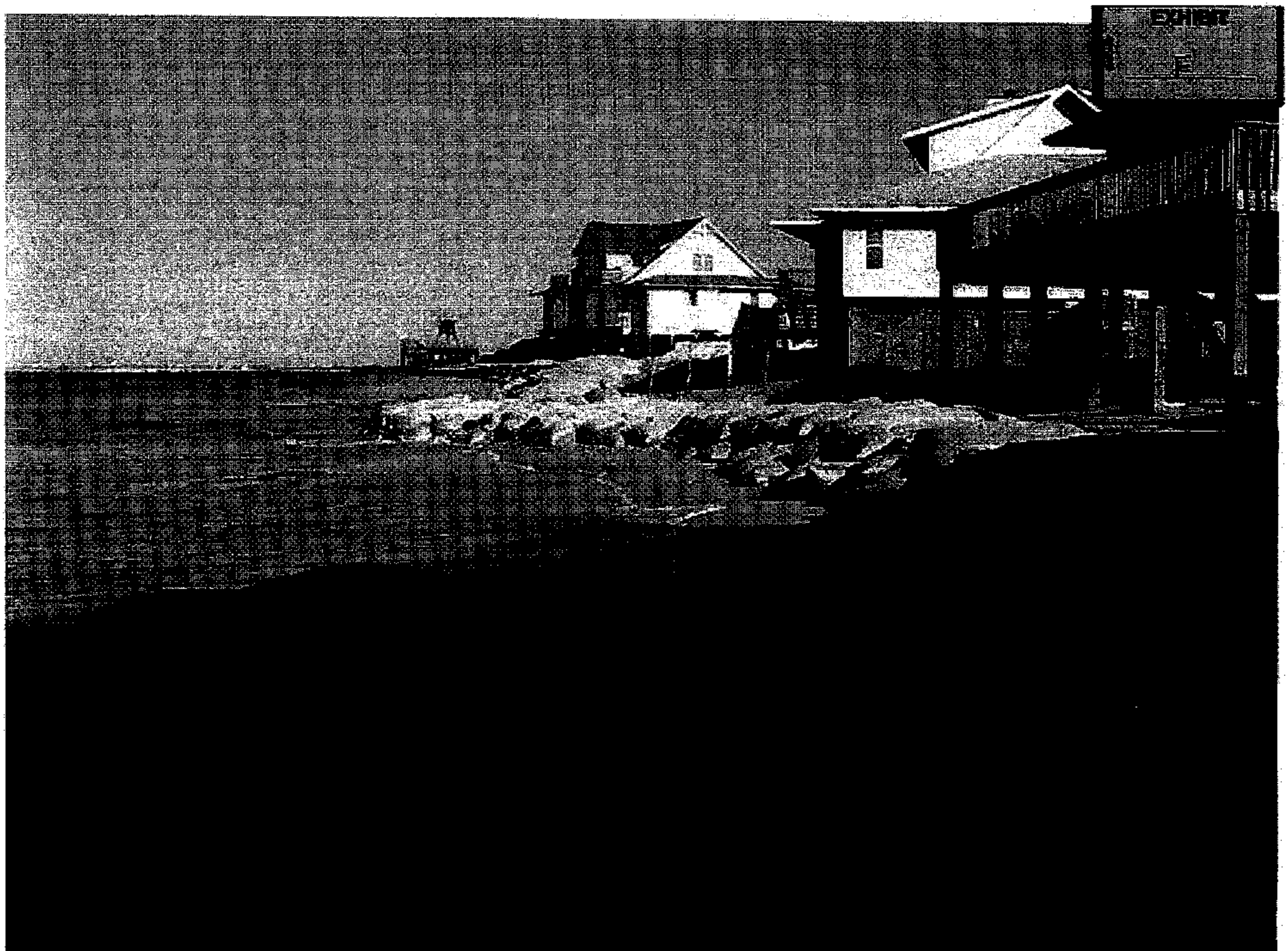


EXHIBIT
E





EXHIBIT

EXHIBIT
6


EXHIBIT

EXHIBIT

EXHIBIT
J

BHI CONSERVANCY

ENDANGERED AND THREATENED SPECIES HABITAT

ON "THE POINT", BALD HEAD ISLAND

16 April, 2009

By: Suzanne E. Dorsey, Ph.D. Executive Director BHI Conservancy and Maureen Dewire, Senior Naturalist, Director of Education BHI Conservancy

The "Point" of land at the juncture of West Beach and South Beach, BHI is of significant and unique ecological importance. The Point is used by many different species of plants and animals in the dune/beach ecosystem and is particularly valuable habitat because of the extensive dune crest habitat – the area above the high-tide line and below the major vegetation. This wide sandy area on BHI is unique, in part, because humans rarely trespass. The dune crest habitat at the Point has been most impacted by the semiannual dredging off the coast of BHI. This year, when dredging has not been complemented by renourishment to replace eroded sand from the Point, essential habitat has disappeared—either eroded away or washed over. There is no longer any sea turtle, shorebird, or endangered plant habitat in the area known as the Point as well as adjacent beaches along West and South Beaches. According to the Endangered Species Act, any listed species are protected from take, and take includes destruction of habitat. Loss of nesting and foraging habitat would certainly fall under the definition of take. Restoration and preservation of habitat is essential for the long term survival of federally endangered or threatened species.

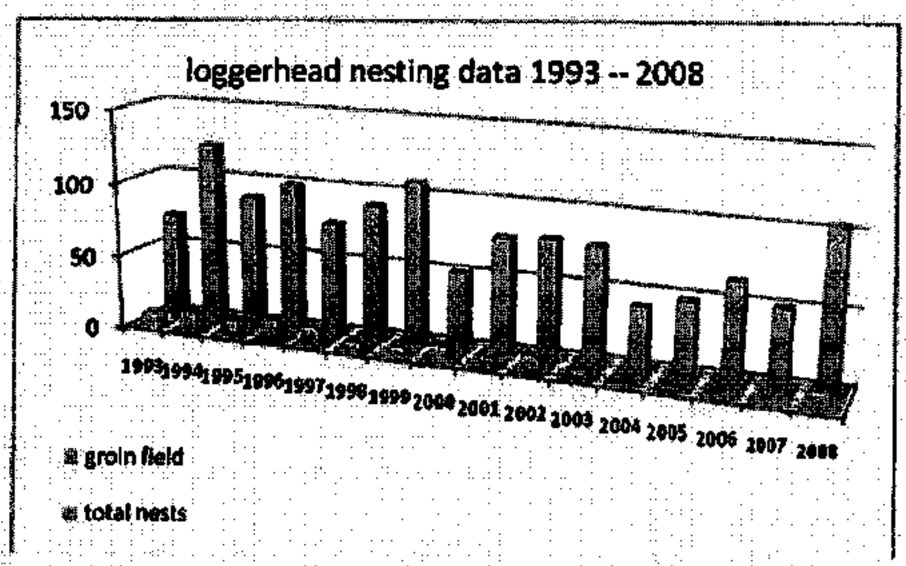
Affected state and federally listed flora/fauna by loss of beach at the South/West "Point":

SEA TURTLE:
Loggerhead Sea Turtle: Federally listed as Threatened
Green Sea Turtle: Federally listed as Endangered
PLANT:
Seabeach Amaranth: Federally listed as Endangered
BIRD:
Least Tern: Species of Special Concern
Piping Plover: Federally listed as Threatened
Wilson's Plover: Listed in North Carolina as a Species of Special Concern
American Oystercatcher: Species of Special Concern
Common Tern: Species of Special Concern
Caspian Tern: Species of Special Concern
Brown Pelican: Significantly Rare

Sandwich Tern: Watch List
Forster's Tern: Watch List

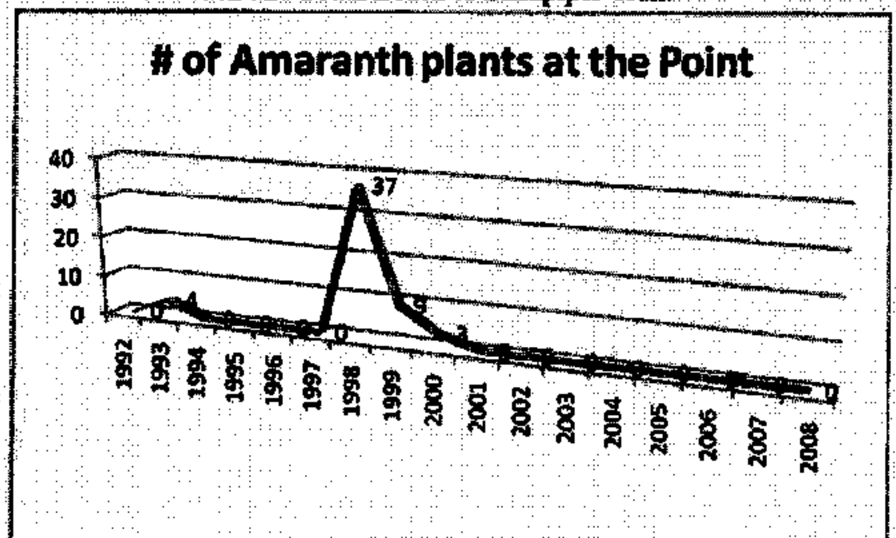
SEA TURTLES

- Loggerhead and green sea turtles have both been documented nesting on Bald Head Island's beaches, including those that run east, south and west. The great majority of nests are laid by the federally threatened loggerhead sea turtle, with a handful of nests laid by the federally endangered green sea turtle. Ocean beaches in the Cape Fear region have the highest density of nesting sea turtles in North Carolina; so maintaining the integrity of their nesting habitat is key to successfully managing sea turtles in the state. These species require a sufficient amount of sand between the high tide line and dune line in order to nest successfully. The more narrow the area between the high tide line and the dune line, the more likely their nests will become inundated with water during a storm event or a simple extreme high tide caused by a full moon or strong onshore winds. Nesting beaches appropriate for sea turtles are becoming more infrequent as development encroaches on what was once suitable habitat.
  - Preliminary analysis of sea turtle nesting data show an increased variance and decreased overall number of sea turtle nests throughout the island and along the groin field from 2000 to 2008 when compared to 1993 to 1999. T-test show significant differences in nesting in both categories between these dates $P<0.05$. Although sea turtles have an internal 2-3 year nesting cycle, the data below seem to demonstrate that nesting improves after nourishment—although further analysis will be needed to support this contention. Additional analysis of nesting trends on the Point will be forthcoming.



PLANTS:

- **Seabeach amaranth**, a federally endangered plant occurring on barrier island beaches, has been documented on the beaches of BHI in scattered locations. This plant is sporadic in its appearance but has been documented by Conservancy staff annually for the past 5 years. Seabeach amaranth's primary habitat "consists of overwash flats at accreting ends of islands and lower foredunes and upper strands of noneroding beaches. This species appears to need extensive areas of barrier island beaches and inlets functioning in a relatively natural and dynamic manner." (FWS: http://www.fws.gov/nc-es/plant/seabamaranth.html). It will often times occur with other mixed vegetation including sea rocket and dune spurge. Seabeach amaranth is also considered to be an effective sand binder, helping to build dunes (USFWS website, same as above).
    - Data collected by the Corps of Engineers indicates that Seabeach Amaranth was found on the "Point" until 2000. After the realignment no examples were noted. The survey was conducted in "Reach C from the area NW of the lighthouse around West Beach and South Beach to Sandpiper Trail."



- Seabeach Amaranth occurs in open sands where there is little or no competition from perennials. It is definitely much more prevalent as a colonizer of the upper beach and unvegetated sand flats above the high tide. Thus it has almost exactly the same habitat as sea rocket, piping plover nesting areas, and loggerhead turtle nesting areas. Intact dunes are highly beneficial in maintaining suitable habitat on a more constant and consistent manner for all these organisms.
    - Alan Weakley, Curator and Adjunct Asst. Professor, University NC Herbarium, NC Botanical Garden Department of Biology UNC-Chapel Hill.
- The erosion of at least 100' on the Point has likely removed a significant portion of the seed bank for this endangered species. The seed bank, seeds stored and protected underground, would have provided a source for new plants when and if conditions

improved on the Point. The level of erosion on the Point has made recolonization Seabeach amaranth unlikely without a restoration program.

BIRDS

- NESTING HABITATS
  - Least terns, piping plovers and Wilson's plovers all use similar beach habitat to lay their eggs. Nesting occurs above the high tide line but below the dune line in fairly open and un-vegetated habitat. Too much vegetation will actually deter the birds from nesting, as that vegetation will hide potential predators and the birds prefer to be in more exposed, open beach habitat. A sand/shell substrate is preferable for successful nesting. The birds lay their eggs in a small depression in the sand with the egg shell closely matching the color of the surrounding sand. This affords the birds protection against predators but also leaves them susceptible to being crushed by unknowing humans or dogs. As beach habitat is quickly being swallowed up by development and a rapid increase in human populations along the coast (53% of the United States' population lives in coastal counties), protection of essential nesting habitat for shorebirds is critical to their continued survival.
- FORAGING HABITATS
  - Habitat such as that found on the Point are ideal for foraging and resting for dozens of species of birds. During low tide, large sand flats are exposed which provide excellent areas for foraging for a number of shorebird species. Worms, crustaceans and other invertebrates are all present below the sand and birds take advantage of this habitat, feeding for hours each day. Areas from the high tide line to the vegetation line are equally important, providing a resting spot for birds, whether they are year-round residents or migratory species in desperate need of an area to rest and re-fuel. Some of the species forage in the water just offshore (all of the tern species and brown pelican), searching for small bait fish. In between foraging trips, they will most often rest on the beach. The tern species use the sandy beach area for mating purposes as well during the months of April and May. Many of the species documented using the south/west point of the beach are here for the majority of the year (April-October) and in some cases, are year-round residents. Several are also colonial birds, preferring to be in large flocks, therefore requiring large expanses of beach to accommodate the birds.
  - The Point on Bald Head Island is important foraging and resting habitat for several bird species listed in the state of North Carolina as Threatened, Species of Special Concern, Significantly Rare or Watch List. One of these species is also listed as Federally Threatened.
    - Threatened in NC:

- Piping Plover (Federally Threatened as well)
- Species of Special Concern in NC:
  - American Oystercatcher – upgraded from Significantly Rare in 2006 to Species of Special Concern in 2008
  - Wilson's Plover – upgraded from Significantly Rare in 2006 to Species of Special Concern in 2008
  - Common Tern
  - Least Tern
- Significantly Rare in NC:
  - Caspian Tern
  - Brown Pelican
- Watch List:
  - Sandwich Tern (W2 & W5)
  - Forster's Tern (W2)

W2= Species rare to uncommon
W5 = Species with increasing amount of threats to its habitat

Suzanne E. Dorsey, Ph.D.
Executive Director, BHI Conservancy

Maureen Dewire
Senior Naturalist/Director of Education, BHI Conservancy

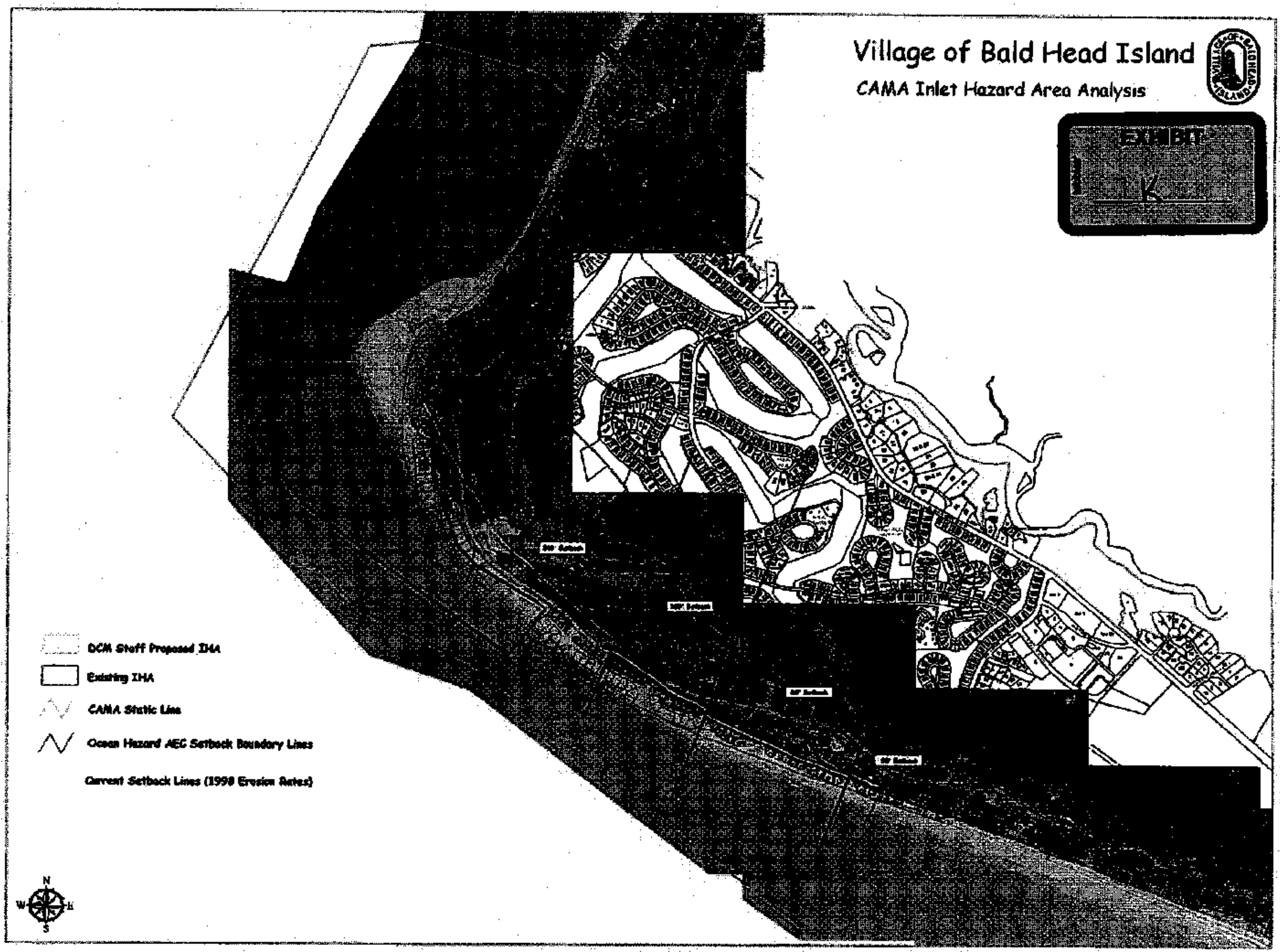

Village of Bald Head Island
CAMA Inlet Hazard Area Analysis
EXHIBIT
K
DCM Staff Proposed IHA
Existing IHA
CAMA Static Line
Ocean Hazard AEC Setback Boundary Lines
Current Setback Lines (1998 Erosion Rates)
N
W
E
S

EXHIBIT L

NORTH CAROLINA DEPARTMENT OF
ENVIRONMENT AND NATURAL RESOURCES
DIVISION OF COASTAL MANAGEMENT

NCDENR

JAMES B. HUNT JR.
GOVERNOR

BILL HOLMAN
SECRETARY

DONNA D. MOFFITT
DIRECTOR

RECEIVED
EXECUTIVE OFFICE
2000 JUN 26 A 11:03

Action: PM-C
CF: DE
DX
DP
TS
OC

June 15, 2000

Colonel James W. DeLony
District Engineer
U.S. Army Corps of Engineers
Wilmington District
P.O. Box 1890
Wilmington, NC 28402-1890

REFERENCE: DCM00-14 EA and CD - Preconstruction Modifications of Authorized Improvements, Wilmington Harbor 96 Project

Dear Col. DeLony:

On May 17, 2000 the State of North Carolina completed its review, pursuant to 15 CFR 930 Subpart C - Consistency for Federal Activities, of the referenced document describing proposed modifications to the authorized Wilmington Harbor 96 Project in New Hanover and Brunswick Counties, North Carolina. The Corps of Engineers submitted the document to the state on February 17, 2000, and the project was assigned the number DCM00-14 for our review purposes.

During the course of our review several environmental concerns were raised by state agencies regarding potential impacts on the resources of the coastal zone. These comments were forwarded to the Corps for its consideration. As the consistency deadline was approaching, we extended our original consistency deadline 15 days, pursuant to 15 CFR 930.41, at the end of March. On April 10, 2000, our review was again extended to allow concerned state agencies to review the Corps' responses to comments on the Environmental Assessment (EA). The Division of Coastal Management received the Corps' responses on May 3 and again solicited comments from concerned state agencies.

The modifications that the Wilmington District Corps of Engineers seeks authorization for are as follows:

1. Construction and maintenance of the Wilmington Harbor entrance channel along a new alignment across the ocean bar.
2. Backfilling the abandoned channel length with dredged material not suited for beach or littoral zone disposal.

3. Placement of material dredged from the new channel alignment and other portions of the project on area beaches in New Hanover and Brunswick Counties.
4. Establishment of a comprehensive plan for dredging and disposal operations for each portion of the harbor, including hopper dredge with overflow.
5. Utilization of blast pressure criteria to measure impacts of blasting on aquatic resources and the elimination of the bubble curtain during blasting operations.
6. Placement of dredged material that does not go to the old channel, the littoral zone, the beaches, or other existing disposal sites, into the Offshore Dredged Material Disposal Site (ODMDS).

The Corps proposes to construct the new entrance channel alignment and place all suitable material on the nearby beaches over an approximately eighteen month period covering two winter seasons and one summer season. Turtle monitoring and shorebird surveys of affected beaches will be conducted. Details of the disposal operations for construction and maintenance of the channel are documented in a Sand Management Plan (SMP). In addition, the Corps has clarified details of the placement, timing, costs, and amount of sand to be deposited on the beaches of Bald Head Island, Caswell Beach, Oak Island, and Holden Beach in a letter dated June 9, 2000from Colonel James W. DeLony, District Engineer, to the mayors of the respective beach towns. We understand that disposal of dredged material from construction and maintenance of the project will be conducted according to the SMP and letter, as agreed to by the NC Division of Water Resources, the Brunswick County beach communities and the Corps of Engineers. We also understand that the use of hopper dredge with overflow will be limited to times of year and reaches of the project in which impacts on coastal resources will be minimized.

Based upon our review of the EA and the Corps of Engineers' response to comments, we do not disagree with your determination that the proposed construction and changes in harbor maintenance procedures are consistent with the North Carolina Coastal Management Program to the maximum extent practicable, provided that the project is performed according to the EA (including the Sand Management Plan and other appendices) and the Corps' responses to comments from the EA, and to Colonel DeLony's letter of June 9, 2000 (including attachments), and that the conditions below are met.

1. Principal amongst the issues raised were potential impacts on sea turtles, shore and water birds, beach and benthic infauna, fisheries, and water quality parameters. It is extremely important that the impacts of this multifaceted project be well documented in order to evaluate the effects on these resources and on the overall coastal environment. The Corps of Engineers will pursue an integrated monitoring plan to address the resources noted in the first sentence of this paragraph, and will coordinate all monitoring efforts with the appropriate state agencies. This will include but not be limited to the North Carolina Division of Coastal Management, the Wildlife Resources Commission, the Division of Marine Fisheries, and the Division of Water Quality. We understand that the Corps intends to initiate monitoring coordination with the resource agencies in June of 2000.
2. As additional mitigation for impacts on fisheries resources, a fish passage structure will be constructed at Lock and Dam 1 on the Cape Fear River. In addition, fish passage alternatives for Lock and Dams 2 and 3 will be investigated. The Corps of Engineers and, as the Wilmington Harbor Project Sponsor, the State of North Carolina, have agreed to these actions.
3. The placement, timing, costs, and amount of sand to be deposited on Bald Head Island, Caswell Beach, Oak Island, and Holden Beach, both during construction and future maintenance; monitoring; and response to impacts shall be in accordance with Col. DeLony's letter of June 9, 2000, to the mayors of the respective towns receiving the sand (attached and incorporated by reference). If the towns, Corps, and project sponsor's representative mutually agree to modifications to the SMP or Col. DeLony's June 9, 2000 letter, those modifications shall be submitted to the North Carolina Division of Coastal Management for a determination of whether another consistency review is necessary on the modifications.
4. The state must have the opportunity to review the project, including monitoring results, to determine if it continues to be consistent with the North Carolina Coastal Management Program in two situations: 1) After five years from the date of this letter, and 2) before any subsequent modifications for future maintenance or other requests to modify the Wilmington Harbor 96 Project are considered. The Corps shall request this review and provide documentation of impacts (or lack thereof) on the coastal resources of concern.

5. If in the future the Corps considers requesting authorization to conduct hopper dredging with over flow or to place maintenance dredge spoil on a beach, outside of the established time periods or locations, a separate consistency review will be required for each of these activities.

While the State of North Carolina supports beach nourishment and the placement of suitable spoil material on the beaches, we remain concerned about the short term and long term impacts on the biologic and ecologic resources of the coast. We maintain that the best time for such beach nourishment and renourishment is outside of the period of peak impacts on infauna, sea turtles, and fisheries. The State discourages individuals and agencies from seeking authorization to perform work outside established moratoria, and caution that our response is not to be interpreted as a precedent assuring authorization for future renourishment or disposal of sand on beaches outside of established dredging and disposal moratoria. We understand that summer beach disposal is necessary only during the construction phase of the project and that maintenance of the harbor channels will be conducted within established biological time frames.

Finally, with the increasing number of beach disposal and renourishment projects, much of the state's southern coast beaches will be in the placement or recovery phases in any given year. To this end, the Division of Coastal Management requests that the Corps consider combining the monitoring studies and environmental considerations of this project, the Wrightsville Beach, Carolina Beach, Kure Beach projects, and all of the Brunswick County Beaches projects to achieve a more comprehensive and cumulative impact analysis. Although these projects are separate in authorization and funding, we feel that concurrent studies could provide beneficial insights on impacts to resources from beach disposal and nourishment along this extended reach of shoreline.

If you have any questions regarding our findings, conditions, or recommendations, please contact Ms. Caroline Bellis, Division of Coastal Management, at (919) 733-2293. Thank you for your consideration of the North Carolina Coastal Management Program.

Sincerely,

Donna D. Moffitt

Donna D. Moffitt

Attachment

cc: Bob Stroud, Division of Coastal Management, Wilmington
Franklin McBride, NC Wildlife Resources Commission
Bennett Wynne, NC Wildlife Resources Commission
Ruth Boettcher, NC Wildlife Resources Commission
Fritz Rohde, NC Division of Marine Fisheries
Mike Street, NC Division of Marine Fisheries
John Dorney, Division of Water Quality
Frank Yelverton, US Army Corps of Engineers
John Meshaw, US Army Corps of Engineers

EXHIBIT L

DEPARTMENT OF THE ARMY
WILMINGTON DISTRICT, CORPS OF ENGINEERS
P.O. BOX 1890
WILMINGTON, NORTH CAROLINA 28402-1890

RECEIVED
JUN 16 2000
COASTAL MANAGEMENT

IN REPLY REFER TO
Project Management Branch

June 9, 2000

Honorable Freeman A. Berne
Mayor of the Village of Bald Head Island
Post Office Box 3009
Baldhead Island, North Carolina 28461

Honorable Harry Simmons
Mayor of Caswell Beach
707 Caswell Beach Road
Caswell Beach, North Carolina 28465

Honorable Joan Altman
Mayor of Oak Island
4601 East Oak Island Drive
Oak Island, North Carolina 28465

Honorable James W. Lowell
Mayor of Holden Beach
110 Rothschild Street
Holden Beach, North Carolina 28462

Dear Mayors:

After years of effort by many, it is a pleasure to see the various elements of the Wilmington Harbor Navigation project (hereinafter the "Project") coming together. As we approach the decision point for the Finding of No Significant Impact (FONSI), I want to bring everyone up to date on the status of our plan to place beach quality sand excavated for the project on Bald Head Island, Caswell Beach, Oak Island, and Holden Beach.

As you know, the details of our plan are presented in the Environmental Assessment, in particular, Appendix A - Sand Management Plan, in the Wilmington Harbor Monitoring Plan, and in the Section 933 Evaluation Report. The shoreline segments recommended to receive sand are the Village of Bald Head Island (up to 16,000 linear feet), Caswell Beach (up to 25,000 linear feet), Oak Island (up to 25,600 linear feet), and Holden Beach (up to 10,600 linear feet). This represents a maximum shoreline length of 77,200 linear feet.

Bald Head Island will be the site of initial beach disposal associated with construction. This site, along with the easternmost 25,000 linear feet of Caswell Beach-Oak Island, represents the least cost alternative of disposal available to the Project; accordingly, placement will be accomplished at Project cost and at no cost to the Village of Bald Head Island.

ATT. 2

Placement will be according to the March 31, 2000 memorandum from Erik J. Olsen, consultant to the Village of Bald Head Island referencing the Village of Bald Head Island Beach Disposal Plan (2000/2001) (enclosed and incorporated by reference) to the U.S. Army Corps of Engineers, Wilmington District (hereinafter "Corps").

Once disposal has begun at the Village of Bald Head Island, fill operations will continue until the estimated minimum of 1,536,000 cubic yards of sand in the channel prism allocated to the Village of Bald Head Island (based on channel surveys conducted in October and December 1999) have been dredged and placed on the beach in accordance with the March 31, 2000 memorandum. Assuming a potential effective reduction of 20 percent in the gross fill dredged, the final in-place fill volume is expected to range between 1,228,000 cubic yards and 1,536,000 cubic yards.

Project construction beach disposal operations at the Village of Bald Head Island will be performed along both West Beach and South Beach, as indicated by the March 31, 2000 memorandum. The Village of Bald Head Island will provide all requisite easements necessary to construct the template(s) provided for by the March 31, 2000 memorandum.

Once the placement of beach quality sand at the Village of Bald Head Island is complete, placement along approximately 25,000 linear feet of shoreline at the easternmost end of Caswell Beach-Oak Island will be accomplished. Placement will be made in accordance with the template agreed to by the Corps, NCDENR, and the communities of Caswell Beach and Oak Island. The final in-place fill volume is expected to range between 1,451,000 cubic yards and 1,814,000 cubic yards. Since this reach comprises the balance of the least cost alternative for disposal available to the Project, placement will be at Project cost and at no cost to those communities. All requisite easements will be provided by the communities at no cost to the Project.

Under the provisions of the draft Section 933 report, the remaining beach quality sand will be placed along approximately 25,600 linear feet of the westernmost shoreline of Oak Island and along approximately 10,600 linear feet of the eastern shoreline of Holden Beach. Placement will be made in accordance with the template agreed to among the Corps, NCDENR, and the affected beach communities and cost shared at the rate of 65 percent Federal (currently estimated at $6,500,000) and 35 percent non-Federal (currently estimated at $3,500,000). The final in-place fill volume along the cost shared reach of Oak Island is expected to range between 1,272,000 cubic yards and 1,590,000 cubic yards. The final in-place fill volume along the cost shared reach of Holden Beach is expected to range between 528,000 cubic yards and 660,000 cubic yards. The communities will provide all required easements at no cost to the Project.

After construction of the Smith Island and Bald Head Island Shoal portions of the project, the U.S. Army Corps of Engineers will conduct periodic maintenance dredging of the navigation channels. The disposal of all beach quality dredged material will be accomplished in accordance with the Environmental Assessment of Preconstruction Modifications of Authorized Improvements, Wilmington Harbor, North Carolina, dated February 2000 and its Sand Management Plan (Appendix A), and the Wilmington Harbor Monitoring Plan (enclosed and incorporated by reference). The associated disposal will be as called for therein, namely:

Year 2: Placement at Bald Head Island (estimated @ 1Mcy)
Year 4: Placement at Bald Head Island (estimated @ 1 Mcy)
Year 6: Placement at Caswell Beach and easternmost end of Oak Island (estimated @ 1 Mcy).

This disposal cycle is planned for the life of the project. As provided on page 8 of the Environmental Assessment and on page 12 of the sand management plan, in some cases problem shoaling involving small quantities of sand may develop in the channel between regular dredging events, making use of a pipeline dredge unfeasible and the sand may need to be deposited in the ocean disposal area.

Prior to each disposal operation at either the Village of Bald Head Island, or Caswell Beach, or the easternmost shoreline of Oak Island, the community receiving the sand may provide advance guidance to the Corps regarding placement distributions and fill template design. The Corps will follow that guidance to the maximum extent practicable.

The Corps will conduct a monitoring program as referred to in the Environmental Assessment and Sand Management Plan, and as set out in the Wilmington Harbor Monitoring Plan, which is enclosed and incorporated by reference. An annual report will be prepared, as described in the Monitoring Plan. The Corps will use this monitoring data to evaluate and adjust the Sand Management Plan, as determined necessary, after coordination with interested parties.

All initial and future disposal activities at the Village of Bald Head Island, Caswell Beach, and easternmost Oak Island, (as described in the Environmental Assessment and its Sand Management Plan, and in the Wilmington Harbor Monitoring Plan) will be at no cost to either community.

If the Project causes significant adverse effects on adjacent beaches, the Corps and the Sponsor will respond by adjusting the Sand Management Plan, after consultation with interested parties. If the Project causes significant adverse effects that cannot be dealt with by modifications to the Sand Management Plan, the Corps and the Sponsor will promptly seek and use their best efforts to implement appropriate corrective measures, such as additional nourishment, subject to consistency review.

Our current schedule for execution of the FONSI is June 14, 2000. Our current schedule for our higher headquarters approval of the draft Section 933 Evaluation Report is July 31, 2000. We expect to award a contract to construct the inshore reaches of the Ocean Bar entrance channel on or about November 15, 2000. We are moving prudently but aggressively to make this important Project a reality.

The support of the members of the Brunswick Beaches Consortium and our Project sponsor represented by Mr. John Morris in optimizing this unique opportunity for nourishing your beaches has been wise, energetic, and timely. We salute your efforts and look forward to continued close coordination through to the successful completion and operation of the Project and the associated beneficial use of beach quality sand.

Sincerely,

James W. DeLony
Colonel, U.S. Army
District Engineer

Enclosures

Copies Furnished:

Mr. John N. Morris, Director
Division of Water Resources
North Carolina Department of Environment
and Natural Resources
1611 Mail Service Center
Raleigh, North Carolina 27699-1611

Ms. Donna D. Moffitt, Director
Division of Coastal Management
North Carolina Department of
Environment and Natural Resources
1638 Mail Service Center
Raleigh, North Carolina 27699-1638

WILMINGTON HARBOR

SAND MANAGEMENT PLAN
OCEAN ENTRANCE CHANNELS
AND INNER HARBOR FROM SNOWS MARSH
THROUGH HORSESHOE SHOAL CHANNELS

1. **General.** Deepening of Wilmington Harbor will involve the removal of large quantities of material including beach quality sand. Most of the beach quality material to be removed during deepening will come from the Ocean Entrance Channels consisting of the following ranges: Baldhead Shoal; Smith Island; Baldhead – Caswell; Southport; Battery Island, and Snows Marsh seaward of station 10+00. These ranges are shown on *Figure 1*. Beach quality sands will also be removed from portions of the Inner Harbor channel extending from the upper 1000 feet of the Snows Marsh Range through the Horseshoe Shoal Range. These Inner Harbor channel ranges are also shown on *Figure 1*. A maximum of 6.0 million cubic yards of beach quality material will be removed from the lower portion of the Snows Marsh Range seaward through the Baldhead Shoal Range. Approximately 0.6 million cubic yards of beach quality material will be removed from the upper Snows Marsh Range through the Horseshoe Shoal Range. Sand management plans for these two segments of the harbor are developed below for both the new work material; i.e., the beach quality material to be removed during deepening; and future maintenance of these harbor segments that will involve the removal of littoral shoal material.

Ocean Entrance Channels – Sand Management Plan

2. **Introduction.** The sand management plan for the ocean entrance channels addresses dredging and disposal issues associated with the realigned Baldhead Shoal Channel as well as the Smith Island, Baldhead – Caswell, Southport, Battery Island, Lower Swash, and Snows Marsh Channels. Construction of the ocean entrance channels into Wilmington Harbor will entail the removal of approximately 15.5 million cubic yards of material, up to 6.0 million cubic yards of which is beach quality sand. Beach quality sand exists throughout all of the entrance channel except the new Baldhead Shoal Channel. Within the Baldhead Shoal Channel, beach quality sand is located between stations 0+00 and 120+00. Between station 0+00 and approximately 66+00, the entire channel prism is considered to be beach quality material. Between station 66+00 and 120+00, beach quality material is layered with the material lying above elevations ranging from -30 to -41 feet MLLW. Material below these depths contains a high percentage of clay and silt and is not suitable for beach disposal. Seaward of station 120+00, the new work material contains high concentrations of silt and clay and is not suited for placement on the beach. The beach quality material will be dredged primarily from the portion of Jay Bird Shoal which overlays the west side of the realigned bar channel and from Baldhead Shoal. Baldhead Shoal forms the east boundary of the existing channel, however, the realigned bar channel will cut across the seaward portion of this shoal. The present alignment of the ocean bar channel and that of the new bar channel are shown on *Figure 1*. As shown on *Figure 1*, the new bar channel passes through the eastern side of the existing Ocean Dredged Material Disposal Site (ODMDS).

3. The Brunswick County beach towns of Bald Head Island, Caswell Beach, Oak Island, and Holden Beach have expressed an interest in receiving the beach quality material. Under Section 933 of the Water Resources Development Act of 1986 (Public Law 99-662), the Federal Government can cost share up to 50 percent of the added cost of depositing the material on the beach providing certain criteria are met. The primary requirement for Federal participation is that any added cost for placing sand on a particular beach segment must be economically justified. A base disposal plan associated with the least costly means of placing the beach quality material and a Section 933 disposal plan are discussed in the following paragraphs. In addition, a disposal plan for the annual maintenance material is presented following the disposal plan for the new work material.

4. **Plan Formulation – Ocean Entrance Channels New Work Material Disposal Plan.** The disposal plan for the new work material contained in the 1996 project feasibility report had all of the material from the Lower Big Island Range through the existing Baldhead Shoal Channel going to the ODMDS. It should be mentioned that the disposal plan in the feasibility report did not include consideration of the realigned Baldhead Shoal Channel. The alignment of the new Baldhead Shoal Channel came from a recommendation contained in a Value Engineering Study that demonstrated significant construction cost savings could be realized by avoiding rock in the existing Baldhead Shoal Channel. In any event, increased utilization of the existing ODMDS for disposal of maintenance and new work material has resulted in the existing ODMDS for Wilmington Harbor approaching full capacity. This combined with the passage of the realigned Baldhead Shoal Channel through the existing ODMDS has necessitated the development of a new ODMDS. The new ODMDS, which is being developed in cooperation with the Environmental Protection Agency (EPA), is located approximately 5 miles offshore of the existing ODMDS as shown on *Figure 1*. The new ODMDS is expected to be available for use by the end of 2001, consequently, the existing ODMDS must have sufficient capacity to accommodate the new work and maintenance material expected to be removed though the year 2001.

5. The remaining capacity of the existing ODMDS was estimated assuming that the area could be filled to an average elevation of 26 feet below mean lower low water (mllw). All future placement of dredge material in the existing ODMDS will take place west of the new channel alignment. In addition, no material would be placed in a 2,500-foot wide corridor parallel to and west of the new entrance channel in order to reduce the chance deposited material will move into and shoal the new channel (see *Figure 1*). The size of the corridor through the ODMDS is needed to prevent the return of deposited material into the channel and was based on the distance between the western toe of the existing ODMDS and the existing ocean entrance channel, which, as shown on *Figure 1*, is about 2,500 feet. Based on these assumptions, the remaining capacity of the existing ODMDS is approximately 17.8 million cubic yards.

6. Deepening of the Wilmington Harbor project is scheduled to begin in May 2000 with the award of a contract to construct the offshore portion of the Baldhead Shoal Channel seaward of station 120+00. The material to be removed from this segment of the new channel, which totals about 6.6 million cubic yards, contains significant quantities of silt and clay and will have to be deposited in the existing ODMDS. The contract for the

landward segment of Baldhead Shoal Channel and the other ocean entrance channels, which will include up to 6.0 million cubic yards of beach quality sand and 2.8 million cubic yards of material not suited for placement on the beach, will be awarded near the end of calendar year 2000. Work on the inner portions of the project from upper Snows Marsh Range to Horseshoe Shoal Range that contains 0.6 million cubic yards will also be performed in early 2001. The economic and engineering viability of options for the disposal of the beach quality material to be removed from upper Snows Marsh to Horseshoe Shoal is presented later in the section of this report entitled " Inner Harbor – Sand Management Plan." Finally, a contract for removal of rock and other sediments from the Big Island Range will be awarded in 2000 as a test to help determine contract scopes for rock removal from other sections of the harbor. All of the material from the Big Island Range (approximately 2.2 million cubic yards) will be deposited in the ODMDS. In summary, construction of the deeper channel between 2000 and 2001 will involve the removal of approximately 18.2 million cubic yards of material with all of this material scheduled to be placed in the existing ODMDS.

7. During the new ocean entrance channel construction period, periodic maintenance of the existing ocean entrance channel will have to continue as will the maintenance of the interior portions of the harbor. This maintenance material, which averages around 800,000 cubic yards per year from the entrance channel and 300,000 cubic yards from the interior channels, is normally placed in the ODMDS. In addition to the Wilmington Harbor maintenance material, material removed for maintenance of the Military Ocean Terminal at Sunny Point (MOTSU) is also normally placed in the ODMDS. Maintenance of MOTSU averages 1 million cubic yards per year. Thus, the combined volume of new work and maintenance material to be removed from Wilmington Harbor and MOTSU between 2000 and 2001 could total 22.4 million cubic yards, exceeding the remaining capacity of the existing ODMDS by more than 4.6 million cubic yards.

8. **Base Disposal Plan-New Work Material.** With the capacity of the existing ODMDS insufficient to accommodate the dredged material disposal volume requirements through 2001, the logical solution is to place up to 6.0 million cubic yards of beach quality material on adjacent beaches. The only other option would be to delay the construction of the harbor deepening project by at least one year which is not acceptable to the State of North Carolina, the project sponsor. Placement of up to 6.0 million cubic yards of new work material on the beach would reduce the volume of material to be placed in the existing ODMDS through the year 2001 to 16.4 million cubic yards, effectively depleting the remaining capacity of the existing ODMDS. Once the new ODMDS becomes operational, all future dredge material requiring ocean disposal will be placed in the new area.

9. The disposal of up to 6.0 million cubic yards of new work beach quality material would be distributed along 16,000 feet on Bald Head Island and 25,000 feet on Oak Island-Caswell Beach. Deposition on Bald Head Island would occur along 2,000 feet of West Beach, which faces the Cape Fear River Entrance, and along 14,000 feet of South Beach. Disposal on Oak Island-Caswell Beach would begin at the west boundary of the Fort Caswell Baptist Assembly grounds and proceed west. The 25,000-foot disposal area on Oak Island-Caswell Beach would extend the fill to the east end of the sea turtle habitat area

on Oak Island. These disposal areas are shown on Figure 2. The sea turtle habitat, which is basically a beach fill with a small dune feature to prevent nesting sea turtles from crossing into the ocean front road, will be constructed under authority of Section 1135 of the Water Resources Development Act of 1986. Construction of the sea turtle habitat will be completed in April 2001. The combined total of new work material to be deposited on Bald Head Island under the base plan would be 2,580,000 cubic yards. The balance of the new work beach quality material (up to 3,420,000 cubic yards) would be equally distributed along the 25,000-foot disposal area on Oak Island-Caswell Beach. The base plan beach fill placement characteristics associated with placement of up to 6.0 million cubic yards of new work material are presented in *Table 1*. Based on the characteristics of the sediment to be removed, about 83 percent of the dredged material is expected to remain in place. The lower placement rates used on West Beach and at the west end of South Beach are intended to reduce the possibility of increased sediment transport from the disposal area back into the navigation channel. Following initial adjustments, the deposited material will begin to erode at a rates comparable to or slightly faster than the erosion rates experienced on the existing beach. The base disposal plan addresses provisions for the disposal of up to 6.0 million cubic yards of beach quality material, however, the maximum volume may be reduced by 20 to 30 percent depending on the final quantitative and qualitative sand analysis and actual dredging operations associated with the dredging contractors decisions to obtain the total allowable overdepth.

Table 1
Base Plan Beach Disposal Characteristics

Location	Length along Shoreline (feet)	Disposal Rate (cubic yds per ft)	Initial Placement Width Range (feet)	Adjusted Placement Width Range (feet)	Initial Placement Volume (cubic yds)	Net In-place Volume (cubic yds)
Bald Head Island	16,000				2,580,000	
West Beach	2,000	120	190 to 210	95 to 105	240,000	200,000
South Beach	2,000	120	190 to 210	95 to 105	240,000	200,000
South Beach	12,000	175	280 to 300	140 to 150	2,100,000	1,734,000
Oak Is - Caswell Beach	25,000	137	220 to 240	110 to 120	3,420,000	2,839,000
Totals	41,000				6,000,000	4,973,000

10. **Section 933 Disposal Plan – New Work Material.** The Brunswick County beach towns of Bald Head Island, Caswell Beach, Oak Island, Holden Beach, Ocean Isle, and Sunset Beach formed the Brunswick County Consortium for the purpose of working together to assure that the beach quality material is placed on the beach. Since Ocean Isle has received approval for a Federal Storm Damage Reduction Project, it is not vying for any of the Wilmington Harbor material. Construction of the Ocean Isle project is scheduled to begin in 2000. As mentioned above, a segment of Oak Island, lying between East 26th Street and East 58th Street, has been approved for a Section 1135 sea turtle habitat. The length of shoreline included in the sea turtle habitat consist of an 8,900-foot main section and 1,600-foot transitions on each end of the main fill. Construction of the sea turtle habitat will involve the removal of about 1.6 million cubic yards of material from an existing upland dredged material disposal area located adjacent to the Atlantic Intracoastal Waterway (AIWW). The expected in place volume resulting from this project is 1.34 million cubic yards. Within the main portion of the sea turtle habitat, the placement rate will be approximately 130 cubic yards/foot of beach. Accordingly, no material from the Wilmington Harbor project will be placed in the main portion of the sea turtle habitat. Some harbor material will be placed in the habitat transition areas to make up the difference in the volume that will be placed under Section 1135 and the rate of fill proposed under Section 933. This volume difference is around 25,000 to 30,000 cubic yards. As discussed below, disposal of material from the Wilmington Harbor project along Oak Island could occur at rates varying from 78 to 110 cubic yards/foot of beach. While these placement rates are less than the placement rate within the main portion of the Sea Turtle Habitat project, the relative protrusion in the shoreline resulting from the sea turtle project would be less than that which would have been produced in the absence of the harbor material. The reduction in the relative seaward protrusion of the shoreline within the habitat area resulting from the placement of the harbor material on the beach would also reduce the expected rate of loss from the habitat project due to end losses.

11. The shoreline segments that could receive material from Wilmington Harbor as a result of the Section 933 study include: 16,000 feet on Bald Head Island; 25,000 feet on Caswell Beach and the east end of Oak Island; 25,600 feet on the west end of Oak Island lying west of the sea turtle habitat; and 10,600 feet on the east end of Holden Beach. This represents a total shoreline length of 77,200 feet. These shoreline segments are shown on *Figure 2*. The distribution of available beach quality sand along the Brunswick County beaches will depend on the final results of the Section 933 study, analysis of project engineering and economic constraints, and the desires of the project sponsor and the Brunswick County consortium. To account for variations in sand placement along the Brunswick County beaches under the section 933 authority, *Table 2* presents the maximum beach fill disposal characteristics associated with the maximum beach fill for each beach segment resulting from the various possible distributions of beach quality material. Although the final distribution of the beach quality material for the Section 933 work along the Brunswick County beaches has not been determined, the total placement will not exceed 6.0 million cubic yards. Six million cubic yards of beach quality material to be removed from the channel equates to 5.0 million cubic yards of in place sand on the beach based on a retention rate of 83 percent discussed previously. Following the initial adjustments, erosion of the fill material will occur at rates equal to or slightly higher than the historic erosion

rates. The Section 933 disposal plan addresses provisions for the disposal of up to 6.0 million cubic yards of beach quality material, however, the maximum volume may be reduced by 20 to 30 percent depending on the final quantitative and qualitative sand analysis and actual dredging operations associated with the dredging contractors decisions to obtain the total allowable overdepth.

Table 2
MAXIMUM
Section 933 Disposal Characteristics

Location	Length along Shoreline (feet)	Disposal Rate (cubic yds per ft)	Initial Placement Width Range (feet)	Adjusted Placement Width Range (feet)	Initial Placement Volume (cubic yds)	Net In-place Volume (cubic yds)
Bald Head Island	16,000				2,200,000	1,826,000
West Beach	2,000	120	190 to 210	95 to105	240,000	200,000
South Beach	2,000	120	190 to 210	95 to 105	240,000	200,000
South Beach	12,000	143	220 to 240	110 to 120	1,720,000	1,426,000
Oak Island	50,500				4,740,000	3,933,000
East Oak Island - Caswell Beach	25,000	110	170 to 190	85 to 95	2,750,000	2,283,000
West Oak Island - Caswell Beach	25,600	78	120 to 140	60 to 70	1,990,000	1,650,000
Holden Beach	10,600	78	120 to 140	60 to 70	830,000	690,000

Inner Harbor – Snows Marsh Range to Horseshoe Shoal Range Sand Management Plan

12. **Introduction.** The sand management plan for the inner harbor addresses dredging and disposal issues associated with the Snows Marsh and Horseshoe Shoal channels. An estimated 0.6 million cubic yards of beach quality material will be removed from this

portion of the project. Disposal islands 3 and 4, located near the intersection of Horseshoe and Snows Marsh channels, are at maximum capacity and contain an estimated 1.3 million cubic yards of beach quality material. Maintenance material removed from this area is predominately sand of beach quality. Existing maintenance dredging operations in this area utilizes the offshore disposal area. The removal of the existing material from disposal islands 3 and 4 in conjuction with the new work dredging will facilitate placement of future maintenance material in islands 3 and 4. Future maintenance material placed in islands 3 and 4 would be used to nourish adjacent beaches.

13. **Plan Formulation.** The disposal plan for material presented in the June 1996 Cape Fear-Northeast Cape Fear Rivers project feasibility report proposed the placement of all dredge material from these channel reaches in the offshore disposal area. Subsequent investigations of material characteristics have shown that this material is of beach quality and this valuable resource would be best utilized to meet nourishment needs of the nearby beaches. Placement options for the 0.6 million cubic yards of new work material from the navigation channel includes potential placement of this material on Carolina Beach, Kure Beach, or Fort Fisher for 7,000 feet south of the southern terminus of the rock revetment. Placement options for the new work material from the navigation channel combined with pump out of islands 3 and 4 includes provisions for placement of 1.9 million cubic yards of material on adjacent beaches including Carolina Beach, Kure Beach, the Fort Fisher area, Bald Head Island , or Caswell Beach. Final placement decisions for the new work and maintenance material associated with the inner harbor from the Snows Marsh reach through the Horseshoe Shoal reach will assure that the dredge material disposal occurs in the least costly, environmentally acceptable manor, consistent with engineering requirements established for the project.

Maintenance Material Disposal Plan

14. **Plan Formulation.** Maintenance of the Wilmington Harbor Entrance Channel has historically required the removal of between 850,000 to 1,000,000 cubic yards of material each year. The maintenance material has normally been deposited in the ODMDS. Of the total volume removed each year, about 300,000 to 400,000 cubic yards has been littoral material derived from the adjacent beaches on Oak Island and Bald Head Island. This volume of littoral sediment constitutes 40 to 50 percent of the gross littoral transport along the Brunswick County beaches. Littoral material deposits in the bar channel primarily as a result of the eastward movement of Jay Bird Shoal and the westward movement of Bald Head Shoal into the channel area. The littoral sands generally deposit in channel reaches between channel stations 0+00 and 120+00. Seaward of station 120+00, the shoal material consist primarily of riverine silts and clays. While the new ocean bar channel will have an alignment different from the existing bar channel, shoaling patterns in the new channel, particularly in the vicinity of Jay Bird Shoal and Bald Head Shoal, are expected to be similar to the existing channel. The rate of shoaling of littoral sand in the new channel is estimated to be 545,000 cubic yards per year. The higher rate of deposition of littoral material in the new bar channel compared to the existing is due to channel modifications that would widen the channel to the west along the Smith Island Range and portions of the Baldhead Shoal range and cut across the seaward portions of Bald Head Shoal, as shown

on *Figure 1*. The volume of riverine silts and clays that will shoal the seaward portions of the new entrance channel are projected to be 538,000 cubic yards per year or about the same as that which occurs in the existing entrance channel.

15. The dredged material disposal plan for the entrance channel maintenance material was developed in accordance with U.S. Army Corps of Engineers policy with regard to the disposal of dredged material from Federal navigation channels. The Corps policy is contained in 33 CFR Parts 335-338 reads as follows:

> **"It is the Corps' policy to regulate the discharge of dredged material from its projects to assure that dredged material disposal occurs in the least costly, environmentally acceptable manner, consistent with engineering requirements established for the project."**

The policy further states:

> **"The least costly alternative, consistent with sound engineering practices and selected through the 404(b)(1) guidelines or ocean disposal criteria, will be designated the Federal standard for the proposed project."**

(Note: Section 404 guidelines of the Clean Water Act apply to beach nourishment, island creation, or construction of underwater berms whereas ocean disposal is covered by the Ocean Dumping Act.)

Finally, with specific reference to the disposal of maintenance material, the policy sates (33 CFR Part 337.9):

> **"(a) District engineers should identify and develop dredged material disposal management strategies that satisfy the long-term (greater than 10 years) needs for Corps projects. Full consideration should be given to all practicable alternatives including upland, open water, beach nourishment, within banks disposal, ocean disposal, etc."**

16. The Federal policy notwithstanding, the State of North Carolina adopted a set of policies in 1992 designated to insure that beach quality sand not be removed from the active beach system. The U.S. Department of Commerce, pursuant to the Federal Coastal Zone Management Act of 1972, has incorporated these policies into the North Carolina Coastal Management Program. As a result, the State of North Carolina includes these policies in its consistency review of Federal activities. In 1993, the North Carolina General Assembly enacted a statute that put the coastal management policy into law. While there is continuing legal debate over the applicability of the State Law to Federal projects, the Federal Government is required to be consistent with the State's coastal management program to the maximum extent practicable. Accordingly, the disposal plan for the maintenance material removed from the Wilmington Harbor entrance channel will attempt to satisfy these State requirements.

17. Based on the Corps policy given above, three factors were considered in the development of a dredged material disposal plan for maintenance of the harbor entrance, namely; engineering requirements of the project, environmental impacts, and cost. These factors are discussed below.

18. **Engineering Requirements**. The construction and maintenance of a deep ocean entrance channel through a tidal inlet will have the same impact on the movement of littoral sediment past the entrance as stabilizing structures such as jetties. However, the impacts of a dredge channel on the adjacent shorelines are generally more subtle than the impacts associated with stabilizing structures. In the case of stabilizing structures, there is usually a visible build-up of material adjacent to the updrift structure with corresponding erosion downdrift of the opposite structure. These impacts are normally clearly visible and measurable within distances of thousands of feet of the structures. Navigation projects that include stabilizing structures are generally formulated to include some means to bypass sand from one side of the entrance to the other in order to prevent project induced erosion on the adjacent beaches. Dredged channels, on the other hand, do not cause material to build-up on one side of the inlet or the other, rather, the impact of sediment removal from the dredged channel tends to be diffused throughout the impacted area. Since this diffusion process can extend over miles of shoreline, the erosive impact of the sediment removed from the navigation channel and its deposition outside the active littoral zone is difficult to detect in the short term since the magnitude of the impact may be of the same order as normal temporal fluctuations in the shoreline position. Also, where stabilizing structures generally have a well-defined impact on the predominant downdrift beach, channel projects affect both sides as material is deposited in the navigation channel from both the updrift and downdrift beaches.

19. The Wilmington Harbor project, historically, has not included the disposal of littoral sands on the adjacent beaches or in the active littoral zone. This has been primarily due to the maintenance practices that were established with the inception of the project over 100 years ago. Dredging technology that existed during the early history of the project dictated maintenance procedures and dredged material disposal practices. In this regard, hopper dredges, with hopper doors that opened by swinging down, were highly efficient in removing shoal material from channels but were restricted by their loaded drafts and swinging hopper doors to depositing the dredged material in relatively deep water. As a result, the "Federal Standard" for maintaining navigation projects, like Wilmington Harbor, became the cost and impacts associated with hopper dredging and ocean disposal of the dredged material in water depths of 30 feet or more.

20. The early establishment of the "Federal Standard" for maintenance of Wilmington Harbor did not consider the overall impacts of removing littoral sediment from the littoral system. This was due in part to the limited coastal development that existed when the projects were first constructed, but also due to lack of sufficient scientific understanding of coastal processes and the sand sharing system associated with tidal inlets and adjacent beaches. Years of research by the U.S. Army Corps of Engineers and practical knowledge gained from the operation of the numerous coastal navigation projects around the country has resulted in the realization that littoral material must be conserved. Natural supplies

from rivers and streams are not replenishing littoral sediments, particularly on the East Coast of the United States. Thus, the removal of a cubic yard of littoral sediment from a tidal entrance or inlet with deposition outside the active littoral zone of the beach will ultimately cause a cubic yard deficit somewhere within the sand sharing system affected by that particular entrance or inlet. The impact of the removal of littoral sediment from the active littoral zone through channel maintenance is identified as a major cause of man-induced erosion in the U.S. Army Corps of Engineers Shore Protection Manual. From an engineering perspective, the primary requirement for the Wilmington Harbor maintenance program, apart from assuring that the channel remains open year-round, is to prevent project induced erosion of the adjacent beaches by conserving the limited natural resource, sand, through deposition directly on the adjacent beaches.

21. Wave transformation/sediment transport studies were conducted by the Coastal and Hydraulics Laboratory (CHL), U.S. Army Corps of Engineers, Engineer Research and Development Center, for the Wilmington District, to determine the theoretical rate of longshore sediment transport moving toward the Cape Fear River Entrance. The results of this study are reported in reference 3.

22. The results of the sediment transport analysis for the existing condition near the Cape Fear River entrance found that sediment transport potential to the east off Caswell Beach is 270,000 cubic yards per year while a comparable rate to the west off Bald Head Island is about 527,000 cubic yards per year. Combining these two transport rates results in a gross transport of littoral sediment moving into the entrance of 797,000 cubic yards per year. In terms of percentages, approximately 66 percent of the sediment shoaling the entrance channel comes from Bald Head Island while 34 percent is derived from Caswell Beach. In order to maintain the sediment balance on both islands, littoral material removed from the entrance channel will be placed back on the beach from whence it came. Accordingly, two out of every three cubic yards of littoral shoal material removed from the entrance channel will be placed back on Bald Head Island and the remaining cubic yard placed on East Oak Island-Caswell Beach. The disposal locations on each island will be based on the results of annual beach profile monitoring surveys. In general, the material will be placed primarily along portions of South Beach and West Beach on Bald Head Island and on East Oak Island-Caswell Beach beginning at a point just east of the Carolina Power and Light Company cooling water discharge canal.

23. The distribution of littoral shoal material between Bald Head Island and East Oak Island – Caswell Beach given above will be accomplished by placing material from two consecutive maintenance operations on Bald Head Island with the third operation involving placement on Oak Island-Caswell Beach. Historically, littoral sediment shoaling in the entrance channel has been the highest in the Smith Island Range as a result of the eastward encroachment of Jay Bird Shoal into the channel. In 1991, a 50-foot channel widener was constructed along the west side of the Smith Island Range and was effective in trapping east moving sediment off of Jay Bird Shoal but was not large enough to significantly increase the time between maintenance dredging operations. In 1996, the widener was increased to 100 feet, which increased the maintenance cycle for this segment of the entrance channel to approximately every two years. The design of the deeper

channel into Wilmington Harbor includes a 150-foot channel widener west of the Smith Island Range, as shown on *Figure 1*. Consequently, maintenance dredging of the Smith Island Range and the landward end of the Baldhead Shoal Range should only be required every two years. Based on a two year maintenance cycle, 1,090,000 cubic yards of littoral material will be placed on Bald Head Island in year 2 and year 4 following the initial deepening of the harbor with this same volume placed on Oak Island-Caswell Beach during the 6th year following channel deepening. This disposal cycle is planned for the life of the project. The equivalent annual deposition of material would be 363,000 cubic yards per year to Bald Head Island and 182,000 cubic yards per year to Oak Island-Caswell Beach.

24. **Environmental Impacts.** The dredged material disposal plan for the new work material and that for the sandy maintenance material would not only improve the condition of the beaches adjacent to the harbor entrance but would maintain the beaches in a more stable condition. The wider more stable beaches, particularly along Bald Head Island and the East Oak Island-Caswell Beach disposal areas, would provide improved sea turtle nesting habitat compared to the present condition of these beaches. Even in their present state, the shorelines of East Oak Island, Caswell Beach, and Bald Head Island provide some of the most important sea turtle nesting habitat in North Carolina. In this regard, statistics compiled by the North Carolina Wildlife Resources Commission over the last 6 years (1994 to 1999 inclusive) show that approximately 33 percent of the sea turtle nest in North Carolina occurred on these three beaches. This relative high percentage of the total statewide nests is even more impressive given that these beaches constitute only 5 percent of the entire shoreline of North Carolina.

25. The disposal of material on the beach will have some short term negative impacts including the temporary increase in turbidity during the disposal operation and the smothering or otherwise displacement of organisms that live in or near the beach foreshore. Turbidity caused by the disposal operation normally does not persist more than one or two tidal cycles (12 to 24 hours) following the cessation of the disposal operation. With regard to the smothering or displacement of the nearshore organisms, studies by the University of Virginia for the U.S. Fish and Wildlife Service on Pea Island have shown that the organisms generally return to the area in about one year. The disposal plan for the maintenance material discussed above would involve the placement of material on Bald Head Island in intervals of 2, 4, and 8 years while disposal on Oak Island-Caswell Beach would occur in 6 year intervals. Thus, the nearshore organisms would not be completely eliminated from the area as a result of the disposal operation. In summary, the positive environmental impacts associated with the deposition of the littoral shoal material on the beach versus depositing it in an ocean disposal site far outweigh the negative impacts.

26. **Cost.** The "Federal Standard" for constructing and maintaining navigation channels focuses on the least-costly method of disposing the material, even though policy dictates that the environmental and engineering requirements must also be considered. With respect to the disposal plan for the new work entrance channel material, the limited capacity of the existing ODMDS dictates that the beach quality material be placed on the adjacent beaches, otherwise, the construction of the deeper project would have to be

delayed by about a year. Even if the project were to be delayed a year to allow ocean disposal of the beach quality material, cost comparisons indicate that beach disposal would still be the most cost effective disposal option.

27. **Maintenance Material Disposal**. Even if beach disposal of the maintenance material resulted in some additional cost, the Corps of Engineers, under authority of Section 207 of the Water Resources Development Act of 1996, can elect to use a slightly more costly disposal method if there are overriding environmental and erosion control benefits associated with the more costly disposal scheme.

28. Future disposal of maintenance material in the ocean will be in the new ODMDS located 5 miles farther offshore than the existing ODMDS. This additional haul distance almost doubles the cost of ocean disposal. As a result, beach disposal of the beach quality maintenance material becomes the least costly option, particularly if maintenance of the beach quality material is only required every two years. While the intent of the sand management plan is to return littoral material to the beach, the primary purpose of the project is to provide safe navigation through the ocean entrance into Wilmington Harbor. In this regard, there may be occasions during the life of the project when problem shoals occur in the entrance channel between normal 2-year maintenance cycle. In order to prevent disruption of navigation, these shoals must be removed in an expedient manner. If the size of these problem shoals are small (for example less than 100,000 cubic yards), mobilization and demobilization of an ocean certified pipeline dredge may not be economical. Therefore, on these occasions, removal of the shoals could be accomplished with a hopper dredge with disposal of the material in the ODMDS. In any event, a comparison of the cost for ocean disposal versus beach disposal of the littoral material is provided in *Table 3*. This cost comparison is made over a 6 year period which corresponds to the time period associated with the sand sharing formula between Bald Head Island and Oak Island-Caswell Beach.

29. **Summary**. The sand management plan developed for the new work beach quality material and maintenance material to be removed from the entrance channels into Wilmington Harbor includes the following:

(a) Disposal of the new work beach quality material on Bald Head Island and Oak Island-Caswell Beach.

(b) In the absence of Section 933, up to 2,580,000 cubic yards of the new work material would be placed on Bald Head Island and up to 3,420,000 on Oak Island-Caswell Beach.

(c) Under Section 933, the material would be distributed along Bald Head Island, Caswell Beach, Oak Island, and Holden Beach.

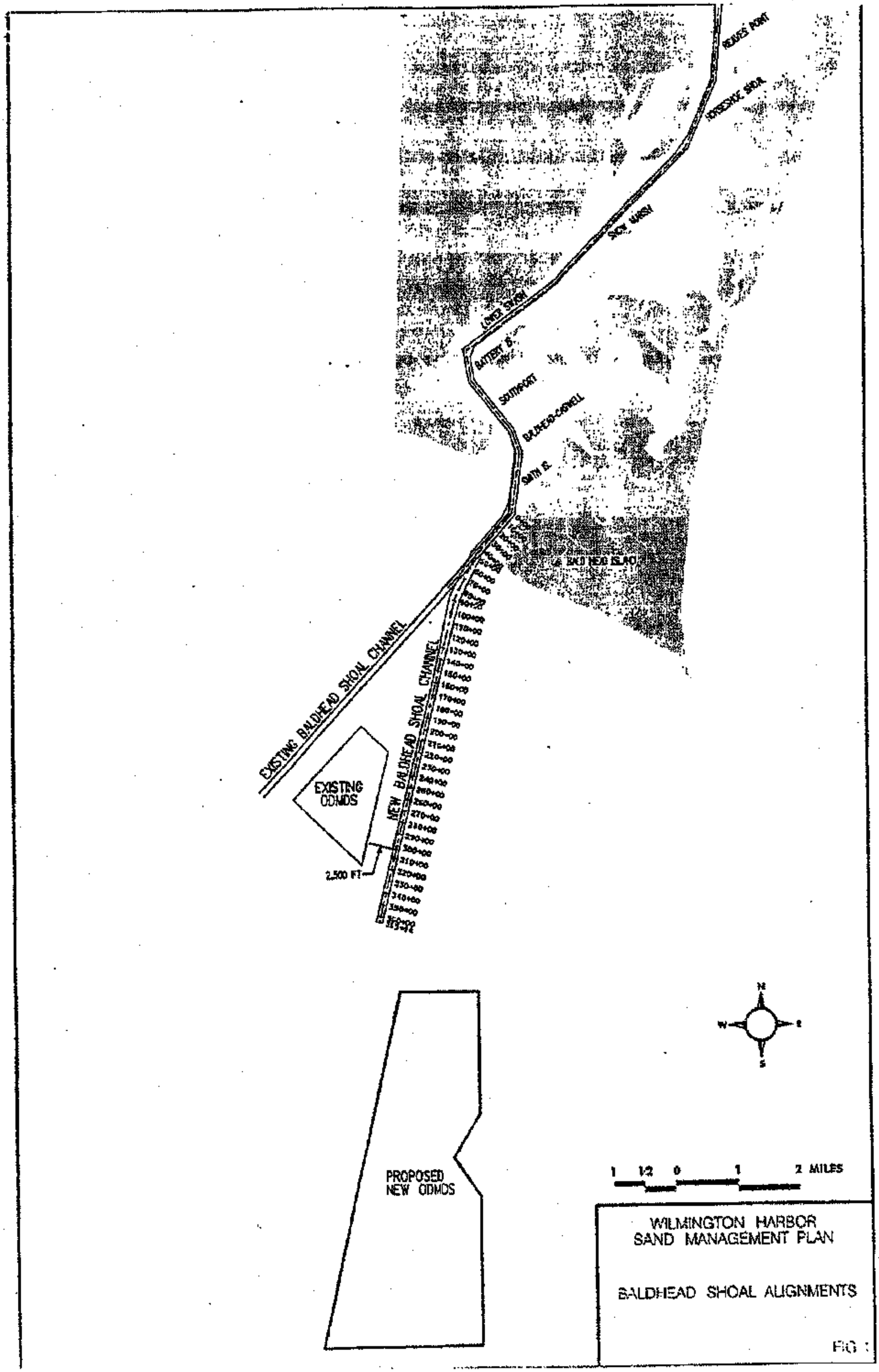
(d) Beach quality maintenance material will be deposited directly on Bald Head Island and Oak Island-Caswell Beach with Bald Head Island receiving 2 yards for every yard placed on Oak Island-Caswell Beach.

Table 3
Cost Comparison – Ocean Disposal versus Beach Disposal
Ocean Entrance Channel Maintenance Material

Item	Quantity	Unit	Unit Cost	Cost
Beach & Ocean Disposal – Maintenance Material				
Year 1: Hopper Dredge Silt & Clay				
Mob & Demob Hopper	1	job	$331,000	$331,000
Dredging w/ Ocean Disposal	538,000	CY	$4.00	$2,152,000
Total Year 1 Dredging Cost				**$2,483,000**
Year 2: Hopper Dredge Silt & Clay				
Mob & Demob Hopper	1	job	$331,000	$331,000
Dredging w/ Ocean Disposal	538,000	CY	$4.00	$2,152,000
Mob & Demob Pipeline Dredge	1	job	$948,000	$948,000
Dredging-Disposal on Bald Head	1,090,000	CY	$3.10	$3,379,000
Total Year 2 Dredging Cost				**$6,810,000**
Year 3: Hopper Dredge Silt & Clay				
Mob & Demob Hopper	1	job	$331,000	$331,000
Dredging w/ Ocean Disposal	538,000	CY	$4.00	$2,152,000
Total Year 3 Dredging Cost				**$2,483,000**
Year 4: Hopper Dredge Silt & Clay				
Mob & Demob Hopper	1	job	$331,000	$331,000
Dredging w/ Ocean Disposal	538,000	CY	$4.00	$2,152,000
Mob & Demob Pipeline Dredge	1	job	$948,000	$948,000
Dredging-Disposal on Bald Head	1,090,000	CY	$3.10	$3,379,000
Total Year 4 Dredging Cost				**$6,810,000**
Year 5: Hopper Dredge Silt & Clay				
Mob & Demob Hopper	1	job	$331,000	$331,000
Dredging w/ Ocean Disposal	538,000	CY	$4.00	$2,152,000
Total Year 5 Dredging Cost				**$2,483,000**
Year 6: Hopper Dredge Silt & Clay				
Mob & Demob Hopper	1	job	$331,000	$331,000
Dredging w/ Ocean Disposal	538,000	CY	$4.00	$2,152,000
Mob & Demob Pipeline Dredge	1	job	$1,275,000	$1,275,000
Dredging-Disposal on Oak Island-Caswell	1,090,000	CY	$4.60	$5,014,000
Total Year 6 Dredging Cost				**$8,772,000**
Total 6-Year Dredging Cost				**$29,841,000**

Ocean Disposal of All Maintenance Material				
Yearly Hopper Dredge Cost for Ocean				
Disposal of all Maintenance Material				
Mob & Demob	1	job	$331,000	$331,000
Dredging w/ Ocean Disposal	1,083,000	CY	$4.40	$4,765,200
Total Annual Dredging Cost				$5,096,200
Total 6-Year Dredging Cost				**$30,577,200**

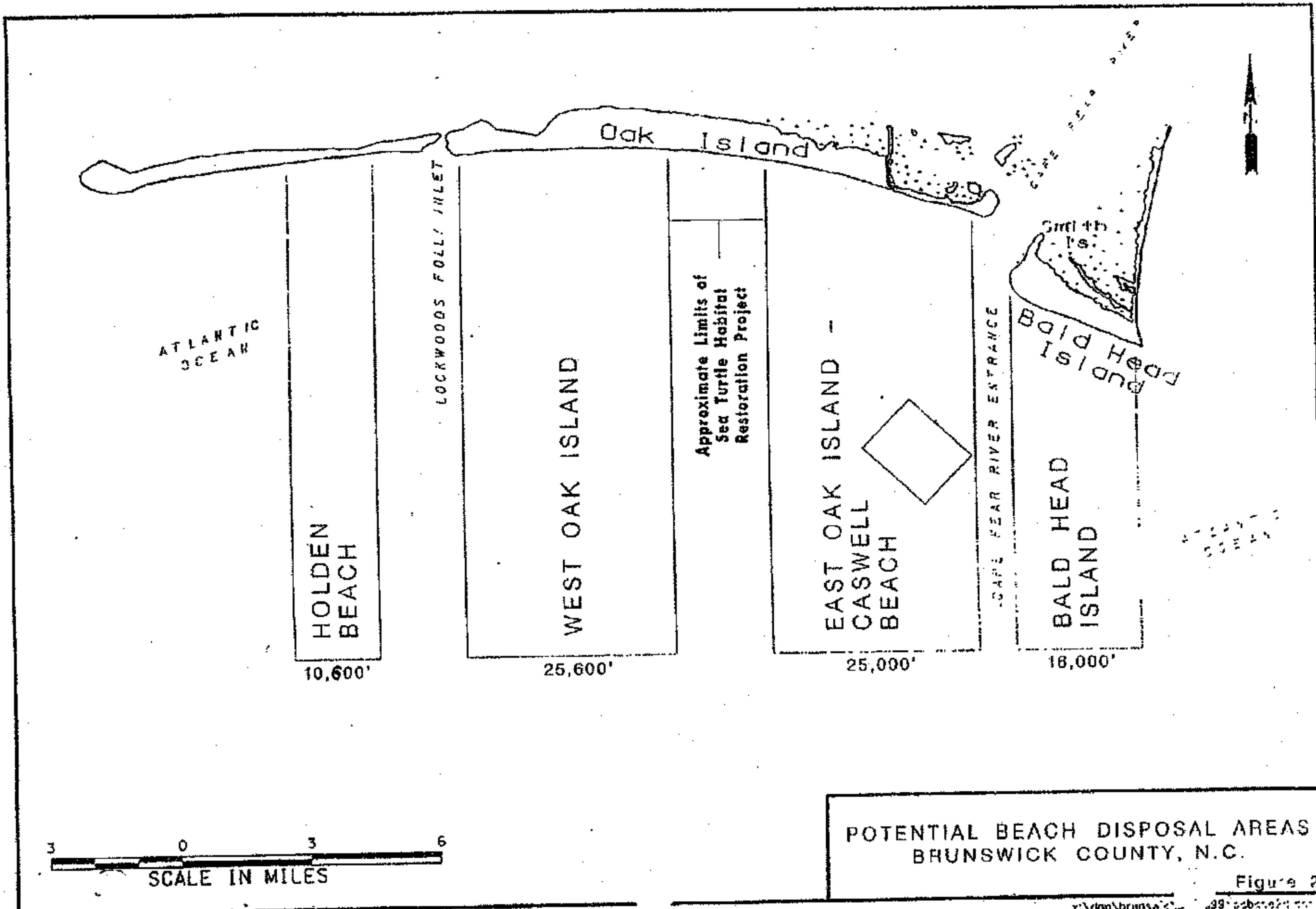
Date Revised: 02/04/00-sv



WILMINGTON HARBOR
SAND MANAGEMENT PLAN

BALDHEAD SHOAL ALIGNMENTS

FIG 1



POTENTIAL BEACH DISPOSAL AREAS
BRUNSWICK COUNTY, N.C.

Figure 2

BEACH EROSION

Village of Bald Head Island

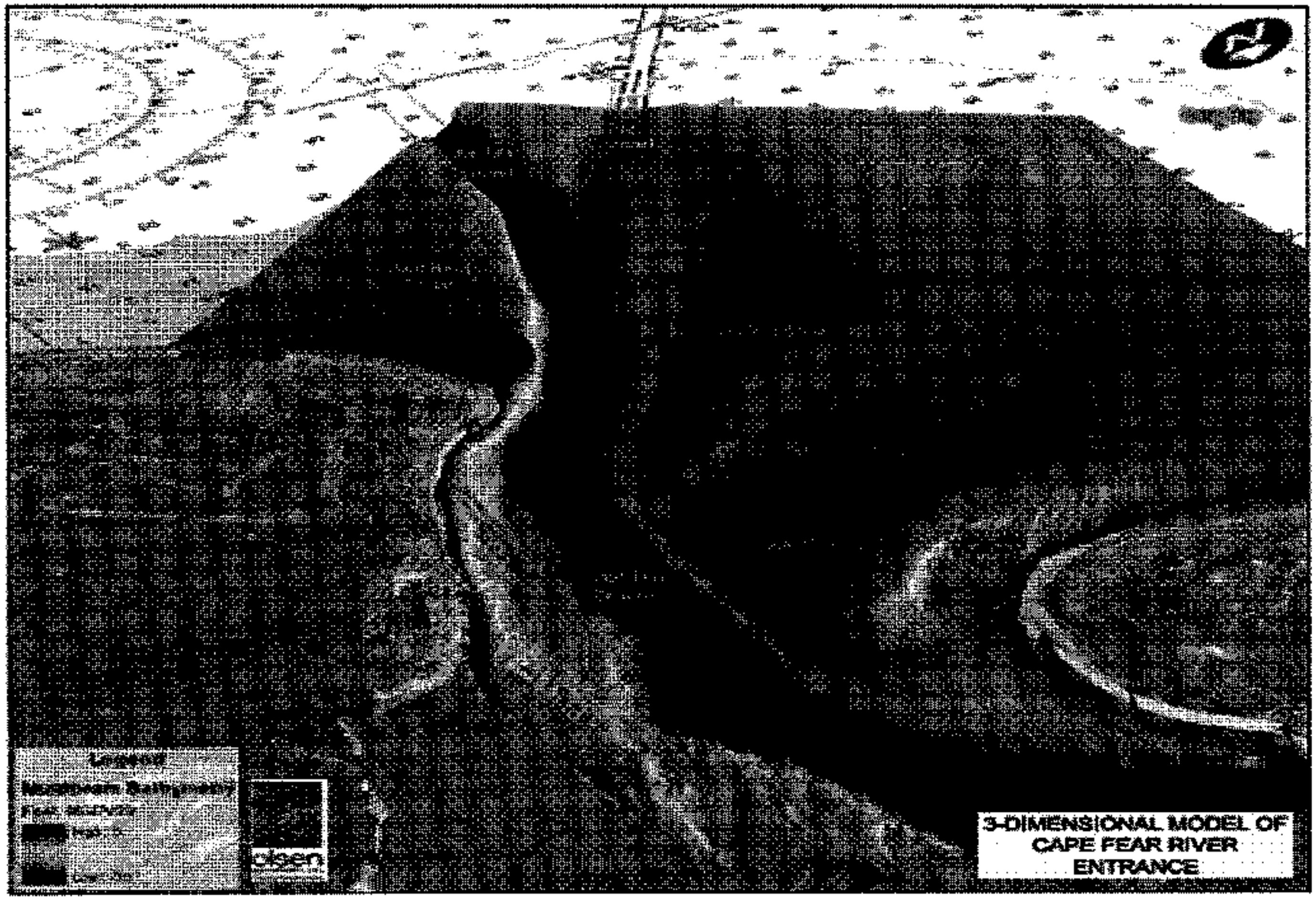
Charles S. Baldwin, IV

Brooks Pierce

Village of Bald Head Island

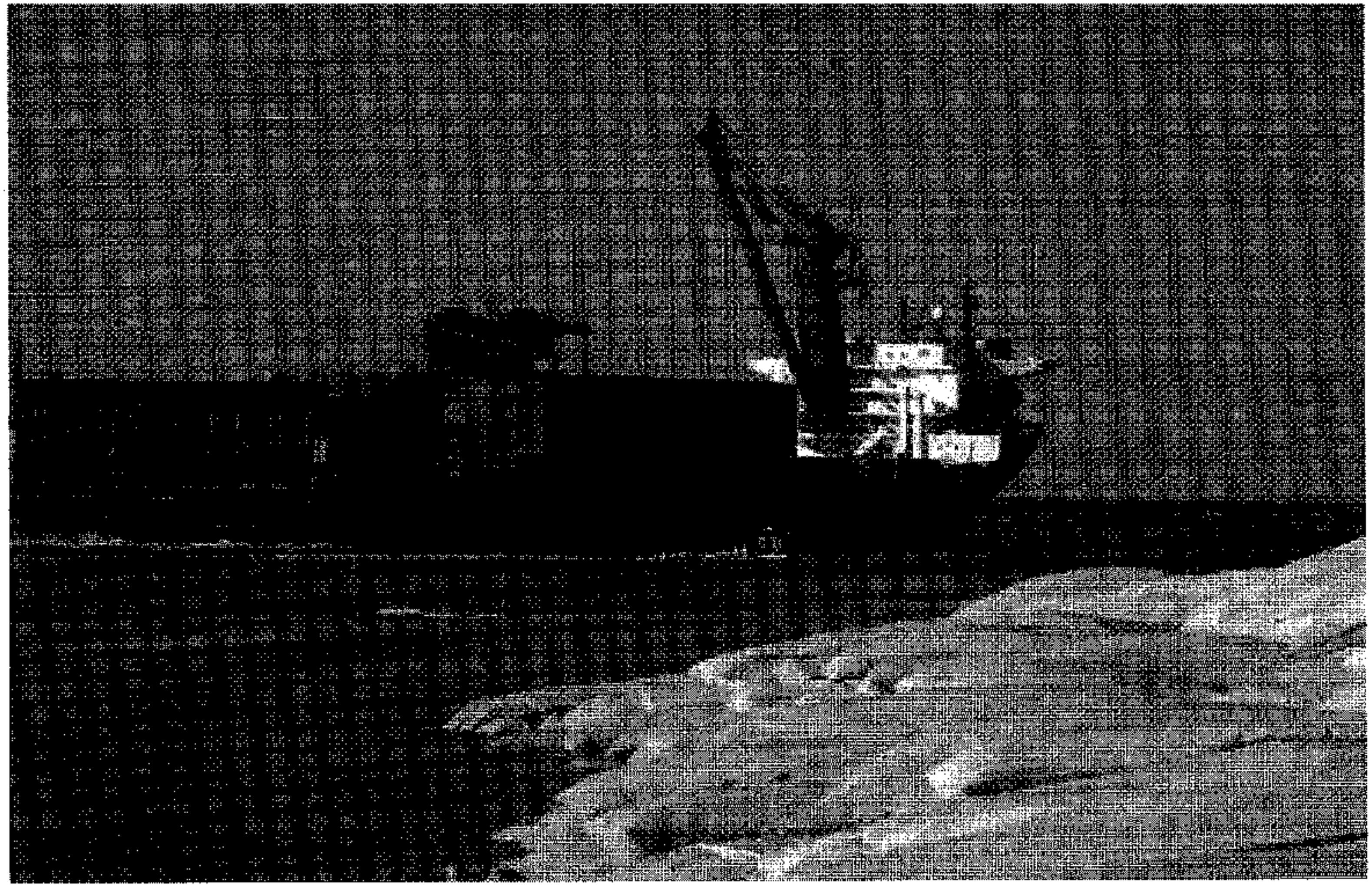
December 14, 2015

Channel is Dominant Influence: *Bathymetry*



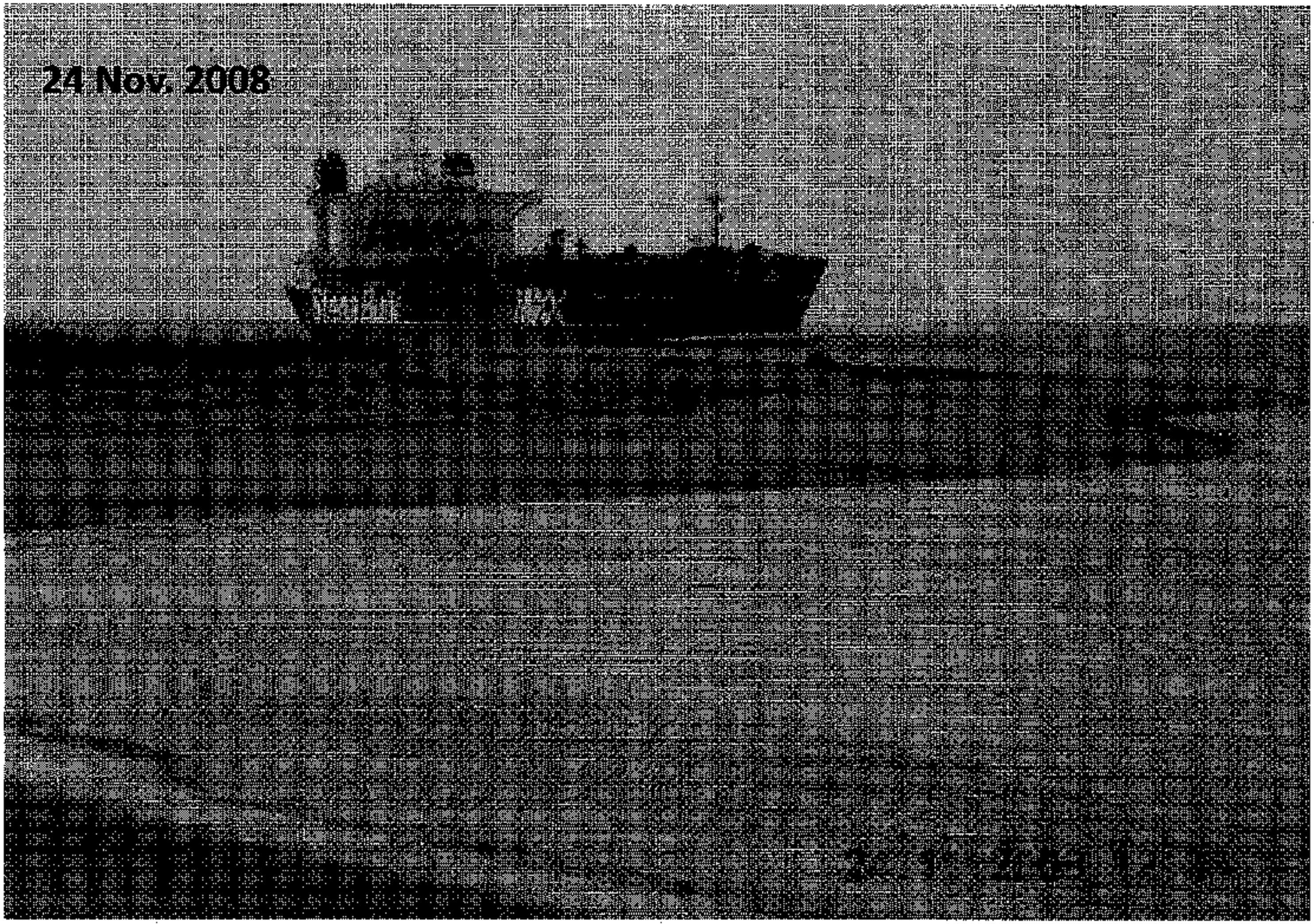
BROOKS PIERCE
FOUNDED 1897

BROOKS PIERCE
FOUNDED 1897



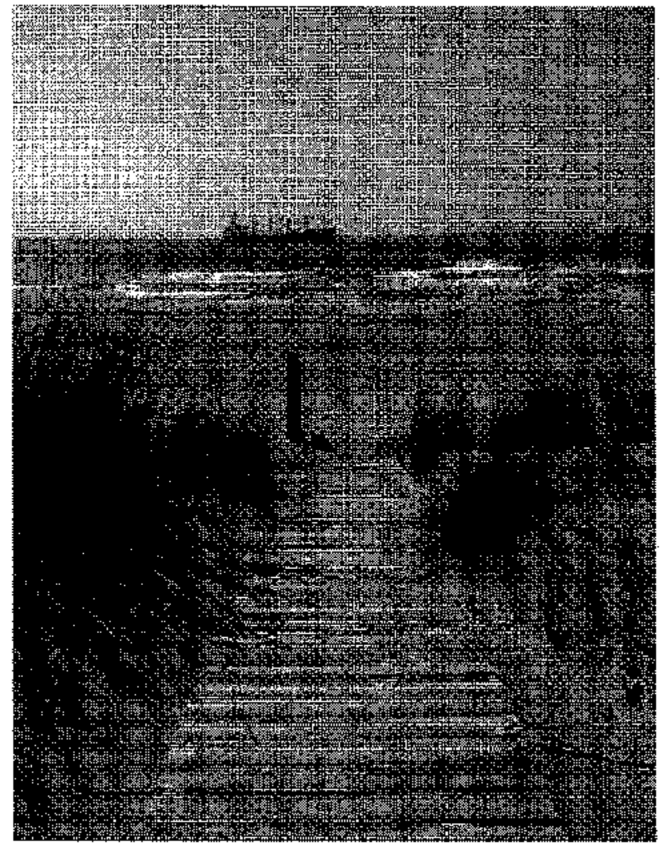
VILLAGE OF BALD HEAD ISLAND

BROOKS PIERCE
FOUNDED 1897


24 Nov. 2008

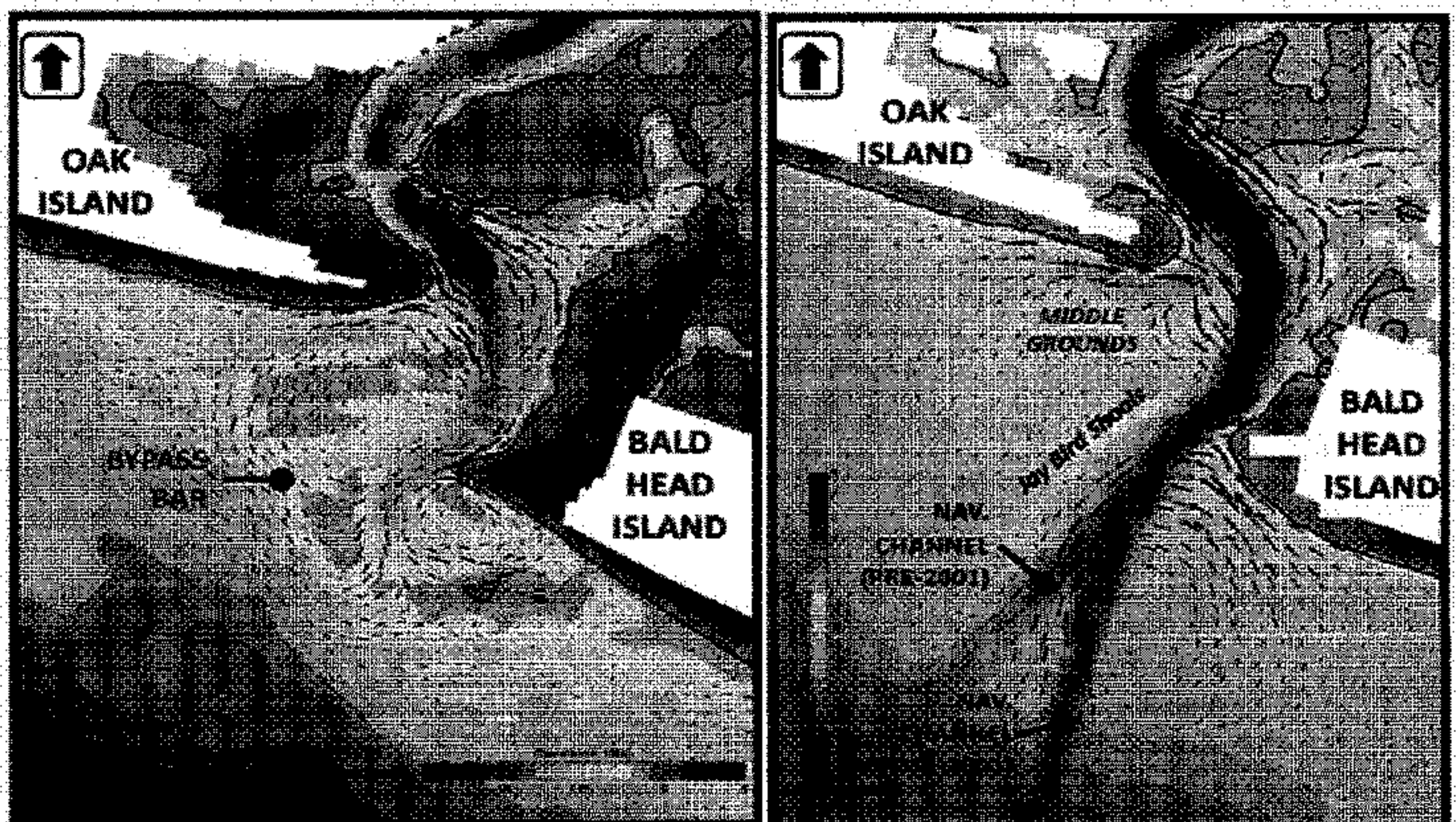
Channel is dominant influence

- *Channel bifurcates the natural sand by-passing system*
- *Channel increases water flow and rate*



BROOKS PIERCE FOUNDED 1897

Channel Locations



1865 (Pre-Navigation Project) 2005/06 (Post-Navigation Project)

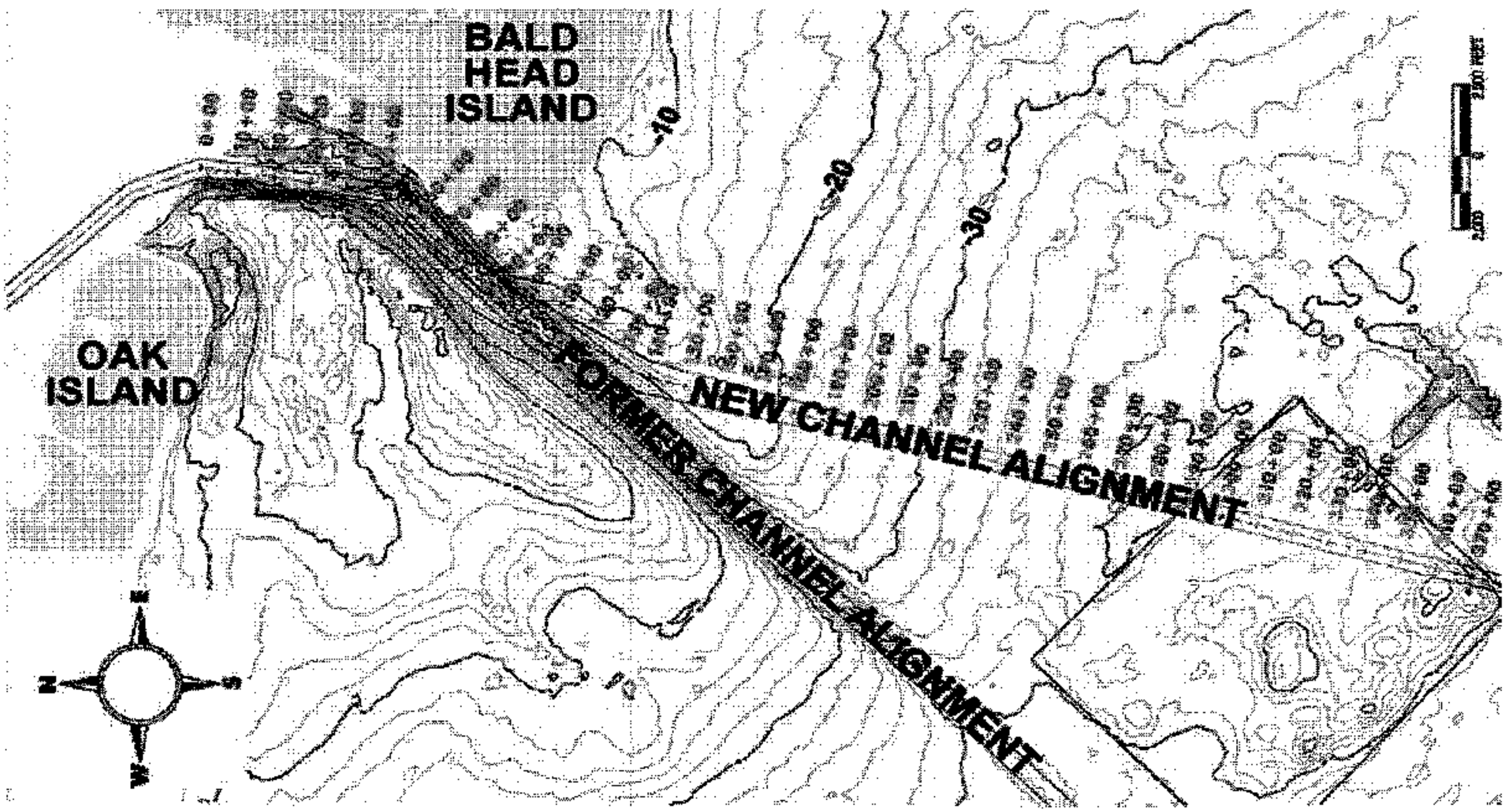
Navigation Project induced morphological changes at the Cape Fear River Entrance.

BROOKS PIERCE FOUNDED 1897

Engineered Channel Location

- Channel is maintained in a particular location
  - Natural inlets migrate
- New Channel alignment (2000-present) cuts through Bald Head's protective shoals

BROOKS PIERCE
FOUNDED 1897

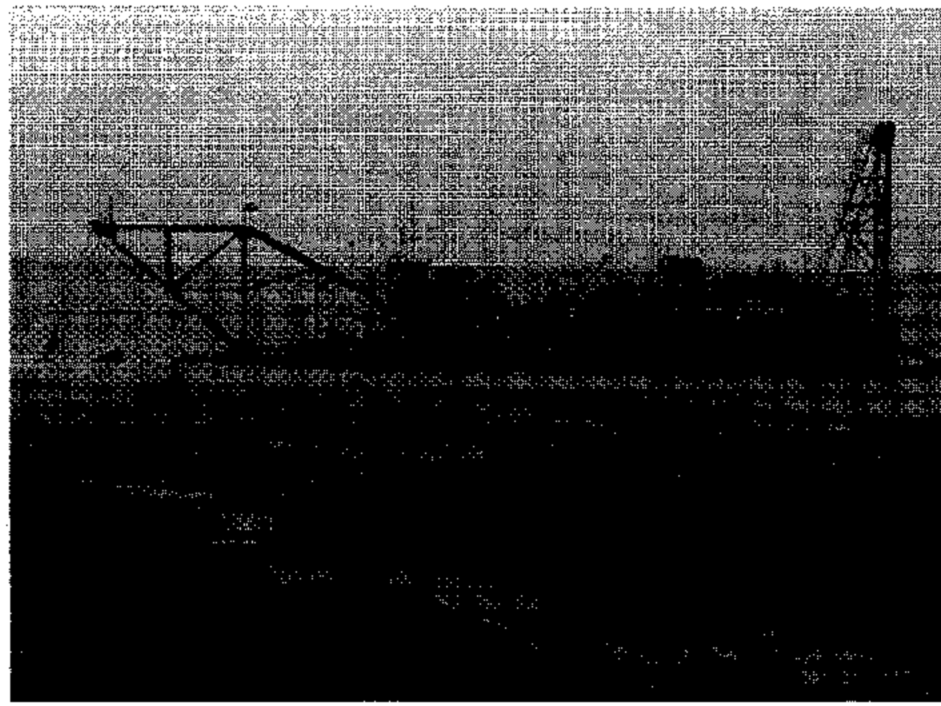


VILLAGE OF BALD HEAD ISLAND

BROOKS PIERCE
FOUNDED 1897

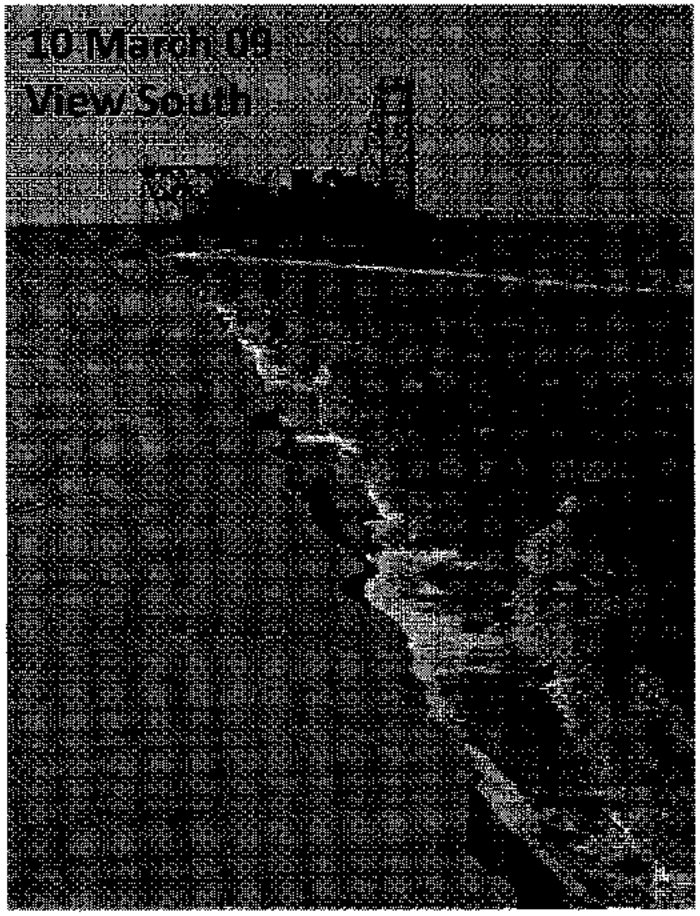
Engineered Channel Location

- Cape Fear AEC is characterized by episodic maintenance dredging activities
  - On going and high erosion rates
  - Shifting and evolving shorelines



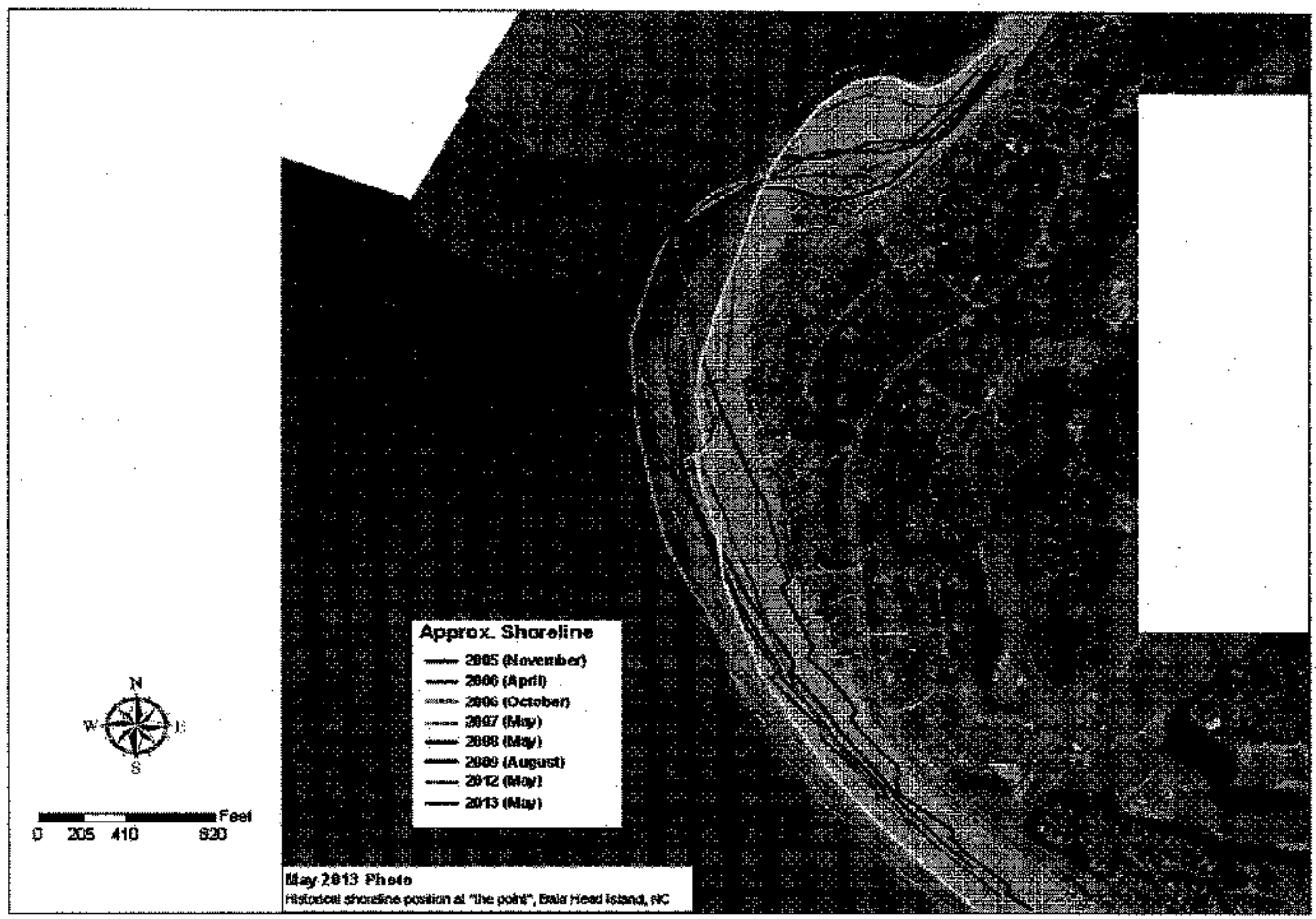
BROOKS PIERCE FOUNDED 1897

Accelerated erosion rates



BROOKS PIERCE

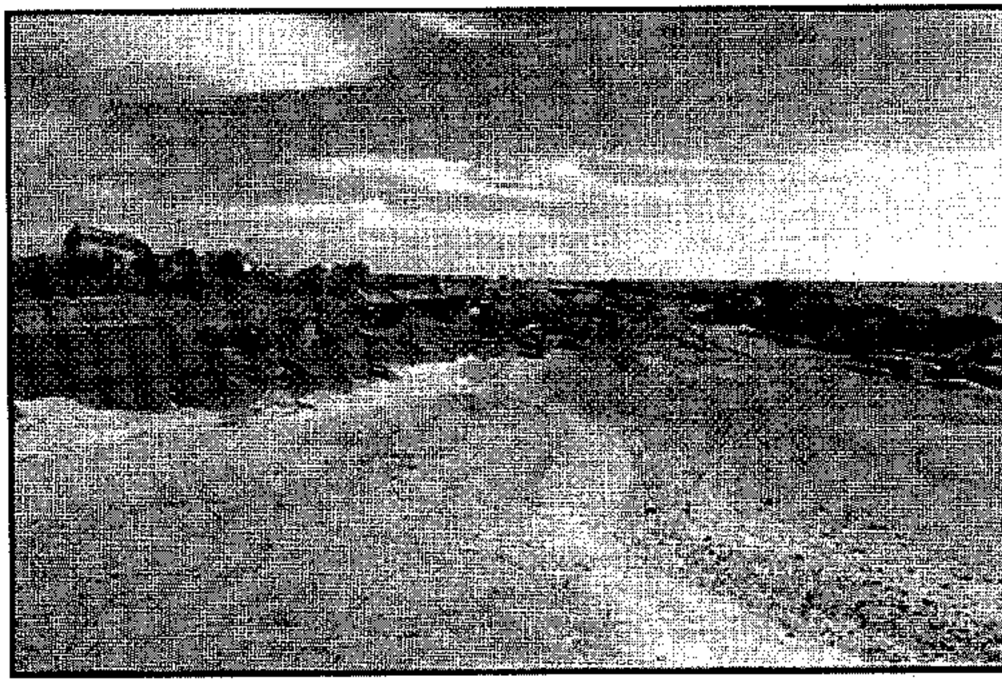
Erosion at 'The Point'



Erik Olsen chronology 2005 - 2013

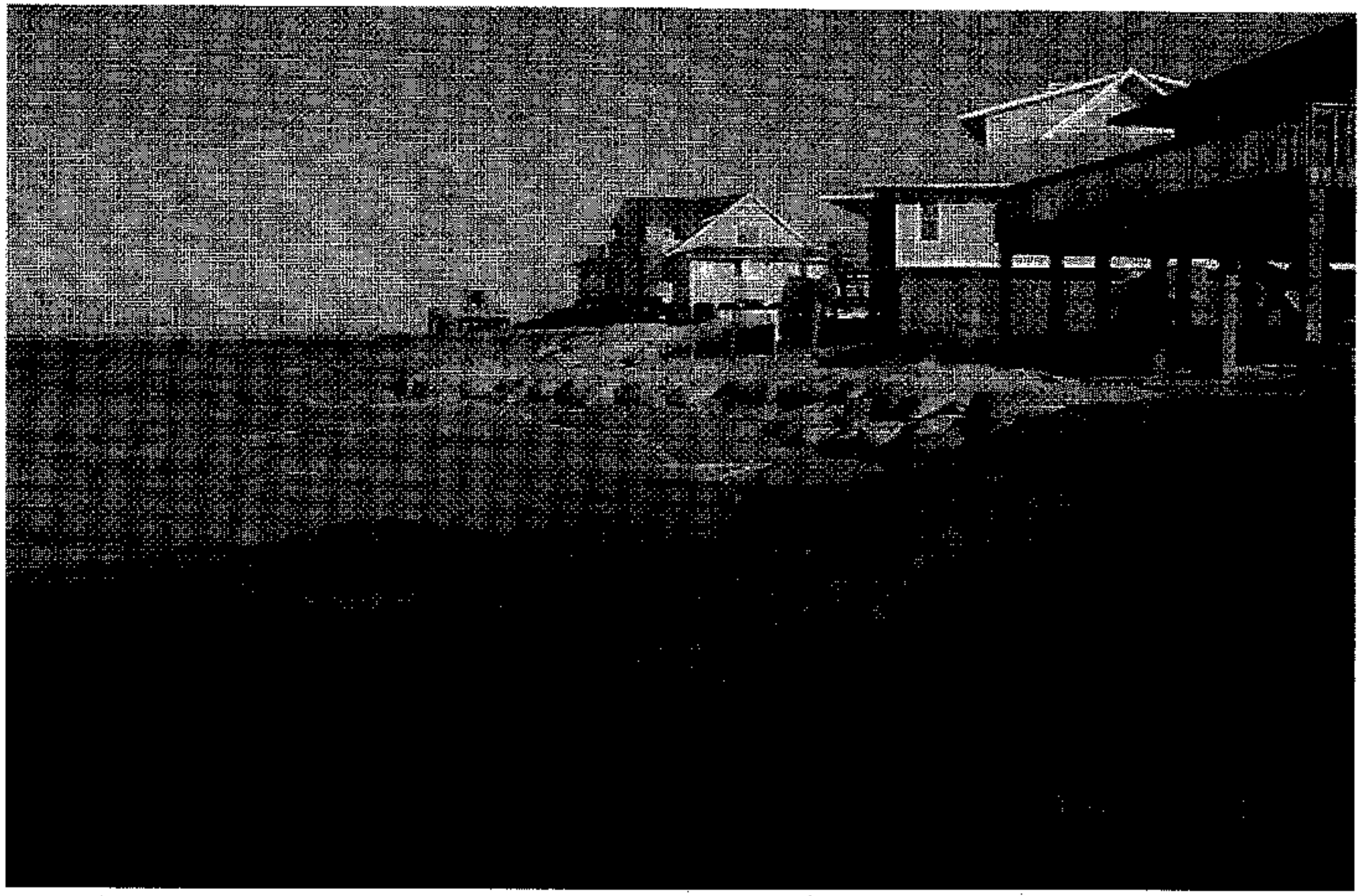
BROOKS PIERCE

- ***Beaches come and go with sand removal and placement from maintenance dredging***

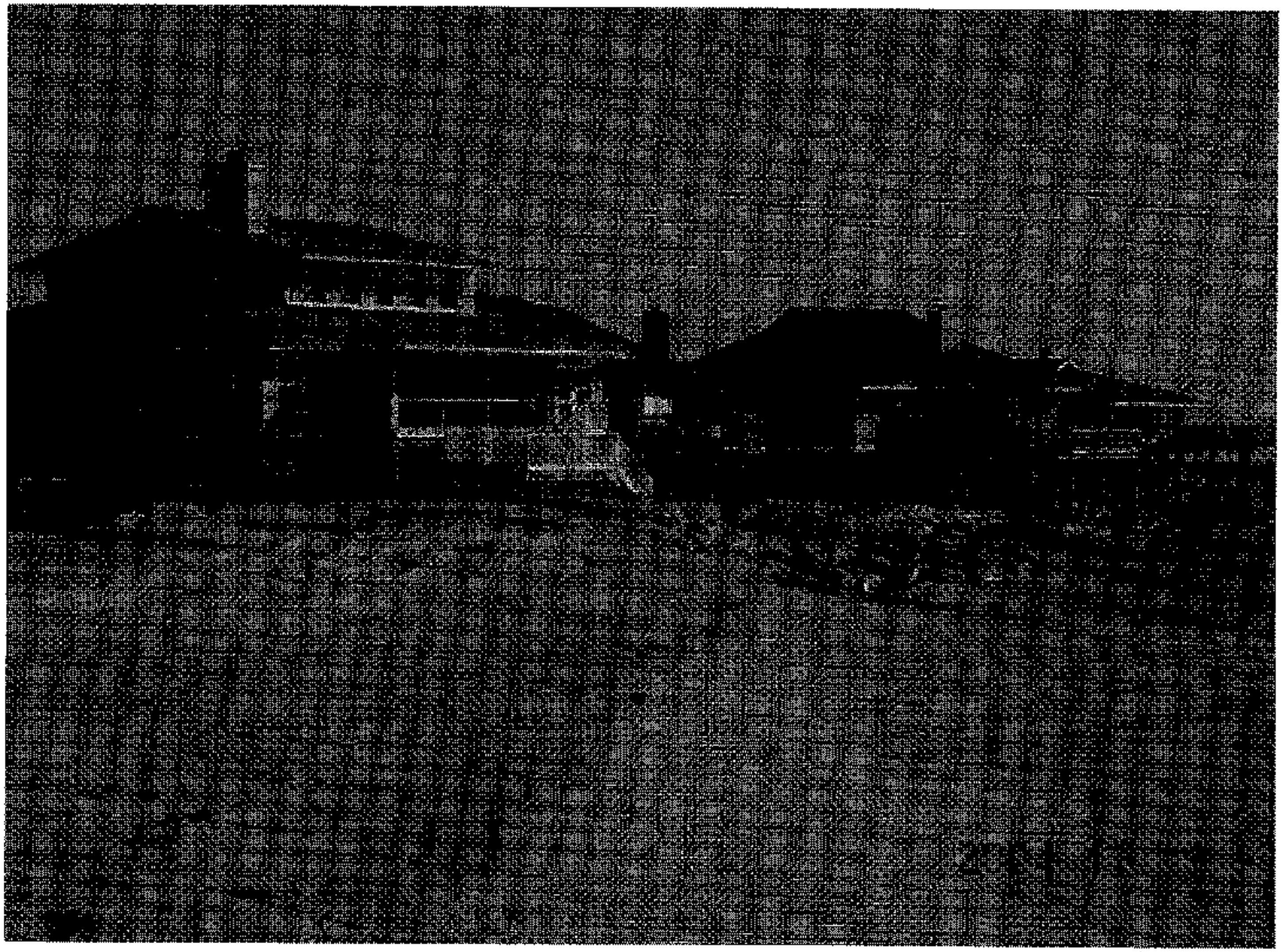


BROOKS PIERCE
FOUNDED 1897

VILLAGE OF BALD HEAD ISLAND



BROOKS PIERCE
FOUNDED 1897

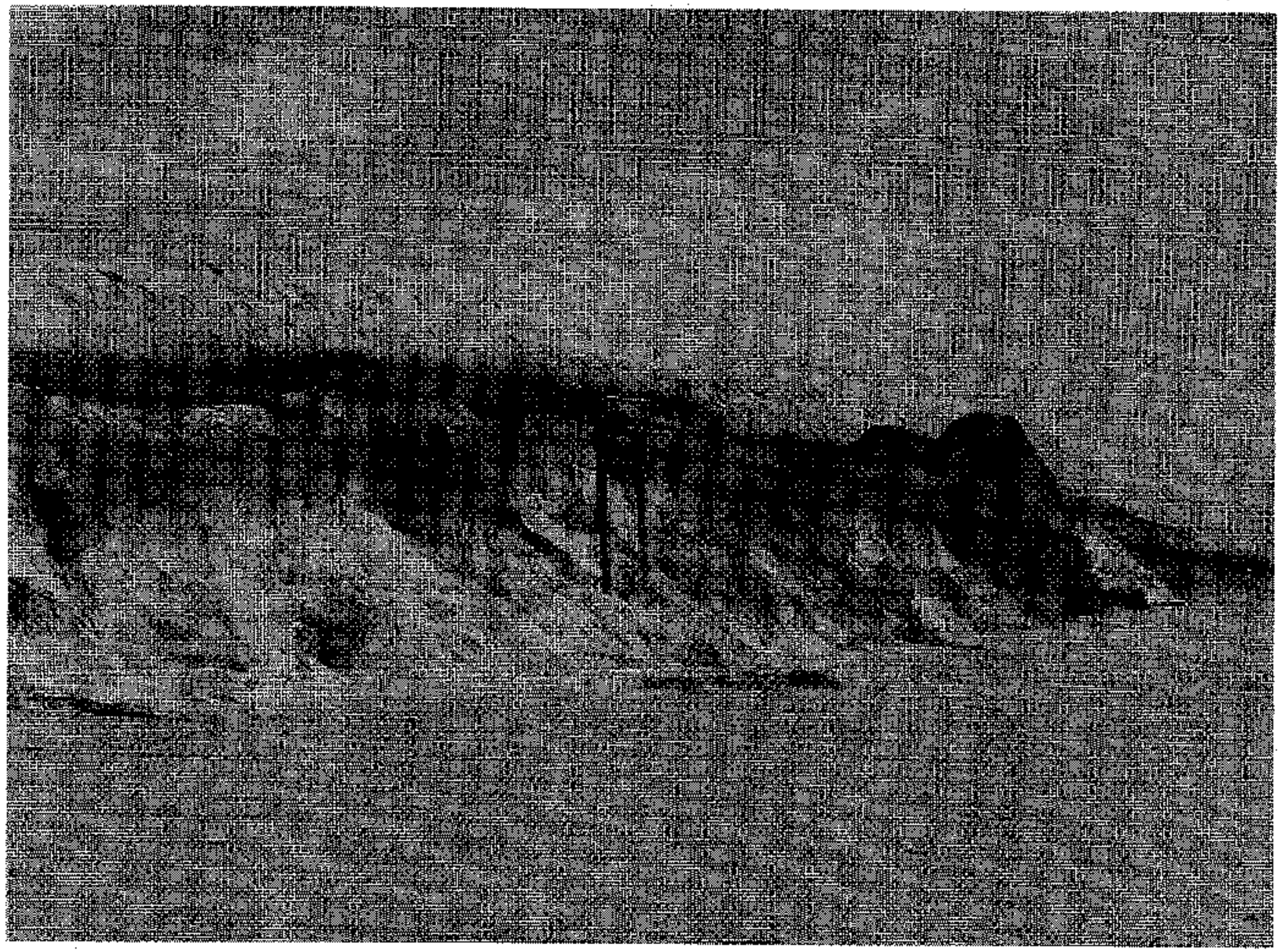


VILLAGE OF BALD HEAD ISLAND

BROOKS PIERCE
FOUNDED 1897

VILLAGE OF BALD HEAD ISLAND

BROOKS PIERCE
FOUNDED 1897



VILLAGE OF BALD HEAD ISLAND

BROOKS PIERCE
FOUNDED 1897

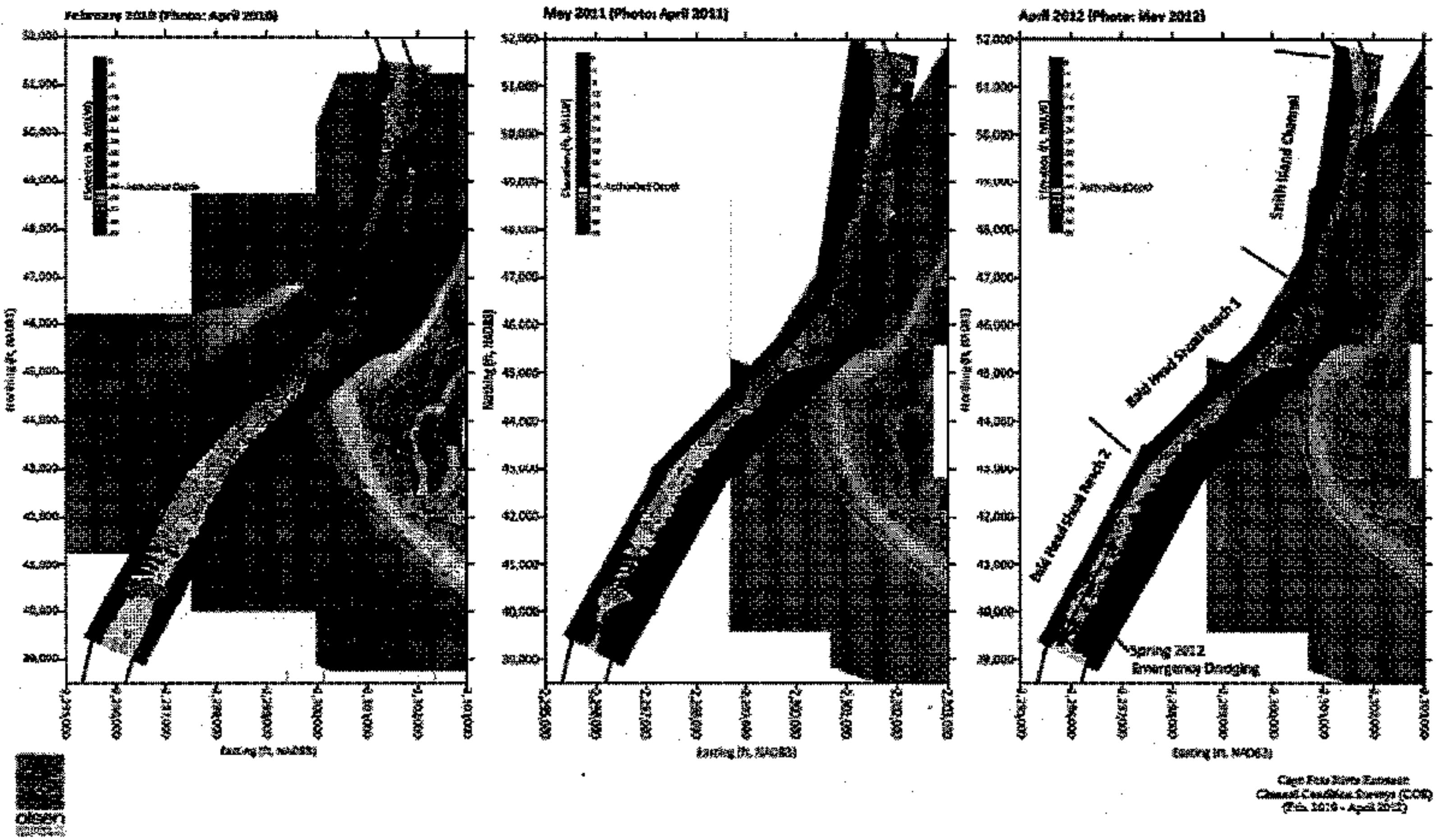
VILLAGE OF BALD HEAD ISLAND

BROOKS PIERCE
FOUNDED

- ***Beach erosion/channel shoaling affects the channel's performance, State Ports Authority operations, and channel maintenance.***

BROOKS PIERCE
FOUNDED 1897

Channel Shoaling



BROOKS PIERCE

Survey Data

- Bald Head Island (as of May 2009) had received well in excess of 4.04M cubic yards of beach fill placement since 2001 on South Beach alone.
- Of that amount, by the COE's surveys, only 118,000 cubic yards remained Island-wide as of May 2009.
- The Village of Bald Head Island surveys between May 2009 and September 2009 document an additional volumetric erosional loss at South Beach in excess of 550,000 cubic yards.

BROOKS PIERCE FOUNDED 1897

Changing BHI morphology as the "The Point" unravels and moves North

BROOKS PIERCE
FOUNDED 1897

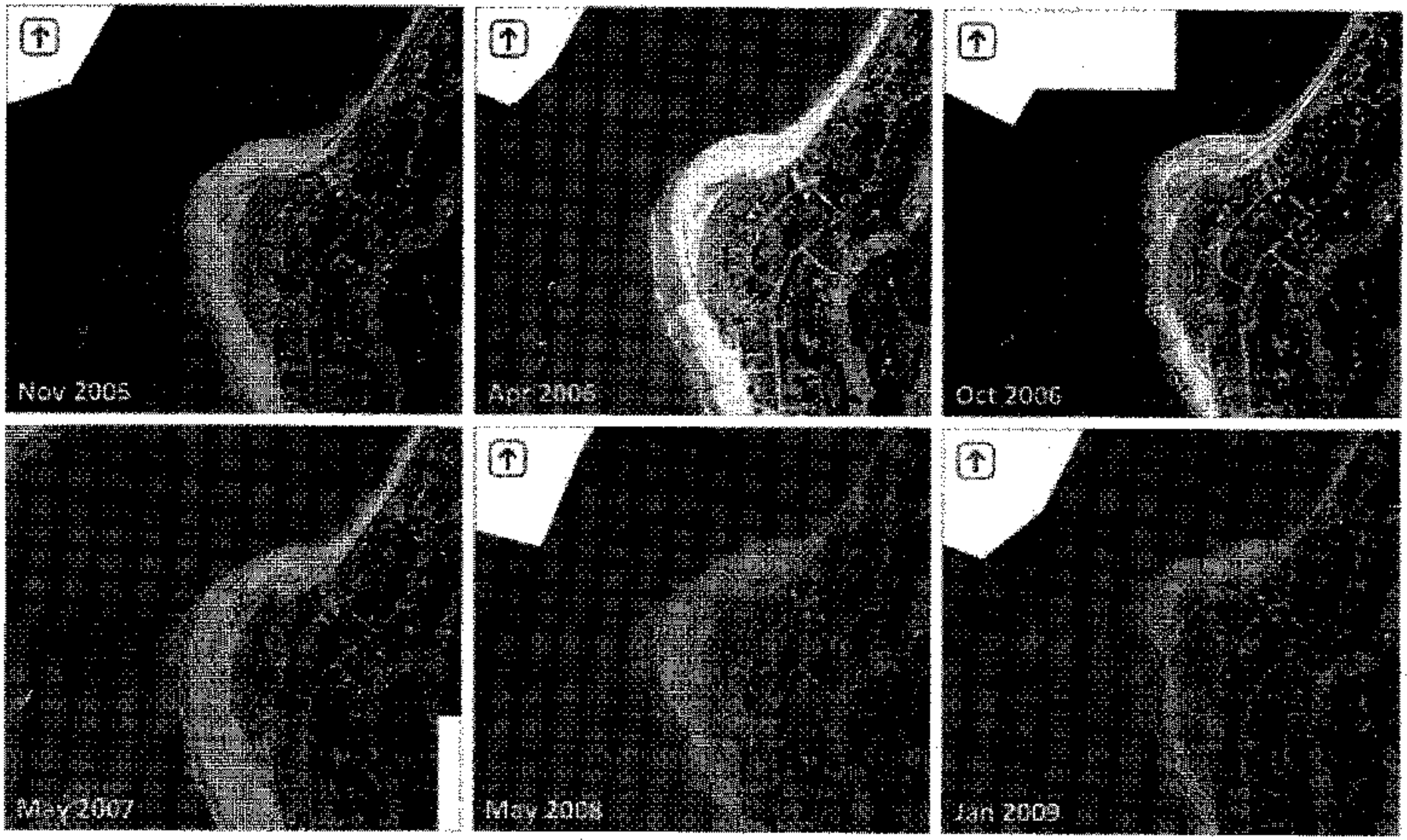
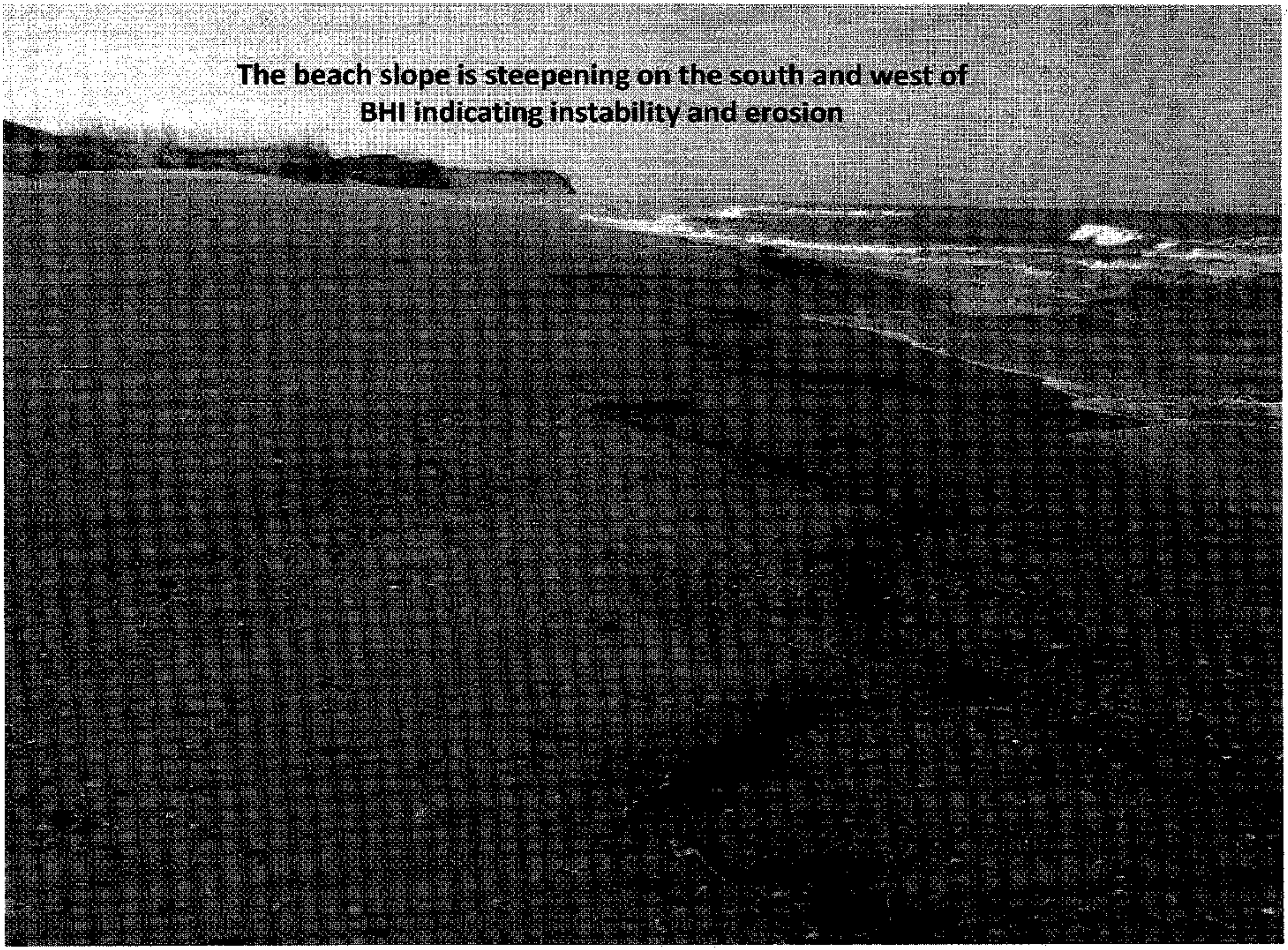


Figure 1: Aerial photography at "The Point", Bald Head Island, NC

Erik Olsen chronology 2005 - 2009

BROOKS PIERCE
FOUNDED 1897


The beach slope is steepening on the south and west of
BHI indicating instability and erosion

Local Financial Impacts

- Village has spent over $22MM to mitigate erosion, prior to $8.0MM terminal groin project

BHI Expenditures Related to Mitigation

• Engineered Beach Project 2009/2010		
• Dredging Contract	$	14,800,000
• Interest Expense	$	1,536,600
• Permitting – *Land Management Group, Inc. Olsen Associates, Inc., Legal*	$	1,000,000
• Sand Filled Geotextile Groinfield		
• 1995	$	320,000
• 2005	$	150,000
• 2009/2010	$	1,150,000
• Road Overwash		
• South Bald Head Wynd Road Repair 2004	$	250,000
• Sandbag Revetment Wall	$	250,000
• Sandpiper Trail Sandbag Wall + 2009 Repairs	$	65,000
• 2007 Sand Placement (Assist USACOE- limited funds)	$	900,000
• Periodic Beach Profile Monitoring	$	595,000
• Required by Bird Shoal Biological Monitoring per Permit	$	43,340
• Required Beach Front Biological Monitoring per Permit	$	16,260
• Install Emergency Sandbag Revetment at the Point	$	230,000
• Repair & Maintenance of Revetment at the Point	$	8,000
• BH Creek 2006 dredging Project w/ sand placed on West Beach	$	217,858
Total	$	22,351,398

Additional Expenditures Reimbursed through FEMA Public Assistance Funds

• Bald Head Creek Dredging Project (Emergency Sand Source to mitigate Erosion due to Hurricane Irene)	$	1,230,000
• Sand-filled Tube Groin Field Repairs due to Hurricane Irene	$	650,000
	$	1,880,000

Additional Expenditures Reimbursed through State of NC/DENR Water Resources Development Grant Funds

• Bald Head Creek Dredging Project 2005 ([illegible] Construction Co.)	$	260,000

BROOKS PIERCE
FOUNDED 1897

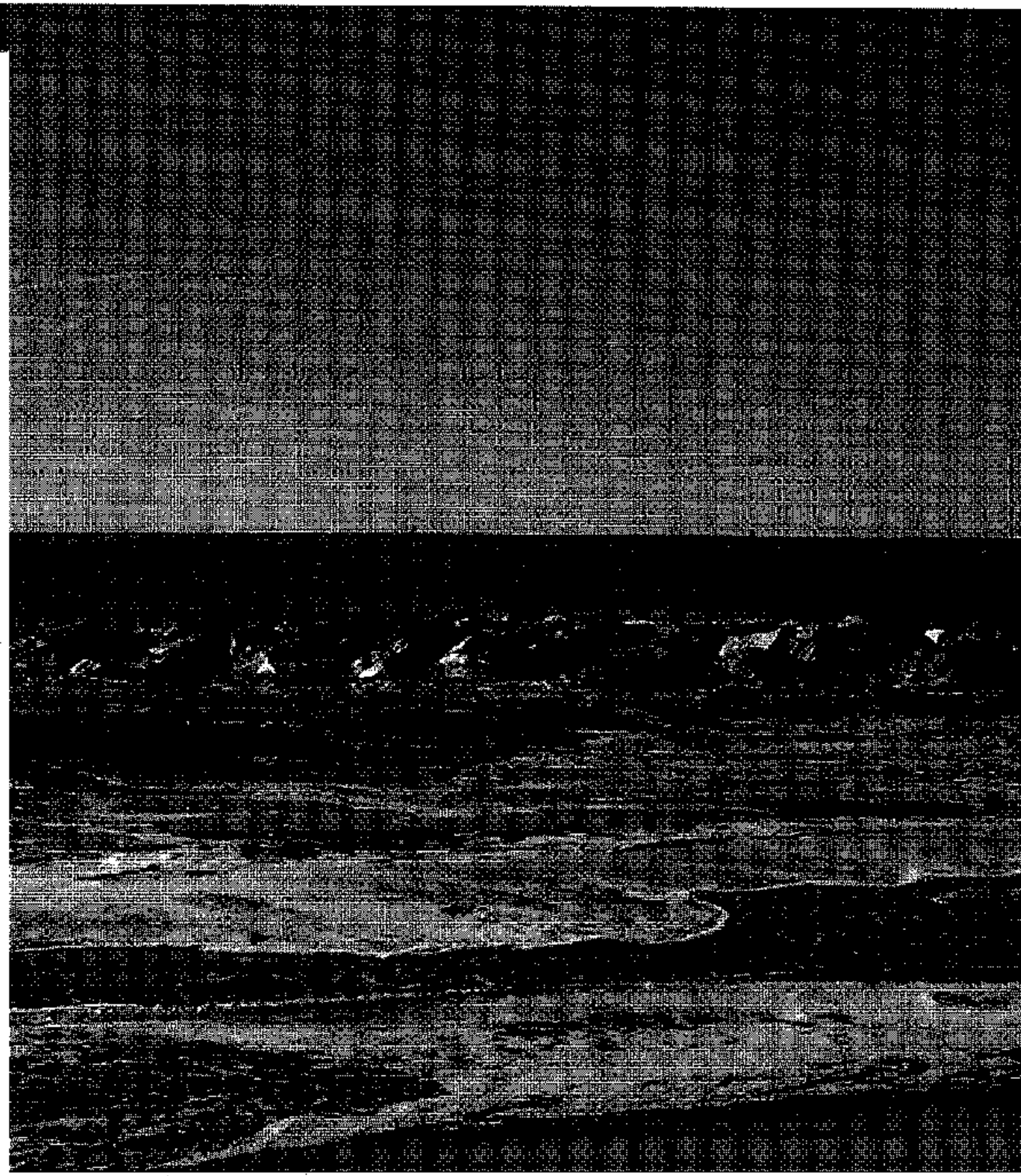
- Potential for future Channel deepening projects to accommodate larger, Post-Panamax vessels
- Channel maintenance is ongoing
- Property owners, BHI Club, Village, non-profits and others are unable to make infrastructure and investment decisions because of regulatory and erosion uncertainties.
  - The real estate market and tax base are harmed.

BROOKS PIERCE FOUNDED 1897

Bald Head Island Terminal Groin
Dec. 2015; $8.0MM Cost

PIERCE
FOUNDED 1857

Note Shipping Channel buoys in background



BEACH EROSION

Village of Bald Head Island

Charles S. Baldwin, IV

Brooks Pierce

Village of Bald Head Island

December 14, 2015

BROOKS PIERCE
FOUNDED 1897

Miller, Tancred

From:	Frank Rush <frush@emeraldisle-nc.org>
Sent:	Wednesday, December 16, 2015 3:10 PM
To:	Miller, Tancred
Cc:	Davis, Braxton C; Lopazanski, Mike
Subject:	Town of Emerald Isle - Official Comments - NC DCM Beach Erosion Study
Follow Up Flag:	Follow up
Flag Status:	Flagged

Mr. Tancred Miller:

Please accept this email as the Town of Emerald Isle's official comments for consideration as part of the State's legislatively mandated study of beach erosion. The Town greatly appreciates the opportunity to comment on this issue, and offers 4 substantive comments for consideration:

1. Dedicated State Fund / State Funding Source for Beach Nourishment Projects
   North Carolina beaches are important economic drivers for the coastal region, the entire State, and the United States. Similar to the "Shallow Draft Navigation Channel and Lake Dredging Fund" established by the NC General Assembly in recent years (with dedicated funding sources), a new fund earmarked specifically for State contributions toward beach nourishment projects is needed to assist coastal communities.

   The State's 2011 Beach and Inlet Management Plan estimated a total annual funding need of $19.1 million for beach nourishment projects in North Carolina. In order to generate the necessary funds, the Town of Emerald Isle proposes the creation of a new **"Storm Protection and Beach Preservation Fund"** by the State of North Carolina, with dedicated revenues derived from a portion of the existing State sales tax (4.75%) paid on transactions in NC Department of Revenue Business Category 708: Hotels, Motels, Cottage Rentals, Etc. within the 8 oceanfront counties ONLY. The total amount of State sales tax collected from Business Category 708 in Currituck, Dare, Hyde, Carteret, Onslow, Pender, New Hanover, and Brunswick counties during FY 14-15 was $48.44 million. The Town of Emerald Isle proposes that the proceeds of 2% (the other 2.75% would continue to be retained by the State for general purposes), or $20.36 million, be statutorily earmarked for the new **"Storm Protection and Beach Preservation Fund"** for distribution by the appropriate State agency to coastal communities engaging in beach nourishment projects.

   The proposed **"Storm Protection and Beach Preservation Fund"** follows the same template successfully used by the "Shallow Draft Navigation Channel and Lake Dredging Fund" by earmarking a small portion of the existing State revenues generated by the users of the resource.

2. A few North Carolina coastal communities have been engaged in beach nourishment activities for nearly 50 years in partnership with the US Army Corps of Engineers. Several other NC coastal communities have completed one or more locally-sponsored beach nourishment projects in the past 15 years, including 5 separate projects (of varying size and scope) by the Town of Emerald Isle since 2003. Collectively, we all have vast experience with beach nourishment in North Carolina. Beach nourishment is "tried and true", and is the most effective, most environmentally-friendly approach to combat beach erosion in North Carolina. The Town requests that official State policy reinforce this notion, and that it recognize that "retreat" is simply not a practical option in most situations (although it may be prudent in certain limited circumstances). The creation of the proposed **"Storm Protection and Beach Preservation Fund"** noted in comment 1. above would, in and of itself, solidify this policy position in the most direct manner.

3. Given the collective vast experience with beach nourishment in North Carolina, much has been learned over the past 15 years. Beach nourishment activities are "routine" in Emerald Isle and many other coastal communities now, and we suggest that there are likely additional opportunities to simplify and expedite the review and approval process for future beach nourishment projects. The State should continue to strive to reduce the time and expense associated with permitting such projects. The Town also requests that the State also carefully review and consider the potential negative impacts on beach nourishment projects associated with additional Federal wildlife designations. The creation of new or expanded critical habitat areas and additional species protections have the potential to negatively impact these important projects in the future.

4. There is already limited competition in the ocean dredging industry, and this reduced competition results in higher beach nourishment project costs and/or delayed projects due to the lack of available dredge plant to construct these projects. The additional limits resulting from the current "dredging window" (November 15 – March 31 only; a total of 4 ½ months of the year) further reduces competition among dredging companies and further increases competition among dredging customers, resulting in even higher project costs and/or delayed projects. The Town requests that the State actively seek to expand the "dredging window" to allow beach nourishment projects to be constructed during 6 – 8 months of the year.

Thank you for your consideration of the Town's comments. We stand ready to assist the State in any way helpful on this issue in the future. Please do not hesitate to contact me if you desire additional information.

Frank A. Rush, Jr.
Town Manager
Town of Emerald Isle
7500 Emerald Drive
Emerald Isle, NC 28594

252-354-3424 Office
252-241-6995 Mobile
252-354-5068 Fax

frush@emeraldisle-nc.org
www.emeraldisle-nc.org

EMERALD ISLE
NORTH CAROLINA

Nice Matters!

Shore Protection Manager

Greg L. Rudolph
Tel: (252) 222.5835
Fax: (252) 222.5826
grudolph@carteretcountync.gov

carteret county Shore protection office
protectthebeach.com

December 17, 2015

Tancred Miller
Coastal and Ocean Policy Manager
N.C. Division of Coastal Management (NCDCM)
400 Commerce Ave
Morehead City, NC 28557

Re: Beach Erosion Strategy Report - Public Comment Appendix

Dear Mr. Miller,

Pursuant to NCDCM's notice pertaining to the legislatively-mandated "Beach Erosion Strategy Report", please accept the following comments to be included in the Strategy Report Appendix. Our comments should be considered as suggestions, recommendations, or ideas and not as harsh directives – they are divided into "themes" in hopes of providing a more-user friendly format. Similarly, we envision the following comments and the Beach Erosion Strategy Report to be partially applicable to the guidance the General Assembly also provided in S.L. 2015-241 relative to the Beach and Inlet Management Plan. And lastly, we're cognizant of the short timeline provided to complete this report and appreciate NCDCM's work to this effect - please don't hesitate to contact me if you have any questions or require additional information.

Respectfully,

Greg "rudi" Rudolph
Shore Protection Manager

LEGISLATIVE DIRECTIVES IN S.L. 2015-241

Beach Erosion Strategy language

SECTION 14.10I.(a) The Division of Coastal Management shall study and develop a proposed strategy for preventing, mitigating, and remediating the effects of beach erosion. The study shall consider efforts by other states and countries to prevent beach erosion and ocean overwash and to renourish and sustain beaches and coastlines and incorporate best practices into the strategy.

SECTION 14.10I.(b) By February 15, 2016, the Division of Coastal Management shall report to the Environmental Review Commission, the chairs of the Senate Appropriations Committee on Natural and Economic Resources and the House Appropriations Committee on Agriculture, Natural, and Economic Resources, and the Fiscal Research Division on the results of the study and its proposed strategy as required by subsection (a) of this section, including any legislative recommendations.

BIMP language

SECTION 14.6.(b)(4) The sum of two hundred fifty thousand dollars ($250,000) shall be reserved for use by the Department of Environment and Natural Resources to update the Beach and Inlet Management Plan (Plan). The Department may enter into a sole-source contract of up to two hundred fifty thousand dollars ($250,000) with the firm that developed the initial Plan to have the firm update the Plan. The updated Plan shall include a recommended schedule for ongoing inlet maintenance. No later than December 1, 2016, the Department shall report to the Environmental Review Commission on the updated Plan, including a four-year cycle of regularly scheduled maintenance projects for beaches and inlets that currently undergo (or are expected to undergo) beach fill or dredging work.

Acronyms Used in Comments:

BIMP - Beach and Inlet Management Plan
USGS – United States Geological Survey
USACE – U.S. Army Corps of Engineers
FEMA – Federal Emergency Management Agency
USFWS – U.S. Fish & Wildlife Service
NMFS – National Marine Fisheries Service
ESA – Endangered Species Act
NEPA – National Environmental Policy Act
SEPA - State Environmental Policy Act
FONSI - Finding of No Significant Impact

MONITORING AND RESEARCH

(A) <u>Coastal Compartment Study</u> - N.C. should fund or cost-share with local governments a ***comprehensive*** study of each coastal compartment provided in the BIMP. The study should at a minimum address;

1. The geologic framework of each coastal compartment.
2. Shoreline change and volumetric changes (sand) through time.
3. Quantify the sediment budget for each coastal compartment; identifying all sources, sinks, and pathways.

USGS Circular 1339 provides a good model for these types of studies and would deliver the fundamental understanding of beach erosion/accretion in each BIMP coastal compartment and aid the State/local communities to develop minimum protection standards and design effective beach nourishment and shore protection plans.

(B) <u>Profile Network</u> - N.C. should develop, coordinate, and fund a Statewide beach profiling network akin those currently implemented in Carteret County, New Hanover County, and Nags Head. Profiles should encompass the shoreface, beach, and dune environments requiring full topo- and bathymetric coverage for each transect. These data will help in the State and local understanding of erosion/accretion, quantify shoreline and volume changes over time, and objectively monitor key benchmarks that can be used in the decision-making process and design for shore protection efforts.

(C) <u>Inlets</u> – In consort with the coastal compartment study mentioned above, a comprehensive assessment of all developed inlets in the State should also be instituted. Ideally all geomorphic features (thalweg, swash bars, ebb delta, flood delta, flood channels, etc.) would be identified and depicted throughout time, possibly using the photographic record. Besides providing more information that could plug into sediment budget models, the impacts of channel orientations to adjacent shorelines could also be constrained and again can aid in corrective measures, i.e., channel relocation, terminal groins, etc. Most of the State's "erosion problems" are located along the margins of the inlets – it's imperative the State and communities put higher focus in these areas.

FUNDING AND MANAGEMENT

(A) <u>Dedicated State Funding</u> - The State should develop a dedicated State funding source for locally-initiated beach nourishment and inlet management projects. The BIMP is an excellent resource document to estimate monetary needs and the State's Shallow Draft Navigation Channel Dredging & Lake Maintenance Fund provides a revenue-producing model and a good cost share template – 1:2 or 1:3 Local:State dollars.

In the past we have formally requested the State to furnish $165,000 to complete the USACE Bogue Banks Feasibility Study (2012), $1.5 million for the local Bogue Banks Master Nourishment Plan (2010), and $4,189,657 million for the Post-*Irene* Nourishment Project (2012). That total request of $6,354,657 would have been leveraged with $5,354,657 local and $7,604,328 federal (USACE & FEMA), yet we did not receive a single State matching dollar. As federal dollars become more and more scare, this paradigm must change.

(B) Regionalization – The State should promote and support regional approaches to beach and inlet management that cross municipal jurisdictions, which are codified by State law, interlocal agreements, or some other legal or meaningful vehicle. This enables communities to better leverage their resources and implement projects that cross geopolitical boundaries to effectively combat erosion. This umbrella management approach can also help pool environmental reviews thereby saving human and financial resources while providing the resource agencies a greater sense of surety in respect to the timing and impact of beach nourishment and inlet management activities. In Carteret County, we have a Beach Commission – Shore Protection Office that operates in a similar vein as a Town Manager – Town Council format. While this type of management system could never be mandated across the State; it could be encouraged and used in the future for more positive permitting and cost share decisions.

(C) Dredged Material Management at the State's Deep Draft Harbors – The State should continue to work with the USACE to ensure disposal of dredged, beach quality shoal material is done in a manner that replicates the sand budget for the inlet systems at Morehead City Harbor (Beaufort Inlet) and Wilmington Harbor (Cape Fear Inlet). This includes beach disposal (nourishment) regardless of the additional/delta costs associated with this practice or restrictions associated with the USACE federal standard (33 C.F.R. 335.7). The State should start endowing the new Deep Draft Navigation Channel Dredging & Maintenance Fund created in section 14.6(c) of S.L. 2015-241 to fund these types of nourishment efforts, and other approaches that minimize shoaling and combats erosion along open beaches and inlet shorelines; particularly jetties, which are also referenced in S.L. 2015-241 for the Morehead City Harbor (see Section 14.6(f)). Memorandum of Agreements or other legal vehicles should be codified allowing local governments to partner with the State (both administratively and financially) to ensure sandy resources are dredged and disposed in manner that sustains reliable navigation, replicates the sand budget for adjacent shorelines, and provides additional opportunities for beneficial use.

REGULATORY

(A) Expand Dredging Windows – The State should be promoting and working with the federal resource agencies (USFWS & NMFS) during Section 7 Endangered Species Act consultation for individual projects and on a more State-wide scale to extend dredging windows for both the pipeline and hopper fleets. For Carteret County, our hopper window is January 1st through March 31st - that puts an inordinate amount of stress on the industry and project sponsors to complete any large-scale beach nourishment project and creates a negative supply and demand bidding environment. Expanding the dredging windows with all the proper safeguards and mitigation measures in place would help save both local and potentially State money while ensuring projects are completed. October 1st through April 30th should be set as the window.

(B) Improve NEPA/SEPA Coordination & Permit Timelines – More support from the State and federal agencies should be laid to bare in an effort to streamline permitting for beach nourishment and inlet management projects. It is an understatement to say beach nourishment is now common place in North Carolina, and the positive and negative impacts are well known. There should be less red tape, bureaucracy, and review when permitting projects, and Environmental Assessments/FONSIs should be required from this point forward for individual nourishment and inlet relocation efforts.

(C) <u>ESA Implementation</u> – When merited, the State should routinely oppose future species listings (endangered or threatened) and compulsory critical habitat designations emanating from the USFWS and/or NMFS that result in additional constraints to beach nourishment and inlet management activities. At minimum the listings and designations provide another layer of review and additional consultation that wastes money, time, and other resources. At worse new mitigation measures are warranted that can be costly and have questionable value to the conservation of the species. The administration of the ESA by the USFWS and NMFS is mired by legal turmoil and has evolved into a broken and frustrating process in our estimation.

Miller, Tancred

From: Brian Kramer <Manager@townofpks.com>
Sent: Thursday, December 17, 2015 11:59 AM
To: Miller, Tancred
Subject: DCM BEACH EROSION STUDY--COMMENTS FROM PINE KNOLL SHORES

Follow Up Flag: Follow up
Flag Status: Flagged

Mr Miller,

Thanks for soliciting input on your study.

Pls consider the following from the Town of Pine Knoll Shores for the Division of Coastal Management's Beach Erosion Study:

1. ***Partnering with the USACOE***. *NCDCM should partner with USACOE to ensure that dredged material from port projects is used in the most beneficial manner for NC coastal communities. The State's objective should be that all USACOE plans and policies allow for NC coastal communities/governments to act as non-federal sponsors in USACOE dredging projects.*

2. ***Funding for Beach Nourishment***. *NCDCM should examine the sources of state funding for beach renourishment in other states and develop viable options in North Carolina that consider the impact of all tourism related industry on the state economy. Such funding options need not be coastal/beach specific, but should consider state revenue streams that support coastal, piedmont, and mountain tourism-related activities. State Occupancy Tax laws in particular should be closely examined as a possible revenue stream.*

3. ***State Assistance in the funding of Dune Restoration***. *NCDCM should explore the creation of grant funds specifically targeted for the restoration of dunes, which are often a first line of defense for storm surge during hurricanes and other storms. Sand Fencing and Beach Vegetation in particular should be partially funded by state grant funds.*

Mr Miller, the Town of Pine Knoll Shores endorses and supports the input from the Carteret County Shore Protection Office and input from the Town of Emerald Isle for the DCM Study.

Vr
Brian

Beach Erosion Strategy language

SECTION 14.10I.(a) The Division of Coastal Management shall study and develop a proposed strategy for preventing, mitigating, and remediating the effects of beach erosion. The study shall consider efforts by other states and countries to prevent beach erosion and ocean overwash and to renourish and sustain beaches and coastlines and incorporate best practices into the strategy.

SECTION 14.10I.(b) By February 15, 2016, the Division of Coastal Management shall report to the Environmental Review Commission, the chairs of the Senate Appropriations Committee on Natural and Economic Resources and the House Appropriations Committee on Agriculture, Natural, and Economic Resources, and the Fiscal Research Division on the results of the study and its proposed strategy as required by subsection (a) of this section, including any legislative recommendations.

V/R
Brian
Visit our Facebook Page: ***Facebook.com/townofpineknollshores***

Brian Kramer
Town Manager
Pine Knoll Shores, NC
Office--(252)-247-4353

The PKS Christmas Parade

[redacted]

*** Contact Susan Toms with questions at 222-0497, or at witoms@hotmail.com***

Where: Garner Park, 160 Oakleaf Drive, PKS

Audubon NORTH CAROLINA

December 18, 2015

Via Electronic Mail
Tancred Miller
N.C. Division of Coastal Management
400 Commerce Avenue
Morehead City, N.C. 28557
Tancred.Miller@ncdenr.gov

RE: Public Comments on Beach Erosion Study

Dear Mr. Miller,

Please accept these comments on behalf of the National Audubon Society's North Carolina State Office regarding the proposed beach erosion study report being prepared by the N.C. Division of Coastal Management for the General Assembly.

While it is difficult to comment on a study that has not yet been made available to the public, we respectfully request that your final study report take note of the significant, negative impact that hardened structures like terminal groins, jetties, and sea walls can have on our beaches and coastline. Our coast is critically important to people and North Carolina's natural heritage. Unfortunately, traditional strategies for controlling erosion have had a deleterious impact on downdrift properties, beaches, people and wildlife.

Terminal groins and other coastal engineering projects that affect inlets and adjacent beaches often result in a narrowing of downdrift oceanfront beach, loss of sediment from the inlet system, impacts to spits at ends of adjacent islands, loss of critical wildlife habitat for birds and fish, and loss of public beach access, among other impacts. We include in these comments over 100 published studies that address the impacts of terminal groins on inlets, beaches, and natural resources. The majority (78%) of peer-reviewed literature we collected regarding the impacts of hard structures at inlets concluded that terminal groins do not function in the manner expected and result in more harm than good.

There are also many adverse impacts that can be caused by beach nourishment projects – and that the State should consider and require to be avoided or minimized to the extent possible before authorizing a nourishment project – including:

1. Crushing, suffocating, and otherwise killing off species at the bottom of the coastal food chain (plants, worms, crustaceans, insects, and bivalve mollusks), thereby disrupting the coastal food chain by diminishing food for birds and other wildlife.

2. Change in sand characteristics and substrate composition on the beach.[1]

3. Change in slope or profile of the beach, which can in turn increase the wave energy on the beach and increased erosion rates.[2]

4. Prevention of wave overwash of narrow barrier islands, which then precludes accretion on the sound side of the island, causes the island to narrow, and diminishes the overwash fans that often provide the best wildlife habitat on a barrier island.[3]

5. Loss of wildlife habitat for species that use the beach and near-shore waters for some or all of their life cycle, including fish, birds, plants, crustaceans, etc., caused by items (1), (2), (3) and/or (4) above.

6. Loss of nesting habitat (and diminished reproductive success) for shore-nesting birds, caused by items (1), (2), (3), and/or (4) above, and by noise and physical disruption if the nourishment is conducted during the spring and summer breeding season and thereby disrupts or altogether prevents courtship, nesting, brooding, and fledging.

7. Loss of nesting habitat for sea turtles (and diminished reproductive success), caused by items (1), (2), (3), and/or (4), and by noise and physical disruption of nesting if the nourishment is conducted during the spring and summer nesting season, as well as years into the future by increased sand compaction and hardness, changes in moisture content and beach slope, etc. that can render a beach unsuitable for turtle nesting.[4]

8. Prohibited take of sea turtles listed as endangered or threatened under the federal Endangered Species Act by injuring sea turtles or hatchlings in the ocean, crushing turtles or hatchlings on the beach, or covering or crushing their nests.

9. Loss of foraging habitat for non-breeding shorebirds caused by items, (1), (2), (3), and/or (4).[5]

10. Encouragement of additional development along unstable shorelines, which then reduces the range of alternatives for managing the shoreline and allowing natural processes to occur.

11. Potential for disruption and stoppage of the dredging and dredged-sand placement on the beach due to the potential impacts to federally-listed species and other protected species that will be in the area, likely in significant numbers, at the time the dredging is proposed to take place.

---

[1] "If the sediment is too coarse or high in shell content it can inhibit the bird's ability to extract food particles in the sand. Fine sediment that reduces water clarity can also decrease feeding efficiency of birds." Atlantic States Marine Fisheries Commission, "Beach Nourishment: A Review of the Biological and Physical Impacts" at 31 (November 2002).

[2] "A steeper beach profile is created when sand is stacked on the beach during the nourishment process. This condition can lead to greater wave energy on the beach and greater beachside erosion." Atlantic States Marine Fisheries Commission, "Beach Nourishment: A Review of the Biological and Physical Impacts" 5 (November 2002).

[3] *Id.* (stating that a nourishment-induced steeper beach profile can "preclude wave overwash, leading to further erosion on the soundside" and can "ultimately result in the[] demise" of barrier islands by preventing them to accrete on the landward side as the ocean side erodes). *See also* S.R. Riggs, *et al.*, "North Carolina's Coasts in Crisis: A Vision for the Future" ("Coasts in Crisis"), which explains how nourishment and dune construction contribute to ocean-side erosion and prevent overwash, exacerbating sound-side erosion. The combined erosion on the ocean and sound sides of the island will lead to a narrowing of the island, potentially to the point that it can no longer support a highway, much less the wildlife habitat that is the purpose of the Refuge.

[4] *See* Fish and Wildlife Service, Recovery Plan for the U.S. Population of Atlantic Green Turtle, 3, 1991.

[5] For instance, "[b]irds may be displaced by dredges, pipelines, and other equipment along the beach, or may avoid foraging on the beach if they are aurally affected." Atlantic States Marine Fisheries Commission, "Beach Nourishment: A Review of the Biological and Physical Impacts" at 31 (November 2002).

In the pursuit of controlling beach erosion, the state should not promote measures that result in new hardened structures on the coast. Beach nourishment projects should be carefully examined to ensure the best outcome for public beach use, downdrift property and the wildlife that represents North Carolina's rich natural heritage.

Sincerely,

Heather Starck Hahn

Heather Hahn
Executive Director
Audubon North Carolina

Attachments:
(1) Geophysical impacts of terminal groins, other hard structures, and beach renourishment
(2) Impacts of shoreline hardening on coastal birds, other wildlife, and their habitats: a literature review with abstracts

Geophysical Impacts of Terminal Groins, Other Hard Structures, and Beach Renourishment

In order to assess environmental impacts, it is necessary to accurately describe how terminal groins and other coastal engineering projects affect inlets and adjacent beaches. Some of the impacts of terminal groins are the narrowing of downdrift oceanfront beach, loss of sediment from the inlet system, impacts to spits at ends of adjacent islands, loss of critical wildlife habitat, and cumulative impacts of the alternatives, among others. Terminal groins are designed to interrupt longshore transport of sand. It is well documented that terminal groins actually accelerate erosion of the shoreline downdrift of the structure (McDougal *et al.* 1987, Kraus *et al.* 1994, Bruun 1995, Cleary and Pilkey 1996, Komar 1998, McQuarrie and Pilkey 1998, Pilkey *et al.* 1998, Brown and McLachlan 2002, Greene 2002, USACE 2002, Morton 2003, Morton *et al.* 2004, Basco and Pope 2004, Speybroeck *et al.* 2006, Rice 2009, Riggs *et al.* 2009, Riggs and Ames 2011, Ells and Murray 2012, Knapp 2012, Pietrafesa 2012, Berry *et al.* 2013), which in turn requires regular replenishment of sand to compensate for sand loss (Hay and Sutherland 1988, Bruun 1995, McQuarrie and Pilkey 1998, French 2001, Galgano 2004, Basco 2006, Riggs *et al.* 2009, Riggs and Ames 2011, Pietrafesa 2012).

An open letter on the subject of downdrift erosion signed by 43 of the leading coastal geologists in the U.S. states:
The negative impact of groins and jetties on downdrift shorelines is well understood. When they work as intended, sand moving along the beach in the so-called downdrift direction is trapped on the updrift side, causing a sand deficit and increasing erosion rates on the downdrift side. This well-documented and unquestioned impact is widely cited in the engineering and geologic literature (Young *et al.* undated).

Fenster and Dolan (1996) found that inlets in Virginia and North Carolina exert influence over adjacent shorelines up to 5.4-13.0 km away and that they are a dominant factor in shoreline change for up to 4.3 km. Permanently modifying an inlet through construction of a terminal groin, or through channelization (Nordstrom 2000), will significantly increase the erosion rate on the downdrift shoreline.

Downdrift effects can be seen elsewhere in North Carolina where terminal groins have been installed. At Fort Macon, three years after the completion of the terminal groin a beach renourishment project occurred because the groin itself was exacerbating erosion, and from 1973-2007, seven renourishment projects have occurred at Fort Macon at the cost of nearly $45 million (Pietrafesa 2012). Riggs and Ames (2011) also provide an excellent review of the impacts of the modifications to Oregon Inlet. To minimize impacts of the Oregon Inlet terminal groin on the downdrift shoreline of Pea Island, sediment from routine Oregon Inlet channel dredging has been placed either directly on the Pea Island beach or in shallow nearshore disposal area near northern Pea Island (Riggs and Ames 2011). Human efforts have only temporarily slowed the process of shoreline recession in a small portion of northern Pea Island by the regular addition of dredged sand at a very high cost, but each new beach nourishment project has quickly eroded away (Riggs and Ames 2009, Riggs *et al.* 2009). Based on several studies, the data strongly suggests that the terminal groin itself is contributing to the accelerated erosion and shoreline recession problems on Pea Island (Riggs and Ames 2003, 2007, 2009; Riggs *et al.* 2008, 2009; Mallinson *et al.* 2005, 2008, 2010; Culver *et al.* 2006, 2007; Smith *et al.* 2008). In addition to impacts on downdrift shorelines, hard structures at inlets permanently remove sand from the inlet system, reducing or eliminating shoal systems from affected inlets (Pilkey *et al.* 1998) and accelerating the loss of saltmarsh in the vicinity of the inlet (Hackney and Cleary 1987). The loss of saltmarsh at an inlet would have significant negative impacts on fisheries, other wildlife, recreation, small businesses, and the local economy. The loss of ebb and flood tidal shoals is illustrated clearly by the case of Masonboro Inlet. A terminal groin was installed on the north end of Masonboro Island; construction of the groin was completed in April 1981 (Cleary and Marden 2009). At the time, the north end of the island featured an extensive sand spit, wide beach, and extensive flood and ebb tidal deltas. In less than one year following the completion of the terminal groin, the spit at the north end of Masonboro Island vanished, and the amount of intertidal shoals in the inlet, already diminished by other coastal engineering projects, had decreased as well. Downdrift of the terminal groin, Masonboro Island's oceanfront beach can be seen forming the expected fillet immediately adjacent to the terminal groin, while narrowing significantly along the downdrift beach.

The habitat lost would be primarily low-energy shoals and sandbars which provide habitat for a variety of benthic invertebrates that are essential food for shorebirds and fishes, and the sandy spit which is prime nesting habitat. Such a loss constitutes the some of the highest quality habitat in an inlet complex. There are at least 100 published studies that address the impacts of terminal groins on inlets, beaches, and natural resources. The majority (78%) of peer-reviewed literature regarding the impacts of hard structures at inlets concluded that terminal groins do not function in the manner expected and cause more harm than good.

Impacts of Hard Structures on Shorebirds

Natural, unmodified coastal inlets are essential habitat for many shorebird species (Charadridae and Scolopacidae), as well as other coastal bird species, because they provide wintering and nesting habitat, stopover and staging sites during migration, an abundant food supply, and safe roosting areas. In the southeastern U.S., the occurrence and numbers of shorebirds that use coastal habitats tends to be greater at inlets than other habitat types, and seven shorebird species: Black-bellied Plover (*Pluvialis squatarola*), the endangered and threatened Piping Plover (*Charadrius melodus*), the threatened Red Knot (*Calidris canutus rufa*), Ruddy Turnstone (*Arenaria interpres*), Snowy Plover (*Charadrius alexandrinus*), Western Sandpiper (*Calidris mauri*) and Wilson's Plover (*Charadrius wilsonia*) were significantly more abundant at inlets than other coastal habitats (Harrington 2008). Additionally, several studies designate inlets as favored habitat by Red Knots and breeding and non-breeding Piping Plovers (Nicholls and Baldassarre 1990, Harrington 2008, Kisiel 2009a, 2009b, Riggs *et al.* 2009, Niles *et al.* 2010, Maslo *et al.* 2011, USFWS 2012, 2013). Kisiel (2009a, 2009b) documented Piping Plovers exhibited a strong preference for nesting areas near inlets, particularly those that were not stabilized with structures since 70.6% of all Piping Plover pairs nested closer to an unstabilized inlet than a stabilized inlet. Piping Plovers in North Carolina exhibit a similar preference for nesting near inlets, and the majority of Piping Plover nests in Cape Hatteras National Seashore and Cape Lookout National Seashore were located near inlets (NPS 2014a, 2014b).

Southeastern North Carolina provides important inlet habitat not only for shorebirds migrating from northern Canada to South America, but also for resident breeding birds (e.g., oystercatchers, plovers and terns). Declines in shorebird populations are driven largely by habitat loss and degradation and inlets are at risk from human interference by dredging and construction of hard stabilization structures. Coastal habitats that are favored by shorebirds are increasingly being degraded or made entirely unsuitable for shorebirds, and in North Carolina, 85% of inlets have been modified, of which 35% are stabilized with hardened structures, and 43% of Atlantic coast inlets in the migration and winter range of the Piping Plover have been stabilized with hard structures (Rice 2012). Loss or degradation of wintering habitat, including habitats associated with coastal engineering projects, was identified as a primary threat to shorebirds (Winn *et al.* 2013). The most significant threats to breeding and non-breeding Piping Plovers includes inlet stabilization and relocation, as well as dredging, sand mining and beach nourishment since it leads to habitat loss and has direct and indirect impacts on adjacent shorelines (Maslo *et al.* 2011, USFWS 2012). Additionally, hard stabilization structures and dredging degrade and often eliminate existing Red Knot habitats, and may prevent the formation of new shorebird habitats (USFWS 2013). For many U.S. shorebird species, existing information is inadequate to quantify how anthropogenic alterations to the coast have affected shorebird populations at specific sites.

The impacts of shoreline alteration and development on the distribution and reproductive success of coastal birds has not been studied extensively. Construction of hardened structures at inlets cause a permanent loss of habitat that birds require for nesting, foraging and resting. The consequences of different management practices (e.g., dredging, hard structures [jetties, groins, sea walls, and breakwaters], and coastal development) can lead to extensive changes in coastal habitats. Groins are positioned perpendicular to the shoreline in order to interrupt longshore transport and trap sediment on the updrift side of the structure; however, the consequence is erosion of the shoreline downdrift of the structure, which requires beach nourishment to compensate for sand loss (Hay and Sutherland 1988, Bruun 1995, McQuarrie and Pilkey 1998, French 2001, Galgano 2004, Basco 2006, Riggs *et al.* 2009, Riggs and Ames 2011, Pietrafesa 2012). Hard structures at inlets permanently remove sand from the inlet and extensive shoal systems that birds rely on throughout the year. Dredging and beach nourishment cause disturbances to both borrow and placement sites and can alter community structure at both locations, and hardened structures can cause significant changes in habitat structure that can lead to decreased species diversity and abundances. The associated dredging and nourishment projects that supplement the installation of hard structures will eliminate habitat that migrating and wintering shorebirds, like Red Knots and Piping Plovers, need at critical times of the year. This would deprive thousands of birds that use inlets for foraging, nesting and roosting of the habitat they need for survival.

The direct impacts of hardened structures on coastal birds are not well documented. Only one study, conducted in southern California, investigated the direct impacts of hardened structures on coastal birds and concluded that armoring negatively impacted coastal birds since significantly lower diversity and abundance of shorebirds, gulls and other seabirds were observed on armored beaches compared to unarmored beaches (Dugan and Hubbard 2006, Dugan *et al.* 2008). All thirteen species (Dugan and Hubbard 2006) and twelve of fourteen species (Dugan *et al.* 2008) of shorebirds observed were significantly more abundant on unarmored beaches compared to armored beaches, and the abundance and diversity of shorebirds was more than three times greater on unarmored beaches compared to armored beaches. Coastal armoring also caused beach widths to narrow significantly, which resulted in the loss of intertidal habitat available to macroinvertebrates, and therefore, the abundance of macroinvertebrates decreased (Dugan and Hubbard 2006, Dugan *et al.* 2008). The diversity and abundance of shorebirds on beaches in southern California was positively correlated with the diversity and abundance of macroinvertebrate prey, and since a decline in prey was observed, a decrease in foraging shorebirds, gulls and other seabirds was also observed (Dugan and Hubbard 2006, Dugan *et al.* 2008). These authors concluded that increasing coastal armoring accelerates beach erosion and increases ecological impacts to sandy beach communities at an unknown rate.

Indirect and cumulative ecological effects of beach nourishment and repeated nourishment are poorly studied and few studies of beach nourishment have investigated the impacts on shorebirds. A handful of studies explored the indirect impacts of beach nourishment on shorebirds and their results varied (Quammen 1982, Peterson and Manning 2001, Peterson and Bishop 2005, Peterson *et al.* 2006, Speybroeck *et al.* 2006, Convertino *et al.* 2011, VanDusen *et al.* 2012, Peterson *et al.* 2014). Since hard stabilization leads to increased erosion at downdrift locations, beach nourishment must supplement the installation of hard structures at a rate of approximately every three to five years. Although beach nourishment is considered a less damaging alternative, this practice also has environmental impacts (Speybroeck *et al.* 2006). Disturbance from beach nourishment projects may cause nesting birds to abandon nests and foraging birds may be negatively impacted by nourishment since it buries their prey and recovery rates of benthic infauna and macroinvertebrates are variable. Three species of shorebirds in Florida were negatively impacted by beach renourishment since Snowy Plovers, Piping Plovers and Red Knots were less likely to use a beach for wintering the year following nourishment and Snowy Plovers were less likely to nest in an area following nourishment (Convertino *et al.* 2011). Speybroeck *et al.* (2006) documented the mortality of just one species of polychaete due to nourishment resulted in decreased abundances of foraging sanderlings. Decreased abundances of shorebirds after nourishment may be due to: the foraging area being reduced substantially, decreased densities of prey, and the occurrence of course sediments further reducing foraging habitat (Peterson *et al.* 2006).

Sediment characteristics control the community structure of benthic invertebrates. Sediment characteristics of nourishment sand influence recovery rates of benthic invertebrates which can indirectly impact foraging birds. Peterson and Manning (2001) documented the type of sediment used in beach nourishment influenced the recovery of macrofauna, therefore impacting surf fishes and shorebirds that consume them, and the impacts were dramatic (86-99% decrease in abundance of *Donax* and *Emerita talpoida*) and long-lasting. VanDusen *et al.* (2012) noted the habitat with the highest amount of course sediments was least used by foraging shorebirds despite the extremely high abundances of polychaetes present. Beach nourishment using coarser sediment grain sizes than native sand caused decreased abundances of macroinvertebrates, therefore reducing habitat value for foraging shorebirds and shorebird use declined drastically (70-90%) on nourished beaches (Peterson *et al.* 2006). Additionally, shorebirds spent significantly less time foraging in areas where sand was added because the increased sand interfered with feeding success (Quammen 1982). Shorebird communities require habitat heterogeneity to survive, which is why unmodified inlets containing heterogeneous intertidal sand and mud flats are important to sustaining diverse shorebird communities (VanDusen *et al.* 2012).

The recovery time for macroinvertebrate and shorebird communities on nourished beaches is variable largely due to the short duration of most monitoring studies and most studies ended before recovery was even established. In North Carolina, shorebird numbers recovered after seven to twelve months on nourished beaches compared to control beaches, *Emerita talpoida* abundance recovered within months, but *Donax* spp. and amphipods did not recover within the time frame of the study (Peterson *et al.* 2006). Peterson *et al.* (2014) monitored the recovery of a sandy beach community for 3-4 years following nourishment and documented haustoriid amphipods and *Donax* spp. had reduced densities for 3-4 years following nourishment, *E. talpoida* had lower densities for 1-2 years following nourishment, ghost crabs had lower abundances for 4 years and foraging shorebirds were less abundant for 2-4 years following nourishment.

Peterson and Bishop (2005) suggested that weaknesses in nourishment studies are due to studies being conducted by project advocates with no peer review process and the duration of monitoring is inadequate to characterize the fauna before and after nourishment, and uncertainty surrounding biological impacts of nourishment can be attributed to the poor quality of monitoring studies. One study found no significant differences in the abundance and diversity of waterbirds or shorebirds after nourishment, with the exceptions of decreased abundances of Black-bellied Plovers, and waterbird feeding significantly decreased after nourishment (Grippo *et al.* 2007). Grippo *et al.* (2007) used only one control site compared to three nourishment sites, they did not evaluate macroinvertebrate communities that the birds prey on, and they were unable to assess the impacts to most shorebird species due to their seasonal or infrequent use of these sites.

A strong correlation between sediment grain size, benthic invertebrate communities and the distribution of foraging shorebirds exists. Beach nourishment degrades beach habitats, thus decreasing densities of invertebrate prey for shorebirds. Intertidal mudflats and sandflats in inlet complexes are important feeding areas for migrating and wintering shorebirds and hard structures eliminate these critical habitats. Inlet flats are valuable foraging areas for many shorebirds due to their proximity to preferred nesting grounds near natural coastal inlets. The impacts of dredging, beach nourishment and hardened structures on ecological communities have been poorly studied, the results are variable and thus, the impacts are still poorly understood. Any structure placed in a coastal environment modifies the physical processes and these changes will impact the species composition, abundance and structure of invertebrate assemblages, and therefore birds and fishes that consume these prey. Although coastal protection structures have an anticipated lifespan, these structures are typically not removed when they reach this point or if they fail to function as predicted, but rather they are repaired, replaced, or strengthened to provide continued protection. In most cases, once a hard structure has been constructed, it is reasonable to assume that it will be a permanent feature of the coastline (Griggs 2005). Further research is needed in order to fully understand the impacts of hardened structures and beach nourishment on the organisms that use these coastal habitats.

Impacts on Infauna

The majority of peer-reviewed literature demonstrates that infaunal species are negatively impacted by beach nourishment, and that the length of time for recovery varies by species (Hayden and Dolan 1974, Jaramillo *et al.* 1987, Rakocinski *et al.* 1996, Peterson *et al.* 2000a, Peterson *et al.* 2000b, Bishop *et al.* 2006, Dolan *et al.* 2006, Peterson *et al.* 2006, Bertasi *et al.* 2007, Colosio *et al.* 2007, Cahoon *et al.* 2012, Leewis *et al.* 2012, Schlachler *et al.* 2012, Viola *et al.* 2013, Manning *et al.* 2014, Petersen *et al.* 2014). In North Carolina, *Emerita talpoida* (mole crab) abundance recovered within months on nourished beaches compared to control beaches, but *Donax* spp. (coquina clam) and amphipods did not recover within the time frame of the study (Peterson *et al.* 2006). Peterson *et al.* (2014) monitored the recovery of a sandy beach community for 3-4 years following nourishment on Bogue Banks, NC, and documented that haustoriid amphipods (small crustaceans) and *Donax* spp. had reduced densities for 3-4 years following nourishment, *E. talpoida* had lower densities for 1-2 years following nourishment, and ghost crabs had lower abundances for four years. Limited data and conflicting results have been documented for impacts to polychaetes. In North Carolina, polychaetes were the most negatively impacted fauna and had decreased abundances for over eight months after the deposition of dredged material (Bishop *et al.* 2006), but other studies found no consistent pattern of difference in abundance of polychaetes (Peterson *et al.* 2006, Manning *et al.* 2014, Peterson *et al.* 2014).

At inlets where terminal groins were constructed, the beach nourishment cycle is every 1-4 years (Riggs *et al.* 2009, Riggs and Ames 2011, Pietrafesa 2012). Pea Island was renourished every year from 1990-2004, and Fort Macon was renourished every 2-6 years from 1973-2007 (Pietrafesa 2012). If some species of the infaunal community recover in 3-4 years, the cumulative impact to the infaunal community due to nourishment at such sites is that the community cannot recover before the next nourishment cycle. In some cases, local extinction of benthic species has occurred (Colosio *et al.* 2007).

The compaction of sand by heavy machinery and changes in grain size and shape, permeability, and penetrability are other common results of beach nourishment that impact infaunal organisms (Greene 2002, McLachlan and Brown 2006). Further, the timing of activity is important to avoid periods of larval recruitment. Beach nourishment degrades beach habitats, thus decreasing densities of invertebrate prey for shorebirds. Each shorebird species has its own foraging microhabitat as well as its own feeding techniques. Shorebirds that collect food from specific depths beneath the sand can no longer rely on food from traditional habitats on nourished beaches (Peterson *et al.* 2006). This will negatively impact species that often forage in oceanfront intertidal and swash habitats, specifically Sanderlings (Macwhirter *et al.* 2002), Willets (Lowther *et al.* 2001), and the threatened Red Knot (Baker *et al.* 2013). Speybroeck *et al.* (2006) documented that the mortality of just one species of polychaete due to nourishment resulted in decreased abundances of foraging Sanderlings. Piping Plovers forage less on oceanfront beaches than other habitats during non-breeding months (Haig and Oring 1985, Cohen *et al.* 2008), but they have been documented foraging occasionally on oceanfront beaches. Therefore, renourishment activities also affect this Piping Plover foraging habitat.

Decreased abundances of shorebirds after nourishment may be due to decreased foraging area, decreased prey densities, and the occurrence of coarse sediments further reducing foraging habitat (Peterson *et al.* 2006). Coastal armoring caused beach widths to narrow significantly in southern California, which resulted in the loss of intertidal habitat available to macroinvertebrates, and, therefore, the abundance of macroinvertebrates decreased (Dugan and Hubbard 2006, Dugan *et al.* 2008). The diversity and abundance of shorebirds on beaches was positively correlated with the diversity and abundance of macroinvertebrate prey, and since a decline in prey was observed, a decrease in foraging shorebirds, gulls, and other seabirds was also observed (Dugan and Hubbard 2006, Dugan *et al.* 2008). These authors concluded that increasing coastal armoring accelerates beach erosion and increases ecological impacts to sandy beach communities.

Any hard structure placed in a coastal environment modifies physical processes there, and these changes will impact the species composition, abundance, and structure of invertebrate communities, and therefore birds that consume these prey will also be impacted. Hard-engineered structures are thought to be responsible for the loss of more than 80% of sandy beach shorelines globally (Brown and McLachlan 2002). Additionally, the placement of a terminal groin as called for in Alternatives 5 and 6, will result in the loss of the spit on the east end of Holden Beach. Although it's been stated above, it bears repeating that the modeling reported for Alternatives 5 and 6 indicate that a significant amount of sediment would be lost from the system, resulting in the loss of habitat, primarily low-energy shoals and sandbars which provide habitat for a variety of benthic invertebrates that are consumed by shorebirds and fishes.

Every recovery or management plan that pertains to species of shorebirds that use the coast recognizes the importance of infaunal organisms and their habitats. These species include the Piping Plover (USFWS 1996, 2001, 2003, 2009), Red Knot (USFWS 2013), Sanderling (Payne 2010), and Dunlin (Fernández *et al.* 2010).

Audubon North Carolina conducted an extensive review of literature regarding the impacts of hardened structures and beach fill activities with a focus on scientific, peer-reviewed articles. We found 43 peer-reviewed articles and included three reports regarding the impacts of renourishment on benthic organisms. Of these 46 documents, 34 (74%) found an impact to one or more species of benthic organism, 4 (9%) found no impact, and 8 (17%) were ambiguous or found equivocal results.

Peterson and Bishop (2005) suggested that weaknesses in nourishment studies are due to studies being conducted by project advocates with no peer review process and the duration of monitoring being inadequate to characterize the fauna before and after nourishment. Thus, uncertainty surrounding biological impacts of nourishment can be attributed to the poor quality of monitoring studies, not an absence of impacts.

Impacts of Fishes

Fishes would be negatively impacted by the construction of a terminal groin and the subsequent beach nourishment projects at Rich Inlet in the following ways 1) the groin would interrupt larval transport through the inlet, therefore impacting productivity, 2) the native fish community would be replaced with a completely different structure-associated fish community, and 3) surf zone fishes would suffer from direct mortality. Hard structures reduce the successful passage of fish larvae from the open ocean to the estuarine nurseries they inhabit until reaching maturity (Hettler and Barker 1993, Pilkey *et al.* 1998). Inlets are critical pathways for adult fishes to get to offshore spawning sites and larvae immigrate through inlets to get to estuarine nurseries (Able *et al.* 2010).

Many surf zone fishes are larval and juvenile individuals that benefit from the shallow water nursery habitat because it provides refuge from predators and foraging areas (Layman 2000). Due to their early ontogenetic stage, fish larvae are not adapted for high mobility in response to habitat burial or increased turbidity levels. Studies have shown that beach nourishment degrades the important swash-zone feeding habitat for both probing shorebirds and demersal surf fishes (Quammen 1982, Manning *et al.* 2013, VanDusen *et al.* 2014). Surf habitats with hardened structures typically support a different community of fishes and benthic prey. Impacted species would include Atlantic menhaden, striped anchovy, bay anchovy, rough silverside, Atlantic silverside, Florida pompano, spot, Gulf kingfish, and striped mullet. Florida pompano and Gulf kingfish use the surf zone almost exclusively as a juvenile nursery area and as juveniles, they are rarely found outside the surf zone (Hackney *et al.* 1996). The dominant benthic prey for pompano and kingfish were coquina clams (*Donax*) and mole crabs (*Emerita*). Despite the fact that fishes in the surf zone are adapted to a high energy environment, rapid changes in their habitat can still cause mortality and other negative impacts. There are documented negative impacts of renourishment on some of the invertebrates (especially mole crabs and coquinas) that are major foods of the fishes (Reilly 1978, Baca *et al.* 1991); therefore, negative impacts could be indirectly transferred to the surf zone fish community.

Manning *et al.* 2013 states:
Beach nourishment can degrade the intertidal and shallow subtidal foraging habitats for demersal surf fishes by three major processes: (1) inducing mass mortality of macrobenthic infaunal prey through rapid burial by up to 1 m or more of dredged fill materials; (2) modifying the sedimentology of these beach zones through filling with excessive proportions of coarse, often shelly sediments that are incompatible with habitat requirements of some important benthic invertebrates, such as beach bivalves; and (3) incorporating into the beach fill excessive quantities of fine sediments in silt and clay sizes, which can induce higher near-shore turbidity during periods of erosion as onshore winds or distant storms generate wave action, thereby inhibiting detection of prey by visually orienting fishes. The opinion repeated in many environmental impact statements and environmental assessments that marine benthic invertebrates of ocean beach habitats are well adapted to surviving the sediment deposition of beach nourishment because of evolutionary experience with frequent erosion and deposition events associated with intense storms and high waves is unsupportable. A recent review of the literature on impacts of storms on ocean-beach macrofauna (Harris et al. 2011) reveals that about half the studies report massive reductions of beach infaunal populations after storms.

Impacts on Sea Turtles

Threatened loggerhead sea turtles (*Caretta caretta*) nest along the length of North Carolina's coast. Information on the impacts of hard structures to sea turtles is limited, but the few studies that exist found negative impacts to sea turtles. Lamont and Houser (2014) documented that loggerhead turtle nest site selection is dependent on nearshore characteristics, therefore any activity that alters the nearshore environment, such as the construction of groins or jetties, may impact loggerhead nest distribution. Loggerhead nesting activity decreased significantly in the presence of exposed pilings, and a 41% reduction in nesting occurred where pilings were present (Bouchard *et al.* 1998). In a study of the impact of coastal armoring structures on sea turtle nesting behavior, Mosier (1998) demonstrated that fewer turtles emerged onto beaches in front of seawalls than onto adjacent, non-walled beaches, and of those that did emerge in front of seawalls, more turtles returned to the water without nesting. Loggerhead sea turtles nests on North Carolina beaches increased in number as distance from hard structures including piers and terminal groins increased (Randall and Halls 2014). Studies in Florida have also found avoidance behavior and decreased hatching success associated with a managed inlet (Herren 1999, Witherington *et al.* 2005).

Beach renourishment also negatively impacts loggerhead sea turtle nesting. Renourishment can cause beach compaction, which can decrease loggerhead nesting success, alter nest chamber geometry, and alter nest concealment, and nourishment can create escarpments, which can prevent turtles from reaching nesting areas (Crain *et al.* 1995). Nourishment can decrease survivorship of eggs and hatchlings by altering characteristics such as sand compaction, moisture content, and temperature of the sand (Leonard Ozan 2011), all of which are variables that can affect the proper development of eggs. The success of incubating eggs may be reduced when the sand grain size, density, shear resistance, color, gas diffusion rates, organic composition, and moisture content of the nourished sand is different from the natural beach sand (Nelson 1991). Negative impacts from beach renourishment include decreases in nesting activity and decreases in hatching success due to the use of incompatible material, sand compaction, and suboptimal beach profile (NMFS and USFWS 1991).

Sea turtles may be impacted by construction on beaches or dredge equipment, especially when work takes place outside the environmental window for sea turtles. During the spring and summertime construction phase of the Bald Head Island terminal groin, an adult female was trapped inside the construction zone for a day and a nest was destroyed when it was dug up by construction equipment (Sarah Finn pers. com. 2015). Pipeline and other obstructions placed on the beach may obstruct hatchling emergences or impede their path to the ocean (NMFS and USFWS 1991). Hopper and cutterhead dredges may also kill sea turtles during dredge work (NMFS and USFWS 1991). The loggerhead sea turtle recovery plan emphasizes that the only beneficial impacts of nourishment are in cases where beaches are so highly eroded, there is "a complete absence of dry beach" (NMFS and USFWS 1991).

Nesting activity on nourished beaches decreased for one to three years following a nourishment event due to changes in the sand compaction, escarpment, and beach profile (NMFS and USFWS 1991, Steinitz *et al.* 1998, Trindell *et al.* 1998, Rumbold 2001, Brock *et al.* 2009). The loggerhead recovery plan includes negative impacts: "In preventing normal sand transport, these structures accrete updrift beaches while causing accelerated beach erosion downdrift of the structures [groins and jetties] (Komar 1983, Pilkey *et al.* 1984, National Research Council 1987), a process that results in degradation of sea turtle nesting habitat" (NMFS and USFWS 1991).

Literature

Able, K.W., Wilber, D.H., Muzeni-Corino, A., and Clarke, D.G. 2010. Spring and Summer

Larval Fish Assemblages in the Surf Zone and Nearshore off Northern New Jersey, USA. Estuaries and Coasts, 33: 211-222.

Airoldi, A., Abbiati, M., Beck, M.W., Hawkins, S.J., Jonsson, P.R., Martin, D., Moschella, P.S., Sundelöf, A., Thompson, R.C., and P. Åberg. 2005. An Ecological Perspective on the Deployment and Design of Low-crested and other Hard Coastal Defense Structures. Coastal Engineering, 52: 1073-1087.

Alexander, R.R., Stanton, R.J., Jr., and Dodd, J.R. 1993. Influence of Sediment Grain Size on the Burrowing of Bivalves: Correlation with Distribution and Stratigraphic Persistence of Selected Neogene Clams. Palaios, 8: 289-303.

Balsillie, J.H. and Berg, D.W. 1972. State of Groin Design and Effectiveness. Proceedings of the 13th International Conference on Coastal Engineering, American Society of Civil Engineers: New York, 1367-1383.

Balsillie, J.H. and Bruno, R.O. 1972. Groins: An Annotated Bibliography. USACE Coastal Engineering Research Center, Miscellaneous Paper No 1-72, 249 p.

Basco, D.R. 2006. Seawall Impacts on Adjacent Beaches: Separating Fact from Fiction. Journal of Coastal Research, SI 39: 741-744.

Basco, D.R. and Pope, J. 2004. Groin Functional Design Guidance from the Coastal Engineering Manual. Journal of Coastal Research, SI 33: 121-130.

Berry, A., Fahey, S., and Meyers, N. 2013. Changing of the Guard: Adaptation Options that Maintain Ecologically Resilient Sandy Beach Ecosystems. Journal of Coastal Research, 29(4): 899-908.

Bertasi, F., Colangelo, M.A., Abbiati, M., and Ceccherelli, V.U. 2007. Effects of an Artificial Protection Structure on the Sandy Shore Macrofaunal Community: The Special Case of Lido di Dante (Northern Adriatic Sea). Hydrobiologia, 586: 277-290.

Bilkovic, D.M. and Mitchell, M.M. 2013. Ecological Tradeoffs of Stabilized Salt Marshes as a Shoreline Protection Strategy: Effects of Artificial Structures on Macrobenthic Assemblages. Ecological Engineering, 61: 469-481.

Bishop, M.J., Peterson, C.H., Summerson, H.C., Lenihan, H.S., and Grabowski, J.H. 2006. Deposition and Long-Shore Transport of Dredge Spoils to Nourish Beaches: Impacts on Benthic Infauna of an Ebb-Tidal Delta. Journal of Coastal Research, 22(3): 530-546.

Bokuniewicz, H. 2004. Isolated Groins at East Hampton, New York. Journal of Coastal Research, SI 33: 215-222.

Bolam, S.G. and Rees, H.L. 2003. Minimizing Impacts of Maintenance Dredged Material

Disposal in the Coastal Environment: A Habitat Approach. Environmental Management, 32 (2): 171–188.

Bolam, S.G., Schratzberger, M., and Whomersley, P. 2006. Macro- and Meiofaunal Recolonisation of Dredged Material Used for Habitat Enhancement: Temporal Patterns in Community Development. Marine Pollution Bulletin, 52: 1746–1755.

Bouchard, S., Moran, K., Tiwari, M.,Wood, D., Bolten, A., Eliazar, P., and Bjorndal, K. 1998. Effects of Exposed Pilings on Sea Turtle Nesting Activity at Melbourne Beach, Florida. Journal of Coastal Research, 14(4): 1343-1347.

Bowman, M.L. and Dolan, R. 1985. The Relationship of *Emerita talpoida* to Beach Characteristics. Journal of Coastal Research, 1(2): 151-163.

Brock, K.A., Reece, J.S., and Ehrhart, L.M. 2009. The Effects of Artificial Beach Nourishment on Marine Turtles: Differences between Loggerhead and Green Turtles. Restoration Ecology, 17(2): 297-307.

Brooks, W.B. 1988. A Historic and Morphologic Study of Mason and Rich Inlets, North Carolina. [M.S. thesis]: Wilmington, North Carolina, University of North Carolina Wilmington, 117 p.

Brown, A.C. and McLachlan, A. 2002. Sandy Shore Ecosystems and the Threats Facing Them: Some Predictions for the Year 2025. Environmental Conservation, 29(1): 62-77.

Bruun, P. 1995. The Development of Downdrift Erosion. Journal of Coastal Research, 11(4): 1242-1257.

Bruun, P. 2001. The Development of Downdrift Erosion. An Update of Paper in JCR, Vol. 11(4). Journal of Coastal Research, 17(1): 82-89.

Bulleri, F. and Chapman, M.G. 2010. The Introduction of Coastal Infrastructure as a Driver of Change in Marine Environments. Journal of Applied Ecology, 47: 26-35.

Burney, C. and Mattison, C. 1992. The Effects of Egg Relocation and Beach Nourishment on the Nesting and Hatching Success of *Caretta caretta* in Broward County, Florida, 1991. New Directions in Beach Management: Proceedings of the 5th Annual National Conference on Beach Preservation Technology, St. Petersburg, Florida, 395-407.

Burroughs, S.M. and Tebbens, S.F. 2008. Dune retreat and shoreline change on the Outer Banks of North Carolina. Journal of Coastal Research, 24(2B): 104-112.

Cahoon, L.B., Carey, E.S., and Blum, J.E. 2012. Benthic Microalgal Biomass on Ocean Beaches: Effects of Sediment Grain Size and Beach Renourishment. Journal of Coastal Research, 28(4): 853-859.

Carr-Betts, E., Beck, T.M., and Kraus, N.C. 2012. Tidal Inlet Morphology Classification and Empirical Determination of Seaward and Down-drift Extents of Tidal Inlets. Journal of Coastal Research, 28(3): 547-556.

Chapman, M.G. and Underwood, A.J. 2011. Evaluation of Ecological Engineering of "Armoured" Shorelines to Improve their Value as Habitat. Journal of Experimental Marine Biology and Ecology, 400: 302-313.

Charlier, R.H., Chaineux, M.C.P., and Morcos, S. 2005. Panorama of the History of Coastal Protection. Journal of Coastal Research, 21(1): 79-111.

Churchill, J.H., Forward, R.B., Luettich, R.A., Hench, J.L., Hettler, W.F., Crowder, L.B., and Blanton, J.O. 1999. Circulation and Larval Fish Transport within a Tidally Dominated Estuary. Fisheries Oceanography, 8 (Suppl. 2): 173-189.

Cleary, W.J. 1996. Inlet Induced Shoreline Changes: Cape Lookout-Cape Fear. *In:* Environmental Coastal Geology: Cape Lookout to Cape Fear, NC. Cleary, W.J., (ed), Carolina Geological Society Field Guidebook: 41-50.

Cleary, W.J. 2002. Variations in Inlet Behavior and Shoreface Sand Resources: Factors Controlling Management Decisions, Figure Eight Island, NC, USA. Journal of Coastal Research, SI 36: 148-163.

Cleary, W.J. and Marden, T.P. 1999. Shifting Shorelines: A Pictorial Atlas of North Carolina's Inlets, NC Sea Grant Program Publication No. UNC-SG-99-04, Raleigh, NC, 51 p.

Cleary, W.J. and Pilkey, O.H. 1996. Environmental Coastal Geology: Cape Lookout to Cape Fear, North Carolina, Regional Overview. *In:* Environmental Coastal Geology: Cape Lookout to Cape Fear, NC. Cleary, W.J., (ed), Carolina Geological Society Field Guidebook: 73-107.

Cleary, W.J., Willson, K.T., and Jackson, C.W. 2006. Shoreline Restoration in High Hazard Zones: Southeastern North Carolina, USA. Journal of Coastal Research, SI 39: 884-889.

Cleary, W.J., McLeod, M.A., Rausher, M.A., Johnston, M.J., and Riggs, S.R. 2001. Beach Nourishment on Hurricane Impacted Barriers in Southeastern North Carolina, USA: Targeting Shoreface and Tidal Inlet Sand Resources. Journal of Coastal Research, SI 34: 232-255.

Coburn, A.S. 2011. A Fiscal Analysis of Shifting Inlets and Terminal Groins in North Carolina. Available online at http://coastalcare.org/2011/01/a-fiscal-analysis-of-shifting-inlets-andterminal-groins-in-north-carolina/.

Colosio, F., Abbiati, M., and Airoldi, L. 2007. Effects of Beach Nourishment on Sediments and Benthic Assemblages. Marine Pollution Bulletin, 54: 1197-1206.

Convertino, M., Donoghue, J.F., Chu-Agor, M.L., Kiker, G.A., Muñoz-Carpena, R., Fischer, R.A., and Linkov, I. 2011. Anthropogenic Renourishment Feedback on Shorebirds: A Multispecies Bayesian Perspective. Ecological Engineering, 37: 1184-1194.

Cook, E.D. 2013. Barrier Island Response to Sea Level Rise in North Carolina. [M.S. thesis]: Miami, Florida, Florida International University, 68 p.

Cooke, B.C., Jones, A.R., Goodwin, I.D., and Bishop, M.J. 2010. Nourishment Practices on Australian Sandy Beaches: A Review. Journal of Environmental Management, 113: 319-327.

Cooper, J.A.G. and Pilkey, O.H. 2012. Pitfalls of Shoreline Stabilization, Selected Case Studies. Coastal Research Libary 3, Springer, Netherlands, 333 p.

Crain, D.A., Bolton, A.B., and Bjorndal, K.A. 1995. Effects of Beach Renourishment on Sea Turtles: Review and Research Initiatives. Restoration Ecology, 3: 95-104.

Culver, S.J., Ames, D.V., Reide Corbett, D., Mallison, D.J., Riggs, S.R., Smith, C.G., and Vance, D.J. 2006. Foraminiferal and Sedimentary Record of Late Holocene Barrier Island Evolution, Pea Island, North Carolina: the Role of Storm Overwash, Inlet Processes, and Anthropogenic Modification. Journal of Coastal Research, 22(4): 836-846.

Culver, S.J., Grand Pre, C.A., Mallinson, D.J., Riggs, S.R., Corbett, D.R., Foley, J., Male, M., Ricardo, J., Rosenberger, J., Smith, C.G., Smith, C.W., Snyder, S.W., Twamley, D., Farrell, K., and Horton, B.P. 2007. Late Holocene Barrier Island Collapse: Outer Banks, North Carolina, U.S.A. The Sedimentary Record, 5(4): 4-8.

Cyrus, D.P. and Blaber, S.J.M. 1987. The Influence of Turbidity on Juvenile Marine Fishes in Estuaries. Part 1. Field Studies at Lake St. Lucia on the Southeastern Coast of Africa. Journal of Experimental Marine Biology and Ecology, 109: 53-70.

Cyrus, D.P. and Blaber, S.J.M. 1987. The Influence of Turbidity on Juvenile Marine Fishes in Estuaries. Part 2. Laboratory Studies, Comparisons with Field Data and Conclusions. Journal of Experimental Marine Biology and Ecology, 109: 71-90.

Dean, R.G. 1986. Coastal Armoring: Effects, Principles and Mitigation. Proceedings of the 20th International Conference on Coastal Engineering, American Society of Civil Engineers: New York, 1843-1857.

Dean, R.G. 1993. Terminal Structures at Ends of Littoral Systems. Journal of Coastal Research, SI 18: 195-210.

Deaton, A.S., Chappell, W.S., Hart, K., O'Neal, J., and Boutin, B. 2010. North Carolina Coastal Habitat Protection Plan. North Carolina Department of Environment and Natural Resources. Division of Marine Fisheries, NC. 639 p.

Defeo, O. and de Alava, A. 1995. Effects of Human Activities on Long-term Trends in Sandy Beach Populations: The Wedge Clam *Donax hanleyanus* in Uruguay. Marine Ecology Progress Series, 123: 73-82.

Defeo, O., McLachlan, A., Schoeman, D.S., Schlacher, T.A., Dugan, J., Jones, A., Lastra, M., and Scapini, F. 2009. Threats to Sandy Beach Ecosystems: A Review. Estuarine, Coastal and Shelf Science, 81: 1-12.

Denison, P.S. 1998. Beach Nourishment/Groin Field Construction Project: Bald Head Island, North Carolina. Shore and Beach, 66(1): 2-10.

Dolan, R., Godfrey, P.J., and Odum, W.E. 1973. Man's Impact on the Barrier Islands of North Carolina. American Scientist, 61: 152-162.

Dolan, R., Fenster, M.S., and Holmes, S.J. 1991. Temporal Analysis of Shoreline Recession and Accretion. Journal of Coastal Research, 7(3): 723-744.

Dolan, R. and Stewart, D. 2006. A Concept for Reducing Ecological Impacts of Beach Nourishment and Tidal Inlet Bypassing. Shore and Beach, 74(1): 28-31.

Dolan, R., Donogue, C., and Stewart, D. 2006. Long-term Impacts of Tidal Inlet Bypassing on the Swash Zone Filter Feeder *Emerita talpoida* Oregon Inlet and Pea Island, North Carolina. Shore and Beach, 74(1): 23-27.

Doughty, S.D. 2006. The Influence of Inlet Modifications, Geologic Framework, and Storms on the Recent Evolution of Masonboro Island, NC. [M.S. thesis]: Wilmington, North Carolina, University of North Carolina Wilmington, 149 p.

Doughty, S.D., Cleary, W.J., and McGinnis, B.A. 2006. The Recent Evolution of Storm-Influenced Retrograding Barriers in Southeastern North Carolina, USA. Journal of Coastal Research, SI 39: 122-126.

Douglass, S.L. 1991. Simple Conceptual Explanation of Down-Drift Offset Inlets. Journal of Waterway, Port, Coastal, and Ocean Engineering, 117(2): 136-142.

Dugan, J.E. and Hubbard, D.M. 2006. Ecological Responses to Coastal Armoring on Exposed Sandy Beaches. Shore and Beach, 74(1): 10-16.

Dugan, J.E., Hubbard, D.M., Rodil, I.F., Revell, D.L., and Schroeter, S. 2008. Ecological Effects of Coastal Armoring on Sandy Beaches. Marine Ecology, 29(Suppl. 1): 160-170.

Edwards, S.F. and Gable, F.J. 1991. Estimating the Value of Beach Recreation from Property Values: An Exploration with Comparisons to Nourishment Costs. Ocean & Shoreline Management, 15: 37-55.

Ells, K. and Murray, A.B. 2012. Long-term, Non-local Coastline Responses to Local Shoreline Stabilization. Geophysical Research Letters, 39: L19401.

Evans, P.R., Ward, R.M., Bone, M., and Leakey, M. 1998. Creation of Temperate-Climate Intertidal Mudflats: Factors Affecting Colonization and Use by Benthic Invertebrates and their Bird Predators. Marine Pollution Bulletin, 37: 535-545.

Fenster, M. and Dolan, R. 1996. Assessing the Impact of Tidal Inlets on Adjacent Barrier Island Shorelines. Journal of Coastal Research, 12(1): 294-310.

Fisher, J.S., Overton, M.F., and Jarrett, T. 2004. Pea Island Shoreline: 100-Year Assessment. Raleigh, North Carolina, FDH Engineering, Inc. for North Carolina Department of Transportation, 18 p.

Fitzgerald, D.M. 1988. Shoreline Erosional-Depositional Processes Associated with Tidal Inlets. Lecture Notes on Coastal and Estuarine Studies, 29: 186-225.

Fitzgerald, D.M. and Hayes, M.O. 1980. Tidal Inlet Effects on Barrier Island Management. Coastal Zone 1980, American Society of Civil Engineers: New York, 2355-2379.

Fletemeyer, J. 1983. The Impact of Beach Nourishment on Sea Turtle Nesting. The New Threat to Beach Preservation: Papers Presented at the 1983 Joint Annual Meeting of the American Shore & Beach Preservation Association and Florida Shore & Beach Preservation Association, Boca Raton, FL, 168-177.

Flynn, B. 1992. Beach Nourishment, Sea Turtle Nesting, and Nest Relocation in Dade County, Florida. New directions in Beach Management: Proceedings of the 5th Annual National Conference on Beach Preservation Technology, St. Petersburg, Florida, 381-394.

French, P.W. 2001. Coastal Defences: Processes, Problems and Solutions. Routledge, London, 388 p.

Galgano, F.A., Jr. 2004. Long-term Effectiveness of a Groin and Beach Fill System: A Case Study Using Shoreline Change Maps. Journal of Coastal Research, SI 33: 3-18.

Gomez-Pina, G. 2004. The Importance of Aesthetic Aspects in the Design of Coastal Groins. Journal of Coastal Research, SI 33: 83-98.

Gopalakrishnan, S., Smith, M.D., Slott, J.M., and Murray, A.B. 2011. The Value of Disappearing Beaches: A Hedonic Pricing Model with Endogenous Beach Width. Journal of Environmental Economics and Management, 61: 297-310.

Gorzelany, J.F. and Nelson, W.G. 1987. The Effects of Beach Replenishment on the Benthos of a Sub-tropical Florida Beach. Marine Environmental Research, 21: 75-94.

Greene, K. 2002. Beach Nourishment: A Review of the Biological and Physical Impacts.

Washington (DC): Atlantic States Marine Fisheries Commission. ASMFC Habitat Management Series No. 7, 174 p.

Griffin, D.B., Murphy, S.R., Frick, M.G., Broderick, A.C., Coker, J.W., Coyne, M.S., Dodd, M.G., Godfrey, M.H., Godley, B.J., Hawkes, L.A., Murphy, T.M., Williams, K.L., and Witt, M.J. 2013. Foraging Habitats and Migration Corridors Utilized by a Recovering Subpopulation of Adult Female Loggerhead Sea Turtles: Implications for Conservation. Marine Biology, 160: 3071-3086.

Griggs, G.B. 2004. Headlands and Groins: Replicating Natural Systems. Journal of Coastal Research, SI 33: 280-293.

Griggs, G.B. 2005. The Impacts of Coastal Armoring. Shore and Beach, 73: 13-22.

Grippo, M.A., Cooper, S., and Massey, A.G. 2007. Effect of Beach Replenishment Projects on Waterbird and Shorebird Communities. Journal of Coastal Research, 23(5): 1088-1096.

Hackney, C.T., Posey, M.H., Ross, S.W., and Norris, A.R. 1996. A Review and Synthesis of Data on Surf Zone Fishes and Invertebrates in the South Atlantic Bight and the Potential Impacts from Beach Nourishment. Prepared for U.S. Army Corps of Engineers, Wilmington District, Wilmington, NC, 111 p.

Hall, M.J. and Pilkey, O.H. 1991. Effects of Hard Stabilization on Dry Beach Width for New Jersey. Journal of Coastal Research, 7(3): 771-785.

Hanson, H. and Larson, M. 2004. Wave Directional Characteristics as a Design Parameter for Groin Performance. Journal of Coastal Research, SI 33: 188-197.

Hay, M.E. and Sutherland, J.P. 1988. The Ecology of Rubble Structures of the South Atlantic Bight: A Community Profile. U.S. Fish and Wildlife Service Biological Report 85(7.20), 67 p.

Hayden, B. and Dolan, R. 1974. Impact of Beach Nourishment on Distribution of *Emerita talpoida*, the Common Mole Crab. Journal of the Waterways, Harbors and Coastal Engineering Division, 100: 123-132.

Hayes, M.O. 1980. General Morphology and Sediment Patterns in Tidal Inlets. Sedimentary Geology, 26: 139-156.

Hayes, M.O. and FitzGerald, D.M. 2013. Origin, Evolution, and Classification of Tidal Inlets. Journal of Coastal Research, SI 69: 14-33.

Hettler, W.F., Jr., and Barker, D.L. 1993. Distribution and Abundance of Larval Fishes at Two North Carolina Inlets. Estuarine, Coastal and Shelf Science, 37: 161-179.

Hettler, W.F., Jr. and Chester, A.J. 1990. Temporal Distribution of Ichthyoplankton Near

Beaufort Inlet, North Carolina. Marine Ecology Progress Series, 68: 157-168.

Hoagland, P., Jin, D., and Kite-Powell, H.L. 2012. The Costs of Beach Replenishment along the U.S. Atlantic Coast. Journal of Coastal Research, 28(1A): 199-204.

Houston, J.R. 1988. Eroding Shorelines Impose Costly Choices. Geotimes, 33(5): 9-14.

Inman, D.L. and Dolan, R. 1989. The Outer Banks of North Carolina: Budget of Sediment and Inlet Dynamics along a Migrating Barrier System. Journal of Coastal Research, 5(2): 193-237.

Jackson, C.W., Cleary, W.J., and Knierim, A.C. 2006. Management and Erosion Mitigation Issues Related to Ebb Channel Repositioning: Rich inlet, North Carolina, USA. Journal of Coastal Research, SI 39: 1008-1012.

Jaramillo, E., Contreras, H., and Bollinger, A. 2002. Beach and Faunal Response to the Construction of a Seawall in a Sandy Beach of South Central Chile. Journal of Coastal Research, 18(3): 523-529.

Jaramillo, E., Croker, R.A., and Hatfield, E.B. 1987. Long-term Structure, Disturbance, and Recolonization of Macroinfauna in a New Hampshire sand beach. Canadian Journal of Zoology, 65: 3024-3031.

Johnsen, C.D., Cleary, W.J., Freeman, C.W., and Sault, M. 1999. Inlet Induced Shoreline Changes on the High Energy Flank of the Cape Fear Foreland, NC. Coastal Sediments '99, American Society of Civil Engineers: New York, 1402-1417.

Joyner, B.P., Overton, M.F., and Fisher, J.S. 1998. Post-stabilization Morphology of Oregon Inlet, NC. Coastal Zone 1998, American Society of Civil Engineers: New York, 3124-3137.

Kana, T.W., Mason, J.E., and Williams, M.L. 1987. A Sediment Budget for a Relocated Inlet. Coastal Sediments '87, American Society of Civil Engineers: New York, 2094-2109.

Kana, T.W., White, T.E., and McKee, P.A. 2004. Management and Engineering Guidelines for Groin Rehabilitation. Journal of Coastal Research, SI 33: 57-82.

Kaplan, E.H., Welker, J.R., and Kraus, M.G. 1974. Some Effects of Dredging on Populations of Macrobenthic Organisms. Fishery Bulletin, 72(2): 445-480.

Kisiel, C.L. 2009. The Spatial and Temporal Distribution of Piping Plovers in New Jersey: 1987-2007. [M.S. thesis]: New Brunswick, New Jersey, The State University of New Jersey, Rutgers, 75 p.

Kisiel, C.L. 2009. The Role of Inlets in Piping Plover Nest Site Selection in New Jersey 1987-2007. New Jersey Birds, 35(3): 45-52.

Knapp, K. 2012. Impacts of Terminal Groins on North Carolina's Coasts [M.E.M. thesis]: Durham, North Carolina, Duke University, 49 p.

Knierim, A.C. 2003. A Hydrographic Investigation of a Mixed Energy Inlet: Rich Inlet, North Carolina. [M.S. thesis]: Wilmington, North Carolina, University of North Carolina Wilmington, 52 p.

Knierim, A.C. and Cleary, W.J. 2003. A Hydrographic Investigation of a Wave-Influenced Mixed Energy Inlet: Rich Inlet, North Carolina. Coastal Sediments '03, American Society of Civil Engineers: New York, 15 p.

Knott, D.M., Van Dolah, R.F., and Calder, D.R. 1984. Ecological Effects of Rubble Weir Jetty Construction at Murrells Inlet South Carolina Volume II: Changes in Macrobenthic Communities of Sandy Beach and Nearshore Environments. U.S. Army Corps of Engineers, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS, Technical Report EL-84-4, 103 p.

Komar, P.D. 1996. Tidal-Inlet Processes and Morphology Related to the Transport of Sediments. Journal of Coastal Research, SI 23: 23-45.

Komar, P.D. 1998. Beach Processes and Sedimentation. Prentice-Hall, Inc., Upper Saddle River, New Jersey, 544 p.

Kraus, N.C. 1988. The Effects of Seawalls on the Beach: An Extended Literature Review. Journal of Coastal Research, SI 4: 1-28.

Kraus, N.C. and McDougal, W.G. 1996. The Effects of Seawalls on the Beach: Part I, An Updated Literature Review. Journal of Coastal Research, 12(3): 691-701.

Kraus, N.C., Hanson, H., and Blomgren, S.H. 1994. Modern Functional Design of Groin Systems. Proceedings of the 24th International Conference on Coastal Engineering, American Society of Civil Engineers: New York, 1327-1342.

Krock, J.R. 2005. Historical Morphodynamics of John's Pass, West-Central Florida. [M.S. thesis]: Tampa, Florida, University of South Florida, 98 p.

Lamont, M.M. and Houser, C. 2014. Spatial Distribution of Loggerhead Turtle (*Caretta caretta*) Emergences along a Highly Dynamic Beach in the Northern Gulf of Mexico. Journal of Experimental Marine Biology and Ecology, 453: 98-107.

Landry, C.E. and Hindsley, P. 2011. Valuing Beach Quality with Hedonic Property Models. Land Economics, 87(1): 92-108.

Landry, C.E., Keeler, A.G., and Kriesel, W. 2003. An Economic Evaluation of Beach Erosion Management Alternatives. Marine Resource Economics, 18: 105-127.

Langfelder, J., French, T., McDonald, R., and Ledbetter, R. 1974. A Historical Review of Some of North Carolina's Coastal Inlets. Center for Marine and Coastal Studies North Carolina State University, Raleigh, N.C., Report No. 74-1, 43 p.

Lankford, T.E. and Baca, B.J. 1989. Comparative Environmental Impacts of Various Forms of Beach Nourishment. Coastal Zone '89: Proceedings of the Sixth Symposium on Coastal and Ocean Management. American Society of Civil Engineers: New York, 2046-2059.

Layman, C.A. 2000. Fish Assemblage Structure of the Shallow Ocean Surf-Zone on the Eastern Shore of Virginia Barrier Islands. Estuarine, Coastal and Shelf Science, 51: 201-213.

Leber, K.M. 1982. Seasonality of Macroinvertebrates on a Temperate, High Wave Energy Sandy Beach. Bulletin of Marine Science, 32(1): 86-98.

Leewis, L., van Bodegoma, P.M., Rozema, J., and Janssen, G.M. 2012. Does Beach Nourishment have Long-term Effects on Intertidal Macroinvertebrate Species Abundance? Estuarine, Coastal and Shelf Science, 113: 172-181.

Leonard, L., Clayton, T., and Pilkey, O. 1990. An Analysis of Replenished Beach Design Parameters on U.S. East Coast Barrier Islands. Journal of Coastal Research, 6(1): 15-36.

Leonard, L.A., Dixon, K.L., and Pilkey, O.H. 1990. A Comparison of Beach Replenishment on the U.S. Atlantic, Pacific, and Gulf coasts. Journal of Coastal Research, SI 6: 127-140.

Leonard Ozan, C.R. 2011. Evaluating the Effects of Beach Nourishment on Loggerhead Sea Turtle (*Caretta caretta*) Nesting in Pinellas County, Florida. [M.S. thesis]: Tampa, Florida, University of South Florida, 60 p.

Lindeman, K.C. and Snyder, D.B. 1999. Nearshore Hardbottom Fishes of Southeast Florida and Effects of Habitat Burial Caused by Dredging. Fishery Bulletin, 97: 508-525.

Lindquist, D.G., Ogburn, M.V., Stanley, W.B., Troutman, H.L., and Pereira, S.M. 1985. Fish Utilization Patterns on Temperate Rubble-mound Jetties in North Carolina. Bulletin of Marine Science, 37(1): 244-251.

Long, T.M., Angelo, J., and Weishampel, J.F. 2011. LiDAR-derived Measures of Hurricane- and Restoration-generated Beach Morphodynamics in Relation to Sea Turtle Nesting Behaviour. International Journal of Remote Sensing, 32 (1): 231-241.

Lucrezi, S., Schlacher, T.A., and Robinson, W. 2010. Can Storms and Shore Armouring Exert Additive Effects on Sandy-Beach Habitats and Biota? Marine and Freshwater Research, 61: 951-962.

Mallinson, D.J., Culver, S.J., Riggs, S.R., Walsh, J.P., Ames, D., and Smith, C.W. 2008. Past, Present and Future Inlets of the Outer Banks Barrier Islands, North Carolina: A White Paper. East Carolina University, Greenville, North Carolina, 22 p.

Mallinson, D.J., Culver, S.J., Riggs, S.R., Thieler, E.R., Foster, D., Wehmiller, J., Farrell, K.M., and Pierson, J. 2010. Regional Seismic Stratigraphy and Controls on the Quaternary Evolution of the Cape Hatteras Region of the Atlantic Passive Margin, USA. Marine Geology, 268: 16-33.

Mallinson, D.A., Riggs, S.R., Thieler, E.R., Culver, S.J., Foster, D., Corbett, D.R., Farrell, K., and Wehmiller, J. 2005. Late Neogene Evolution of the Northeastern Coastal System: Filling the Northern Albemarle Sound. Marine Geology, 217: 97-117.

Manning, L.M. 2003. Ecology of ocean beaches: The Importance of Human Disturbances and Complex Biological Interactions within a Physically Rigorous Environment. [PhD dissertation]: Chapel Hill, North Carolina, University of North Carolina at Chapel Hill, 164 p.

Manning, L.M., Peterson, C.H., and Bishop, M.J. 2014. Dominant Macrobenthic Populations Experience Sustained Impacts from Annual Disposal of Fine Sediments on Sandy Beaches. Marine Ecology Progress Series, 508: 1-15.

Manning, L.M., Peterson, C.H., and Fegley, S.R. 2013. Degradation of Surf Fish Foraging Habitat Driven by Sedimentological Modifications Caused by Beach Nourishment. Bulletin of Marine Science, 89: 83-106.

Marsh, G.A. and Turbeville, D.B. 1981. The Environmental Impact of Beach Nourishment: Two Studies in Southeastern Florida. Shore and Beach, 49(3): 40-44.

Martin, D., Bertasi, F., Colangelo, M.A., de Vries, M., Frost, M., Hawkins, S.J., Macpherson, E., Moschella, P.S., Satta, M.P., Thompson, R.C., and Ceccherelli, V.U. 2005. Ecological Impact of Coastal Defence Structures on Sediment and Mobile Fauna: Evaluating and Forecasting Consequences of Unavoidable Modifications of Native Habitats. Coastal Engineering, 52: 1027-1051.

Maslo, B., Handel, S.N., and Pover, T. 2011. Restoring Beaches for Atlantic Coast Piping Plovers (*Charadrius melodus*): A Classification and Regression Tree Analysis of Nest-Site Selection. Restoration Ecology, 19(201): 194-203.

Maurer, D., Keck, R.T., Tinsman, J.C., and Leathem, W.A. 1981. Vertical Migration and Mortality of Benthos in Dredged Material: Part I- Mollusca. Marine Environmental Research, 4: 299-319.

Maurer, D., Keck, R.T., Tinsman, J.C., and Leathem, W.A. 1981. Vertical Migration and Mortality of Benthos in Dredged Material: Part II- Crustacea. Marine Environmental Research, 5: 301-317.

Maurer, D., Keck, R.T., Tinsman, J.C., and Leathem, W.A. 1982. Vertical Migration and

Mortality of Benthos in Dredged Material: Part III- Polychaeta. Marine Environmental Research, 6: 49-68.

Maurer, D., Keck, R.T., Tinsman, J.C., and Leathem, W.A., Wethe, C., Lord, C., and Church, T.M. 1986. Vertical Migration and Mortality of Marine Benthos in Dredged Material: A Synthesis. International Review of Hydrobiology, 71(1): 49-63.

McDougall, W.G., Sturtevant, M.A., and Komar, P.D. 1987. Laboratory and Field Investigations of the Impact of Shoreline Stabilization Structures on Adjacent Properties. Coastal Sediments '87, American Society of Civil Engineers: New York, 961-973.

McGinnis, B.A. 2004. Late Holocene Evolution of a Retrograding Barrier: Hutaff Island, North Carolina. [M.S. thesis]: Wilmington, North Carolina, University of North Carolina Wilmington, 92 p.

McLachlan, A. 1996. Physical Factors in Benthic Ecology: Effects of Changing Sand Particle Size on Beach Fauna. Marine Ecology Progress Series, 131: 205-217.

McLean, M.R.W. 2009. Effects of Inlet Migration on Barrier Island Planform and Oceanfront Change: New Topsail Inlet, N.C. [M.S. thesis]: Wilmington, North Carolina, University of North Carolina Wilmington, 127 p.

McNamara, D.E., Murray, A.B., and Smith, M.D. 2011. Coastal Sustainability Depends on how Economic and Coastline Responses to Climate Change Affect Each Other. Geophysical Research Letters, 38: L07401.

McNamara, D.E., Gopalakrishnan, S., Smith, M.D., and Murray, A.B. 2015. Climate Adaptation and Policy-Induced Inflation of Coastal Property Value. PLoS ONE, 10(3): e0121278.

McQuarrie, M. and Pilkey, O.H. 1998. Evaluation of Alternative or Non-Traditional Devices for Shoreline Stabilization. Journal of Coastal Research, SI 26: 269-272.

Miller, H.C., William A. Dennis, W.A., and Wutkowski, M.J. 1996. A Unique Look at Oregon Inlet, NC USA. Proceedings of the 25th Conference on Coastal Engineering, American Society of Civil Engineers: New York, 25: 4517-4530.

Moffatt & Nichol. 2010. Terminal Groin Study: Final Report. Raleigh, North Carolina, 450 p., 5 Append.

Mohanty, P.K., Patra, S.K., Bramha, S., Seth, B., Pradhan, U., Behera, B., Mishra, P., and Panda, U.S. 2012. Impact of Groins on Beach Morphology: A Case Study Near Gopalpur Port, East Coast of India. Journal of Coastal Research, 28(1): 132-142.

Montague, C.L. 1993. Ecological Engineering of Inlets in Southeastern Florida: Design Criteria for Sea Turtle Nesting Beaches. Journal of Coastal Research, SI 18: 267-276.

Montague, C.L. 2008. Recovering the Sand Deficit from a Century of Dredging and Jetties along Florida's Atlantic Coast: A Reevaluation of Beach Nourishment as an Essential Tool for Ecological Conservation. Journal of Coastal Research, 24(4): 899-916.

Morton, R.A. 2003. An overview of coastal land loss: With emphasis on the southeastern United States. USGS Open File Report 03-337. U.S. Geological Survey Center for Coastal and Watershed Studies, St. Petersburg, FL, Available at <http://pubs.usgs.gov/of/2003/of03-337/pdf.html>.

Morton, R.A., T.L. Miller, and L.J. Moore. 2004. National assessment of shoreline change: Part 1: Historical shoreline changes and associated coastal land loss along the U.S. Gulf of Mexico. Open-file report 2004-1043. U.S. Geological Survey Center for Coastal and Watershed Studies, St. Petersburg, FL, Available at <http://pubs.usgs.gov/of/2004/1043/>.

Mosier, A.E. 1998. The Impact of Coastal Armoring Structures on Sea Turtle Nesting Behavior at Three Beaches on the East Coast of Florida. M.S. Thesis. St. Petersburg, Florida, University of South Florida. 112 p.

Nascimentot, L. and Lavenere-Wanderley, A.A. 2006. Effect of Shore Protection Structures (Groins) on Sao Miguel Beach, Ilheus Bahia Brazil. Journal of Coastal Research, SI 39: 858-862.

National Marine Fisheries Service [NMFS] and U.S. Fish and Wildlife Service [USFWS]. 1991. Recovery Plan for U.S. Population of Loggerhead Turtle. National Marine Fisheries Service, Washington, D.C. 64 p.

Naylor, E. and Kennedy, F. 2003. Ontogeny of Behavioural Adaptations in Beach Crustaceans: Some Temporal Considerations for Integrated Coastal Zone Management and Conservation. Estuarine, Coastal and Shelf Science, 58S: 169-175.

Nel, R., Campbell, E.E., Harris, L., Hauser, L., Schoeman, D.S., McLachlan, A., du Preez, D.R., Bezuidenhout, K., and Schlacher, T.A. 2014. The Status of Sandy Beach Science: Past Trends, Progress, and Possible Futures. Estuarine, Coastal and Shelf Science, 150: 1-10.

Nelson, W.G. 1988. An Overview of the Effects of Beach Nourishment on the Sand Beach Fauna. *In:* Tait, L.S. (editor), Beach Preservation Technology 88. Problems and Advancements in Beach Nourishment. Florida Shore and Beach Preservation Association, Tallahassee, Florida: 295-310.

Nelson, W.G. 1993. Beach Restoration in the Southeastern US: Environmental Effects and Biological Monitoring. Ocean & Coastal Management, 19: 157-182.

Nelson, W.G. 1993. Beach-inlet Ecosystems of Southeastern Florida: A Review of Ecological Research Needs and Management Issues. Journal of Coastal Research, SI 18: 257-266.

Nordstrom, K.F. 2000. Beaches and Dunes of Developed Coasts. Cambridge University Press, Cambridge, UK, 338 p.

Nordstrom, K.F., Allen, J.R., and Gares, P.A. 1979. The Effect of Groin Removal on Shoreline Stability. Coastal Structures '79, American Society of Civil Engineers: New York, 904-920.

North Carolina Department of Environment and Natural Resources (NCDENR). 2011. North Carolina Beach and Inlet Management Plan (BIMP) Final Report. Raleigh, N.C., 1005 p.

North Carolina Department of Transportation (NCDOT). 1989. Environmental Assessment and Finding of No Significant Impact, Construction of a Terminal Groin and Revetment at Pea Island, Protection of the Herbert C. Bonner Bridge and North Carolina Highway 12 Dare County, North Carolina, 97 p.

Overton, M.F., Fisher, J.S., Dennis, W.A., and Miller, H.C. 1992. Shoreline Change at Oregon Inlet Terminal Groin. Proceedings of the 23rd International Conference on Coastal Engineering, American Society of Civil Engineers: New York, 2332-2343.

Park, J.-Y. and Wells, J.T. 2005. Longshore Transport at Cape Lookout, North Carolina: Shoal Evolution and the Regional Sediment Budget. Journal of Coastal Research, 21(1): 1-17.

Park, J.-Y. and Wells, J.T. 2007. Spit Growth and Downdrift Erosion: Results of Longshore Transport Modeling and Morphologic Analysis at the Cape Lookout Cuspate Foreland. Journal of Coastal Research, 23(3): 553-568.

Parsons, J.R. and M. Powell. 2001. Measuring the Cost of Beach Retreat. Coastal Management, 29: 91-103.

Pereira da Silva, C. 2006. Landscape Perception and Coastal Management: A Methodology to Encourage Public Participation. Journal of Coastal Research, SI 39: 930-934.

Peterson, C.H. 1985. Patterns of Lagoonal Bivalve Mortality after Heavy Sedimentation and Their Paleoecological Significance. Paleobiology, 11(2): 139-153.

Peterson, C.H. and Bishop, M.J. 2005. Assessing the Environmental Impacts of Beach Nourishment. BioScience, 55: 887-896.

Peterson, C.H. and Manning, L. 2001. How Beach Nourishment Affects the Habitat Value of Intertidal Beach Prey for Surf Fish and Shorebirds and Why Uncertainty Still Exists. Proceedings of the Coastal Ecosystems and Federal Activities Technical Training Symposium, Abstract, 2 p.

Peterson, C.H. and Peterson, N.M. 1979. The Ecology of Intertidal Flats of North Carolina: A Community Profile. U.S. Fish and Wildlife Service, Office of Biological Services. FWS/OBS-79/39. 73 p.

Peterson, C.H., Hickerson, D.H.M., and Johnson, G.G. 2000. Short-Term Consequences of Nourishment and Bulldozing on the Dominant Large Invertebrates of a Sandy Beach. Journal of Coastal Research, 16: 368-378.

Peterson, C.H., Summerson, H.C., Thomson, E., Lenihan, H.S., Grabowski, J., Manning, L., Micheli, F., and Johnson, G. 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., Bishop, M.J., Johnson, G.A., D'Anna, L.M., and Manning, L.M. 2006. Exploiting Beach Filling as an Unaffordable Experiment: Benthic Intertidal Impacts Propagating Upwards to Shorebirds. Journal of Experimental Marine Biology and Ecology, 338: 205-221.

Peterson, C.H., Bishop, M.J., D'Anna, L.M., and Johnson, G.A. 2014. Multi-year Persistence of Beach Habitat Degradation from Nourishment Using Coarse Shelly Sediments. Science of the Total Environment, 487: 481-492.

Pezzuto, P.R., Resgalla, Jr., C., Abreu, J.G.N., and Menezes, J.T. 2006. Environmental Impacts of the Nourishment of Balneario Camboriu Beach, SC, Brazil. Journal of Coastal Research, SI 39: 863-868.

Pietrafesa, L.J. 2012. On the Continued Cost of Upkeep Related to Groins and Jetties. Journal of Coastal Research, 28(5): iii-ix.

Pietrafesa, L.J. and Janowitz, G.S. 1988. Physical Oceanographic Processes Affecting Larval Transport around and through North Carolina Inlets. American Fisheries Society Symposium, 3: 34-50.

Pilkey, O.H. 2001. Beach nourishment: Two sides to every story. Proceedings of the Geological Society of America 50th Annual Meeting (Raleigh, North Carolina, GSA). A-8, Abstract 4295.

Pilkey, O.H. and Clayton, T.D. 1987. Beach Replenishment: The National Solution? Fifth Symposium on Coastal and Ocean Management. Coastal Zone 1987, American Society of Civil Engineers: New York, 1408-1419.

Pilkey, O.H. and Clayton, T.D. 1989. Summary of Beach Replenishment Experience on U.S. East Coast Barrier Islands. Journal of Coastal Research, 5(1): 147-159.

Pilkey, O.H. and Cooper, J.A.G. 2014. Are natural beaches facing extinction? *In:* Green, A.N. and Cooper, J.A.G. (eds.), Proceedings 13th International Coastal Symposium (Durban, South Africa) Journal of Coastal Research, SI 70: 431-436.

Pilkey, O.H. and Wright, H.L., III. 1988. Seawalls versus Beaches. Journal of Coastal Research, SI 4: 41-64.

Pilkey, O.H. and Dixon, K.L. 1996. The Corps and the Shore. Island Press, Washington D.C., 272 p.

Pilkey, O.H., Neal, W.J., Riggs, S.R., Webb, C.G., Bush, D.M., Pilkey, D.F., Bullock, J., and Cowan, B.A., 1998. The North Carolina Shore and Its Barrier Islands: Restless Ribbons of Sand. Duke University Press, Durham, North Carolina, 318 p.

Posey, M. and Alphin, T. 2002. Resilience and Stability in an Offshore Benthic Community: Responses to Sediment Borrow Activities and Hurricane Disturbance. Journal of Coastal Research, 18(4): 685-697.

Quammen, M.L. 1982. Influence of Subtle Substrate Differences on Feeding by Shorebirds on Intertidal Mudflats. Marine Biology, 71: 339-343.

Rakocinski, C.F., Heard, R.W., LeCroy, S.E., McLelland, J.A., and Simons, T. 1996. Responses by Macrobenthic Assemblages to Extensive Beach Restoration at Perdido Key, Florida, U.S.A. Journal of Coastal Research, 12(1): 326-353.

Reed, D.J., Hijuelos, A.C., and Fearnley, S.M. 2012. Ecological Aspects of Coastal Sediment Management in the Gulf of Mexico. Journal of Coastal Research, SI 60: 51-65.

Reilly, F.J. and Bellis, V.J. 1983. The Ecological Impact of Beach Nourishment with Dredged Materials on the Intertidal Zone at Bogue Banks, North Carolina. U.S. Army Corps of Engineers, Coastal Engineering Research Center, Misc. Rept. No. 83-3, 73 p.

Rice, E. and Cameron, S. 2008. Final Report: Bogue Inlet Waterbird Monitoring and Management 2003 -2008. Prepared for Town of Emerald Isle, NC. 31 p.

Rice, T.M. 2009. Best Management Practices for Shoreline Stabilization to Avoid and Minimize Adverse Environmental Impacts. Prepared for the USFWS, Panama City Ecological Services Field Office, 22 p.

Rice, T.M. 2012. Inventory of Habitat Modifications to Tidal Inlets in the Coastal Migration and Wintering Range of the Piping Plover (*Charadrius melodus*). Appendix 1B *in* Draft Comprehensive Conservation Strategy for the Piping Plover (*Charadrius melodus*) Coastal Migration and Wintering Range, U.S. Fish and Wildlife Service, 35 p.

Riggs, S.R. and Ames, D.V. 2003. Drowning of North Carolina: Sea-Level Rise and Estuarine Dynamics. NC Sea Grant College Program, Raleigh, NC, Pub. No. UNC-SG-03-04, 152 p.

Riggs, S.R. and Ames, D.V. 2007. Effect of Storms on Barrier Island Dynamics, Core Banks, Cape Lookout National Seashore, North Carolina, 1960-2001. U.S.

Geological Survey Scientific Investigations Report 2006-5309, 78 p.

Riggs, S.R. and Ames, D.V. 2009. Impact of the Oregon Inlet Terminal Groin on Downstream Beaches of Pea Island, NC Outer Banks. A White Paper. East Carolina University, Greenville, North Carolina, 19 p.

Riggs, S.R. and Ames, D.V. 2011. Consequences of Human Modifications of Oregon Inlet to the Down-drift Pea Island, North Carolina Outer Banks. Southeastern Geology, 48(3): 103-128.

Riggs, S.R., Ames, D.V., Culver, S.J., Mallinson, D.J., Corbett, D.R., and Walsh, J.P. 2009. Eye of a human hurricane: Pea Island, Oregon Inlet, and Bodie Island, northern Outer Banks, North Carolina, *in* Kelley, J.T., Pilkey, O.H., and Cooper, J.A.G., eds., America's Most Vulnerable Coastal Communities: Geological Society of America Special Paper 460: 43-72.

Riggs, S.R., Cleary, W.J., and Snyder, S.W. 1995. Influence of Inherited Geologic Framework on Barrier Shoreface Morphology and Dynamics. Marine Geology, 126: 213-234.

Riggs, S.R., Culver, S.J., Ames, D.V., Mallinson, D.J., Corbett, D.R., and Walsh, J.P. 2008. North Carolina's Coasts in Crisis: A Vision for the Future. A White Paper. East Carolina University, Greenville, North Carolina, 28 p.

Rizkalla, C.E. and Savage, A. 2011. Impact of Seawalls on Loggerhead Sea Turtle *(Caretta caretta)* Nesting and Hatching Success. Journal of Coastal Research, 27(1): 166-173.

Rocha, M.V.L., Coelho, C., and Fortes, C.J.E.M. 2013. Numerical Modeling of Groin Impact on Nearshore Hydrodynamics. Ocean Engineering, 74: 260-275.

Ross, S.W. and Lancaster, J.E. 2002. Movements and Site Fidelity of Two Juvenile Fish Species Using Surf Zone Nursery Habitats along the Southeastern North Carolina Coast. Environmental Biology of Fishes, 63: 161-172.

Rumbold, D.G., Davis, P.W., and Perretta, C. 2001. Estimating the Effect of Beach Nourishment on *Caretta caretta* (Loggerhead Sea Turtle) Nesting. Restoration Ecology, 9(3): 304-310.

Sampaio, L.C. 2011. A Comparison of Inlet-Induced Geomorphic Changes Related to Unmodified Inlets along a Sand Rich Coastal System. [M.S. thesis]: Wilmington, North Carolina, University of North Carolina Wilmington, 130 p.

Schlacher, T.A., Noriega, R., Jones, A., and Dye, T. 2012. The Effects of Beach Nourishment on Benthic Invertebrates in Eastern Australia: Impacts and Variable Recovery. Science of the Total Environment, 435-436: 411-417.

Schlacher, T.A., Dugan, J., Schoeman, D.S., Lastra, M., Jones, A., Scapini, F., McLachlan, A., and Defeo, O. 2007. Sandy Beaches at the Brink. Diversity and Distributions, 13: 556-560.

Schlacher, T.A., Weston, M.A., Schoeman, D.S., Olds, A.D., Huijbers, C.M., and Connolly, R.M. 2015. Golden Opportunities: A Horizon Scan to Expand Sandy Beach Ecology. Estuarine, Coastal and Shelf Science, 157: 1-6.

Schwartz, R.K. and Birkemeier, W.A. 2004. Sedimentology and Morphodynamics of a Barrier Island Shoreface Related to Engineering Concerns, Outer Banks, NC, USA. Marine Geology, 211: 215-255.

Scyphers, S.B., Picou, J.S., and Powers, S.P. 2015. Participatory Conservation of Coastal Habitats: The Importance of Understanding Homeowner Decision Making to Mitigate Cascading Shoreline Degradation. Conservation Letters, 8(1): 41–49.

Smith, C.G., Culver, S.J., Riggs, S.R., Ames, D., Corbett, D.R., and Mallinson, D. 2008. Geospatial Analysis of Barrier Island Width of Two Segments of the Outer Banks, North Carolina, USA: Anthropogenic Curtailment of Natural Self-sustaining Processes. Journal of Coastal Research, 24(1): 70-83.

Smith, M.D., Slott, J.M., McNamara, D., and Murray, A.B. 2009. Beach Nourishment as a Dynamic Capital Accumulation Problem. Journal of Environmental Economics and Management, 58: 58-71.

South Atlantic Fishery Management Council (SAMFC). 2014. Policies for the Protection and Restoration of Essential Fish Habitats from Beach Dredging and Filling and Large-scale Coastal Engineering. South Atlantic Fishery Management Council, Charleston, South Carolina, 7 p.

Speybroeck, J., Bonte, D., Courtens, W., Gheskiere, T., Grootaert, P., Maelfait, J., Mathys, M., Provoost, S., Sabbe, K., Stienen, E., VanLancker, V., Vincx, M., and Degraer, S. 2006. Beach Nourishment: An Ecologically Sound Coastal Defence Alternative? A Review. Aquatic Conservation: Marine and Freshwater Ecosystems, 16: 419-435.

Steinitz, M.J., Salmon, M., and Wyneken, J. 1998. Beach Renourishment and Loggerhead Turtle Reproduction: A Seven Year Study at Jupiter Island, Florida. Journal of Coastal Research, 14(3): 1000-1013.

Taylor, J.C., Miller, J.M., Pietrafesa, L.J., Dickey, D.A., and Ross, S.W. 2010. Winter Winds and River Discharge Determine Juvenile Southern Flounder (*Paralichthys lethostigma*) Recruitment and Distribution in North Carolina Estuaries. Journal of Sea Research, 64: 15-25.

Taylor, J.C., Mitchell, W.A., Buckel, J.A., Walsh, H.J., Shertzer, K.W., Martin, G.B. and Hare, J.A. 2009. Relationships between Larval and Juvenile Abundance of Winter-Spawned Fishes in North Carolina, USA. Marine and Coastal Fisheries: Dynamics, Management, and Ecosystem Science, 1: 12-21.

Theuerkauf, E.J. and Rodriguez, A.B. 2014. Evaluating Proxies for Estimating Subaerial Beach Volume Change across Increasing Time Scales and Various Morphologies. Earth Surface Processes and Landforms, 39: 593-604.

Thieler, E.R., Brill, A.L., William J. Cleary, W.J., Hobbs, C.H., III, and Gammisch, R.A. 1995. Geology of the Wrightsville Beach, North Carolina Shoreface: Implications for the Concept of Shoreface Profile of Equilibrium. Marine Geology, 126: 271-287.

Thrush, S.F., Hewitt, J.E., Norkko, A., Cummings, V.J., and Funnell, G.A. 2003. Macrobenthic Recovery Processes Following Catastrophic Sedimentation on Estuarine Sandflats. Ecological Applications, 13(5): 1433-1455.

Traynum, S.B., Kana, T.W., and Simms, D.R. 2010. Construction and Performance of Six Template Groins at Hunting Island, South Carolina. Shore and Beach, 78(3): 1-12.

Trembanis, A.C., Valverde, H.R., and Pilkey, O.H. 1998. Comparison of Beach Nourishment Along the U.S. Atlantic, Great Lakes, Gulf of Mexico and New England Shorelines. Journal of Coastal Research, SI 26: 246-251.

U.S. Army Corps of Engineers [USACE]. 2002. Coastal engineering manual. Engineer manual 1110-2-1100. USACE, Washington, DC, Available at <http://chl.erdc.usace.army.mil/cem>.

Vallianos, L. 1975. A Recent History of Masonboro Inlet, North Carolina. *In:* Cronin, L.E. (ed.) Estuarine Research, Volume II: Geology and Engineering. New York: Academic Press, 151-166.

Valverde, H.R. and Pilkey, O.H. 1996. Shoreline Stabilization in Onslow Bay. *In:* Environmental Coastal Geology: Cape Lookout to Cape Fear, NC. Cleary, W.J., (ed), Carolina Geological Society Field Guidebook, 59-63.

Valverde, H.R., Trembanis, C., and Pilkey, O.H. 1999. Summary of Beach Nourishment Episodes on the U.S. East Coast Barrier Islands. Journal of Coastal Research, 15(4): 1100-1118.

Van Dolah, R.F., Calder, D.R., and Knott, D.M. 1984. Effects of Dredging and Open-Water Disposal on Benthic Macroinvertebrates in a South Carolina Estuary. Estuaries, 7(1): 28-37.

Van Dolah, R.F., Wendt, P.H., Wenner, C.A., Martore, R.M., Sedberry, G.R., and Moore, C.J. 1987. Ecological Effects of Rubble Weir Jetty Construction at Murrells Inlet South Carolina Volume III: Community Structure and Habitat Utilization of Fishes and Decapods Associated with the Jetties. U.S. Army Corps of Engineers, U.S. Army

Engineer Waterways Experiment Station, Vicksburg, MS, Technical Report EL-84-4, 164 p.

Van Dusen, B.M., Fegley, S.R., Peterson, C.H. 2012. Prey Distribution, Physical Habitat Features, and Guild Traits Interact to Produce Contrasting Shorebird Assemblages among Foraging Patches. PLoS ONE, 7(12): e52694.

van Rijn, L.C. 2011. Coastal Erosion and Control. Ocean & Coastal Management, 54: 867-887.

Van Tomme, J., Eede, S.V., Speybroeck, J., Degraer, S., and Vincx, M. 2013. Macrofaunal Sediment Selectivity Considerations for Beach Nourishment Programmes. Marine Environmental Research, 84: 10-16.

Viola, S.M., Hubbard, D.M., Dugan, J.E., and Schooler, N.K. 2014. Burrowing Inhibition by Fine Textured Beach Fill: Implications for Recovery of Beach Ecosystems. Estuarine, Coastal and Shelf Science, 150: 142-148.

Walker, R., Rudolph, G., and Rogers, S. 2011. Fort Macon Terminal Groin, Beaufort Inlet, North Carolina. Shore and Beach, 78(4): 75-83.

Warrick, J.A. 2013. Dispersal of Fine Sediment in Nearshore Coastal Waters. Journal of Coastal Research, 29(3): 579-596.

Welsh, J.M. 2004. Characterization of the Evolution of a Relocated Tidal Inlet: Mason Inlet, North Carolina. [M.S. thesis]: Wilmington, North Carolina, University of North Carolina Wilmington, 99 p.

Wilber, D.H. and Clarke, D.G. 2001. Biological Effects of Suspended Sediments: A Review of Suspended Sediment Impacts on Fish and Shellfish with Relation to Dredging Activities in Estuaries. North American Journal of Fisheries Management, 21: 855-875.

Wilber, D.H. and Clarke, D.G. 2007. Defining and Assessing Benthic Recovery Following Dredging and Dredged Material Disposal. WODCON XVIII Conference, Lake Buena Vista, FL. 603-618.

Wilber, D.H., Clarke, D.G., Ray, G.L., and M. Burlas, L. 2003. Response of Surf Zone Fish to Beach Nourishment Operations on the Northern Coast of New Jersey, USA. Marine Ecology Progress Series, 250: 231-246.

Williams, S.J. and Gutierrez, B.T. 2009. Sea-level Rise and Coastal Change: Causes and Implications for the Future of Coasts and Low-lying Regions. Shore and Beach, 77(4): 13-21.

Williams, S.J., Dodd, K., and Gohn, K.K. 1991. Coasts in Crisis. Department of the Interior, U.S. Geological Survey Circular 1075, Washington, D.C.: United States Government Printing Office, 32 p.

Witherington, B., Hirama, S., and Mosier, A. 2011. Sea Turtle Responses to Barriers on Their Nesting Beach. Journal of Experimental Marine Biology and Ecology, 401: 1-6.

Wood, D.W. and Bjorndal, K.A. 2000. Relation of Temperature, Moisture, Salinity, and Slope to Nest Site Selection in Loggerhead Sea Turtles. Copeia, 1: 119-128.

NATIONAL AUDUBON SOCIETY

Impacts of Shoreline Hardening on Coastal Birds, other Wildlife, and their Habitats

A Literature Review with Abstracts

Prepared by Tara McIver

8/20/2015

Audubon
NORTH CAROLINA

Able, K.W., Wilber, D.H., Muzeni-Corino, A., and Clarke, D.G. 2010. Spring and Summer Larval Fish Assemblages in the Surf Zone and Nearshore off Northern New Jersey, USA. Estuaries and Coasts, 33: 211-222.

Larval fish use of surf zone and nearshore habitats at northern latitudes has received little attention. Consequently, potential impacts of beach nourishment and other forms of disturbance are not well understood. This study, on a northwestern Atlantic coastline spanning May through July over 4 years, demonstrates that recently hatched larvae are common in both surf zone and nearshore habitats. Taxonomic compositions of surf zone and nearshore assemblages were similar to each other and those from an adjacent estuary. An influence of upwelling events was apparent in coincident changes in abundance and/or size of several species in the surf zone. Other changes over the late spring–summer transition, including buoyancy-driven flows from the Hudson River plume, demonstrate the dynamic nature of larval fish assemblages in the New York Bight area.

Airoldi, A., Abbiati, M., Beck, M.W., Hawkins, S.J., Jonsson, P.R., Martin, D., Moschella, P.S., Sundelöf, A., Thompson, R.C., and P. Åberg. 2005. An Ecological Perspective on the Deployment and Design of Low-crested and other Hard Coastal Defense Structures. Coastal Engineering, 52: 1073-1087.

Coastal areas play a crucial role in the economical, social and political development of most countries; they support diverse and productive coastal ecosystems that provide valuable goods and services. Globally flooding and coastal erosion represent serious threats along many coastlines, and will become more serious as a consequence of human-induced changes and accelerated sea-level rise. Over the past century, hard coastal defense structures have become ubiquitous features of coastal landscapes as a response to these threats. The proliferation of defense works can affect over half of the shoreline in some regions and results in dramatic changes to the coastal environment. Surprisingly little attention has been paid to the ecological consequences of coastal defense. Results from the DELOS (Environmental Design of Low Crested Coastal Defense Structures, EVK3-CT-2000-00041) project indicate that the construction of coastal defense structures will affect coastal ecosystems. The consequences can be seen on a local scale, as disruption of surrounding soft-bottom environments and introduction of new artificial hard-bottom habitats, with consequent changes to the native assemblages of the areas. Proliferation of coastal defense structures can also have critical impacts on regional species diversity, removing isolating barriers, favoring the spread of nonnative species and increasing habitat heterogeneity. Knowledge of the environmental context in which coastal defense structures are placed is fundamental to an effective management of these structures as, while there are some general consequences of such construction, many effects are site specific. Advice is provided to meet specific management goals, which include mitigating specific impacts on the environment, such as minimizing changes to surrounding sediments, spread of exotic species or growth of nuisance species, and/or enhancing specific natural resources, for example enhancing fish recruitment or promoting diverse assemblages for eco-tourism. The DELOS project points out that the downstream effects of defense structures on coastal processes and regional-scale impacts on biodiversity necessitate planning and management at a regional (large coastline) scale. To effectively understand and manage coastal defenses, environmental management goals must be clearly stated and incorporated into the planning, construction, and monitoring stages.

Alexander, R.R., Stanton, R.J., Jr., and Dodd, J.R. 1993. Influence of Sediment Grain Size on the Burrowing of Bivalves: Correlation with Distribution and Stratigraphic Persistence of Selected Neogene Clams. Palaios, 8: 289-303.

Burrowing ability of 21 species of clams from Oregon, New Jersey, and Scotland was determined in each sieved sediment ranging from fine gravel to mud in half phi increments. A burrowing rate index (BRI), which normalizes burrowing time for specimen mass, was calculated for each species in each sediment. Skewness and kurtosis of the profile of average BRI's across the range of grain sizes was used to categorize species as substrate generalists, substrate sensitive, or substrate specialists. Substrate generalists (*Anadara ovalis, Mercenaria mercenaria, Astarte sulcata, Venerupis decussata, Venus striatula, Venus casina, Mya arenaria*) burrowed slowly into a wide range of grain sizes. Burrowing rate gradually diminished in progressively coarser and finer grained sediments away from the optimum grain size, producing a platykurtic (genty arching) BRI profile. Substrate specialists (*Spisula solida, Nucula sulcata, Cardium edule, Abra alba, Cultellus pellucidus*) burrowed rapidly in a very limited range of grain sizes, but failed to burrow into either or both grain size extremes, thereby producing leptokurtic (peaked) BRI profiles. Substrate sensitive species (*Donax variabilis, D. vittatus, Tellina* (Angulus) *tenuis, Ensis directus, Clinocardium nuttalli, Protothaca staminea, Petricola pholadiformis, Macoma nasuta, Scrobicularia plana*) penetrated a wider range of grain sizes than specialists, although burrowing rates are slower at the coarse textured extreme in comparison to generalists. In San Francisco Bay and Mississippi Delta habitats, generalists (*Anadara, Mercenaria, Mya*) occur commonly in most sediment categories and show high mean percent occurrence and low coefficient of variation from the seven and eight sediment-influenced molluscan communities, respectively. Substrate specialists (*Spisula, Nucula*) and some sensitive taxa (e.g., *Petricola*) are sediment-restricted, show fidelity to one or two communities, have low mean percent occurrence, and high coefficient of variation. Substrate generalists (*Anadara trilineata, Mya arenaria*), and species transitional with generalists (*Macoma nasuta*), based on experimental data on either conspecific or congeneric individuals, show high mean percent occurrences and low coefficient of variation in the Pliocene Pecten Zone communities of the San Joaquin Formation of the Kettleman Hills, California. Generalists show stratigraphic persistence, i.e., they are found in 12- 14 of 20 successive biostratigraphic units in the Etchegoin and San Joaquin Formations, whereas specialists (*Spisula, Acila* (*Nucula*)) are never found in more than four biostratigraphic units.

Balsillie, J.H. and Berg, D.W. 1972. State of Groin Design and Effectiveness. Proceedings of the 13th International Conference on Coastal Engineering, American Society of Civil Engineers: New York, 1367-1383.

An annotated bibliography on groins, compiled by Balsillie and Bruno (1972) has provided the background for this paper. A review of functional design criteria is presented including groin length, height, spacing, permeability-adjustability, and orientation. A discussion of coastal processes and their relationship to groin design and effectiveness is also given.

Balsillie, J.H. and Bruno, R.O. 1972. Groins: An Annotated Bibliography. USACE Coastal Engineering Research Center, Miscellaneous Paper No 1-72, 249 p.

A groin is a shore protective structure built (usually perpendicular to the shore) to trap littoral drift or to retard erosion of the shore. Considering all types of shore protective structures used by coastal engineers, the groin is one of the most controversial and most difficult to design. Because the functional and structural guidelines for design are incomplete, many groin installations fail to fulfill their intended purpose. CERC supports a continuing research program devoted to gaining a better understanding of groins. This bibliography evolved from the groin research program. About 460 articles published since 1900 on groins and groin-type structures are presented in this bibliography. Annotations accompany each bibliographic entry where possible. Indexes of authors, titles, and subjects are included to aid the researcher. Unavailable literature such as foreign articles, although not annotated, are included as entries in both the annotated section and the indexes.

Basco, D.R. 2006. Seawall Impacts on Adjacent Beaches: Separating Fact from Fiction. Journal of Coastal Research, SI 39: 741-744.

The common perception in the US that seawalls "... increase erosion and destroy the beach" is examined by summarizing available field data including our own research efforts at Sandbridge, Virginia, beginning in 1990. Sand trapped behind seawalls is removed from the system, but is a relatively small fraction of the active sand volume across the entire profile to closure depth. End-of-wall or flanking effects may not be due to sand trapping but other mechanisms such as interior drainage, rip current formation, groin effect, and the seawall/adjacent beach system acting as a rocky headland/parabolic-shaped beach system. Suggestions are made for when seawalls are appropriate and when they are not, including methods to mitigate downdrift impacts, if appropriate. Many misconceptions, false assumptions and misleading statements have been made in the US literature. This paper begins to separate fact from fiction.

Basco, D.R. and Pope, J. 2004. Groin Functional Design Guidance from the Coastal Engineering Manual. Journal of Coastal Research, SI 33: 121-130.

Groins are constructed to retain sand on the subaerial beach. Modern coastal engineering practice combines beach nourishment with a groin design suitable to permit sand bypassing of the groin field without loss to the system. This paper summarizes elements in the functional design of groins as presented in the new Coastal Engineering Manual (CEM) of the U S Army Corps of Engineers. The CEM replaces the Shore Protection Manual. The most significant change is the explicit acknowledgement of a minimum, dry beach width as a central empirical design criterion for the use of groins in coastal storm protection. Modern numerical models are helpful to study coastal processes both alongshore and on-offshore for the project location and in conducting an analysis of design elements. Field monitoring and the development of performance criteria are also recommended to determine the level of performance success, to establish triggers prompting the need for project maintenance, and to identify adverse impacts to adjacent beaches. Such practices and safeguards will help to overcome the negative perceptions of groins and groin fields as a viable technology for coastal erosion mitigation.

Berry, A., Fahey, S., and Meyers, N. 2013. Changing of the Guard: Adaptation Options that Maintain Ecologically Resilient Sandy Beach Ecosystems. Journal of Coastal Research, 29(4): 899-908.

Sandy beach ecosystems adapt to sea-level rise by retreating landward. Retreat enables a sandy beach ecosystem to adapt while maintaining structure and function over various spatial and temporal scales. However, adaptation options, such as engineered barriers to shoreline retreat, reduce adaptive capacity and, therefore, ecological resilience to sea-level rise. Species richness and diversity becomes threatened when sandy beaches are squeezed between "fortifications" and increasing sea levels. Unidimensional management gives precedence to the protection of coastal investments at the expense of ecological resilience. This article provides a critical assessment of adaptation options to identify those capable of maintaining the ecological resilience of sandy beach ecosystems to sea-level rise. Hard- and soft-engineered options impede sand transport and storage systems and prevent retreat from advancing seas. In contrast, ecosystem conservation and setbacks enable coastal processes to continue and thereby maintain ecological resilience to sea-level rise. Managing sandy beach ecosystems from multidimensional perspectives allows coastal managers to better understand the consequences of implementing adaptation options. However, political, economic, and social necessity often dictates coastal managers employ unidimensional adaptation options to achieve quick results. This article proposes a four-dimensional lens through which sandy beach ecosystems can be viewed and managed. Longitudinal, transverse, vertical, and temporal dimensions characterise the function and structure of sandy beach ecosystems. A staged approach to adaptive management that takes a long-term view and considers a range of adaptation options tailored to achieve ecologically resilient sandy beach ecosystems is discussed.

Bertasi, F., Colangelo, M.A., Abbiati, M., and Ceccherelli, V.U. 2007. Effects of an Artificial Protection Structure on the Sandy Shore Macrofaunal Community: The Special Case of Lido di Dante (Northern Adriatic Sea). Hydrobiologia, 586: 277-290.

This study analysed the benthic compartment at Lido di Dante (Northern Adriatic Sea, Italy) within the frame of an integrated European project (DELOS), which aimed to identify, describe and quantify the effects of the Low Crested Structures (LCS) on the beach environment of many European coastlines. Both macrofaunal benthic communities and sediment characteristics were analysed in a sandy beach protected by a LCS parallel to the shoreline and laterally connected to land by two groynes, which have been responsible for changes of hydrodynamic patterns. A first survey (2001) focused on three exposure levels with respect to wave action. A higher species richness and a different community structure were found in the sheltered site as compared to the exposed and partially exposed sites. In addition, changes in sediment variables were found according to the exposure levels. A second survey (2002) assessed the combined effects of exposure and depth on both benthic communities and sediment variables. Our results suggest that both exposure and depth interact on measured biotic and abiotic variables. Species richness, community structure and size-classes distribution of the macrofauna, as well as the sediment composition, showed the greatest differences among the shallowest exposed zone and the deepest sheltered ones. On the contrary no difference at all occurred between the shallowest sheltered zone and the deepest exposed ones.

Bilkovic, D.M. and Mitchell, M.M. 2013. Ecological Tradeoffs of Stabilized Salt Marshes as a Shoreline Protection Strategy: Effects of Artificial Structures on Macrobenthic Assemblages. Ecological Engineering, 61: 469-481.

Armoring shorelines to prevent erosion is a long-standing global practice that has well-documented adverse effects on coastal habitats and organisms. A relatively new form of shoreline protection, referred to as hybrid stabilization, incorporates created marsh in combination with a stabilizing structure such as a low-profile stone sill and is being implemented in many US coastal states as a means to not only control erosion but also to restore coastal habitat. However, there has been limited scientific investigation of ecological benefits and impacts associated with implementation of hybrid stabilization. We evaluated relative habitat capacity of marsh-sills by comparing plant, sediment, and benthic macroinvertebrate attributes in intertidal and subtidal zones of existing marsh-sills, natural marshes, tidal flats, and riprap revetment within two subestuaries of Chesapeake Bay, USA. Low and high marsh plant characteristics (stem count and height) of marsh-sills were similar to or greater than natural marshes. However, sediment was coarser, total organic carbon and total nitrogen concentrations were lower, and benthic macrofaunal community structure differed in marsh-sills compared to natural marshes. Marsh-sills supported lower deposit-feeding infaunal biomass than marshes in the intertidal. Epifaunal suspension-feeders were most prevalent at sites with artificial structure (riprap and marsh-sill), but highly variable among subestuaries. Infaunal abundance, biomass, diversity, and proportion of suspension/interface and deposit feeding animals were greater in shallow subtidal than in intertidal environments. Conversion of existing habitat to marsh-sills may cause localized loss of benthic productivity and sediment bioturbation and nutrient-cycling functions, with the opportunity to enhance filtration capacity by epifaunal recruitment to structures. When creating marshes that require structural support, there should be a balance of minimizing loss of existing habitats while encouraging use of suitable structural habitat for suspension- feeders. If properly implemented, the addition of structural habitat could subsidize secondary productivity particularly in areas where loss of complex biogenic habitat (e.g., oyster reefs) has occurred.

Bishop, M.J., Peterson, C.H., Summerson, H.C., Lenihan, H.S., and Grabowski, J.H. 2006. Deposition and Long-Shore Transport of Dredge Spoils to Nourish Beaches: Impacts on Benthic Infauna of an Ebb-Tidal Delta. Journal of Coastal Research, 22(3): 530-546.

Dredged materials from maintenance and deepening of inlets on coastal barriers are typically transported for disposal in deep water or on land. An alternative is to treat dredged materials as a resource, placing them on the ebb-tidal delta or subtidal shoals at depths where they are retained within the long-shore transport system and can nourish eroding down-drift beaches. Deposition of sediments onto subtidal shoals may, however, bury and selectively kill populations of benthic invertebrates, or indirectly alter assemblages by modifying sediment characteristics. Core sampling of the eastern (control) and western (disturbed) sides of Beaufort Inlet, North Carolina, twice before and once 8 months after a large (660,000 m3) disposal revealed significant coarsening of sediments and associated changes to assemblages of benthic macroinvertebrates in response to the perturbation. Impacts to sediments and macroinvertebrates were closely correlated and, although greatest where sediment was directly deposited, extended over a wider (at least 1 km to the east) area than the deposition. Of the taxa comprising faunal assemblages, spionid polychaetes were most affected by the disposal, declining in abundance. These results, which tie the deposition and dispersal of coarse sediments on an ebb-tidal delta to changes in benthos, imply a biological cost that may be less than that of direct nourishment of biologically productive intertidal beaches.

Bokuniewicz, H. 2004. Isolated Groins at East Hampton, New York. Journal of Coastal Research, SI 33: 215-222.

Two large groins were constructed soon after a severe erosion episode in 1962. The gross longshore transport is substantially larger than the net drift at the location. Depending on the sequence of conditions sand fillets sometimes accumulate on the east side and sometimes on the west. Over the long term the average beach is expected to be wider on the east side. The structures and associated sand deposits that have developed over the last forty years function as artificial headland. The local wave climate is altered, and in the absence of a predominant net longshore transport, a crenulate shoreline can form on both sides of the pair of structures in conformance with wave refraction and diffraction around a headland.

Bolam, S.G. and Rees, H.L. 2003. Minimizing Impacts of Maintenance Dredged Material Disposal in the Coastal Environment: A Habitat Approach. Environmental Management, 32 (2): 171–188.

At present, coastal disposal of maintenance dredged material constitutes one of the most important problems in coastal zone management and in some coastal areas represents the major anthropogenic disturbance to the benthos. In this review we first propose, based on the classic literature, that macrofaunal communities typical of environmentally stressed habitats are more resilient than those of more environmentally stable habitats, and we outline the macrofaunal successional changes following a disturbance. Second, from a review and analysis of the published and unpublished literature on macrofaunal recovery following maintenance dredged material deposition in the coastal environment, we compare the successional sequences and recovery rates in euhaline and polyhaline systems. The review reveals that invertebrate recovery following dredged material disposal in relatively unstressed marine environments generally takes between 1 and 4 years, while in more naturally stressed areas, recovery is generally achieved within 9 months, although deeper polyhaline habitats can take up to 2 years to recover. Differences in recovery times are attributed to the number of successional stages required to regain the original community composition and that species typical of naturally unstressed assemblages do not possess life-history traits to allow rapid recolonization of disturbances. In the last section of this review, the management implications of these findings are discussed in terms of minimizing dredged material disposal impacts on fisheries resources. Since the natural disturbance regime appears to be very important in determining the response of a benthic community following dredged material disposal, it is recommended that when predicting the potential environmental impact of an operation, the nature of the physical environment in combination with the status (and role) of associated marine benthic communities should be considered.

Bolam, S.G., Schratzberger, M., and Whomersley, P. 2006. Macro- and Meiofaunal

Recolonisation of Dredged Material Used for Habitat Enhancement: Temporal Patterns in Community Development. Marine Pollution Bulletin, 52: 1746–1755.

In recent years, dredged material has become regarded as a potential resource and used to create and/or improve intertidal habitats (i.e., beneficial use). This paper presents the results of a sampling programme to investigate the long-term (42 months post-recharge) macro- and meiofaunal recolonisation processes of a beneficial use scheme in south-east England. While univariate indices of community structure indicated that the scheme's meiofaunal community was never significantly different from that of a nearby reference area, such attributes for macrofauna were continually significantly below those of the reference area, although this was not the case for all reference stations. Multivariate analyses revealed that macro- and meiofaunal community structures were always significantly different from those of the reference communities. We discuss the factors responsible for these observations and propose that assessing recovery of a beneficial use scheme should be undertaken using pre-defined criteria in addition to comparisons with a reference site.

Bouchard, S., Moran, K., Tiwari, M.,Wood, D., Bolten, A., Eliazar, P., and Bjorndal, K. 1998. Effects of Exposed Pilings on Sea Turtle Nesting Activity at Melbourne Beach, Florida. Journal of Coastal Research, 14(4): 1343-1347.

Beach stabilization and nourishment are critical needs in Florida and along much of the U.S. coast. Because offshore sand resources are diminishing, there is much interest in the installation of beach structures for stabilization and nourishment projects. The STABLER™ Disc System (Shoreline Reclamation Inc., Manasquan, NJ) is an example of one such structure in which a series of cement discs is anchored into the beach by pilings. When functioning properly, the discs are buried by the accretion of sand, and only the pilings are exposed. Before any structure can be installed into Florida beaches, however, its impact on sea turtle nesting should be assessed. This study investigated the effects of exposed pilings on sea turtle nesting activity. Artificial pilings constructed from PVC pipe were installed on Melbourne Beach, Florida, and nesting activity was monitored in areas with and without pilings. Nesting activity decreased significantly in the presence of pilings. However, the installation of structures remains an option on sea turtle nesting beaches because some nesting continued to occur. Further research is needed on the effect of exposed pilings on hatchling orientation.

Bowman, M.L. and Dolan, R. 1985. The Relationship of *Emerita talpoida* to Beach Characteristics. Journal of Coastal Research, 1(2): 151-163.

The distribution of *Emerita talpoida* on the foreshore is strongly influenced by inshore processes and the grain size and morphology of the beach deposit. *E. talpoida* populations increase in density across the foreshore toward the lower part of the beach (step). High density cells frequently lie within areas of reduced wave energy, such as in the troughs of beach cusps. The depth at which *Emerita* occur within the sediment of the upper beach is rarely more than 5 cm. Their numbers increase and they burrow deeper toward the lower part of the beach. Structures extending across the foreshore, such as the research pier used in this study, modify wave action and thus cause redistribution of beach sediment and beach morphology. This, in turn, results in modifications of *E. talpoida* distributions. Onshore migration of the overwintering population occurred in early April during a period of rapidly increasing water temperature. Numbers increased through spring and summer to a seasonal maximum in late summer and early fall. Large and rapid fluctuations in the population are superimposed on the seasonal cycle. These fluctuations are related to variations in wave energy and tide level, and reflect onshore and offshore migration in response to energy conditions and feeding requirements.

Brock, K.A., Reece, J.S., and Ehrhart, L.M. 2009. The Effects of Artificial Beach Nourishment on Marine Turtles: Differences between Loggerhead and Green Turtles. Restoration Ecology, 17(2): 297-307.

Marine turtle reproductive success is correlated with the stability and quality of the nesting environment. Female marine turtles show fidelity to nesting beaches, making artificial beach nourishment practices directly relevant to their recovery. We evaluated the impacts of artificial beach nourishment on Loggerhead (*Caretta caretta*) and Green turtles (*Chelonia mydas*) between artificially nourished and nonnourished beaches. We observed reduced nesting success (ratio of nesting emergences to emergences not resulting in nest deposition) for both species. This negative effect lasted for one season in Loggerheads and for at least one season in Green turtles. Physical attributes of the fill sand did not impede nesting attempts. We argue that the decrease in nesting success resulted from an altered beach profile not favorable for nest deposition, which subsequently improved in later seasons as the beach equilibrated to a more natural slope. We observed a 52.2% decrease in reproductive output (hatchlings km^{-1} yr^{-1}) for Loggerheads one year postnourishment, with a 44.1% increase observed the two seasons post-nourishment. In Green turtles, a 0.8% reduction was observed the first season postnourishment, despite a 13% increase in the nonnourished area. The reduction in reproductive output in both cases was primarily a consequence of decreased nesting success, lowering nest numbers. These results reveal stronger negative effects of beach nourishment on Loggerheads compared to Green turtles and the importance of minimizing excessive nonnesting emergences associated with artificial beach nourishment. Nourished areas also experienced more than 600% increase in the number of Loggerhead hatchlings disoriented by artificial lighting over two years post-nourishment.

Brooks, W.B. 1988. A Historic and Morphologic Study of Mason and Rich Inlets, North Carolina. [M.S. thesis]: Wilmington, North Carolina, University of North Carolina Wilmington, 117 p.

Figure Eight Island is an 8-km long barrier island located 20 Jan northeast of Wilmington, North Carolina. Analyses of 50 digitized sets of aerial photographs (1938-1986) and historic charts indicated contrasting inlet histories, which control long and short term erosion and accretion patterns and, ultimately, the island morphology. The 300-m wide recurved beach ridge system that characterizes the northern 1.2-km of Figure Eight Island is a byproduct of the processes associated with Rich Inlet, a stable, 600-m wide, pre-colonial feature. Cyclical deflections of the main ebb channel, positioned adjacent to the updrift shoulder, across the large ebb delta (950,000 m^2) initiates aperiodic bypassing events of large volumes of sand. Ebb channel repositioning from a shore normal (ESE) orientation to a skewed downdrift position results in the deepening of the downdrift marginal flood channel and a period of rapid erosion along a portion of the downdrift Figure Eight Island shoreline. Ebb channel reorientation to the shore normal (ESE) position follows an ebb delta breaching event that releases a large volume of sand downdrift. Superimposed on this long-term cycle (3-8 yrs) are bar migration events that produce shoreline convolutions (200-300-m long), which can be attributed to erosion and accretion adjacent to and in the lee of the sand packet. Mason Inlet, a southwesterly migrating inlet with a small ebb delta (255,000 m^2), borders Figure Eight Island to the southwest. During the past 50 years Mason Inlet has migrated 1.7 km (36 m yr^{-1}). Chronic erosion (4-12 m yr^{-1}), which exists along the southern 1 km of Figure Eight Island, stems from the truncation and realignment of the trailing shoreline. In contrast to Rich Inlet, cycles of channel switching at Mason Inlet provide a mechanism where sand is bypassed updrift. The main ebb channel is deflected from shore normal (ESE) to an updrift (ENE).

Brown, A.C. and McLachlan, A. 2002. Sandy Shore Ecosystems and the Threats Facing Them: Some Predictions for the Year 2025. Environmental Conservation, 29(1): 62-77.

Pollution, mining, disruption of sand transport and tourism development widely affect sandy shores, and these systems may be subject to increased erosion in future, yet there have been few attempts to review them. The present review focuses largely on ocean sandy beaches, providing an introduction to much of the relevant literature, and predicting possible states of the system by 2025. Sandy shores are dynamic harsh environments, the action of waves and tides largely determining species diversity, biomass and community structure. There is an interchange of sand, biological matter and other materials between dunes, intertidal beaches and surf zones. Storms and associated erosion present the most substantial universal hazard to the fauna. Human-related perturbations vary from beach to beach; however, structures or activities that impede natural sand transport or alter the sand budget commonly lead to severe erosion, often of a permanent nature. Many beaches also suffer intermittent or chronic pollution, and direct human interference includes off-road vehicles, mining, trampling, bait collecting, beach cleaning and ecotourism. These interferences typically have a negative impact on the system. Identified long-term trends include chronic beach erosion, often largely due to natural causes, as well as increased ultraviolet (UV) radiation and changes related to global warming. It is not expected that predicted temperature changes will have dramatic effects on the world's beaches by 2025, but the expected rise in sea level, if coupled with an increase in the frequency and/or intensity of storms, as predicted for some regions, is likely to lead to escalating erosion and consequent loss of habitat. It is suggested that increased UV radiation is unlikely to have significant effects. Increases in coastal human populations and tourism, thus increasing pressure on the shore, while serious, may be largely offset in developed and developing countries by better management resulting from greater understanding of the factors governing sandy-shore systems and better communication with beach managers and developers. Beach nourishment is likely to become more widely practised. However, the continuing hardening of surfaces in and above the dunes is bound to be damaging. Human pressures in many underdeveloped countries show no signs of being mitigated by conservation measures; it is likely that their sandy shores will continue to deteriorate during the first quarter of this century. A long-term trend that cannot be ignored is the excessive amount of nitrogen entering the sea, particularly affecting beaches in estuaries and sheltered lagoons. The data presently available and the uncertainty of a number of predictions do not permit of quantitative assessment or modelling of the state of the world's sandy shores by the year 2025, but some tentative, qualitative predictions are offered.

Bruun, P. 1995. The Development of Downdrift Erosion. Journal of Coastal Research, 11(4): 1242-1257.

Downdrift erosion is a common feature of shores occurring where a headland, inlet, river, bay, canyon, reef or shoal blocks the natural longshore drift of materials, that is transport of sand and gravel by waves and currents. Sediment transport results in accumulations on updrift or receiving side and in the adjoining ocean. There is a corresponding depletion of materials on the downdrift side. The terminology "Littoral Drift Barrier" is accordingly developed. This paper is "an interim report" which reviews practical cases of leeside erosion and attempts to explain the development as a function of time.

Bruun, P. 2001. The Development of Downdrift Erosion. An Update of Paper in JCR, Vol. 11(4). Journal of Coastal Research, 17(1): 82-89.

Leeside-erosion is the terminology for the adverse effect on shore stability occurring on the downdrift side of a littoral drift barrier. Paper by BRUUN titled "The Development of Downdrift Erosion" published by the Journal of Coastal Research, vol. 14(4), 1995, explains that leeside erosion may have a short-range as well as a long-range effect, the latter being caused by the former. Between the two effects one may in some cases find an area of relatively less erosion making it protruding somewhat from the adjoining shorelines. In this paper more examples are given. It is concluded that the only fully reliable answer to the extent of the leeside erosion downdrift can only be obtained by qualitative research which will probably reveal that the leeside effect extends further downdrift than indicated by shoreline developments on the downdrift side.

Bulleri, F. and Chapman, M.G. 2010. The Introduction of Coastal Infrastructure as a Driver of Change in Marine Environments. Journal of Applied Ecology, 47: 26-35.

1. Coastal landscapes are being transformed as a consequence of the increasing demand for urban infrastructure to sustain commercial, residential and tourist activities. A variety of man-made structures, such as breakwaters, jetties and seawalls have thus become ubiquitous features of intertidal and shallow subtidal habitats. This transformation will accelerate in response to the exponential growth of human populations and to global changes, such as sea-level rise and increased frequency of extreme meteorological events (e.g. storms). Here, we provide a critical overview of the major ecological effects of increasing infrastructure to marine habitats, we identify future research directions for advancing our understanding of marine urban ecosystems and we highlight how alternative management options might mitigate their impacts.
2. Urban infrastructure supports different epibiota and associated assemblages and does not function as surrogate of natural rocky habitats. Its introduction in the intertidal zone or in nearshore waters can cause fragmentation and loss of natural habitats. Furthermore, the provision of novel habitat (hard substrata) along sedimentary shores can alter local and regional biodiversity by modifying natural patterns of dispersal of species, or by facilitating the establishment and spread of exotic species.
3. Attempts to use ecological criteria to solve problems of urban infrastructure are promising. Incorporating natural elements of habitat (e.g. wetland vegetation; seagrass) into shoreline stabilization can reduce ecological impacts, without impinging on its efficacy in halting erosion.

Likewise, improving the ecological value of artificial structures by adding features of habitat that are generally missing from such structures (e.g. rock-pools) can contribute to mitigation of the detrimental effects of urbanization on biodiversity. Management of anthropogenic disturbances (e.g. maintenance works; harvesting) to artificial habitat is, however, necessary if such attempts are to be successful.
4. Synthesis and applications. Increasing our understanding of the ecological functioning of marine habitats created by urban infrastructure and incorporating ecological criteria into coastal engineering are crucial for preserving biodiversity in the face of the growth of human populations in coastal areas and of forecasted global changes. Achieving this goal will need strong collaboration between engineers, managers and ecologists.

Burney, C. and Mattison, C. 1992. The Effects of Egg Relocation and Beach Nourishment on the Nesting and Hatching Success of *Caretta caretta* in Broward County, Florida, 1991. New Directions in Beach Management: Proceedings of the 5th Annual National Conference on Beach Preservation Technology, St. Petersburg, Florida, 395-407.

The hatching successes of 438 relocated and 137 undisturbed *Caretta caretta* nests from the same beach were compared. The relocated nests produced 30,311 hatchlings from 49,689 total eggs (61.0% success) while 14,995 undisturbed eggs yielded 9,363 hatchlings (62.4% success). Comparison of the mean daily hatching successes of all the individual relocated and natural nests by one-way ANOVA showed no Significant differences between groups (P=0.615), but a 2 x 2 contingency table indicated a significant (P< .002) influence of egg relocation on hatching success on Hillsboro beach. However, this effect was small (166 egg difference between observed and estimated frequencies) and hatching success of the relocated nests would have been much lower if they had remained in the hazardous locations where they were laid. Hatching success decreased significantly in nests deposited later in the season, but the rates of decline in relocated and undisturbed nests were indistinguishable. At John Lloyd State Recreation Area (JLSRA), 81 relocated nests produced 7,395 hatchlings from 8,337 eggs (88.7% success) while 3,914 of 4,929 eggs (79.4%) from 47 natural nests hatched successfully. Both one-way ANOVA and contingency table analyses indicated highly significant (P<< .001) differences between groups, but there was less than a 288 egg difference between the observed and estimated frequencies in the latter analysis. Effects of a recent beach renourishment project were evaluated at JLSRA. The hatching success of undisturbed nests in the southernmost 1 km of the park, which was not renourished, was compared to the adjacent 1 km section which was renourished in 1989. A total of 2,120 eggs from 20 nests in the renourished zone produced 1,601 hatchlings (75.5% success) while 2,028 of 2,648 eggs (76.6%) from 24 nests hatched in the unrenourished zone. A 2 x 2 contingency table indicated no significant effect of renourishment on hatching success (P=.390). Nesting success (nests / total crawls) was also not significantly different in these adjacent renourished and unrenourished zones (P=.310). Hollywood and Hallandale beaches were renourished during the 1991 nesting season. Only 6.9 nests were deposited per km of beach during 1991, compared to 14.9 nests per km in 1990. Overall nesting success on Hollywood-Hallandale beach was 30.2% in 1991 compared to 58.7% for the previous year.

Burroughs, S.M. and Tebbens, S.F. 2008. Dune retreat and shoreline change on the Outer Banks of North Carolina. Journal of Coastal Research, 24(2B): 104-112.

Barrier islands are popular recreational areas of economic importance and are constantly undergoing change. Costly efforts are made to maintain beaches and stabilize dunes within this dynamic environment. Light detection and ranging data collected in September 1997 and 1998 along a 175-km stretch of the Atlantic coast of the Outer Banks, North Carolina, provide the basis for quantitative determination of the changes in beach morphology. The 1998 survey was conducted just after the passage of Hurricane Bonnie. During the 1-year study interval, beach widths throughout the study region tended to decrease. Maximum dune retreat was determined for each 1-m bin of 1997 beach width. For comparable beach widths, maximum dune retreat increased from south to north. The maximum dune retreat was greatest for supratidal beaches with widths of ~20 m. For wider supratidal beaches, from 20 to 60 m, the associated maximum dune retreat gradually decreased. There was no further decrease in maximum dune retreat for beaches wider than ~60 m. Relatively little change in beach width, dune height, and dune base position occurred along the less developed beaches of the Core Banks. The greatest morphological changes occurred on Ocracoke Island and Hatteras Island. Of the geomorphic parameters examined, preexisting beach width and the dune base elevation were the best indicators of vulnerability to dune retreat.

Cahoon, L.B., Carey, E.S., and Blum, J.E. 2012. Benthic Microalgal Biomass on Ocean Beaches: Effects of Sediment Grain Size and Beach Renourishment. Journal of Coastal Research, 28(4): 853-859.

Benthic microalgal biomass was measured as sediment chlorophyll *a* at two open ocean beaches in southeastern North Carolina between December 2003 and December 2004, spanning beach renourishment projects in spring 2004 at both beaches. Sampling design included replicate sampling ($n = 6$) at three elevations in the surf zone along paired transects at paired renourished and unnourished (control) sites at each beach 17 times during the study period. Grain-size analyses of beach sediments and measurements of water temperature were also conducted. Sediment grain size, expressed as mean grain size and percentage of total sediments <500 pm diameter, significantly affected sediment chlorophyll a values. Renourishment drove a small and temporary but significant increase in sediment chlorophyll *a* at one beach, which was interpreted as an effect of source material but otherwise had no detectable negative effects. The grain-size effects reinforce the importance of efforts to match material used for renourishment with existing beach sediments because benthic microalgae likely form a significant portion of the base of the food chain in surf-zone communities.

Carr-Betts, E., Beck, T.M., and Kraus, N.C. 2012. Tidal Inlet Morphology Classification and Empirical Determination of Seaward and Down-drift Extents of Tidal Inlets. Journal of Coastal Research, 28(3): 547-556.

The Hayes classification of tidal inlet geomorphic type and the distances from the inlet to the most seaward and down-drift extents of ebb deltas are examined. For this purpose, a database was compiled for 89 tidal inlets along the Atlantic Ocean, Gulf of Mexico, and Pacific Ocean coasts of the United States. The database contains spring or diurnal tidal prism and the average significant wave height and wave period from a 20-year hindcast. The Hayes diagram aims to classify inlet planview morphology by tide range and wave height. Based on the work presented here, it is concluded that the inlet classification of Hayes has limited applicability for describing the morphology of typical tidal inlets, and replacement of tide range by inlet tidal prism did not improve the classification. Best correlation for the two ebb delta extents was found for inlets segregated by wave exposure (as mild, moderate, or high) and by tidal prism. There was poor or no correlation for moderately wave-exposed inlets, and moderate to high correlation was found for mildly and highly exposed inlets. The seaward and down-drift extents of inlets tend to remain constant up to a tidal prism less than 10^8 m^3, depending on wave exposure, and then increase linearly with tidal prism. It is postulated that a tidal prism less than approximately 10^8 m^3 is a tipping point required to overcome other factors controlling tidal inlet plan-form morphology.

Chapman, M.G. and Underwood, A.J. 2011. Evaluation of Ecological Engineering of "Armoured" Shorelines to Improve their Value as Habitat. Journal of Experimental Marine Biology and Ecology, 400: 302-313.

People have caused major impacts on nearshore and intertidal habitats by building infrastructure associated with shipping, recreation, residential and commercial developments. Together with the desire or need to control erosion, these have led to increased "armouring" of intertidal shorelines, with seawalls, revetments, onshore and offshore groynes and other defence systems, piers and docks replacing natural habitats. Despite the long history of such changes, until relatively recently there had been limited research on the impacts of such alterations to shorelines, especially when compared to research into effects of urbanisation on terrestrial habitats. In addition, most research to date has focussed on the impacts of such changes on the ecological structure of assemblages, i.e. the numbers and types of organisms affected, rather than on ecological processes. With the realisation that most coastal infrastructure cannot be removed, there is now an increasing research effort into ways that infrastructure can be built to meet engineering requirements, but to also increase its value as habitat – ecological engineering. In this review, we discuss the major impacts and the experimental research that has been and is being done to build coastal infrastructure in a more biodiversity-friendly manner. Much of the review has focused on seawalls, which is where most of the experimental work has been done to date. Finally, we raise some concerns about the types of research effort that are still needed and caution against wholesale implementation of what seem like simple remedies, without evidence that they will have the desired effect in the long term.

Charlier, R.H., Chaineux, M.C.P., and Morcos, S. 2005. Panorama of the History of Coastal Protection. Journal of Coastal Research, 21(1): 79-111.

Changes of sea-level, retreat of shorelines have occurred throughout geological times. They have taken a special significance since Man has appeared. Man has been simultaneously awed by the sea and attracted by its shores. He has consistently attempted to protect his settlements against the onslaughts of the sea. Coastal defenses can be traced back to remote times. It is probable that dams or walls were erected before the Frisians did, but their "defenses" were described by Pliny, and, jusqu'i preuve du contraire, are considered as the first "dike builders". Earthen artificial hillocks are the forerunners of stone constructions built to hold back the advances of the sea, particularly when sizeable areas of land were gobbled up by the waters along coasts, but also in estuaries, witness i.e. the Dutch Verdronken Land van Saeftingen. The groins, seawalls, breakwaters and the like proved to be illusory shields, to solve little, but to create new problems. Engineers and scientists tried different approaches, inspired by Nature's own ways, nourishment for instance. Other methods are being honed. They must as well consider the economic and social impacts of coastal erosion. The paper follows the historical evolution of man's attempts to retain his "land".

Churchill, J.H., Forward, R.B., Luettich, R.A., Hench, J.L., Hettler, W.F., Crowder, L.B., and Blanton, J.O. 1999. Circulation and Larval Fish Transport within a Tidally Dominated Estuary. Fisheries Oceanography, 8 (Suppl. 2): 173-189.

In March 1996 two surveys of larval fish abundance and water flow were carried out within the estuarine region near Beaufort Inlet, NC. Each survey extended over two full semidiurnal tidal cycles and included measurements of larvae concentration and velocity distribution at several locations. There was a large across-channel variation in the subtidal flow passing through Beaufort Inlet, with net inflow over the eastern and central portions of the inlet and net outflow on the western side of the inlet. This pattern was consistent with moored current meter measurements of a previous study, and was reproduced by a numerical model circulation forced only by the M_2 tide. A net ingress of larvae from the open ocean into the estuary was observed during both surveys. Most larvae entered the estuary over the eastern and central portions of the inlet, where the subtidal flow was up-estuary. However, the mean circulation played a minor role in the net movement of larvae into the estuary. Rather, net up-estuary transport of larvae was principally due to variation of larval abundance with tidal flow; with abundance during flood tide usually far exceeding ebb tide abundance. This mode of transport was likely driven by a behavioural response to tidal flow in which larvae tended to descend to the bottom on falling tides and reside throughout the water column on rising tides.

Cleary, W.J. 1996. Inlet Induced Shoreline Changes: Cape Lookout-Cape Fear. *In:* Environmental Coastal Geology: Cape Lookout to Cape Fear, NC. Cleary, W.J., (ed), Carolina Geological Society Field Guidebook: 41-50.

It is increasingly evident that the dynamics of inlets are site specific, with each system exhibiting individualized responses to local environmental and geological factors. It is the intent of this paper to provide a brief overview of the coastwise variability of inlet types, morphological changes within the inlet system and the role the inlets play in the patterns of erosion and accretion on the adjacent shorelines. The overview is based on current investigations and published data from studies of the majority of inlets in southeastern North Carolina.

Cleary, W.J. 2002. Variations in Inlet Behavior and Shoreface Sand Resources: Factors Controlling Management Decisions, Figure Eight Island, NC, USA. Journal of Coastal Research, SI 36: 148-163.

Although beach nourishment is considered the only viable option for maintaining oceanfront beaches, the prohibition of large-scale mining of mainland sites and estuarine channels has made it difficult for communities with severe erosion problems to plan mitigation. Figure Eight Island, North Carolina, is an example of a community where erosion during the past decade has increased dramatically due to the combined effects of the bordering inlets and the impacts of recent hurricanes. The chronic erosion has prompted a system wide investigation aimed at inventorying the offshore sand resources for long-term management of the oceanfront beach.

The contrasting behavior patterns of Rich and Masons Inlets, which form the island's northern and southern boundaries respectively, have influenced historic shoreline change patterns. Although Rich Inlet has been relatively stable, the ebb channel has shifted repeatedly; and as a consequence, reconfiguration of the expansive ebb delta has led to severe erosion along a 2 km reach downdrift of the inlet. Mason Inlet is a small migrating system whose soundside channels have shoaled since the mid 1990's, resulting in a dramatically reduced tidal prism and increased migration rates that exceeded 140m y^{-1}. Migration and consequent realignment of the trailing barrier resulted in oceanfront erosion that extended for 3 km updrift. Relocation of the inlet is planned for early 2002. Less than 10% of the 4.0 million m^3 needed for nourishment will be available as a result of the relocation efforts. Although the shoreface has been viewed as a potential borrow source, data indicate it has a low potential for providing significant volumes of quality sand. The lack of shoreface sand resources and the minor amount available from future dredging activities at Mason Inlet strengthens the need for developing a sound sand management strategy for Rich Inlet for long-term maintenance of the oceanfront.

Cleary, W.J. and Marden, T.P. 1999. Shifting Shorelines: A Pictorial Atlas of North Carolina's Inlets, NC Sea Grant Program Publication No. UNC-SG-99-04, Raleigh, NC, 51 p.

The inlets along the North Carolina coast originated in several distinct ways. Three modes of origin are recognized, but each has several subtypes. Ten of the 22 inlets, about 45%, formed as a result of storm breaches across barrier spits or islands. All inlets in this category-including Oregon, Mason and Mad Inlets-are unstable. A second category, with nine of 22 inlets or about 41%, represents larger inlet systems, including Ocracoke, Bogue and Cape Fear River Inlets. These inlets occupied ancestral river channels as sea level rose during the past several thousand years. A third category, includes three of 22 inlets-Drum, Carolina Beach and Tubbs Inlets-or about 14%. Tubbs Inlet originated as a storm-related breach, but was artificially relocated in 1970.

Cleary, W.J. and Pilkey, O.H. 1996. Environmental Coastal Geology: Cape Lookout to Cape Fear, North Carolina, Regional Overview. *In:* Environmental Coastal Geology: Cape Lookout to Cape Fear, NC. Cleary, W.J., (ed), Carolina Geological Society Field Guidebook: 73-107.

Cleary, W.J., Willson, K.T., and Jackson, C.W. 2006. Shoreline Restoration in High Hazard Zones: Southeastern North Carolina, USA. Journal of Coastal Research, SI 39: 884-889.

A number of high-risk segments along southeastern North Carolina have partially recovered from the impacts of the hurricanes in the late 1990s; however many severely impacted areas are still at risk. A primary management concern related to these high hazard areas, is the controversial issue of beach nourishment. More than 80% of the 180 km long shoreline between Cape Lookout and Cape Fear is extensively developed. All communities that comprise this reach are involved in some form of replenishment activities ranging from feasibility studies to major nourishment projects. Aside from the financial aspects of nourishment, many communities are concerned with the availability of sand resources for nourishment programs. Long-term chronic erosion and the lack of significant recovery have prompted a re-examination of offshore areas for sand resources for erosion and storm damage reduction projects. Many of these sediment-starved reaches have little storm protection in place and have a marginal potential for locating suitable beach fill resources for nourishment purposes. Consequently, major sections of some high hazard reaches will have to be abandoned, as relocation is not an option. The study focuses on Topsail Island, a 40 km long transgressive barrier, as an exemplary barrier setting where three communities with different environmental and erosion histories are confronted with identifying large volumes of sand to meet their nourishment needs.

Cleary, W.J., McLeod, M.A., Rausher, M.A., Johnston, M.J., and Riggs, S.R. 2001. Beach Nourishment on Hurricane Impacted Barriers in Southeastern North Carolina, USA: Targeting Shoreface and Tidal Inlet Sand Resources. Journal of Coastal Research, SI 34: 232-255.

Southeastern North Carolina is a rapidly growing tourist destination. A primary concern of management officials is the environmentally sensitive issue of beach nourishment for hurricane-impacted shorelines. Long term erosion and lack of shoreline recovery has prompted a re-examination of the shoreface and tidal inlets for beachfill quality sand resources. North Topsail Beach and Oak Island are exemplary study sites situated in different geologic settings with contrasting development, erosion, and nourishment histories. In addition to a variety of published and unpublished information, the database for this study consisted of 100 vibracores, 50 km of seismic profiles and 140 km^2 of sidescan-sonar data, petrographic analyses and diver surveys. North Topsail Beach located adjacent to the New River submarine headland in Onslow Bay, was once extensively developed prior to 1996 hurricanes. This reach fronts a shoreface dominated by hardbottoms some of which crop out just seaward of the surf zone. On some portions of the shoreface sand trapped on the seaward side of the hardbottoms during storms is lost to the beach system. Other losses occur through shore-normal channel-like features that are probable pathways for cross-shore transport. The shoreface in this area has no resource potential. Maintenance dredging of New River Inlet may provide small volumes of material for erosion mitigation but no long term borrow sources are available. Continued development is the focus of debate due to the lack sand resources. South facing Oak Island in low energy Long Bay is composed of a 3.5 km long Pleistocene subaerial headland segment flanked by two transgressive spits. Caswell Beach, a low relief 4 km barrier extends into the Cape Fear River estuary toward the east while Long Beach a 14km spit extends westward towards Lockwoods Folly Inlet. Chronic erosion is commonplace along Oak Island except near the bordering inlets. The volume of sand retained in the ebb-tidal deltas varies from 7 million m^3 for Lockwoods Folly Inlet to 125 million m^3 for the entrance shoals of the Cape Fear River along Caswell Beach. Initial beach fill requirements are conservatively estimated to be 4.0 million m^3. Material dredged from Lockwoods Folly Inlet will provide only a short-term and localized solution. Dredging activities at the Cape Fear River entrance will play a major role in mitigating the erosion. Activities include the deepening and realignment of the ship channel across the shoreface that will yield 6.6 million m^3 of material. The exact volume of usable material and the volume to be placed on Oak Island is currently being determined. Significant portions of the shoreface are characterized by outcropping Cretaceous - Paleocene age sandstones and limestones. The sediment cover is variable and consists of 10-300 cm units of muddy sands and gravely muddy sands. The distribution of hardbottoms, the variable thickness, and the muddy nature of the sediment preclude the use of the majority of the shoreface as a long term borrow source. Pockets of 1-2 million m^3 of beach fill compatible sands are found along a zone that straddles the outer fringes of the active beach. The only viable long-term borrow source is Jay Bird Shoals at the Cape Fear River entrance. A number of environmental concerns must be addressed before any of these areas can be utilized.

Coburn, A.S. 2011. A Fiscal Analysis of Shifting Inlets and Terminal Groins in North Carolina. Available online at http://coastalcare.org/2011/01/a-fiscal-analysis-of-shifting-inlets-andterminal-groins-in-north-carolina/.

North Carolina contains some of the most unique and biologically rich coastal ecosystems in the United States, providing immeasurable aesthetic, habitat, recreational and economic benefits. In order to successfully - and equitably - balance long-term environmental and sustainability needs with short-term economic development concerns, state and local coastal management policies, rules and laws must be both technically and fiscally-sound. Nowhere is this more evident than at North Carolina's tidal inlets where these dynamic natural features, once used to lure economic development, are now considered the primary threat to the very development they were used to attract. In response to the risk shifting inlets pose to static economic development, NC coastal communities and property owners typically rely on three mechanisms to protect vulnerable coastal property: 1) Beach restoration 2) Inlet channel realignment and 3) Sandbags.
Beach restoration involves the import and emplacement of sand on an eroding beach in order to artificially stabilize inlet and ocean shorelines. Inlet channel realignment modifies the position and orientation of an inlet's main ebb channel in an effort to reduce impacts and erosion rates along adjacent shorelines. Sandbags are a temporary measure intended to provide short-term protection to imminently threatened structures until a more "permanent" solution can be implemented. A fourth approach, now being actively promoted by some in North Carolina, is the use of terminal groins: shore-perpendicular erosion control structures made of rock or steel placed at the ends of islands near dynamic coastal inlets. Session Law 2009-479 in 2009 instructed the NC Coastal Resources Commission (CRC) to study the feasibility and advisability of terminal groins as erosion control devices. The study, completed in April 2010 at a cost of $280,000, included an assessment of the potential economic impacts of shifting inlets to the state, local governments and the private sector from erosion due to shifting inlets, but failed to provide compelling evidence regarding the economic or fiscal benefits of terminal groins.
As a follow-up to that study, the Program for the Study of Developed Shorelines (PSDS) at Western Carolina University examined the economic role of coastal property at ten North Carolina tidal inlets (Bogue, New River, New Topsail, Rich, Mason, Carolina Beach, Cape Fear, Lockwood Folly, Shallotte and Tubbs) to evaluate the potential fiscal costs of property loss as well as fiscal benefits of terminal groins in ten coastal municipalities (Emerald Isle, North Topsail Beach, Topsail Beach, Wrightsville Beach, Carolina Beach, Bald Head Island, Caswell Beach, Oak Island, Holden Beach and Ocean Isle Beach), five coastal counties (Carteret, Onslow, Pender, New Hanover and Brunswick) and one private island (Figure 8 Island).

Colosio, F., Abbiati, M., and Airoldi, L. 2007. Effects of Beach Nourishment on Sediments and Benthic Assemblages. Marine Pollution Bulletin, 54: 1197-1206.

Beach nourishment (i.e. the addition of sediments transported from other source locations) is increasingly used to counteract erosion of coastal areas. We tested whether sediment descriptors (grain size structure and organic content) and macrobenthic assemblages (species composition and abundance) differed among replicated shores previously exposed to nourishment alone (N), nourishment in combination with pre-existing hard structures (N + H) or no nourishment (NoN) along about 50 km of shores of the Emilia Romagna region (North Adriatic Sea, Italy). There was large variation among shores. Two out of three N shores were nearly defaunated, while one N shore had species composition and abundances comparable to NoN shores. There were also large differences between N and N + H shores, the latter possessing higher abundances of organisms and the presence of species that do not usually occur in the nearshore surf habitats in this region. More than 50% of the variability in the benthic assemblages was related to variations in the grain size structure of the sediments among shores. The results suggest that beach nourishments may lead to modifications of sedimentary environments and inhabiting fauna, but the resulting effects may be strongly related to local conditions, which dictate the rate at which added sand is redistributed.

Convertino, M., Donoghue, J.F., Chu-Agor, M.L., Kiker, G.A., Muñoz-Carpena, R., Fischer, R.A., and Linkov, I. 2011. Anthropogenic Renourishment Feedback on Shorebirds: A Multispecies Bayesian Perspective. Ecological Engineering, 37: 1184-1194.

In this paper, the realized niche of the Snowy Plover (*Charadrius alexandrinus*), a primarily resident Florida shorebird, is described as a function of the scenopoetic and bionomic variables at the nest-, landscape-, and regional-scale. We identified some possible geomorphological controls that influence nest-site selection and survival using data collected along the Florida Gulf coast. In particular, we focused on the effects of beach replenishment interventions on the Snowy Plover (SP), and on the migratory Piping Plover (PP) (*Charadrius melodus*) and Red Knot (RK) (*Calidris canutus*). Additionally, we investigated the potential differences between the SP breeding and wintering distributions using only regional-scale physiognomic variables and the recorded occurrences. To quantify the relationship between past renourishment projects and shorebird species we used a Monte Carlo procedure to sample from the posterior distribution of the binomial probabilities that a region is not a nesting or a wintering ground conditional on the occurrence of a beach replenishment intervention in the same and the previous year. The results indicate that it was 2.3, 3.1, and 0.8 times more likely that a region was not a wintering ground following a year with a renourishment intervention for the SP, PP and RK respectively. For the SP it was 2.5 times more likely that a region was not a breeding ground after a renourishment event. Through a maximum entropy principle model we observed small differences in the habitat use of the SP during the breeding and the wintering season. However, the habitats where RK was observed appeared quite different. While ecological niche models at the macro-scale are useful for determining habitat suitability ranges, the characterization of the species' local niche is fundamentally important for adopting concrete multispecies management scenarios. Maintaining and creating optimal suitable habitats for SP characterized by sparse low vegetation in the foredunes areas, and uneven/low-slope beach surfaces, is the proposed conservation scenario to convert anthropic beach restorations and SP populations into a positive feedback without impacting other threatened shorebird species.

Cook, E.D. 2013. Barrier Island Response to Sea Level Rise in North Carolina. [M.S. thesis]: Miami, Florida, Florida International University, 68 p.

The state of North Carolina is home to some of the most spectacular barrier islands in the world. These features are constantly shifting, impacted by waves, tides, and wind. Studies of the Outer Banks, North Carolina have resulted in varied results, but a detailed analysis of the barrier system as a whole is lacking. Using historic topographic surveys (T-sheets) from the 19th, the positions of various barrier segments were analyzed in relation to modern imagery. Changes in area, width, and center line locations were evaluated over the past 150 years. In total, 74 percent of modern transects have decreased in area. Total reductions in size were 130 km2 for the study period. Mean centerlines as a function of migration showed that 53 percent of segments were demonstrating directional movement away from the ocean. The average movement towards the bay between modern and historic centerlines was 8 meters. Thusly, barrier islands in North Carolina are demonstrating both decreases in total area and directional movement inland in response to sea level rise.

Cooke, B.C., Jones, A.R., Goodwin, I.D., and Bishop, M.J. 2010. Nourishment Practices on Australian Sandy Beaches: A Review. Journal of Environmental Management, 113: 319-327.

It is predicted that the coastal zone will be among the environments worst affected by projected climate change. Projected losses in beach area will negatively impact on coastal infrastructure and continued recreational use of beaches. Beach nourishment practices such as artificial nourishment, replenishment and scraping are increasingly used to combat beach erosion but the extent and scale of projects is poorly documented in large areas of the world. Through a survey of beach managers of Local Government Areas and a comprehensive search of peer reviewed and grey literature, we assessed the extent of nourishment practices in Australia. The study identified 130 beaches in Australia that were subject to nourishment practices between 2001 and 2011. Compared to projects elsewhere, most Australian projects were small in scale but frequent. Exceptions were nine bypass projects which utilised large volumes of sediment. Most artificial nourishment, replenishment and beach scraping occurred in highly urbanised areas and were most frequently initiated in spring during periods favourable to accretion and outside of the summer season of peak beach use. Projects were generally a response to extreme weather events, and utilised sand from the same coastal compartment as the site of erosion. Management was planned on a regional scale by Local Government Authorities, with little monitoring of efficacy or biological impact. As rising sea levels and growing coastal populations continue to put pressure on beaches a more integrated approach to management is required, that documents the extent of projects in a central repository, and mandates physical and biological monitoring to help ensure the engineering is sustainable and effective at meeting goals.

Cooper, J.A.G. and Pilkey, O.H. 2012. Pitfalls of Shoreline Stabilization, Selected Case Studies. Coastal Research Libary 3, Springer, Netherlands, 333 p.

Shoreline stabilization issues have been around since antiquity, but the scale of the challenge has been multiplied by several orders of magnitude by the rush to the shore. It is now a major societal challenge to work out a way to live with an ever-changing coast and what to do with the buildings, roads and other infrastructure we have placed there. Historically and, for the most part, currently the response has been to defend wherever we can. Now we are learning that this isn't the only way and indeed it is a way littered with pitfalls. In this book we bring together accounts of efforts from around the world to stabilize the shoreline. The accounts all show that from the traditional hard engineering (Anthony and Sabatier, Kench, Jackson, Romine and Fletcher), through various kinds of soft engineering (Coburn, Finkl, Brayshaw and Lemckert) to innovative 'alternative' approaches (Anfuso et al., Pilkey and Cooper), efforts to stabilize the shoreline always encounter pitfalls. Indeed the findings point to the conclusion that shoreline stabilization cannot be achieved at any meaningful timescale.

Crain, D.A., Bolton, A.B., and Bjorndal, K.A. 1995. Effects of Beach Renourishment on Sea Turtles: Review and Research Initiatives. Restoration Ecology, 3: 95-104.

Beach nourishment is an engineering solution to erosion of beaches. As in any restoration project, the goals of beach nourishment are the restoration of habitat to promote survival of plants and animals and to maintain aesthetically pleasing sites for humans. Unfortunately, beach nourishment sometimes alters parameters of the natural beach, decreasing the reproductive success of sea turtles. Engineers have recognized this problem and are working to improve nourishment practices. Biologists must specify problems incurred by sea turtles as a result of beach nourishment so that they may be addressed. A review of the literature on sea turtles and beach nourishment found certain problems repeatedly identified. For nesting females, characteristics induced by nourishment can cause (1) beach compaction, which can decrease nesting success, alter nest-chamber geometry, and alter nest concealment, and (2) escarpments, which can block turtles from reaching nesting areas. For eggs and hatchlings, nourishment can decrease survivorship and affect development by altering beach characteristics such as sand compaction, gaseous environment, hydric environment, contaminant levels, nutrient availability, and thermal environment. Also, nests can be covered with excess sand if nourishment is implemented in areas with incubating eggs. The extent and implication of each problem are discussed, and future research initiatives are proposed.

Culver, S.J., Ames, D.V., Reide Corbett, D., Mallison, D.J., Riggs, S.R., Smith, C.G., and Vance, D.J. 2006. Foraminiferal and Sedimentary Record of Late Holocene Barrier Island Evolution, Pea Island, North Carolina: the Role of Storm Overwash, Inlet Processes, and Anthropogenic Modification. Journal of Coastal Research, 22(4): 836-846.

Foraminiferal and sedimentary data, supplemented with geochemical dating and ground penetrating radar transects, show that the barrier island at Pea Island National Wildlife Refuge just north of Rodanthe, North Carolina, has been dominated by a combination of inlet and overwash processes for at least 1000 years. The stratigraphic record of several vibracores does not preserve every, or even many, overwash events but, instead, is characterized by three to four fining-upward sequences. The last three commence with overwash sand or gravel that is overlain by a variety of finer-grained estuarine, inlet, and marsh deposits. The dynamic nature of this segment of the Outer Banks was muted in the late 1930s by construction of artificial barrier dune ridges, extensive planting of grass and shrubs, and construction of Highway 12 in 1953. Subsequently, the road and barrier dune ridge were rebuilt and relocated several times following storm events.

Cyrus, D.P. and Blaber, S.J.M. 1987. The Influence of Turbidity on Juvenile Marine Fishes in

Estuaries. Part 1. Field Studies at Lake St. Lucia on the Southeastern Coast of Africa. Journal of Experimental Marine Biology and Ecology, 109: 53-70.

Lake St. Lucia, the largest estuarine system in Africa (325 km^2), was chosen as the field study area for a 3.5-yr (1980-83) investigation into relationships between water turbidity and estuarine fish distribution. The variety of habitats, from clear water, open sandy shores to shallow muddy substrata and turbid waters, together with high species diversity (108 species) rendered the area suitable for this study. The relationships between fish distribution and environmental factors were monitored by monthly seine netting of fishes at seven sites representative of the range of conditions in St. Lucia. Simultaneously, water turbidity, salinity, and temperature were recorded. The possible influences of substratum type and food availability were also investigated by using recently published data on invertebrate benthos and zooplankton distributions. Published data were also used to determine the diet of the common fish species. The results showed that the distribution of juveniles of the 20 commonest fish species were statistically correlated only with water turbidity, water temperature, and food availability. The correlation with temperature was related to seasonal not spatial temperature patterns. Turbidity and food type influences were difficult to separate but exceptions were the anchovy *Thryssa vitrirostris* (Gilchrist & Thompson) and the sole *Solea bleekeri* Boulenger which occurred only in turbid water despite the widespread occurrence of their prey, and *Gerres acinaces* Bleeker, *G. rappi* (Barnard), and *G. filamentosus* Cuvier, all of which occurred only in clear water although the greatest densities of their bivalve prey were in turbid waters. Similarly, the sparids *Rhabdosargus holubi* (Steindachner) and *R. sarba* (Forsskal) were distributed according to turbidity and not their preferred foods. Principal component analysis with a minimum spanning tree plot and *a* canonical correlation test showed that the fish fauna could be divided into five groups according to their occurrence in various turbidities. These were: clear water species (e.g. Gerreidae) in < 10 NTU, clear to partially turbid species (e.g. *Liza dumerilii* (Steindachner) and *L. macrolepis* (Smith)) in <50 NTU, intermediate turbidity species (e.g. *Valamugil cunnesius* (Valenciennes) and *Leiognathus equula* (Forsskal)) in 10-80 NTU, turbid-water species (e.g. *Eiops machnata* (Forsskal) and *Tbryssa vitrirosms*) in > 50 NTU, and species indifferent to turbidity (e.g. *Acanthopagrus berda* (Forsskal) and *Terapon jarbua* (Forsskal). It is, therefore, suggested that turbidity plays a significant role, either singly, or in combination with other variables in determining the distribution of juvenile marine fishes in estuaries.

Cyrus, D.P. and Blaber, S.J.M. 1987. The Influence of Turbidity on Juvenile Marine Fishes in Estuaries. Part 2. Laboratory Studies, Comparisons with Field Data and Conclusions. Journal of Experimental Marine Biology and Ecology, 109: 71-90.

The turbidity preferences of juveniles of 10 marine species common in estuaries of southeastern Africa were investigated in an experimental turbidity gradient. The tests allowed the elimination of all environmental factors except turbidity. *Liza dumerilii* (Steindachner), was found to be a clear-water species (< 10 NTU); *L. macrolepis* (Smith), *Rhabdosargus sorba* (Forsskal). *Gerres filamentosus* Cuvier, and *Valamugil buchanani* (Bleeker), preferred "clear to partially turbid" water (<50 NTU); *Monodactylus argenteus* (L.) preferred intermediate turbidities (to-80 NTU); and the remaining four, *Rhabdosargus holubi* (Steindachner). *Acanthopagrus berda* (Forsskal), *Pomadasys commersonni* (Lacepede) and *Terapon jarbua* (Forsskal), were indifferent to turbidity. Statistical analysis of laboratory and field data revealed significant correlations. The results of these are discussed in relation to fish distribution patterns, ecology, and the importance of turbidity to juvenile marine fishes in estuaries.

Dean, R.G. 1986. Coastal Armoring: Effects, Principles and Mitigation. Proceedings of the 20th International Conference on Coastal Engineering, American Society of Civil Engineers: New York, 1843-1857.

An attempt is made to conduct a rational assessment of the potential adverse effects of coastal armoring on adjacent shorelines and to propose methodology for mitigation, where appropriate. Specific attention is directed toward claims that armoring causes: profile steepening, increased longshore sediment transport, intensified local scour, transport of sand to substantial offshore distances, etc. The assessment presented here is based on a combination of sound principles and the availability or lack, of laboratory and field data to either support or refute the claims. Although it is found that data relating to coastal armoring effects are sparse, conclusions can be drawn. There seems to be no factual data to support the contentions that armoring causes profile steepening, increased longshore transport, transport of sand to a substantial distance offshore, or significantly delayed profile recovery following a severe erosion event. Armoring does have the potential to cause intensified local scour both in front of and at the ends of an armored segment. Reasons for these effects, based on knowledge of response of a natural profile, are presented. Additionally, armoring which projects into the active surf zone can act as a partial barrier to the net longshore sediment transport, thereby causing downdrift erosion. Methodology is presented for quantifying the appropriate mitigation for a particular armoring situation. The proposed mitigation is the annual placement of sand in the vicinity of the armoring to offset its potential adverse effects. The two potential adverse effects addressed in the methodology include the reduction of sediment supplied to the system as a result of the armoring and the blockage of longshore sediment transport by a protruding armoring installation.

Dean, R.G. 1993. Terminal Structures at Ends of Littoral Systems. Journal of Coastal Research, SI 18: 195-210.

The interaction of deepened navigation channels with the adjacent shorelines is examined with the conclusion that the effect is to cause sediment transport from and draw down of the adjacent beaches, thereby contributing to two undesirable effects: (1) erosion on the adjacent shorelines, and (2) accelerated deposition in the deepened channel. A conceptual method is presented for representing the effect of a deepened channel on the sediment budgets of the adjacent shorelines including the effects of terminal structures (jetties). Through this analysis and examination of several entrances in Florida and elsewhere, it is shown that under the proper conditions, terminal structures can be effective in alleviating both of these undesirable effects.

Deaton, A.S., Chappell, W.S., Hart, K., O'Neal, J., and Boutin, B. 2010. North Carolina Coastal Habitat Protection Plan. North Carolina Department of Environment and Natural Resources. Division of Marine Fisheries, NC. 639 p.

North Carolina's coastal fisheries are among the most productive in the United States because of the diversity of habitats available in the largest estuarine system (2.3 million acres) of any single Atlantic coast state. The state's coastal fisheries also benefit from the location of North Carolina at the transition between mid-Atlantic and south Atlantic regions and a management system that supports active citizen participation. The current management system was developed following the decline of some important fish stocks during the late 1980s and early 1990s (for example, river herring, weakfish, and summer flounder) as fish kills and water-borne disease outbreaks increased. Protection and enhancement of fish habitats utilized by such species was considered especially beneficial in supporting stock recovery. Recognizing the critical importance of healthy and productive habitats to produce fish for human benefits, the North Carolina General Assembly included a provision in the Fisheries Reform Act of 1997 instructing the Department of Environment and Natural Resources (DENR) to prepare Coastal Habitat Protection Plans (CHPPs). *The legislative goal of the plans is long-term enhancement of coastal fisheries associated with each habitat.* Unlike other planning efforts, the Fishery Reform Act mandated that three environmental regulatory commissions (Environmental Management, Coastal Resources, and Marine Fisheries Commissions) must adopt and implement the plan, thus requiring a coordinated management approach. The purpose of the CHPP is to compile the latest scientific information on each habitat so that management needs can be identified to protect, enhance, and restore associated fish populations. The CHPP area includes all habitats within the coastal draining river basins in North Carolina. Because the Fall Line is the upper limit for migration of almost all coastal fisheries species, emphasis is placed on the area downstream from that point. The plan is organized by six fish habitat categories: water column, shell bottom, submerged aquatic vegetation, wetlands, soft bottom, and hard bottom. Each habitat chapter includes information on the distribution, ecological function, status and trends, and threats to those habitats; and management needs to address the threats. The interdependence of these habitats and the need to manage them at an ecosystem level is discussed in the Ecosystem Management and Strategic Habitat Areas Chapter. CHPP goals and recommendations are included in the final chapter.

Defeo, O. and de Alava, A. 1995. Effects of Human Activities on Long-term Trends in Sandy Beach Populations: The Wedge Clam *Donax hanleyanus* in Uruguay. Marine Ecology Progress Series, 123: 73-82.

A long-term analysis of the structure of a bivalve population consisting of the wedge clam *Donax hanleyanus* is described for an exposed temperate sandy beach of Uruguay. The potential effects of human harvesting on the sympatric bivalve *Mesodesma mactroides* (yellow clam) and of salinity were analyzed through time and space (longshore variation). Inter- and intra-annual fluctuations of the different population components (recruits, juveniles and adults) were detected. *D. hanleyanus* showed uneven periods of abundance, with the occurrence of peaks of different magnitude that appeared related to fluctuations in the fishing effort targeting on the yellow clam. *D. hanlepanus* showed a marked longshore variability in population structure and abundance along the 22 km of sandy beach sampled. Spatial variations in salinity and also in the amount of fishing effort exerted on *M. mactroides* seem to be key factors in explaining this variation. This study suggests that further research on sandy beach populations should include human activities as important factors affecting long-term trends.

Defeo, O., McLachlan, A., Schoeman, D.S., Schlacher, T.A., Dugan, J., Jones, A., Lastra, M., and Scapini, F. 2009. Threats to Sandy Beach Ecosystems: A Review. Estuarine, Coastal and Shelf Science, 81: 1-12.

We provide a brief synopsis of the unique physical and ecological attributes of sandy beach ecosystems and review the main anthropogenic pressures acting on the world's single largest type of open shoreline. Threats to beaches arise from a range of stressors which span a spectrum of impact scales from localised effects (e.g. trampling) to a truly global reach (e.g. sea-level rise). These pressures act at multiple temporal and spatial scales, translating into ecological impacts that are manifested across several dimensions in time and space so that today almost every beach on every coastline is threatened by human activities. Press disturbances (whatever the impact source involved) are becoming increasingly common, operating on time scales of years to decades. However, long-term data sets that describe either the natural dynamics of beach systems or the human impacts on beaches are scarce and fragmentary. A top priority is to implement long-term field experiments and monitoring programmes that quantify the dynamics of key ecological attributes on sandy beaches. Because of the inertia associated with global climate change and human population growth, no realistic management scenario will alleviate these threats in the short term. The immediate priority is to avoid further development of coastal areas likely to be directly impacted by retreating shorelines. There is also scope for improvement in experimental design to better distinguish natural variability from anthropogenic impacts. Sea-level rise and other effects of global warming are expected to intensify other anthropogenic pressures, and could cause unprecedented ecological impacts. The definition of the relevant scales of analysis, which will vary according to the magnitude of the impact and the organisational level under analysis, and the recognition of a physical–biological coupling at different scales, should be included in approaches to quantify impacts. Zoning strategies and marine reserves, which have not been widely implemented in sandy beaches, could be a key tool for biodiversity conservation and should also facilitate spillover effects into adjacent beach habitats. Setback and zoning strategies need to be enforced through legislation, and all relevant stakeholders should be included in the design, implementation and institutionalization of these initiatives. New perspectives for rational management of sandy beaches require paradigm shifts, by including not only basic ecosystem principles, but also incentives for effective governance and sharing of management roles between government and local stakeholders.

Denison, P.S. 1998. Beach Nourishment/Groin Field Construction Project: Bald Head Island, North Carolina. Shore and Beach, 66(1): 2-10.

Bald Head Island is a small barrier island near the southeast corner of North Carolina. Its south facing beach began experiencing severe erosion in the early 1970's. By 1994, the problem approached emergency conditions with structures and beach front property being lost at an alarming rate. The decision was made to undertake a large scale beach nourishment project incorporating a groin field to provide relief from the problem. The advent of a combined beach fill/groin field project is not particularly unique or unusual, but extremely restrictive environmental regulations in North Carolina prohibited such projects. To overcome this problem, an innovative project employing large size geotextile material tubes as groins was proposed. This paper describes the actions that were employed to obtain the required permit authorizations, general design considerations, and a summary of construction techniques and problems encountered in completion of the project.

Dolan, R., Godfrey, P.J., and Odum, W.E. 1973. Man's Impact on the Barrier Islands of North

Carolina. American Scientist, 61: 152-162.

A case study of the implications of large-scale manipulation of the natural environment.

Dolan, R., Fenster, M.S., and Holmes, S.J. 1991. Temporal Analysis of Shoreline Recession and Accretion. Journal of Coastal Research, 7(3): 723-744.

The precision with which estimates of shoreline rates-of-change reflect actual changes and predict future changes is dependent on: (1) the accuracy achieved in collecting shoreline position data, (2) the temporal variability of the shoreline movement, (3) the number of measurements used in the computation, (4) the proximity of the observations to actual changes in the trend (sampling bias), (5) the period of time between measurements, (6) the total time span of the record, and (7) the method used to calculate the rate. Over 75% of the data we have assembled in a comprehensive United States shoreline information system (CEIS) were computed using the end point rate (EPR) method. The EPR utilizes only two shoreline positions to calculate rate-of-change values. Methods used less frequently include the average of rates (AOR), linear regression (LR), and jackknife (JK) methods. All of these computation methods fit a linear model to shoreline response. For coastal areas with constant rates of shoreline change through time, the results of all the methods are identical. For a coastline with a non-linear response, a linear estimation method can only approximate the average rate-of-change. As the response of the coastline becomes more non-linear, the differences among the rate-of-change estimates given by the various methods increase. Using data from a 65 km long section of the Outer Banks of North Carolina, we demonstrate the differences in computational methods for estimating shoreline changes and we show how the potential sources of error can bias the final statistics.

Dolan, R. and Stewart, D. 2006. A Concept for Reducing Ecological Impacts of Beach Nourishment and Tidal Inlet Bypassing. Shore and Beach, 74(1): 28-31.

Fifteen years of monitoring and research on the beaches of the Outer Banks of North Carolina have confirmed that the maximum loss of surf-zone organisms occur when nourishment or bypassed sand is placed on the beach in a straight-line configuration along the coast. Our research suggests that if new sand can be distributed in a crescentic configuration that more closely resembles the natural morphology, there will be improvement in maintaining a robust population of wash-zone filter feeders as well as a reduction in rime for recovery following dredging (Donoghue 1999: Dolan et al. 2006). In this discussion, we outline a concept for an alternative nodal design to straight-line dredge disposal on beaches that leaves segments of the nourished beach in a natural state to serve as seed areas for more rapid recovery from the impacts of large-scale beach nourishment. We also suggest that the added cost in using the nodal approach in beach nourishment is justified, given the possibility of a significant reduction in the time required for the organisms to recover and to reoccupy the beach.

Dolan, R., Donogue, C., and Stewart, D. 2006. Long-term Impacts of Tidal Inlet Bypassing on the Swash Zone Filter Feeder *Emerita talpoida* Oregon Inlet and Pea Island, North Carolina. Shore and Beach, 74(1): 23-27.

Over the past 15 years, approximately 5 million m^3 (6.5 million yd^3) of sand has been removed from the navigation channel through Oregon Inlet, North Carolina to maintain water depths for safe passage between the Atlantic Ocean and Pamlico Sound. The sand has been bypassed downdrift to the Pea Island National Wildlife Refuge (PINWR), located on one of the barrier islands of the Outer Banks of North Carolina. The redistribution of the bypassed sand has been monitored to document physical and ecological changes associated with the dredging and bypassing. Our focus has been on the sand sizes and mineralogy, and the numbers and distribution of organisms common to the swash zone. For biological changes, we selected the most common filter feeder inhabiting Atlantic Coast beaches, the mole crab, *Emerita talpoida*. *E. talpoida* spend much of their lives in the swash zone of sand beaches where the maximum physical impacts from bypassing and nourishment occur. They are important in the coastal marine and terrestrial food chain and are, therefore, frequently used as indicator species for nourishment projects. Mole crabs adjust their vertical and horizontal positions across and along the beaches by "surfing" wave uprush, backwash, and inshore currents. Change in the beach slope, sand sizes, mineral composition and compaction can result in a reduction in their numbers. The results of our monitoring show that sand bypassing from Oregon Inlet to Pea Island over the past 15 years has led to a distinct reduction in the sand size, an increase in the heavy mineral composition (primarily illmenite, hornblende, garnet, and magnetite), and a reduction in mole crab numbers. The timing of bypassing relative to the biological cycles of the organisms, the methods used in dredging and disposal (pipeline versus hopper dredge), and the volume and compatibility of sand placed on the beach are all factors determining the magnitude of impacts and the time required for the recovery of *E. talpoida* in large-scale beach fills. In addition to *E. talpoida,* we collected systematic samples of several other organisms that inhabit the swash zone and upper parts of the beach, including *Donax variabilis* (coquina clam) and *Ocypode quadrata* (ghost crab). Papers addressing changes in the population of these species will be submitted in the near future. In this initial discussion, our purpose is to provide an overview of the monitoring program and a summary of the initial large-scale results that have land management implications, and to call attention to the availability of the monitoring data.

Doughty, S.D. 2006. The Influence of Inlet Modifications, Geologic Framework, and Storms on the Recent Evolution of Masonboro Island, NC. [M.S. thesis]: Wilmington, North Carolina, University of North Carolina Wilmington, 149 p.

Masonboro Island is a 13 km long undeveloped barrier island located within a sand deficient southwestern portion of Onslow Bay. The island is situated along major storm tracks and is chronically impacted by tropical and extra-tropical storm events (HOSIER and CLEARY, 1977). The response of the island to storms is a function of the pre-storm condition of the island, the lack of sand in the offshore environment, the influence of adjacent inlets, and the underlying geology (CLEARY et al., 1999). Masonboro Island provides an exemplary setting to study changes in barrier island morphology and shoreline change in response to inlet modifications, geologic framework, and storm impact because the island is undeveloped, remains relatively unnourished, and is flanked by two modified inlets. A GIS based study utilizing aerial photography was used to ascertain shoreline change occurring during 1938 – 2002. The island was divided into a northern, central, and southern segment based on distinct erosional characteristics. Masonboro Island experienced island wide erosion during the 64-year study period. The northern segment, which includes the fillet adjacent to Masonboro Inlet, eroded an average distance of 43 m. The central segment had net shoreline erosion of 110 m, while an area of shoreline within the central reach that was perched on a paleo-interfluve eroded only 106 m. The greatest amount of shoreline change was 164 m of erosion, which occurred along the southern segment of the island adjacent to Carolina Beach Inlet. Short-term analysis (1.3 yr.) of a 2.5 km section of the island/estuary related the influence of a small Pleistocene interfluve to morphological changes within the area. Vibracore data from the estuary behind this area indicate that the Holocene fill is relatively shallow and ranged in thickness from greater than 4 m over the infilled valleys to less than 1.5 m over the interfluves. The network of interfluves extends from the mainland, beneath the estuary, and is overridden by the island. Survey data indicate that the shoreline perched on the interfluve was restricted to ~17 m of erosion compared to an average of ~30 m to either side. The profile of this entire section was lowered in elevation, and approximately 53,000 m^3 of material were removed from the area. The lowered profile made this section of the island increasingly vulnerable to overwash. The coarse grained nature of existing washover fans prevented the regrowth of new dunes. Petrologic analyses indicated that the source of the coarse grained material was a sandy limestone found along the shoreface of the southern two-thirds of the island. Further analyses indicated that the limestone was similar in nature to the coquina facies of the Neuse Formation intermittently exposed in the region.

Doughty, S.D., Cleary, W.J., and McGinnis, B.A. 2006. The Recent Evolution of Storm-Influenced Retrograding Barriers in Southeastern North Carolina, USA. Journal of Coastal Research, SI 39: 122-126.

The coastline along southeastern North Carolina consists of a series of low-relief retrogradational barriers that are frequently impacted by storm activity. The response of two of these barriers to storms is a function of the pre-storm condition of the beach, the nature of the underlying geology, the offshore sediment supply, and the presence of inlets. Hutaff and Masonboro Islands provide exemplary but contrasting barrier settings to study the long-term role of storms and the influence of the adjacent inlets and shoreface on the recent evolution of the barrier system. Both barriers are located in regions where the offshore sediment cover is thin (<1.0 m). Thickness of the Holocene estuarine fill was generally less than 4m on the interfluves and exceeded 8 m in some of the backfilled valleys. The bulk of the estuarine fill is muddy sand that reflects the shallow intertidal nature of the lagoon during the Holocene Transgression. The presence of peat exposures beneath the low tide beach suggest that inlets have played a dominant but variable role in the evolution of the barriers. Since the barriers are situated along major storm tracks, they are chronically impacted by both tropical and extra-tropical storms and are frequently overtopped. The relatively high erosion rates and increased washover susceptibility appear to be directly attributable to a combination of variables including the storm climate and persistent presence of inlets. The low relief of the islands has led to the rapid translation of the barriers during a recent increase of hurricane activity (1996-1999) when four storms made landfall.

Douglass, S.L. 1991. Simple Conceptual Explanation of Down-Drift Offset Inlets. Journal of Waterway, Port, Coastal, and Ocean Engineering, 117(2): 136-142.

A very simple, conceptual explanation of the cause of down-drift offset inlets is presented. Sheltering of a time-varying wave climate by the inlet's ebb-tidal shoal causes the offset. Wave sheltering is defined to include all of the nearshore wave transformations that occur across the ebb-tidal shoals, including wave refraction, diffraction, shoaling, breaking, and other forms of attenuation. Sheltering tacitly includes the effect of the shoal on the directional spread of incident wave energy. This explanation of down-drift offsets is better than the oftquoted explanation of refraction around the ebb shoal for two reasons: (I) The present explanation, sheltering of a variable wave climate, specifically includes the factor of time, which is obviously important in geomorphologic feature development; and (2) there is little justification for explaining the current reversal only in terms of wave refraction. All that is needed to create a down-drift offset inlet is an ebb shoal and a wave environment with a dominant direction of littoral drift and periods of reversal.

Dugan, J.E. and Hubbard, D.M. 2006. Ecological Responses to Coastal Armoring on Exposed Sandy Beaches. Shore and Beach, 74(1): 10-16.

We develop a conceptual model for assessing potential ecological responses to coastal armoring that incorporates the presence, extent and functioning of multiple intertidal zones, as well as changes in beach width in general. We propose that ecological responses to the narrowing of beaches associated with coastal armoring are related to changes in the widths and the dynamics of the different intertidal zones of the beach and that, as habitat narrows in response to armoring, intertidal zones are lost disproportionately from the upper beach. The reduction and loss of intertidal zones, along with expected changes in the deposition and retention of macrophyte wrack, are predicted to depress the diversity and abundance of macroinvertebrates on armored beaches. The combination of reductions in 1) habitat, 2) accessibility at high tides, and 3) macroinvertebrate prey availability is predicted to reduce biocomplexity and affect the use of armored beaches by shorebirds. We investigated several predictions of our model using comparisons of armored and unarmored segments of narrow bluff-backed sandy beaches in southern California. Our results supported those predictions and revealed some unexpected responses to armoring. Intertidal zones were fewer and narrower where armoring was present compared to adjacent unarmored segments. This was evident in the absence of the upper intertidal zones on armored segments of coastline and narrower mid-intertidal zones on armored segments. The standing crop of macrophyte wrack was significantly greater (one to nearly three orders of magnitude) on unarmored segments than on armored segments. Shorebirds responded to coastal armoring as predicted by our model with significantly lower species richness (2.3 times) and abundance (>3 times) on armored segments of beach. All 13 species of shorebirds observed were more abundant on unarmored segments than on armored segments. Although not predicted by our model, the three species of gulls observed also responded to coastal armoring with significantly lower abundance (4.7 times) on armored segments. We predict that the amount of interaction between a coastal armoring structure and the coastal processes of waves and tides will affect the ecological responses to the structure. Our model provides a framework that could be used in investigating ecological responses to coastal armoring of other types and tidal heights and in other coastal regions. The accelerated loss of beaches associated with rising sea levels and the implications of our results indicate further investigation of ecological responses to coastal armoring is needed.

Dugan, J.E., Hubbard, D.M., Rodil, I.F., Revell, D.L., and Schroeter, S. 2008. Ecological Effects of Coastal Armoring on Sandy Beaches. Marine Ecology, 29(Suppl. 1): 160-170.

Use of coastal armoring is expected to escalate in response to the combination of expanding human populations, beach erosion, and sea level rise along the coasts. To provide a conceptual framework, we developed hypotheses concerning the ecological effects of beach habitat loss associated with coastal armoring. As beaches narrow in response to armoring, dry upper intertidal zones should be lost disproportionately, reducing the habitat types available and the diversity and abundance of macroinvertebrates. Predators, such as shorebirds, could respond to a combination of (i) habitat loss; (ii) decreased accessibility at high tides; and (iii) reduced prey availability on armored beaches. To examine those predictions, zone widths and the distribution and abundance of macroinvertebrates and birds were compared on paired armored and unarmored segments of narrow bluff-backed beaches in southern California. Our results supported the predictions and revealed some unexpected effects of armoring on birds. Dry upper beach zones were lacking and mid-beach zones were narrower (>2 times) year-round on armored segments compared to adjacent unarmored segments. The abundance, biomass and size of upper intertidal macroinvertebrates were also significantly lower on armored segments. Shorebirds, most of which were foraging, responded predictably with significantly lower species richness (two times) and abundance (>3 times) on armored segments. Gulls and other birds (including seabirds), which use beaches primarily for roosting, were also significantly lower in abundance (>4 times and >7 times respectively) on armored segments, an important unexpected result. Given the accelerating pressures on sandy beaches from coastal development, erosion and rising sea levels, our results indicate that further investigation of ecological responses to coastal armoring is needed for the management and conservation of these ecosystems.

Edwards, S.F. and Gable, F.J. 1991. Estimating the Value of Beach Recreation from Property Values: An Exploration with Comparisons to Nourishment Costs. Ocean & Shoreline Management, 15: 37-55.

This paper explores how the economic value of recreation at local public beaches can be estimated from nearby property values. The negative effect of distance from the nearest public beach on coastal property values was used to reveal recreational value. Estimates of recreational value were also compared to the costs of beach nourishment that were calculated from a simulation of beach erosion caused, in part, by increases in relative sea-level. Although a complete benefit-cost analysis was not feasible, the results suggest that potential losses of recreational value by local users alone could establish the efficiency of beach nourishment projects.

Ells, K. and Murray, A.B. 2012. Long-term, Non-local Coastline Responses to Local Shoreline Stabilization. Geophysical Research Letters, 39: L19401.

The future of large-scale coastline evolution will be strongly coupled to human manipulations designed to prevent erosion. We explore the consequences of this coupling using a numerical model for large-scale coastline evolution to compare the long-term, non-local effects of two generalized classes of shoreline stabilization: 1) beach nourishment (the addition of dredged sand to an eroding beach), and 2) hard-structures (e.g., seawalls, groynes, etc.) which fix the position of the shoreline without adding sand. In centurial model experiments where localized stabilization is maintained in the context of changing climate forcing, both forms of stabilization are found to significantly alter patterns of erosion and accretion at distances up to tens of kilometers. On a cuspate-cape coastline similar to the North and South Carolina coast, USA, with stabilization applied to the eroding updrift flank of a single cape, perturbations to coastline evolution are qualitatively similar within ~20 km for each stabilization scenario, though they differ in magnitude both updrift and downdrift of the stabilized shoreline. The "human" signal in coastline change can extend as far as a neighboring cape (approximately 100 km away), but these long-range effects differ for each scenario. Nourishment resulted in seaward growth of the stabilized cape, increasing the extent that it blocked sediment flux in downdrift regions of the coast through wave shadowing. When stabilized with a hard structure the cape's initial position remain fixed, decreasing wave shadowing.

Evans, P.R., Ward, R.M., Bone, M., and Leakey, M. 1998. Creation of Temperate-Climate Intertidal Mudflats: Factors Affecting Colonization and Use by Benthic Invertebrates and their Bird Predators. Marine Pollution Bulletin, 37: 535-545.

Colonization of a recreated area of intertidal land by marine invertebrates and their bird predators was studied from April 1993 to August 1997. The most important food of large shorebirds, the ragworm *Nereis diversicolor*, did not reappear until late summer 1995 and did not become abundant until the following autumn. Annual attempts at colonization by the crustacean *Corophium volutator*, the main food of several small shorebird species, failed until summer 1996 when animals survived through the subsequent winter for the first time. Colonization by the mudsnail *Hydrobia ulvae* took place a year after flooding of the site, but densities in 1997 were still well below those found elsewhere on the adjacent estuary. The delay in successful colonization by *Nereis* and *Corophium* may be attributable in part to the compaction of the intertidal muds caused by the earthmoving equipment used to contour the site. The slow increase in *Hydrobia* density may be a consequence of low organic content of the mud. Bird use is concentrated chiefly during the hours when the adjacent estuarine mudflats (with unrestricted tidal flow) are covered by the tide, since the new site then provides a supplementary feeding area. Peak daytime usage occurs during the migratory passage periods when birds need to feed for longer periods than usual, in order to refuel for their migrations; high usage is also anticipated in cold winters. On this evidence, creation of intertidal areas in mitigation for any lost nearby to industrial or other development should take place at least three years before the losses, in order to make the new areas profitable for feeding waterfowl.

Fenster, M. and Dolan, R. 1996. Assessing the Impact of Tidal Inlets on Adjacent Barrier Island Shorelines. Journal of Coastal Research, 12(1): 294-310.

We investigated barrier island-tidal inlet sand sharing systems along the United States' mid-Atlantic coast to determine the impact of tidal inlets on adjacent shorelines. We used two reaches in our analyses with different natural (unstructured) settings: the wave-dominated Outer Banks of North Carolina and the mixed-energy, tide-dominated Virginia barrier islands. Three criteria were used to delineate inlet domination and inlet influence on the adjacent barrier shorelines based on the spatial distribution of shoreline rate-of-change values: (1) the cessation of abrupt changes, i.e., the reduction in variability in the rates of change along-the-shore;(2) a change in the sign of the rate value from erosion to accretion or vice versa; and (3) a change in the increasing or decreasing trends in rate values. The maximum distances of inlet influence extend to 6.8 km updrift and 5.4 km downdrift of inlets along the Virginia barrier islands and 6.1 km and 13.0 km for the updrift and downdrift inlet shorelines along the Outer Banks barriers. Additionally, shoreline changes can be dominated by inlet processes to a maximum distance of 4.3 km. These results support previous conclusions that sand bypassing processes exert greater influence on mixed-energy, short barrier island shorelines than on the wave-dominated, long, linear barrier island shorelines.

Fisher, J.S., Overton, M.F., and Jarrett, T. 2004. Pea Island Shoreline: 100-Year Assessment. Raleigh, North Carolina, FDH Engineering, Inc. for North Carolina Department of Transportation, 18 p.

The ocean shoreline on Pea Island between Oregon Inlet and Rodanthe (North Carolina Outer Banks) is highly variable and includes some of the highest shoreline erosion rates found along the entire North Carolina coast. FDH Engineering, Inc. was retained by URS Corporation to participate in a study for the North Carolina Department of Transportation to estimate the cost to stabilize this shoreline with beach nourishment for a 100-year period. This shoreline stabilization would be used in conjunction with a new bridge over Oregon Inlet that would incorporate the existing position of NC12 between the Oregon Inlet and the Village of Rodanthe. The study begins at a point approximately 1 mile south of the Oregon Inlet terminal groin and extends about 12 miles south along Pea Island to the southern limit of the Pea Island National Wildlife Refuge or just north of the Village of Rodanthe.

Fitzgerald, D.M. 1988. Shoreline Erosional-Depositional Processes Associated with Tidal Inlets. Lecture Notes on Coastal and Estuarine Studies, 29: 186-225.

Tidal inlets strongly influence the overall dynamics of barrier island shorelines. The average barrier length along a coast is controlled by the size and number of tidal inlets, which in turn, are primarily a function of a region's tidal range and bay area. The greatest magnitude erosional depositional changes along a barrier chain occur next to tidal inlets, and these losses and gains of sand are a direct consequence of tidal inlet processes. During a transgression, as at present, ephemeral, migrating and stable inlets provide a means for transferring a large proportion of the coastal sand reserves landward past the eroding shoreline. This is accomplished through the transport of sand to flood-tidal deltas, tidal creeks and the marsh surface, and through the building of recurved spits. Ebb-tidal deltas represent a large sand reservoir which may be comparable in volume to that of the adjacent barrier islands. Slight changes in the size of an ebb delta, due to changes in the inlet tidal prism, can greatly affect the sand supply to nearby beaches. The sand shoals associated with ebb-tidal deltas may act as natural offshore breakwaters, reducing wave energy on landward beaches. Their removal may cause or accelerate shoreline erosion. Along mixed energy shorelines inlet sediment bypassing occurs by three major mechanisms: 1. inlet migration and spit breaching, 2. stable inlet processes, and 3. ebb-tidal delta breaching. Migrating tidal inlets tend to have relatively shallow inlet channels that erode through non-resistant sediments. Spit breaching is an uncommon event, but its occurrence results in the bypassing of large amounts of sand. In the other two methods of bypassing, large bar complexes are formed on the downdrift side of the ebb-tidal delta. These bars, which may be over 1 km long and may contain more than 500,000 m^3 of sand, migrate onshore welding to the landward beach. The process of bar attachment dictates the shape of many barriers.

Fitzgerald, D.M. and Hayes, M.O. 1980. Tidal Inlet Effects on Barrier Island Management. Coastal Zone 1980, American Society of Civil Engineers: New York, 2355-2379.

Effective management of barrier islands necessitates an understanding of the processes which cause short: and long-term shoreline erosional-depositional changes. Equally important is determining the locations where these changes are most likely to occur. Fieldwork at mesotidal barrier islands along the coasts of New England, South Carolina, Northwestern Germany and the Gulf of Alaska has led to the very basic conclusion that barriers are most unstable at their ends and that the shoreline changes which occur at these locations are a result of tidal inlet processes. The ebb-tidal deltas which front inlets are huge reservoirs of sand and may be comparable in volume to that of adjacent barriers. Slight changes in the size of the ebb-tidal delta can increase or decrease the supply of sediment to the downdrift beaches, resulting in their buildup or erosion. The landward transport of sand through inlets to the flood-tidal deltas is another process which can decrease a barrier's sediment supply. Wave refraction around the ebb-tidal delta causes a long-shore transport reversal along the downdrift barrier. At this location sand is transported back toward the inlet which often results in a progradation of the updrift end of the barrier island. This sediment trapping process can also be responsible for sand starved beaches further down the barrier. During storms the ebb-tidal delta acts as an offshore breaker and protects the adjacent shoreline from storm wave attack. Inlet migration, which occurs in areas that have high longshore sediment transport rates relative to the tidal scour ability of the inlets, results in erosion of the downdrift barrier and the addition of curved beach ridges to the updrift barrier. The recurved spit that builds during this process is an unstable part of a barrier island due to breachings that frequently occur along its length. The processes of inlet sediment bypassing control the rate at which sand is transported through a tidal inlet from the updrift barrier to the downdrift barrier. The sand that is added to the downdrift barrier normally occurs in packets in the form of large landward-migrating bar complexes. The location where these bar complexes weld to the beach, substantially building up that portion of the barrier, is a function of the size of the tidal inlet, the orientation of the inner inlet channel and the nature of the channel bank sediments. Collectively, the tidal inlet processes can account for dramatic shoreline changes along the ends of the barriers and indirectly may also be responsible for erosional-depositional patterns along the middle of the barriers. The effects of these processes can be measured over a period of several years or in as little time as a few hours. Management decisions which do not consider tidal inlet influences may suffer costly consequences.

Fletemeyer, J. 1983. The Impact of Beach Nourishment on Sea Turtle Nesting. The New Threat to Beach Preservation: Papers Presented at the 1983 Joint Annual Meeting of the American Shore & Beach Preservation Association and Florida Shore & Beach Preservation Association, Boca Raton, FL, 168-177.

The impact of beach renourishment on sea turtle nesting was investigated during an eight-year period from 1976 to 1983. Results of this investigation indicated that both short-term and long-term effects on nesting could be defined. On a short-term basis, turtles were observed to abandon renourished beaches and select natural beaches (i.e., those not renourished) neighboring on the north and south. On a long-term basis, when data was compared between nesting behavior on natural beaches and renourished beaches, the following observations could be made: (1) turtles nesting on renourished beaches constructed nests at a shallower depth, and (2) nesting success was lower on renourished beaches. Despite these findings, which suggest that beach renourishment has a negative impact on sea turtle nesting, it is believed that beach renourishment is ultimately beneficial to nesting because it is responsible for increasing the area of the beach available for nest site selection.

Flynn, B. 1992. Beach Nourishment, Sea Turtle Nesting, and Nest Relocation in Dade County, Florida. New directions in Beach Management: Proceedings of the 5th Annual National Conference on Beach Preservation Technology, St. Petersburg, Florida, 381-394.

Considerable controversy now exists in the development and implementation of federal and state management policies to protect endangered sea turtles. One of the major points of discussion involves the viability of sea turtle nest relocation as a management tool where factors such as urbanization, predation, or coastal construction activities might otherwise result in poor hatch rates. Management policies now proposed by State and Federal regulatory agencies discourage the routine relocation of sea turtle nests unless an immediate and unavoidable threat to the viability nest exists. These positions are largely based on potential detrimental effects to hatchlings related to the handling of the eggs and the effects of altered environmental conditions during hatchery incubation. Proponents of nest relocation point to the large number of successful programs throughout the State. In many cases the documented hatch rates of relocated clutches can exceed those of adjacent in-situ nesting sites. In addition, they point out, the criteria for determining when relocation should be used can be highly variable and location-specific. Discounting the need for relocation without careful consideration of the full potential for nest destruction, predation, inundation or other threats on a site-specific basis may inadvertently result in a greater risk than that posed by competently conducted relocation. Another concern regarding the application of more stringent sea turtle protection policies is their potential effect on beach restoration and management programs throughout the state. Regulatory concerns already exist regarding the potential effects of beach nourishment on sea turtle nesting activity and success due to scarping of the beach face, the creation of sand characteristics unsuitable for nesting, and the disturbance of nesting behavior due to construction. Although not their primary intent, these proposed policies can, in some cases, have a secondary effect of restricting beach restoration activities to the less favorable winter months. This can result in more difficult and less predictable project planning, significantly higher cost, and a greater net environmental impact resulting from the project to other components of the marine and coastal systems. This paper will describe and discuss two Dade County sea turtle protection programs representing highly urbanized (Miami Beach) and relatively natural (Key Biscayne) Dade beach areas. These programs are directly relevant to the issues above in that they have historically emphasized nest relocation, and have evolved in conjunction with one of the largest beach restoration efforts in the State. The data indicate that since 1980, the annual rate of Dade County sea turtle nesting has increased more than ten-fold. This increase may be at least partially attributable to the creation or enhancement of over 15 miles of additional beach nesting habitat through beach restoration projects constructed during that time. The rationale for relocation, and the past and present status of these Dade County programs are also discussed.

Galgano, F.A., Jr. 2004. Long-term Effectiveness of a Groin and Beach Fill System: A Case Study Using Shoreline Change Maps. Journal of Coastal Research, SI 33: 3-18.

Along the eastern coast of the United States, groins have been emplaced to stabilize beaches for more than 100 years. The popular assessment of their performance is that they typically have not worked and have caused more problems than they have solved. In many cases, these assessments have been made based upon anecdotal information and without the benefit of long-term shoreline change data. As a consequence, some states and local governments have altogether banned the use of groins as a shoreline protection structure. However, in many circumstances, groins have functioned effectively and stabilized an eroding beach without seriously harming adjacent areas. In the face of beach erosion and property loss, groins combined with beach fill should be available as an option as a beach stabilization system where appropriate. This study employs high-quality, spatially and temporally robust (147-year) shoreline change data to assess the performance a groin field. Historical literature and shoreline change maps were studied at Bethany Beach, Delaware to assess the effectiveness of a groin field built there in the 1930s and 40s. The data illustrate shoreline movements before and after groin emplacement. The results of the analysis suggest that the groins at Bethany Beach were poorly constructed they required several renovations and were built too short to be truly effective. However, the data also indicate that the groins, in conjunction with beach fill, arrested beach erosion at the site and effectively stabilized the beach for nearly 50-years notwithstanding their structural deficiencies.

Gomez-Pina, G. 2004. The Importance of Aesthetic Aspects in the Design of Coastal Groins. Journal of Coastal Research, SI 33: 83-98.

Typical coastal groin field systems are associated with significant negative visual impact, independent on the undesirable effects that such groins might cause on downdrift beaches. Nevertheless, few nation-wide coastal zone policies have tried to minimize the negative visual intrusion of such groins. Spain, however, has led that kind of policy. Despite any unattractive aspects, coastal groins are, in many cases, an unavoidable and necessary complement to beach nourishment. They delay fill erosion and lessen periodic renourishment costs. This solution has been socially well accepted in many cases when aesthetic aspects have been incorporated explicitly as a crucial part of the whole beach restoration project. In particular terminal groins can improve the social acceptance of beach restoration projects when adequately designed from both aesthetic and recreational standpoints.

Gopalakrishnan, S., Smith, M.D., Slott, J.M., and Murray, A.B. 2011. The Value of Disappearing Beaches: A Hedonic Pricing Model with Endogenous Beach Width. Journal of Environmental Economics and Management, 61: 297-310.

Beach nourishment is a policy used to rebuild eroding beaches with sand dredged from other locations. Previous studies indicate that beach width positively affects coastal property values, but these studies ignore the dynamic features of beaches and the feedback that nourishment has on shoreline retreat. We correct for the resulting attenuation and endogeneity bias in a hedonic property value model by instrumenting for beach width using spatially varying coastal geological features. We find that the beach width coefficient is nearly five times larger than the OLS estimate, suggesting that beach width is a much larger portion of property value than previously thought. We use the empirical results to parameterize a dynamic optimization model of beach nourishment decisions and show that the predicted interval between nourishment projects is closer to what we observe in the data when we use the estimate from the instrumental variables model rather than OLS. As coastal communities adapt to climate change, we find that the long-term net value of coastal residential property can fall by as much as 52% when erosion rate triples and cost of nourishment sand quadruples.

Gorzelany, J.F. and Nelson, W.G. 1987. The Effects of Beach Replenishment on the Benthos of a Sub-tropical Florida Beach. Marine Environmental Research, 21: 75-94.

Changes in the benthic fauna of the near-shore zone were examined before and after a beach replenishment project on the central Florida east coast. Results indicated that the near-shore sand beach community is relatively species rich, although abundance is dominated by only two species of bivalves, the coquina clams *Donax variabilis* and *Donax parvula.* Strong gradients of increased species richness and abundance were found with values increasing at the more seaward sites for both control and nourishment locations. This distributional pattern was unchanged by beach nourishment. Comparison of mean number of individuals per core across dates and among transects (two-way analysis of variance) showed no indication of significant negative effects of beach nourishment. Similar analysis for mean number of species per core also failed to show significant negative effects. Negative biological effects of beach nourishment may have been minimized in the present case due to a seasonal offshore movement of the dominant coquina clams. The close match of mean fill grain size to ambient grain size and an apparent lack of substantial fill movement into the biologically more diverse offshore areas may also have diminished biological damage.

Greene, K. 2002. Beach Nourishment: A Review of the Biological and Physical Impacts. Washington (DC): Atlantic States Marine Fisheries Commission. ASMFC Habitat Management Series No. 7, 174 p.

Various monitoring studies have been conducted over the years, with impacts ranging from essentially benign, to long-term consequences to the marine environment. The majority of east coast beach nourishment studies conducted to date, have taken place in the Southeast and there is a need to carry out more studies in the Mid-Atlantic and the Northeast region. This paper will review major studies that have concluded insignificant impacts, with a brief discussion of the findings. Those beach nourishment studies that have found the effects to be more serious, or non-beach nourishment studies and laboratory experiments whose results suggest potential impacts, may be discussed in greater detail. This will allow state's the opportunity to follow up on studies that may be pertinent to their locale. This information will provide states with a basic understanding of what beach nourishment is, the level of each state's involvement, and how these activities are affecting the marine and beach environment. If these actions are deemed to be having possible deleterious effects on Commission-managed species and their habitat, the Habitat Program may respond by developing measures to address these problems. Finally, this paper can serve to educate the general public and provide sources that can be further examined to gain an in-depth knowledge of beach nourishment.

Griffin, D.B., Murphy, S.R., Frick, M.G., Broderick, A.C., Coker, J.W., Coyne, M.S., Dodd, M.G., Godfrey, M.H., Godley, B.J., Hawkes, L.A., Murphy, T.M., Williams, K.L., and Witt, M.J. 2013. Foraging Habitats and Migration Corridors Utilized by a Recovering

Subpopulation of Adult Female Loggerhead Sea Turtles: Implications for Conservation. Marine Biology, 160: 3071-3086.

From 1998 to 2008, 68 adult female loggerhead sea turtles (*Caretta caretta*) were instrumented with platform transmitter terminals at nesting beaches in Georgia, North Carolina (NC) and South Carolina (SC) on the East Coast of the United States of America (30°48'N, 81°28'W to 33°51'N, 77°59'W). The majority of post-nesting loggerheads (N = 42, 62%) migrated to foraging habitats in the Mid-Atlantic Bight during May–October, with a subsequent migration occurring during November–March to foraging habitats south of Cape Hatteras, NC. Nine (13%) loggerheads initially foraged in the near-shore, coastal areas of the South Atlantic Bight, but moved to offshore habitats—closer to the Gulf Stream—during November– March, while fourteen (21%) loggerheads remained in foraging areas along the mid-continental shelf off of the eastern coast of Florida and/or continued southward to Florida Bay and the Bahamas. The present study delineates important, post-nesting foraging habitats and migration corridors where loggerheads may interact with commercial fisheries—providing managers opportunities to develop and implement optimally effective conservation actions for the recovery of this threatened species.

Griggs, G.B. 2004. Headlands and Groins: Replicating Natural Systems. Journal of Coastal Research, SI 33: 280-293.

California is the most populous state in the nation, and 80 percent of its 35 million people now live within 50 km. of the coast. Beaches play a major role in the state's economy as recreational outlets and vacation destinations but also serve to buffer developed coastal bluffs and cliffs from direct wave attack. A reduction of beach sand supply has taken place over the past several decades due to a combination of dams on coastal streams, armoring of eroding seacliffs, mining of sand directly from river beds as well as the shoreline and the reduction in large sand contributions from coastal construction projects. The most common historical response to both seasonal beach erosion and long-term shoreline retreat in California has been seawalls and rip-rap. In recent years beach nourishment has been advocated by local government and the tourist industry as a solution to shoreline erosion and beach losses. More recently, the concept of removing dams which no longer serve any useful purpose and have trapped large volumes of beach sand have begun to be seriously evaluated. Groins have been successfully used in California to create, widen or stabilize beaches. Many of California's beaches exist because of natural littoral drift barriers such as headlands and a number owe their existence to artificial barriers such as groins, jetties and breakwaters. Groins mimic natural features and with appropriate planning, can be used more extensively to hold the sand on California's beaches in place, thereby increasing both shoreline protection and recreational areas at far less maintenance, cost and with less negative environmental impact than either armoring or artificial nourishment.

Griggs, G.B. 2005. The Impacts of Coastal Armoring. Shore and Beach, 73: 13-22.

The increasing development of our coastlines combined with the effects of sea level rise, hurricanes, and El Niño and other storm events with their associated elevated sea level and wave attack, have all contributed to the continuing erosion or retreat of the shoreline. Historically, hardening the shoreline through the construction of seawalls or rock revetments has been the most common approach to reducing the impacts of wave attack and attempting to halt or slow coastal retreat. Ten percent or 110 miles of California's entire coastline has now been armored, although coastal protection structures can vary widely in their cost, size, effectiveness, lifespan and impacts. The increase in the amount of coastline armored in recent decades as well as proposals for new projects has been accompanied by an increased concern with the cumulative impacts of these protection structures. The potential impacts of armoring the coastline include visual effects, impoundment or placement losses, reduction of beach access, loss of sand supply, and passive and active erosion. Each of these issues should be given more careful consideration as new structures are proposed.

Grippo, M.A., Cooper, S., and Massey, A.G. 2007. Effect of Beach Replenishment Projects on Waterbird and Shorebird Communities. Journal of Coastal Research, 23(5): 1088-1096.

In an effort to identify the potential effects of beach replenishment projects on waterbird and shorebird communities, avian abundance, species richness, and behavior were monitored at three transects before and after beach replenishment. The length of the study was 2 years with weekly surveys for most of the year. Data were analyzed with a Before/After Control Impact Pairs (BACIP) design, which incorporated spatial and temporal data from a control beach and replenished beaches into one analysis. No significant changes in mean waterbird and shorebird abundance were detected after replenishment, although the data do suggest that habitat use by waterbirds might have increased at replenished beaches. Of the individual waterbird and shorebird species examined, only Laughing Gulls and Black- bellied Plovers exhibited a significant change in abundance after replenishment, with these species exhibiting an increase and a decrease, respectively. Postreplenishment changes in waterbird and shorebird species richness were not consistent. Waterbird feeding activity declined significantly after replenishment, but, overall, there was no strong evidence that shorebird and waterbird feeding activity were altered by replenishment. Despite the BACIP design, high variability was common for most parameters. Recommendations for future bird monitoring projects include the use of multiple control sites and scheduling surveys to reduce all potential sources of variability.

Hackney, C.T., Posey, M.H., Ross, S.W., and Norris, A.R. 1996. A Review and Synthesis of Data on Surf Zone Fishes and Invertebrates in the South Atlantic Bight and the Potential Impacts from Beach Nourishment. Prepared for U.S. Army Corps of Engineers, Wilmington District, Wilmington, NC, 111 p.

This review identified important fish and invertebrate species that use the beach zone, supratidal to subtidal, along the South Atlantic Bight (SAB). All information available on these species is summarized and cited. When data were not available on species of the SAB, information from closely related species was used.

Hall, M.J. and Pilkey, O.H. 1991. Effects of Hard Stabilization on Dry Beach Width for New Jersey. Journal of Coastal Research, 7(3): 771-785.

Disagreement exists over the role of seawalls and other forms of hard stabilization in degradation of recreational beaches. Potential detrimental effects of sea walls are categorized as placement loss, passive erosion and active erosion. In this study, however, the impact of hard stabilization is studied independently of the question of mechanism of beach degradation. Dry beach widths were measured for the open ocean coast of New Jersey in order to determine the relationship between hard stabilization structures and dry beach width. Beaches were classified as one of five types discriminating on the basis of: (1) shore-parallel structure such as seawalls and revetments, (2) shore-perpendicular structures such as groins and jetties, (3) shore-perpendicular groins with no sand offset on either side, and (4) no hard stabilization structures. Beaches with stabilization structures were statistically narrower than the unstructured beaches. Although most of the beaches with shore parallel structures also contained groins, they were classified as a Type I beach and had the narrowest average dry beach width of 9 m. Beaches with groins only (Type II and III) had an average width of 18 m. Unstructured beaches were significantly wider than those with hard structures, averaging 55 m in dry width. Although hard structures may have successfully protected upland property on the New Jersey shoreline, significant beach degradation has resulted from this approach to shoreline management.

Hanson, H. and Larson, M. 2004. Wave Directional Characteristics as a Design Parameter for Groin Performance. Journal of Coastal Research, SI 33: 188-197.

The functioning of a groin system is based on the separation of the open coast into compartments, allowing the coastal stretch within each compartment to rotate to become locally close to parallel to the breaking wave crests. In doing so, the coast becomes more stable as the local longshore sediment transport rate reaches a minimum. However, as reported in several studies, even though properly designed, it is possible that groin systems not only cause down-drift beaches to erode, but also contribute to the generation of rip currents. These rip currents run along the updrift side of the structure, moving sediment offshore where it may be, at least in part, lost from the system. It is well known that the directionality of the incident waves is a central factor for the shoreline response to groins. Until now, however, this directionality has been characterized only by the ratio of net transport rate Q_n to gross transport rate Q_g. In this study it is concluded that the phase lag between the forcing and the morphodynamic response is another key factor responsible for these offshore losses. Based upon this, a relaxation time for open-coast systems and a non-dimensional morphodynamic response factor for groin compartments are introduced as new design parameters for groin systems.

Hay, M.E. and Sutherland, J.P. 1988. The Ecology of Rubble Structures of the South Atlantic Bight: A Community Profile. U.S. Fish and Wildlife Service Biological Report 85(7.20), 67 p.

This community profile provides an introduction to the ecology of communities on rubble structures in the South Atlantic Bight (Cape Hatteras, North Carolina, to Cape Canaveral, Florida). The most prominent rubble structures in this area are jetties built at the entrances to major harbors. We concentrate much of our discussion on these types of structures since most of the available literature concerns jetties or biological communities similar in species composition to those that occur on jetties. However, we also discuss the ecology of natural hard substrate habitats in general and how these compare with the communities that develop on rubble structures. It is our hope that this text will serve as a general, yet thorough, review of why such structures are built, their general effects on near shore sediment dynamics, and what forces affect the organisms that live in close association with these structures.

Hayden, B. and Dolan, R. 1974. Impact of Beach Nourishment on Distribution of *Emerita talpoida*, the Common Mole Crab. Journal of the Waterways, Harbors and Coastal Engineering Division, 100: 123-132.

In 1972, under the sponsorship of the National Park Service, the writers were contracted to assess the ecological and physical impact of a large beach nourishment program at Cape Hatteras, N.C. The location of the nourishment is shown in Fig. 1. Since all aspects of the beach-face ecology could not be monitored, it was decided to concentrate on the common mole crab. As an inhabitant of the swash zone, *Emerita talpoida* is vulnerable to beach-face modification and thus likely to exhibit a response to such activity. In addition, *E. talpoida* is an important link between subaqueous and subaerial food chains; it feeds on plankton in the swash zone and, in turn, is subject to predaceous shorebirds. Significant disruption of *E. talpoida* populations could have ecological implications to the barrier-island ecosystem.

Hayes, M.O. 1980. General Morphology and Sediment Patterns in Tidal Inlets. Sedimentary Geology, 26: 139-156.

Tidal inlet sediments make up a significant portion of most barrier island complexes. Inlet-affiliated sedimentary units usually include an ebb-tidal delta (seaward shoal), a flood-tidal delta (landward shoal) and inlet-fill sequences created by inlet migration and recurved spit growth. The morphological components of ebb-tidal deltas include a main ebb channel flanked by linear bars on either side and a terminal sand lobe at the seaward end. This channel is bordered by a platform of sand dominated by swash bars which is separated from adjacent barrier beaches by marginal flood channels. The ebb-delta sand body is coarser grained than other sedimentary units of the inlet and contains polymodal cross-bedding with a slight ebb dominance. Flood-tidal deltas consist of a flood ramp and bifurcating flood channels on the seaward side, which are dominated by flood currents and flood-oriented sand waves, and ebb shields, ebb spits and spillover lobes on the landward side, which contain an abundance of ebb-oriented bedforms. A proposed stratigraphic sequence for a typical flood tidal-delta contains bidirectional, large-scale crossbedded sand at the base, predominantly large-scale (flood-oriented) crossbedded sand in the middle, and finer-grained tidal flat and marsh sediment at the top. Inlets migrate at rates that vary from a few to several tens of meters per year, depending upon such variables as rate of longshore sediment transport and depth of the inlet. Inlet-fill sequences, which fine upward, contain coarse, bidirectional crossbedded sediments at the base, polydirectional crossbedded sands in the middle, and finer-grained aeolian sand at the top. Both tidal-delta morphology and relative size and abundance of ebb- and flood-tidal deltas are considerably different in different oceanographic settings. Microtidal (tidal range T.R.=0-2 m) areas tend to have smaller ebb-tidal deltas and larger flood-tidal deltas; whereas, .mesotidal (T.R. = 2-4 m).areas show just the opposite trend. Large waves tend to inhibit the development of ebb-tidal deltas and accentuate the growth of flood-tidal deltas.

Hayes, M.O. and FitzGerald, D.M. 2013. Origin, Evolution, and Classification of Tidal Inlets. Journal of Coastal Research, SI 69: 14-33.

Tidal inlets are defined as major tidal channels separating individual barrier islands or harrier spits and adjacent headlands. Two types of barrier islands are recognized: (1) those that consistently migrate landward (transgressive), and (2) those that build seaward (prograding or regressive). The most common types include those that formed from (1) elongation of sand spits from major headlands; (2) drowning of coastal sand ridges; and (3) landward migrating transgressive barriers that stabilized and then prograded seaward during the mid-Holocene on the interfluves between the major lowstand valleys. Large tidal inlets developed in these former river valleys. The influence of tidal range vs. average wave height plays an important role in determining the morphology of the barrier islands and the character of the tidal inlets. As an example, the outer margins of the Georgia Bight, where the tidal range is microtidal and wave heights are greatest, most barrier islands are long (28-30 km), wave-dominated, and transgressive. Toward the mixed energy head of the Bight, where the tidal range is mesotidal and waves are relatively small, barrier islands tend to be short (<15 km), regressive, and drumstick-shaped. Tidal inlets having large flood-tidal deltas are mostly restricted to the microtidal margins of the Bight, whereas inlets with large ebb-tidal deltas dominate the mesotidal head of the Bight. Most tidal inlets form by the following mechanisms: (1) storm-generated scour channels; (2) spit growth across the entrances to flooded valleys during the mid-Holocene; (3) intersection of major tidal channels by landward-migrating transgressive harrier islands; and (4) tidal prism-controlled, evenly spaced inlets that evolve in regions lacking major former river valleys.

Hettler, W.F., Jr., and Barker, D.L. 1993. Distribution and Abundance of Larval Fishes at Two North Carolina Inlets. Estuarine, Coastal and Shelf Science, 37: 161-179.

Two major barrier island inlets that connect Pamlico Sound with the Atlantic Ocean were quantitatively sampled for larvae at new moon monthly intervals during 1988-89. Simultaneous tows of bottom and surface 1 m, 500 micron mesh nets were made day and night at single stations inside of Oregon Inlet and Ocracoke Inlet. Oregon Inlet, located in a more temperate marine province, was expected to have a different taxonomic community than Ocracoke Inlet, but, of 77 taxa collected from both inlets, 54 occurred at both inlets. Clupeoids and sciaenids were the dominant taxa in both inlets. At Oregon Inlet the lowest abundance of larvae occurred in February and the highest occurred in late August, whereas at Ocracoke Inlet, November and June were the lowest and highest months of larval abundance. At Oregon Inlet, 63% of the total number of larvae were caught near the bottom, but at Ocracoke Inlet, only 38% were caught near the bottom. Atlantic menhaden, *Brevoortia tyrannus,* were 40 times more abundant at the surface than at the bottom at Ocracoke Inlet. Most larvae were caught at night at both inlets. The times of occurrence and peak abundance for most species did not appear linked between inlets. Twenty-one species were significantly different in mean length between the two inlets.

Hettler, W.F., Jr. and Chester, A.J. 1990. Temporal Distribution of Ichthyoplankton Near Beaufort Inlet, North Carolina. Marine Ecology Progress Series, 68: 157-168.

Temporal distribution of the larval/early juvenile fish community of a major inlet on the North Carolina coast was studied from August 1986 through July 1987 using bow-mounted pushnets. Three main seasonal assemblages were observed: winter/early spring, late spring, and summer. Peak abundance occurred in late spring; few fishes were caught in November. Cold-water (<20 °C) species were primarily late post-flexion and transforming larvae, whereas many of the warm-water species were pre-flexion or flexion stage larvae (indicating near-by, possibly estuarine, spawning). Families with the most species were Bothidae, Gobiidae, and Sciaenidae. A total of 74 species or species groups were collected. Engraulidae made up 70 % of the total catch out of the 34 families collected. High variability was noted between samples within collections. One-third of the species collected were found to invade adjacent saltmarsh habitat as juveniles.

Hoagland, P., Jin, D., and Kite-Powell, H.L. 2012. The Costs of Beach Replenishment along the U.S. Atlantic Coast. Journal of Coastal Research, 28(1A): 199-204.

Most existing studies of beach replenishments make approximations or use rules-of-thumb for the cost of the volume of material applied or the cost per length of shoreline. Using published historical data from the US Atlantic coast, we develop a statistical model of the costs of beach replenishment episodes. The model can be used to evaluate the costs of replenishment as a function of the volume of material, the beach length, the episode location, the year, the type of episode, and the source of funding. Although it has been observed that beach replenishment activities are small and declining in number in some areas, such as in New England, we expect that future coastal erosion expected from changes in sea levels as exacerbated by storm events eventually may lead to increased attention to the use of beach replenishment as a ''soft'' structural response. It is critical for coastal planners to compare sound estimates of the costs of soft structures to the costs of alternative responses, including hard structures, retreat, and abandonment.

Houston, J.R. 1988. Eroding Shorelines Impose Costly Choices. Geotimes, 33(5): 9-14.

Coastal geologists and engineers are dealing with an environmental crisis at the American shoreline. Rising sea levels and ever more densely developed beachfronts near retreating shorelines have left thousands of buildings teetering on the brink of disaster. As the rate of sea-level rise accelerates in coming decades-possibly an indirect result of the greenhouse effect's melting of the West Antarctic Ice Sheet- the rate of shoreline recession will increase. *In* Responding to changes in sea level: engineering implications, a National Research Council report released last fall, an NRC committee that included Robert G. Dean (University of Florida) and Orrin H. Pilkey Jr. (Duke University) reviewed the practical implications of sea-level rise for coastal planning. According to Dean, who chaired the committee, 'the good news is that we have planning time.' On the other hand, Dean points out that if communities choose the wrong method for dealing with beach erosion, they could face enormous costs as well as loss of property. So far we have 3 basic choices for responding to this problem. We can build hard structures such as sea walls to hold the shoreline in place (hard stabilization); we can pump up more sand to replenish eroding beaches (soft stabilization); or we can relocate buildings away from the beach. Recently, the use of sea walls to combat erosion has come into question. Some coastal geologists like Pilkey argue that sea walls contribute to or accelerate loss of beaches. According to Pilkey, former editor of the Journal of sedimentary petrology, sea walls 'eventually end up with a much degraded or non-existent beach in front of them. Evidence for this is overwhelming, and the type of wall seems to make little difference.' Engineers like James R. Houston, chief of the Coastal Engineering Research Center in Vicksburg, Miss., disagree. Houston, citing studies completed recently at his center, the largest research laboratory in the U.S. Army Corps of Engineers, maintains walls that are designed properly and do not interrupt the littoral flow of sand, should not accelerate erosion. According to Houston, a sea wall protects the area landward of it-blaming the wall for erosion on its seaward side is 'confusing cause and effect. ' To air these differing views on the choices at hand for dealing with eroding shorelines, Pilkey, Dean, and Houston have answered these questions for Geotimes: Do sea walls cause beach erosion and are they detrimental to the quality of natural beaches? Should sea walls be banned in non-urban environments? Is beach nourishment the best national solution in time of rising sea level? Is relocating communities a feasible alternative?

Inman, D.L. and Dolan, R. 1989. The Outer Banks of North Carolina: Budget of Sediment and Inlet Dynamics along a Migrating Barrier System. Journal of Coastal Research, 5(2): 193-237.

The Outer Banks are barrier islands separating Pamlico, Albemarle and Currituck Sounds from the Atlantic Ocean. These barriers are transgressing landward, with average rates of shoreline recession of 1.4 m/yr between False Cape and Cape Hatteras. Oregon Inlet, 63 km north of Cape Hatteras, is the only opening in the nearly 200 km between Cape Henry and Cape Hatteras which bounds the Hatteras Littoral Cell. Oregon Inlet is migrating south at an average rate of 23 m/yr and landward at a rate of 5 m/yr. The net southerly longshore transport of sand in the vicinity of Oregon Inlet is between one-half and one million m^3/yr. Oregon Inlet is the most dynamic physical feature within the Hatteras Littoral Cell. The combination of waves and tidal currents deposit ebb-tide bars offshore of the entrance and form extensive tidal islands, bars and shoals in Pamlico Sound. These deposits lag behind as the inlet migrates. The offshore deposits are gradually returned to the beach by waves and reincorporated into the littoral drift system. The flood-tide inlet deposits in the sound are eventually reincorporated into the landward migrating barrier as the inlet moves to the south. The integrity of the landward side of the transgressing barrier is maintained by washover deposits, wind-blown sand deposits, and inlet deposits. Averaged over the 160 km from False Cape to Cape Hatteras, sealevel rise accounts for 21% of the measured shoreline recession of 1.4 m/yr. Analysis of the budget of sediment indicates that the remaining erosion of 1.1 m/yr is apportioned between overwash processes (39%), long-shore transport out of the cell (22%), windblown sand transport (18%), inlet deposits (10%), and removal by dredging at Oregon Inlet (11%). This analysis indicates that the barrier system moves as a whole, so that the sediment balance is relative to the moving shoreline (Lagrangian grid). Application of a continuity model to the budget suggests that, in places, the barrier sys-tem is supplied with sand from the shelf.

Jackson, C.W., Cleary, W.J., and Knierim, A.C. 2006. Management and Erosion Mitigation Issues Related to Ebb Channel Repositioning: Rich inlet, North Carolina, USA. Journal of Coastal Research, SI 39: 1008-1012.

Natural inlets have the ability to promote significant oceanfront shoreline changes through movements of the ebb channel and the attendant shape changes in the ebb-tidal delta. Rich Inlet is one of the larger, more dynamic inlets in southeastern NC where cyclical oceanfront erosion related to this complex linkage is a primary management concern. A GIS-based study of 17 sets of aerial photographs covering the period 1938 to 2003 suggest channel migration is restricted to an ~ 460 m wide pathway. The orientation of the channel as it passes through the outer bar has ranged between ~ 83° to 181°. The cyclic nature of changes in the ebb channel's position has promoted variations in the oceanfront erosion and accretion patterns. The northern 2 km long segment of Figure Eight Island's shoreline has eroded ~ 90 m due to a combination of channel migration and realignment over the past 7 years. The optimum channel orientation is ~ 145° when the ideal channel alignment approximates the position of the ebb channel depicted on the 1938 and 1980 aerial photos. In this arrangement the most favorable configuration is attained for accretion along the oceanfront shoreline. These analyses are essential for the development of sand management strategies and long -term inlet/shoreline management plans.

Jaramillo, E., Contreras, H., and Bollinger, A. 2002. Beach and Faunal Response to the Construction of a Seawall in a Sandy Beach of South Central Chile. Journal of Coastal Research, 18(3): 523-529.

The community structure and across shore zonation of the sandy beach macroinfauna has been found to be closely related to beach morphodynamics. Thus, any changes in beach morphodynamics may result in macroinfaunal changes. The construction during 1997 and 1998, of a concrete seawall at the northern and middle section of a beach in south central Chile (ca. 39°S) to protect the coast from erosion, provided the opportunity to look at the effects of changing morphodynamics on beach fauna. To do that, we used physical and biological data collected at both sides of the beach, before and after the seawall was constructed. Sediment samples (0.03 m^2, 30 cm deep) were collected at ten equally spaced levels along three replicated transects extending from above the drift line to the swash zone. The sediment was sieved through a 1 mm mesh and the organisms collected were stored in 5% formalin until sorting and measuring. Physical measurements included width of the intertidal, height and period of waves, sand fall velocity and Dean's parameter. Values of this parameter showed that both sides had reflective to low intermediate features. The results of ANOVA indicate that no significant differences ($p>0.05$) were found between before and after or control and impact sites. BACI analyses were carried out with physical characteristics, i.e. the means of differences between both sides of the beach were similar. We found no significant differences when similar BACI analyses were carried out with macroinfaunal community characteristics such as species richness, macroinfaunal abundances and body sizes of the most common species (the cirolanid isopod *Excirolana hirsuticauda* Menzies and the anomuran decapod *Emerita analoga* (Stimpson)). Thus, it is concluded that during the study period the presence of the seawall has not influenced the physical and macroinfaunal characteristics at the beach studied.

Jaramillo, E., Croker, R.A., and Hatfield, E.B. 1987. Long-term Structure, Disturbance, and Recolonization of Macroinfauna in a New Hampshire sand beach. Canadian Journal of Zoology, 65: 3024-3031.

The southern portion of Foss Beach, New Hampshire, was totally eroded of sand during the second quarter of 1977. Long-term community data from the beach since 1971 served as background for studying recolonization by burrowing invertebrates after redeposition of sand. About 2 years were required for the beach to regain much of its sand, and another year passed before a complete coverage of sand was long lasting. Twenty-five species of macroinfauna were recorded from the beach during a 13-year period, seven of these only from the postdisturbance beach. The polychaetes *Scolelepis squamata* and *Paraonis fulgens,* and the amphipods

Acanthohaustorius millsi and *Amphiporeia virginiana*, were the most abundant species. The numbers of species and abundances of polychaetes were the primary influences on the pattern of variation of the total macroinfauna before disturbance. Polychaetes also dominated during early recolonization, 1.5-2 years after sand erosion, particularly species with planktonic larval stages. During this time, *Capitella* sp. exhibited abundances up to 10 times mean values for the predisturbance period. Four years after sand erosion, the macroinfauna had largely recovered.

Johnsen, C.D., Cleary, W.J., Freeman, C.W., and Sault, M. 1999. Inlet Induced Shoreline Changes on the High Energy Flank of the Cape Fear Foreland, NC. Coastal Sediments '99, American Society of Civil Engineers: New York, 1402-1417.

Inlets in southeastern North Carolina between Cape Fear and New River are a diverse group of mixed energy systems. In this 100km sector, nearly all chronic erosion zones are inlet related. Unstable inlets migrated to the southwest at rates varying from five to 150mlyr. In addition to downdrift erosion, migration resulted in realignment of the trailing shoreline. Recession rates updrift ranged from two to 12.0mlyr. Erosion decreased as the updrift barrier adjusted to the inlet's new position. An additional consequence of migration was the deterioration of the soundside channels. Encroachment of the flood delta on the channels resulted in a reduction in the tidal prism, an increase in the migration rate and a decrease in the ebb delta volume. Shoreline changes adjacent to stable inlets were related to changes in the ebb delta orientation and corresponding position and size changes of the ebb and flood channels. The process of ebb channel reorientation provided a mechanism for downdrift bypassing of sand packets. This scenario is unlike the conditions at migrating inlets where ebb delta breaching leads to updrift bypassing. Inlet modification by dredging resulted in an increase in tidal prism, a larger ebb delta retention capacity and disruption of the ebb delta breaching cycle. Changes are reflected in an alteration of the barrier-offset pattern and an extension of the ebb channel across the ebb platform. Beach renourishment is the only viable means of "preserving" developed beaches. Because of environmental restrictions flood tidal deltas are unlikely targets. As a result, ebb deltas are targeted as borrow sites although ebb delta modification is a controversial issue in this sand-starved area.

Joyner, B.P., Overton, M.F., and Fisher, J.S. 1998. Post-stabilization Morphology of Oregon Inlet, NC. Coastal Zone 1998, American Society of Civil Engineers: New York, 3124-3137.

The behavior of Oregon Inlet, located north of Cape Hatteras, North Carolina, on the Pamlico Sound estuary, and its commercial, ecological, and recreational importance have been the subject of much study and controversy. The construction of a terminal groin on the southern shoulder of the inlet in 1990 served to heighten this interest. Both the U.S. Army Corps of Engineers (USACE) and the NC Department of Transportation (NCDOT) have maintained monitoring programs since that time to study the impact of the terminal groin on the morphology of the inlet and the adjacent shorelines. This paper utilizes data from the USACE and NCDOT programs to examine the relationship between the growth of the Bodie Island spit and the resulting bathymetric changes in the inlet. Data collected are compared with results from the literature. The morphology of Oregon Inlet exhibited changes expected with the stabilization of a single shoulder of a tidal inlet. In contrast, the cross-sectional area of the channel at the minimum inlet width changed little. When analyzed in light of empirical equilibrium conditions reported in the literature, the results supported the conclusion that the inlet had achieved a new equilibrium configuration due to the presence of the terminal groin.

Kana, T.W., Mason, J.E., and Williams, M.L. 1987. A Sediment Budget for a Relocated Inlet. Coastal Sediments '87, American Society of Civil Engineers: New York, 2094-2109.

In March 1983, Captain Sams Inlet (South Carolina) (Fig, 1) was relocated to a position 2 kilometers (km) updrift of its previous location for purposes of erosion control along the downdrift beach. Since that time, the abandoned tidal delta and new channel have been left in a natural state to undergo changes uninfluenced by control structures. Sequential surveys and aerial photographs have documented dramatic morphological changes in the three-year period since construction. The authors have developed a detailed sediment budget for the new tidal delta and downdrift zone of accretion which evolved rapidly after a sand spit was breached by the new inlet. The results provide new insight into ebb-tidal delta evolution for a moderate-sized mesotidal inlet [tidal prism ~ 5×10^6 cubic meters (m^3)] and an estimate of the rate and total quantity of sediment made available for accelerated bypassing.

Kana, T.W., White, T.E., and McKee, P.A. 2004. Management and Engineering Guidelines for Groin Rehabilitation. Journal of Coastal Research, SI 33: 57-82.

This paper offers management and coastal engineering guidelines for groin installation and rehabilitation based on project experience in South Carolina. It includes a short history of practice during the 1930s to 1960s, when most groins were built. Traditional practice in South Carolina involved pile-supported timber structures, extending 75-100 m offshore, spaced ~200 m apart. Timber groins typically had uniform profiles at slopes of 1 on 40 to 1 on 50, compared to 1 on 25 for the native beach. Early groin fields did not include nourishment to fill the cells, and in some cases (e.g., Edisto Beach), resulted in downcoast property damage. Timber structures typically deteriorated within 20 years and were replaced by quarry stone. However, inadequacy of armorstone weights led to failure of structures. Recent projects at Edisto Beach and Pawleys Island (detailed herein) demonstrate the feasibility of using grout to create a stable, impermeable structure at modest cost without changing the existing groin cross-sections. Monitoring results after the Edisto Beach project demonstrate the nourishment requirement to satisfy trapping can be approximated by ?one-half the difference in area between the groin profile and average beach profile in the updrift cell times the length of a cell. Results suggest the degree of adverse downcoast erosion and shoreline recession due to groins is directly related to the regional erosion rate. South Carolina case studies demonstrate mixed results. Where groins were placed along slowly eroding shorelines (e.g., Pawleys Island), updrift of areas having a long-term trend of accretion because of shoal bypassing or other inlet-related processes, there was negligible adverse impact. Where groins were placed along rapidly eroding shorelines or ones lacking an adequate upcoast supply (e.g., Edisto Beach), adverse downcoast impacts were magnified. In the Edisto Beach case, the groin field has reduced the erosion rate within the protected area by 5-10 fold and preserved property worth 50 times more than the capital cost of the shore protection. Periodic nourishment is considered to be the only practicable way to maintain adequate protection and mitigate downcoast impacts in that setting.

Kaplan, E.H., Welker, J.R., and Kraus, M.G. 1974. Some Effects of Dredging on Populations of Macrobenthic Organisms. Fishery Bulletin, 72(2): 445-480.

Populations of epi- and infauna were studied from 10 mo before to 11 mo after a navigation channel was dredged through a small, shallow lagoon. A new sampler which penetrated 20-30cm into the substratum was used. Current velocities and sedimentation patterns were changed due to an altered distribution of tidal currents, although flushing time was not appreciably altered. Values of certain particulate and dissolved nutrients changed after dredging, but no correlation was observed between animal populations and fluctuations in nutrients. Significant reductions in standing crop figures and species and specimen numbers occurred in both the bay and the dredged channel. *Mercenaria mercenaria* populations were reduced, but there was no evidence of mass mortality. Recovery of biomass in the channel was affected by sediment composition, but seasonal and sediment type variations were not significant in the bay as a whole. Goose Creek had a high predredging epi- and infaunal standing crop estimated at 36.83 g/m^2, but the number of organisms/m^2 was relatively low, indicating a preponderance of large forms. Productivity of Goose Creek was calculated at 89.87 g/m^2/yr before dredging and 31.18 g/m^2/yr after dredging. Productivity figures for the mixed peripheral marsh were calculated and the annual loss due to replacement of 10.87 ha of marsh by spoil areas was estimated at 49,487 kg. Altered land usage patterns tended to fix this loss on a permanent basis. The unusually profound effects of dredging reported for Goose Creek are attributed to its small size and shallowness.

Kisiel, C.L. 2009. The Role of Inlets in Piping Plover Nest Site Selection in New Jersey 1987-2007. New Jersey Birds, 35(3): 45-52.

Understanding the distribution of NJ's plovers might allow us to determine why we are unable to emulate other states' population increases. Although ENSP compiles yearly reports and NJ information is folded into Atlantic coast reports, there has not been an effort to conduct a long-term examination of the spatial and temporal distribution of nesting Piping Plovers in this state. The ability to understand the factors that influence site selection may offer valuable insight into their habitat requirements as well as focus management efforts into the areas that are the most important in the state for nesting success. Past is prologue and understanding the distribution of the birds over the last 20 years may be the best way to determine future directions of New Jersey Piping Plover conservation efforts.

Kisiel, C.L. 2009. The Spatial and Temporal Distribution of Piping Plovers in New Jersey: 1987-2007. [M.S. thesis]: New Brunswick, New Jersey, The State University of New Jersey, Rutgers, 75 p.

The Piping Plover (*Charadrius melodus melodus*) is a small shorebird that nests along the Atlantic coast beaches of New Jersey. The combination of habitat degradation and human disturbance caused a precipitous population decline during the last century. It was listed as state endangered in 1984 and federally threatened in 1986. New Jersey biologists have taken protective measures, such as fencing nesting sites and restricting human activities in sensitive areas, in an attempt to increase the population. Despite these intense efforts, Piping Plover pair numbers are not recovering in New Jersey. The objective of this research was to create a spatial representation of all nesting areas, and pair use at those sites, utilized in New Jersey from 1987-

2007 to better understand site selection of breeding Piping Plovers. Analysis of this information indicated that the plovers showed a strong preference for selecting nesting areas near inlets, particularly those that were not shored with jetties or other stabilization features. Beach replenishments, however, did not appear to significantly attract or deter nesting birds to or from sites. Nest fate and reproductive success were found to be fairly consistent throughout the state (for the factors tested) and the rates were lower than what was necessary to sustain and grow the population. Since there are a limited number of unshored inlet areas left in New Jersey, it is imperative that large-scale restoration efforts and more aggressive management techniques (i.e., widespread predator control) are implemented to initiate recovery of the Piping Plover in this state.

Knapp, K. 2012. Impacts of Terminal Groins on North Carolina's Coasts [M.E.M. thesis]: Durham, North Carolina, Duke University, 49 p.

In 1985, North Carolina banned the use of hard structures along its coastline for the purposes of protecting private property. The policy was heralded as the way to manage barrier islands in the light of sea level rise. In 2011, the General Assembly overturned this ban to allow the construction of up to four terminal groins at inlets where some of the most vulnerable beachfront properties are located. This project examines the potential impacts of terminal groins to North Carolina's coastline. Biological and physical impacts to the coastal environment were assessed, as well as human and economic impacts to the coastal region. Case studies were conducted to determine the long-term impacts of hard structures in New Jersey and Florida, two states that have traditionally relied on coastal armoring to protect private properties. Results show that faced with rising sea levels, terminal groins are likely to cause more harm than good. Recommendations of the best course of action, including rolling easements, stricter building codes in inlet hazard areas, and a property buy-out program are made to North Carolina in order to help them better protect and manage the coastline.

Knierim, A.C. 2003. A Hydrographic Investigation of a Mixed Energy Inlet: Rich Inlet, North Carolina. [M.S. thesis]: Wilmington, North Carolina, University of North Carolina Wilmington, 52 p.

Management issues related to tidal inlets and their associated environmental impacts have become a primary focus for coastal research in North Carolina. Research needs stem from a variety of issues relating to the targeting of tidal inlets for sand resources for beach fill. Rich Inlet, located approximately 55km northeast of Cape Fear, is one such inlet marked for modification. Detailed hydrographic data for Rich Inlet, as well as for most North Carolina inlets, is extremely limited and in most cases is non-existent. This study provides physical and hydraulic data that are currently being used to formulate an inlet management plan and a baseline for long-term monitoring. Rich Inlet is a large wave-influenced transitional system that separates Figure Eight Island, a privately developed barrier to the south, from Hutaff Island to the north. A variety of data indicated that the inlet is a flood dominant system. Data from ADCP throat surveys recorded greater maximum flood (~1.17m/s) than ebb (~1.05m/s) current velocities. A water-level meter placed adjacent to the inlet throat recorded longer ebb (6.78hr) than flood (5.63hr) durations. Tidal prism ranged from 9.4-21.22 x 10^6 m^3. An estimated ebb-tidal delta volume of 6.7 x 10^6 m^3 was determined using the average tidal prism. Future inlet modification can have a significant impact on the aforementioned parameters. Alteration of the inlet could potentially lead to an increase in tidal prism and as a consequence an increase in the retention capacity of the ebb-tidal delta. Changes in the extent of the ebb-tidal delta will have a negative impact on adjacent oceanfront shorelines.

Knierim, A.C. and Cleary, W.J. 2003. A Hydrographic Investigation of a Wave-Influenced Mixed Energy Inlet: Rich Inlet, North Carolina. Coastal Sediments '03, American Society of Civil Engineers: New York, 15 p.

Management issues related to tidal inlets and their associated environmental impacts have become a primary focus for coastal research in North Carolina. Research needs stem from a variety of issues relating to targeting tidal inlets for sand resources for beach fill. Rich Inlet, located approximately 55km northeast of Cape Fear, is one such inlet marked for modification. Detailed hydrographic data for Rich Inlet, as well as for most North Carolina inlets, is extremely limited and in most cases is non-existent. This study provides physical and hydraulic data that are currently being used to formulate a inlet management plan and a baseline for long-term monitoring. Rich In let is a large wave-influenced transitional system that separates Figure Eight Island, a privately developed barrier to the south, from Hutaff Island to the north. A variety of data indicated that the inlet is a flood dominant system. Data from ADCP throat surveys recorded greater maximum flood (~1.17 m/s) than ebb (~1.05 m/s) current velocities. A water-level meter placed adjacent to the inlet throat recorded longer ebb (6.78hr) than flood (5.63hr) durations. Tidal prism ranged from 9.4-21.22 x 10^6 m^3. An estimated ebb-tidal delta volume of 6.7 x 10^6 m^3 was determined using the average tidal prism. Future inlet modification can have a significant impact on the aforementioned parameters. Alteration of the inlet could potentially lead to an increase in tidal prism and as a consequence an increase in the retention capacity of the ebb-tidal delta. Changes in the extent of the ebb-tidal delta will have a negative impact on adjacent oceanfront shorelines.

Knott, D.M., Van Dolah, R.F., and Calder, D.R. 1984. Ecological Effects of Rubble Weir Jetty Construction at Murrells Inlet South Carolina Volume II: Changes in Macrobenthic Communities of Sandy Beach and Nearshore Environments. U.S. Army Corps of Engineers, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS, Technical Report EL-84-4, 103 p.

Beach and nearshore areas were sampled at Murrells Inlet, South Carolina, to evaluate the effects of jetty construction on the benthic macroinvertebrate communities in those habitats. Quantitative samples were collected seasonally during jetty construction (1977-78) and again 5 years later along transects located adjacent to and distant from the jetties. Polychaetes, amphipods, and pelecypods were the dominant organisms in both the intertidal and subtidal zones during jetty construction. Although differences were noted in the community structure between these zones, several of the dominant species were abundant in both habitats. Five years later, some of these species were not commonly observed, and oligochaetes and nematodes were abundant in the area. Many of these differences were attributed to normal seasonal and yearly variations. Changes resulting from jetty construction included increased species diversity in a wave-sheltered area, as well as changes in abundance and species composition near the jetties.

Many of the observed changes were short term or limited to the area between the jetties where sediment characteristics were altered. Beach and nearshore areas south of the jetties were also changed by extensive shoaling, which presumably altered community structure in that vicinity. Similar modifications in the beach profile were not observed north of the jetties.

Komar, P.D. 1996. Tidal-Inlet Processes and Morphology Related to the Transport of Sediments. Journal of Coastal Research, SI 23: 23-45.

Tidal inlets are complex due to the presence of reversing currents and varying levels of wave activity, and their morphologies are characterized by large shoals and systems of channels containing sand waves and megaripples. The transport of sediment is the link that connects the processes of waves and currents to the morphology. The objective of this review is to examine inlets as sediment-transport systems, including summaries of their morphologies and how the patterns of shoals and channels reflect the paths of sediment movement. A review is presented of investigations that have been undertaken to either measure short-term sediment transport rates or to calculate the potential long-term transport from measurements of current velocities or wave energy levels. This review concludes with a discussion of the difficulties inherent in evaluating sediment transport within tidal inlets, and considers what additional research is needed.

Komar, P.D. 1998. Beach Processes and Sedimentation. Prentice-Hall, Inc., Upper Saddle River, New Jersey, 544 p.

Introduces beach processes within an approach that balances an engineering perspective against a purely geological one. Provides an up-to-date review of the current understanding of beach processes as well as applications to solve coastal problems (erosion, management issues, etc.). Discusses issues related to beach erosion and other processes. The second edition of *Beach Processes and Sedimentation* has been updated to include information gathered from two decades of science and engineering in the field, reflecting the vast increase in knowledge since the first edition. Discusses the rise of coastal zone management as well as patterns of wave transformations and dissipation within the surf zone, and how these water motions produce cross-shore movements of sediment resulting in beach-profile variations. An essential reference book for many readers: from beach front property owners to politicians contending with beachfront erosion to engineers addressing beachfront reclamation projects.

Kraus, N.C. 1988. The Effects of Seawalls on the Beach: An Extended Literature Review. Journal of Coastal Research, SI 4: 1-28.

A previous review by the author of the literature on the effects of seawalls on the beach is extended to include recent work and more thorough coverage of past studies. The present review covers approximately 100 technical papers on laboratory, field, and theoretical and conceptual studies published through mid-1988 and has three objectives: (1) to collect results of well-documented studies, (2) to summarize the state of knowledge on the seawall and beach interaction, and (3) to make recommendations for further study and field monitoring programs. It is concluded that beach change near seawalls, both in magnitude and variation, is similar to that on beaches without seawalls, if a sediment supply exists. Sediment volumes eroded by storms at beaches with and without seawalls are comparable, as are post-storm recovery rates. In addition, the shape of the beach profile after construction of a seawall is similar to the pre-construction shape if a sediment supply exists, showing the same number of bars with approximately the same volumes and relative locations. The form of the erosional response to storms at seawalls is typically different, however, with foreshore erosion that occurs on beaches without seawalls manifested as more localized toe scour and end effects of flanking and impoundment at seawalls. Limited evidence indicates that the subaqueous nearshore profile on a sediment-deficient coast with seawalls does not steepen indefinitely, but approaches an equilibrium configuration compatible with the coarser-grained particles comprising the bottom sediment.

Kraus, N.C. and McDougal, W.G. 1996. The Effects of Seawalls on the Beach: Part I, An Updated Literature Review. Journal of Coastal Research, 12(3): 691-701.

A previous review by the first author of the literature on the effects of seawalls on the beach is extended to cover the period 1988 to the present. The review synthesizes knowledge on beach profile change, longshore sand transport, and scour in the vicinity of seawalls. Remarkable progress has been made since 1988, with new phenomena and observations reported, such as on longshore transport processes at walls. Some previous results and conclusions of the 1988 review have been cast into doubt, with example new results being that (1) wave reflection at walls may not be a significant contributor to profile change, and (2) scour at seawalls in the field may be more a product of longshore transport and return of overtopping water than a result of direct cross-shore wave action. The validity or usefulness of small-scale physical model tests is questioned. Conclusions and recommendations for future work are given. This paper is the first of a companion set of papers that investigate the effects of seawalls on the beach. The second paper presents a numerical model of cross-shore transport and beach profile change at seawalls that includes wave reflection, and it compares predictions to measurements made at the SUPERTANK project and to recent results found in the literature on scour at walls.

Kraus, N.C., Hanson, H., and Blomgren, S.H. 1994. Modern Functional Design of Groin Systems. Proceedings of the 24th International Conference on Coastal Engineering, American Society of Civil Engineers: New York, 1327-1342.

Coastal zone management policy in the United States and many other countries discourages use of groins for shore protection, even though properly designed groins can maintain beach width, increase longevity of beach fills, and prevent loss of sand into inlets, navigation channels, and submarine canyons. A lack of a systematic approach to groin functional design and a poor image from incorrect applications are probably responsible for the aversion to groins. In this study, a modern approach to groin functional design is demonstrated by applying the shoreline response model GENESIS to simulate the action of single and multiple groins. Groin bypassing and permeability, evolution of the shoreline in a groin field, and groin tapering are discussed. The balance between net and gross sand longshore transport rates emerges as an important factor controlling groin functioning. A criterion is introduced for judging groin success, and an example design diagram is developed based on this criterion to demonstrate the feasibility of developing a general and rational functional design procedure. Predictions are tested in reproducing shoreline change observed at the 15 groins at Westhampton, Long Island, New York.

Krock, J.R. 2005. Historical Morphodynamics of John's Pass, West-Central Florida. [M.S. thesis]: Tampa, Florida, University of South Florida, 98 p.

John's Pass is a stable mixed-energy inlet located on a microtidal coast in Pinellas County, Florida. It is hydraulically connected to the northern portion of *Boca Ciega Bay*. Morphological analysis using a time-series of aerial photographs indicated that anthropogenic activities have influenced the evolution of the tidal deltas and adjacent shorelines at John's Pass. Previous studies have documented the channel dimensions at the location of the existing bridge and calculated the tidal prism. A chronological analysis of these data yielded an increasing trend in the cross-sectional area at John's Pass from 1873 to 2001. Anthropogenic activities occurring in *Boca Ciega Bay* impacting this trend begin in the 1920's when Indian Pass, approximately 7 km north of John's Pass, was artificially closed. Other significant events causing an increase or decrease in the crosssectional area at John's Pass include dredging and filling in the bay, channel dredging at John's Pass, and jetty construction. More recent data collected from a simultaneous current meter deployment at John's Pass and Blind Pass were used to calculate the bay area serviced by each inlet resulting in an area serviced by John's Pass being $1.8x10^4$ km^2 and $0.33x10^4$ km^2 serviced by Blind Pass. In comparison, Blind Pass captures 14 percent of the tidal prism that John's Pass captures and John's Pass captures 87 percent of the bay prism while Blind Pass captures 13 percent. Using the discharge equation and assuming the channel area was largely constant the tidal prism at John's Pass was $1.07x10^7$ m^3 during the twenty-one day deployment. Based on a historical analysis of the tidal prism this study is within 40 percent of the tidal prism calculated by Mehta (1976) and Becker and Ross (2001) and within 20 percent of the tidal prism calculated by Jarrett (1976) and Davis and Gibeaut (1990). An analysis of the current meter time-series indicated that flood velocities in the channel were influenced by a frontal system passing through the study area during the deployment increasing the amount of potential sediment being deposited in the channel thalweg. The maximum ebb and flood-tidal velocities during the deployment were 143 cm/s and 115 cm/s, respectively. Morphological analysis of cross-sectional data from 1995 to 2004 indicated that sediment tends to accumulate along the northern portion of the channel. The channel thalweg tends to accumulate more sediment east of the bridge where wave energy is lower and currents are not as strong. An average net accumulation of 0.5 m per year was estimated along all seven cross-sections. Given the length and width of the surveyed channel, 610 m by approximately 150 m, the sediment flux through the inlet is approximately 45,800 m^3/yr along the channel thalweg. A small amount of sediment accumulation has occurred southwest of the bridge in response to channelized flood flows along the newly constructed jetty. An annual sediment budget was estimated for the John's Pass inlet system using the beach profiles and inlet bathymetry data between 2000 and 2001. Overall, the inlet system has accumulated more sediment than it has lost during this time period.

Lamont, M.M. and Houser, C. 2014. Spatial Distribution of Loggerhead Turtle (*Caretta caretta*) Emergences along a Highly Dynamic Beach in the Northern Gulf of Mexico. Journal of Experimental Marine Biology and Ecology, 453: 98-107.

As coastlines change due to sea level rise and an increasing human presence, understanding how species, such as marine turtles, respond to alterations in habitat is necessary for proper management and conservation. Survey data from a major nesting beach in the northern Gulf of Mexico, where a revetment was installed, was used to assess spatial distribution of loggerhead emergences. Through use of Quadrat analysis and piecewise linear regression with breakpoint, we present evidence to suggest that nest site selection in loggerheads is determined in the nearshore environment, and by characteristics such as wave height, alongshore currents, depth and patterns of erosion and accretion. Areas of relatively dense nesting were found in areas with relatively strong alongshore currents, relatively small waves, a steep offshore slope and the largest historical rates of erosion. Areas of relatively dense nesting also corresponded to areas of low nesting success. Both nesting and non-nesting emergences were clustered immediately adjacent to the revetment and at other eroding sites along the beach. These results suggest that alterations to the nearshore environment from activities such as construction of a jetty, dredging or installation of pilings, may impact sea turtle nest distribution alongshore. We also show that piecewise linear regression with breakpoint is a technique that can be used with geomorphological and oceanographic data to predict locations of nest clumping and may be useful for managers at other nesting beaches.

Landry, C.E. and Hindsley, P. 2011. Valuing Beach Quality with Hedonic Property Models. Land Economics, 87(1): 92-108.

This paper explores the influence of beach quality on coastal property values. We hypothesize that beach and dune width provide local public goods in the form of recreation potential and storm/erosion protection, but services are limited by distance from the shoreline. Our findings support this hypothesis, as extending the influence of beach quality beyond 300 m from the shore generally results in statistically insignificant parameter estimates. For houses within this proximity bound, beach and dune widths increase property value. We argue that interpretation of marginal willingness to pay for beach quality depends upon individual understanding of coastal processes and expectations of management intervention.

Landry, C.E., Keeler, A.G., and Kriesel, W. 2003. An Economic Evaluation of Beach Erosion Management Alternatives. Marine Resource Economics, 18: 105-127.

This paper examines the relative economic efficiency of three distinct beach erosion management policies — beach nourishment with shoreline armoring, beach nourishment without armoring, and shoreline retreat. The analysis focuses on (i) the recreational benefits of beaches, (ii) the property value effects of beach management, and (iii) the costs associated with the three management scenarios. Assuming the removal of shoreline armoring improves overall beach quality, beach nourishment with shoreline armoring is the least desirable of the three alternatives. The countervailing property losses under a retreat strategy are of the same order of magnitude as the foregone management costs when the beneficial effects of retreat — higher values of housing services for those houses not lost to erosion — are considered. The relative desirability of these alternative strategies depends upon the realized erosion rate and how management costs change over time.

Langfelder, J., French, T., McDonald, R., and Ledbetter, R. 1974. A Historical Review of Some of North Carolina's Coastal Inlets. Center for Marine and Coastal Studies North Carolina State University, Raleigh, N.C., Report No. 74-1, 43 p.

This report is intended to be mainly a photographic display of the history of most of North Carolina's inlets. A brief description and various measurements that were made on the inlets are also included. The difficulty of numerically characterizing the changes in inlet configuration should be recognized, since the values that are obtained are highly dependent on the actual locations of the measurement points. However, the data tables are considered useful for obtaining a general pattern of inlet behavior.

Lankford, T.E. and Baca, B.J. 1989. Comparative Environmental Impacts of Various Forms of Beach Nourishment. Coastal Zone '89: Proceedings of the Sixth Symposium on Coastal and Ocean Management. American Society of Civil Engineers: New York, 2046-2059.

Environmental monitoring studies have been conducted following various forms of beach nourishment projects in the southeastern United States. The studies have shown that negative impacts can occur at both nourished and borrow sites. Impacts at nourished sites result from nearshore turbidity, direct burial of organisms, and extreme habitat alterations. However, these impacts were of short duration and exhibited little variability between nourishment methodologies. Conversely, studies of borrow sites show that often these areas incur the most serious impacts. Comparisons of borrow site impacts were made for upland, supralittoral, nearshore tidal, nearshore subtidal, offshore, and various combinations of sites. Degrees of impacts at nourished and borrow sites were assessed based on ten criteria pertaining to biological resources and nourishment characteristics. Assuming direct impacts at nourished sites were similar between most projects, borrow-site impacts most determined the overall impacts of each project on the environment. Offshore borrow sites often exhibited the most extreme and variable impacts, which were (based on the above ten criteria) directly related to the presence or absence of hard-bottom communities. Intertidal beach scraping and unique projects such as inlet relocation resulted in large, but short-lived, initial impacts to resident infauna. Understandably, the use of upland borrow sites caused the least environmental impacts of all forms of beach nourishment. Upland habitat alteration and loss of dune vegetation, when present, during transport were the sole impacts. The use of nearshore, subtidal sand also resulted in minimal impacts. Using the above criteria and comparisons, a number of beach-nourishment methods are catalogued herein by degree of impact. An index is provided for pre-assessment of impacts from various methods and for use in evaluating the choice of methods. Original unpublished data are provided for various nourishment projects in South Carolina, and these are supplemented with, and compared to, results in Florida and other areas of the United States in order to develop the pre-assessment index.

Layman, C.A. 2000. Fish Assemblage Structure of the Shallow Ocean Surf-Zone on the Eastern Shore of Virginia Barrier Islands. Estuarine, Coastal and Shelf Science, 51: 201-213.

This study provides an in-depth description of the fishes in the shallow surf-zone (<0.4 m), a little-studied micro-habitat of the ocean surf. Fish assemblages were examined with respect to three temporal cycles (seasonal, diel and tidal) and at both large and small spatial scales. Sampling was conducted at the Virginia barrier islands using an 8 m bag seine dragged parallel to the beach in water with an average depth of 0.2 m. The fish assemblage was relatively species poor, in fact, there were only two year-round residents, *Membras martinica* (rough silverside) and *Mugil curema* (white mullet). Three species, *M. martinica, Trachinotus carolinus* (Florida pompano) and *Menticirrhus littoralis* (gulf kingfish), comprised 94% of all species captured. Both fish species richness and total abundance peaked in the late summer and were lowest in the winter. Multidimensional scaling analysis failed to identify a distinct nighttime fish assemblage. However, univariate analyses found there was a significant increase in species richness at night, due to an influx of predatory adult fishes. Further, significantly more species were collected at high than low tide. Higher species richness and total fish abundance occurred in the shallow water (<0.4 m) of runnels, low wave energy habitats on the backside of small sand bars. The increased richness and abundance suggests a small-scale movement of fishes parallel to the beach face as fishes seek sheltered runnel habitats. This study quantifies the observation that many fishes do utilize the shallow surf-zone, perhaps to minimize predator encounters and/or take advantage of an under-utilized intertidal food source.

Leber, K.M. 1982. Seasonality of Macroinvertebrates on a Temperate, High Wave Energy Sandy Beach. Bulletin of Marine Science, 32(1): 86-98.

Seasonal changes in macrobenthic community structure on a temperate, western Atlantic, high energy beach were examined over a IS-month period during 1976 and 1977. Twelve macroinvertebrate species were collected from the intertidal and nearshore surf zones during bimonthly day and night sampling. There were distinct patterns in species fluctuations on both a seasonal and diel scale. Decapod crustaceans and molluscs were more numerous during warmer months, while haustoriid amphipods were dominant in winter. Vertical distribution of the five top dominant species varied seasonally, tidally and with sunlight. Portunid and ocypodid crabs moved into the intertidal wash zone at night and fed on mole crabs *(Emerita talpoida)* and coquina clams *(Donax variabilis* and *Donax parvula).* Mole crabs and coquinas appear to be important trophic links on this beach between plankton and detrital energy sources and beach predators. Trophic relationships and migration patterns reveal that considerable overlap exists between intertidal and subtidal faunal assemblages.

Leewis, L., van Bodegoma, P.M., Rozema, J., and Janssen, G.M. 2012. Does Beach Nourishment have Long-term Effects on Intertidal Macroinvertebrate Species Abundance? Estuarine, Coastal and Shelf Science, 113: 172-181.

Coastal squeeze is the largest threat for sandy coastal areas. To mitigate seaward threats, erosion and sea level rise, sand nourishment is commonly applied. However, its long-term consequences for macroinvertebrate fauna, critical to most ecosystem services of sandy coasts, are still unknown. Seventeen sandy beaches - nourished and controls - were sampled along a chronosequence to investigate the abundance of four dominant macrofauna species and their relations with nourishment year and relevant coastal environmental variables. Dean's parameter and latitude significantly explained the abundance of the spionid polychaete *Scolelepis squamata*, Beach Index (BI), sand skewness, beach slope and latitude explained the abundance of the amphipod *Haustorius arenarius* and Relative Tide Range (RTR), recreation and sand sorting explained the abundance of *Bathyporeia sarsi*. For *Eurydice pulchra*, no environmental variable explained its abundance. For *H. arenarius*, *E. pulchra* and *B. sarsi*, there was no relation with nourishment year, indicating that recovery took place within a year after nourishment. *Scolelepis squamata* initially profited from the nourishment with "over-recolonisation". This confirms its role as an opportunistic species, thereby altering the initial community structure on a beach after nourishment. We conclude that the responses of the four dominant invertebrates studied in the years following beach nourishment are species specific. This shows the importance of knowing the autecology of the sandy beach macroinvertebrate fauna in order to be able to mitigate the effects of beach nourishment and other environmental impacts.

Leonard, L., Clayton, T., and Pilkey, O. 1990. An Analysis of Replenished Beach Design Parameters on U.S. East Coast Barrier Islands. Journal of Coastal Research, 6(1): 15-36.

Forty-three beach replenishment projects on the United States Atlantic Coast are divided into 3 categories based on time of fill retention: (1) less-than-1-year beaches (26%), (2) 1-to-5 year beaches (62%), and (3) greater-than-five-year beaches (12%). Filled or replenished beaches north of Florida generally have lifetimes of fewer than 5 years. Storm history is the most important factor in determining beach durability-so important that the effects of the other parameters, which may also play a role in artificial beach behavior, are overshadowed. Beach length, grain size, shoreface slope, shelf width and method of fill emplacement show no correlation to regional replenished beach lifetime. Inlet proximity and a combination of shoreline orientation and dominant angle of wave approach may exert minor influence on beach behavior. Initial density of fill (volume per unit length) exerts significant influence on the percentage of fill remaining after one year, but the effect becomes less well defined beyond the first year.

Leonard, L.A., Dixon, K.L., and Pilkey, O.H. 1990. A Comparison of Beach Replenishment on the U.S. Atlantic, Pacific, and Gulf coasts. Journal of Coastal Research, SI 6: 127-140.

The record of beach replenishment on the U.S. Atlantic, Gulf, and Pacific coasts has been examined. For the most part, past beach replenishment projects have not been monitored. As a result, limited durability data exist. Fewer durability data exist for the Gulf and Pacific coasts than for the Atlantic coast. Available data suggest, however, that the durabilities experienced by Atlantic and Gulf coast replenished beaches are similar, and that, in general, the Pacific has a better record of artificial beach maintenance than the Atlantic or Gulf coasts. On all three coasts, most fills lasted between one and five years. The majority of Gulf and Pacific coast replenished beaches are shorter than Atlantic coast replenished beaches. Atlantic coast replenished beaches range in length from 0.5 mile to 10.5 miles; the average length is 3.2 miles. Gulf coast beaches range in length from 1,000 feet to 5 miles; the average length is 1.2 miles. Pacific coast replenished beaches range from 0.2 of a mile to 6 miles; the average length is 1.2 miles.
In general, Pacific coast replenished beaches have the greatest cumulative density (volume per unit length) averaging 6,228,000 cy/mi, followed by the Atlantic coast averaging 1,585,000 Cy/mi. Gulf coast beaches tend to have the lowest densities, averaging 547,000 cy/mi. Storms, as opposed to grain size, length, and density, appear to be the main factor responsible for variation in replenished beach durability for all three coasts.

Leonard Ozan, C.R. 2011. Evaluating the Effects of Beach Nourishment on Loggerhead Sea Turtle (*Caretta caretta*) Nesting in Pinellas County, Florida. [M.S. thesis]: Tampa, Florida, University of South Florida, 60 p.

The health of Florida's beaches are vital to the survival of loggerhead sea turtles (*Caretta caretta*), as nearly half of the world's loggerheads nest on the states beaches. Many of the beaches utilized by the turtles have undergone nourishment projects in hopes of combating erosion of the shoreline, protecting beachfront property, and creating more suitable beaches for tourism. Although it is argued that beach nourishment benefits sea turtles by providing more nesting habitat, the effects of the Pinellas County nourishment projects on loggerhead nesting are unknown. Beach nourishment can alter the compaction, moisture content, and temperature of the sand, all of which are variables that can affect nest site selection and the proper development of eggs. This research has four objectives: (1) to create a GIS dataset using historic loggerhead sea turtle data collected at the individual nest level along the West coast of Florida, (2) to examine the densities of loggerhead nests, the densities of false crawls (i.e. unsuccessful nesting attempts), and the nest-to-false crawl ratio on natural and nourished beaches for the 2006-2010 nesting seasons; (3) to determine the effects of beach nourishment projects on the hatchling success rates and emergence success rates; and (4) to determine areas preferred or avoided by turtles for nesting. The study found that nesting and false crawl densities significantly differed between natural and nourished beaches during three of the five nesting seasons. Nesting densities increased directly following nourishment and false crawl densities were higher in nourishment areas during every nesting season. False crawl densities were higher than statistically expected on nourished beaches and lower than expected on natural beaches. No significant differences were found between hatchling and emergence success rates between natural and nourished beaches. However, when the rates were analyzed by nesting season, the average hatching and emergence success rates were always lower on nourished beaches than on natural beaches. A hotspot analysis on nests and false crawls revealed that turtles preferred natural beaches that border nourished areas for nesting while false crawls were more evenly distributed through the study area. Although this study documents the negative effects of beach nourishment on loggerhead sea turtle nesting, nourishment projects are likely to continue because of their benefits to human populations. Further examining of the impacts that humans have on nesting and developing loggerheads will ultimately aid policy formation as we continue to manage and protect the future of the species.

Lindeman, K.C. and Snyder, D.B. 1999. Nearshore Hardbottom Fishes of Southeast Florida and Effects of Habitat Burial Caused by Dredging. Fishery Bulletin, 97: 508-525.

Fish assemblages of nearshore hardbottom habitats of southeast Florida were quantified at three sites from April 1994 to June 1996. Random 2 × 15 m transects were visually censused within two replicate areas at each site. The hardbottom at one site was buried by a dredge project to widen a beach one year into the study. A total of 394 transects were sampled. Eighty-six taxa (77 identified to species) from 36 families were censused. Grunts (Haemulidae) were the most diverse family (11 species), followed by the wrasses (Labridae) and parrotfishes (Scaridae) with seven and six species, respectively. The most abundant species were sailors choice (*Haemulon parra*), silver porgy (*Diplodus argenteus*), and cocoa damselfish (*Stegastes variabilis*) with mean abundances (individuals/transect) of 4.5, 3.8, and 3.7, respectively. Early life stages (newly settled, early juvenile, and juvenile) represented over 80% of the individuals at all sites. Newly settled stages of over 20 species were observed in association with hardbottom reef structure. Outside of lagoons, nearshore hardbottom areas are the primary natural structures in shallow waters of mainland Florida's east coast and were estimated to have nursery value for 34 species of fishes. After one year, burial of approximately five ha of hardbottom habitat at one site lowered the numbers of individuals and species by over 30× and 10×, respectively. Due to their early ontogenetic stage, many of these species may not be adapted for high mobility in response to habitat burial. Dredging effects may be amplified by burial prior to and during spring and summer periods of peak larval recruitment.

Lindquist, D.G., Ogburn, M.V., Stanley, W.B., Troutman, H.L., and Pereira, S.M. 1985. Fish Utilization Patterns on Temperate Rubble-mound Jetties in North Carolina. Bulletin of Marine Science, 37(1): 244-251.

Quantitative visual surveys were conducted on a recently constructed jetty (1980) and an older jetty (1966) at Masonboro Inlet, North Carolina, U.S.A., in order to compare the noncryptic fishes as follows: between the two jetties; between the inlet and ocean sides of the older jetty; between the mid-depth (2 m) and jetty base (4 m depth) of the old jetty. Collections of four resident reef fishes were made in order to assess dietary dependence on reef-associated prey. The primary reef residents were three porgies *(Archosargus probatocephalus, Diplodus holbrooki,* and *Lagodon rhomboides),* black sea bass *(Centropristis striata),* tautog *(Tautoga onitis),* and pigfish *(Orthopristis chrysoptera).* Bluefish *(Pomatomus saltatrix)* and round scad *(Decapterus punctatus)* were the primary transient pelagics while spot *(Leiostomus xanthurus)* was a primary transient sand bottom species. Except for greater numbers of pigfish and sheepshead *(A. probatocephalus)* at the new jetty, the abundance and composition of fishes on the two jetties were similar. The abundance and composition of near-bottom fishes on the inlet and ocean side were also similar except for a greater abundance of pigfish at the ocean side. Mid-depth surveys indicated that spottail pinfish were more abundant on the ocean side while black sea bass and spot were more abundant on the inlet side. A major difference was observed in increased abundance of the porgies, bluefish, and pigfish populations at the mid-depth stations and increased abundance of black sea bass at the jetty base stations. The dietary analysis of the three porgies and tautog indicated a dependence on reef-associated prey.

Long, T.M., Angelo, J., and Weishampel, J.F. 2011. LiDAR-derived Measures of Hurricane- and Restoration-generated Beach Morphodynamics in Relation to Sea Turtle Nesting Behaviour. International Journal of Remote Sensing, 32 (1): 231-241.

Coastal ecosystems provide sea turtle nesting habitat, and thus their maintenance is vital to promote conservation of the species. Before and after a very active hurricane season, airborne Light Detection and Ranging (LiDAR) was used to quantify the topographic dynamics of a critical nesting beach in east central Florida, USA, that was subjected to erosion and restoration. The surface area and volume of the beaches along a 41 km stretch, which is home to the highest concentration of loggerhead and green turtle nests in North America, differed significantly between pre- and post-hurricane and between pre-hurricane and post-restoration periods. Sea turtle nesting success (nesting emergences : total emergences) in the season after the hurricanes was correlated with various LiDAR-detected characteristics to determine how sea turtles responded to beach dynamics resulting from the storms and subsequent restoration. We found that the more the shape of the beach profile was altered from its pre-hurricane morphology, the more nesting success decreased.

Lucrezi, S., Schlacher, T.A., and Robinson, W. 2010. Can Storms and Shore Armouring Exert

Additive Effects on Sandy-Beach Habitats and Biota? Marine and Freshwater Research, 61: 951-962.

Increased storminess is a likely consequence of global climate change; its effects may be most dramatic on coasts dominated by sandy beaches. This scenario demands that the impacts of storms and the role of armouring structures, constructed as storm defences, are better understood. Here, we assess how a relatively small storm affected beach morphology and macrobenthos, and whether a seawall can modulate such impacts. The study system was a small (<1.5 km long) beach, bisected into parts with and without a seawall. The beach became narrower and steeper during the storm, when 26% of the subaerial sediment prism eroded from the armoured section; sand losses on the unarmoured part were one-fifth of those on the armoured part. Densities of ghost crabs (*Ocypode*) dropped significantly (36%) and were to some extent modulated by shore armouring; losses were high (62%) just seawards of the seawall where post-storm densities remained consistently lower. There was no ecological recovery in the short term, with most (83%) post-storm density values of crabs being lower, and crab counts in front of the seawall being depressed up to 3 months after the storm. Seawalls can change the resilience of beaches to storms, which may result in stronger ecological effects on armoured coasts.

Mallinson, D.J., Culver, S.J., Riggs, S.R., Walsh, J.P., Ames, D., and Smith, C.W. 2008. Past, Present and Future Inlets of the Outer Banks Barrier Islands, North Carolina: A White Paper. East Carolina University, Greenville, North Carolina, 22 p.

For centuries, humans have depended on inlets as a means of navigating between the ocean and the protected coastal waters behind barrier islands. Inlets along the North Carolina Outer Banks barrier islands offered access to the first English settlers in the New World during the late 16th century, and continue to offer access for commercial and recreational vessels. Although promising passage to sheltered waters, the dynamic, shifting sands of the inlet shoals have led to the grounding and destruction of numerous vessels, contributing to the infamous label "graveyard of the Atlantic" for the North Carolina coast. With time, some inlets provided access to port towns which became locations for trade, and which would provide a local pilot to help navigate ships through the shifting channels. Thus, inlets became an important economic asset. Today, inlets are still vital to navigation, trade, and commerce, especially commercial and recreational fishing. In addition to their clear historical and economic significance, inlets provide a vital service to the maintenance of estuaries and barrier islands, and play a fundamental role in the evolution of transgressive (landward migrating) barrier islands. In spite of their name, inlets could more appropriately be termed "outlets" as they provide an exit for fresh water flowing down the rivers. Within the estuaries, the fresh riverine water mixes with salty ocean water to produce the mixed salinity or brackish waters. The riverine flow volumes and ocean storm dynamics determine the residence time of water within the estuaries, which is important to biological systems. Inlets also provide a pathway for sand to be transferred from the shorezone on the ocean-side of the island to the estuarine side of the island. The sand is deposited as vast flood-tide deltas which are colonized by marsh plants upon inlet closure. The resulting back-barrier shoals and marshes maintain island width, and provide a shallow platform over which the island may migrate landward. The occurrence of inlet channel sediments and flood-tide delta sediments beneath the barrier islands affects the variety of sediment available to the beach system as the ocean shoreline recedes. As such, island, beach, and shoreface morphologies are related to the occurrence of paleo-inlet channels beneath the islands. In turn, the island geomorphology is a key factor in determining where future inlets are most likely to occur. Thus, it is important to understand the dynamics of past inlets and their relationship to the sediment budget and island geomorphology. Inlets are vital to the short-term maintenance of barrier island systems and their estuaries, and long-term barrier island evolution in response to ongoing sea-level rise.

Mallinson, D.J., Culver, S.J., Riggs, S.R., Thieler, E.R., Foster, D., Wehmiller, J., Farrell, K.M., and Pierson, J. 2010. Regional Seismic Stratigraphy and Controls on the Quaternary Evolution of the Cape Hatteras Region of the Atlantic Passive Margin, USA. Marine Geology, 268: 16-33.

Seismic and core data, combined with amino acid racemization and strontium-isotope age data, enable the definition of the Quaternary stratigraphic framework and recognition of geologic controls on the development of the modern coastal system of North Carolina, U.S.A. Seven regionally continuous high amplitude reflections are defined which bound six seismic stratigraphic units consisting of multiple regionally discontinuous depositional sequences and parasequence sets, and enable an understanding of the evolution of this margin. Data reveal the progressive eastward progradation and aggradation of the Quaternary shelf. The early Pleistocene inner shelf occurs at a depth of ca. 20–40 m beneath the western part of the modern estuarine system (Pamlico Sound). A mid- to outer shelf lowstand terrace (also early Pleistocene) with shelf sand ridge deposits comprising parasequence sets within a transgressive systems tract, occurs at a deeper level (ca. 45–70 m) beneath the modern barrier island system (the Outer Banks) and northern Pamlico Sound. Seismic and foraminiferal paleoenvironmental data from cores indicate the occurrence of lowstand strandplain shoreline deposits on the early to middle Pleistocene shelf. Middle to late Pleistocene deposits occur above a prominent unconformity and marine flooding surface that truncates underlying units, and contain numerous filled fluvial valleys that are incised into the early and middle Pleistocene deposits. The stratigraphic framework suggests margin progradation and aggradation modified by an increase in the magnitude of sea-level fluctuations during the middle to late Pleistocene, expressed as falling stage, lowstand, transgressive and highstand systems tracts. Thick stratigraphic sequences occur within the middle Pleistocene section, suggesting the occurrence of high capacity fluvial point sources debouching into the area from the west and north. Furthermore, the antecedent topography plays a significant role in the evolution of the geomorphology and stratigraphy of this marginal system.

Manning, L.M. 2003. Ecology of ocean beaches: The Importance of Human Disturbances and Complex Biological Interactions within a Physically Rigorous Environment. [PhD dissertation]: Chapel Hill, North Carolina, University of North Carolina at Chapel Hill, 164 p.

This dissertation highlights the importance of anthropogenic disturbance as well as complex biological interactions for a benthic community within a physically rigorous, soft-sediment system. Sandy beaches are thought to be structured primarily by physical factors and to have infaunal communities that are well adapted to sediment disturbances. In chapter 1, I investigate the effect of the disturbance of beach nourishment on the macroinfauna of the beach. Despite limited understanding of its impacts, beach nourishment, or the addition of sediment from an outside source to the beach, is currently the most frequently employed response to shoreline erosion in the United States. Results of benthic sampling demonstrate that abundances of several taxa and productivity of the community were reduced following the disturbance. I also conduct experiments in specialized wave-tanks to test hypotheses about specific side-effects often associated with beach nourishment projects (e.g., altered sedimentology, elevated turbidity in the nearshore zone) and the mechanisms by which these physical factors affect beach infauna. Results indicate that elevated turbidity and altered sedimentology can impact beach organisms and slow the rate of recovery of the community. Biological interactions are considered insignificant in structuring communities of high-energy sandy beaches. In chapter 2, I examine a case in which predation may play a role in the evolution and maintenance of intraspecific diversity of the coquina clam, *Donax variabilis*. The coquina clam is highly polymorphic for both shell color and pattern, and results of predation experiments indicate that such variation provides protection against visual predators. Results also provide support for the hypothesis that both visual selection and apostatic selection are acting on the observed polymorphism. In chapter 3, I evaluate the nature of the often-observed association between *Donax* spp. and an epibiotic hydroid, *Lovenella gracilis* (Cnidaria). Field and laboratory experiments reveal that the nature of the association is context dependent and ranges from being mutually beneficial to being detrimental to the host. Chapters 2 & 3 serve to highlight the role of predation on sandy beaches and indicate the need for future studies on sandy beaches to consider biotic interactions as well as a broader range of biotic interactions.

Manning, L.M., Peterson, C.H., and Bishop, M.J. 2014. Dominant Macrobenthic Populations Experience Sustained Impacts from Annual Disposal of Fine Sediments on Sandy Beaches. Marine Ecology Progress Series, 508: 1-15.

Despite increasing use of dredged materials as beach fill to protect coastal property and public beaches from storm damage, knowledge of how this practice affects sandy beach ecosystems remains poor. We coupled field monitoring of 2 successive beach disposal events with mesocosm experiments to assess mechanisms of ecological effects of fine sediment disposal. Macrobenthic sampling on Topsail Island, North Carolina, revealed that disposal of dredge spoils transformed beach grain sizes from medium to fine sand. Water sampling documented substantially elevated surf-zone turbidity during and occasionally after sediment deposition. When disposal occurred before spring invertebrate recruitment to the beach, it negatively influenced recruitment of the mole crab *Emerita talpoida* and the amphipod *Parahaustorius longimerus*. When disposal followed recruitment, it affected abundances of the bean clam *Donax variabilis* and 3 species of haustoriid amphipods negatively, and abundance of the spionid polychaete *Scolelepis squamata* positively. Effects lasted for the full warm season, and suppressions of invertebrate abundances were repeated across successive annual disposal events. In mesocosms, turbidity matching that induced in the field slowed growth of clams and modified habitat choices by predatory fishes. Hence, annual disposal of fine-grained dredge spoils on these sandy beaches maintained depressed abundances of 5 of 6 macroinvertebrate prey of shorebird and surf fish, without sustaining elevated volumes of beach sediments as long as a year. Implementation of disposal projects before the beginning of the seasonal recruitment of benthos resulted in fewer negative impacts on abundance than disposal projects conducted after the recruitment season, probably reflecting a more universal risk from burial and suffocation.

Manning, L.M., Peterson, C.H., and Fegley, S.R. 2013. Degradation of Surf Fish Foraging Habitat Driven by Sedimentological Modifications Caused by Beach Nourishment. Bulletin of Marine Science, 89: 83-106.

Novel wave-tank mesocosms allowed hydrodynamically realistic tests of how sediment modifications affect feeding by a surf fish, Florida pompano, *Trachinotus carolinus* (Linnaeus, 1766). Pompano demonstrated visually based selection, preferentially preying on bean clams, *Donax variabilis* Say, 1822, colored in contrast with background. Pompano often took shell into their mouths instead of live bean clams. Sediments of nourished Bogue Banks (North Carolina) beaches exhibited >2.5-yr persistence of elevated coarse shell content at levels that suppressed pompano feeding in wave tanks. Elevated turbidity 4–8 mo after nourishment indicated that wave-induced erosion of buried fine sediments in sacrificial beach fill resulted in repeated turbidity events, reaching levels that in wave tanks reduced pompano feeding on *Donax* and mole crabs, *Emerita talpoida* (Say, 1817). Burial speeds of these prey in the beach swash zone were progressively reduced by increasing shell concentrations. Reduced burial rates reduce feeding opportunity and expose these mobile invertebrates to greater risk of wave transport out of the swash-zone habitat. Sampling six beaches revealed that density of *Donax* decreased linearly with increasing sediment size and shell concentration. Beyond the immediate mass mortality of invertebrate prey caused by >1 m of sediment deposition during beach filling, coarse shell fragments and other large particles persist as a press disturbance for years after the nourishment ends, and elevated silts/clays can become resuspended by erosive wind events in repeated pulse disturbances for at least months afterward, in each case reflecting demonstrable long-term degradation of sandy-beach foraging habitat for surf fish.

Marsh, G.A. and Turbeville, D.B. 1981. The Environmental Impact of Beach Nourishment: Two Studies in Southeastern Florida. Shore and Beach, 49(3): 40-44.

Rising sea levels and improper beachfront development practices have created serious erosion problems along most of Florida's coastline. Beach nourishment projects involving the dredging of sand from offshore deposits have become increasingly common in recent years and will undoubtedly continue in the future. The problem appears to be especially severe along the Gold Coast - Palm Beach, Broward, and Dade Counties - where several large-scale nourishment operations have recently been completed or are now in progress, including a $67 million project along 10.5 miles of eroded shoreline at Miami Beach. Despite the fact that state and federal regulatory agencies almost routinely approve these dredge and fill operations, we know very little about their impact on the marine environment. In fact, prior to our studies at Florida Atlantic University, no quantitative reports of this type were available for southeastern Florida. In this article we review briefly two studies which we have recently conducted in Broward County, one at Hillsboro Beach and one at Hallandale.

Martin, D., Bertasi, F., Colangelo, M.A., de Vries, M., Frost, M., Hawkins, S.J., Macpherson, E., Moschella, P.S., Satta, M.P., Thompson, R.C., and Ceccherelli, V.U. 2005. Ecological Impact of Coastal Defence Structures on Sediment and Mobile Fauna: Evaluating and Forecasting Consequences of Unavoidable Modifications of Native Habitats. Coastal Engineering, 52: 1027-1051.

We analyse the effects of coastal defence structures, mainly low crested (LCS), on the surrounding intertidal and subtidal infaunal assemblages and mobile fauna. The results summarise joint studies within the DELOS project in Spain (Mediterranean Sea), Italy (Adriatic Sea) and UK (English Channel and Atlantic Ocean). We demonstrate that univariate analysis did not generally identify LCS impacts, but multivariate analyses did, this being a general trend across all locations and countries. Changes in sediment and infauna seem to be inevitable and usually tend to induce negative changes, particularly on the landward side and in the presence of additional structures or after beach nourishment. The consequences of LCS construction always depend on the response of the assemblages inhabiting a given region. However, to assess the ecological importance of the induced changes and to provide additional monitoring criteria, likely indicator species should be taken into account. The presence of species either coming from the new hard bottoms or associated to physical disturbances is viewed as a negative impact, while the potential nursery role of LCS is a positive one. The combined use of monitoring and forecast models allows to identify these impacts and may play a relevant role in mitigation protocols. Finally, our work supports the feasibility of introducing design criteria tending to facilitate a positive evolution of the assemblages surrounding the structures once the changes due to the presence of the LCS are completed and the new situation tends to become more stable.

Maslo, B., Handel, S.N., and Pover, T. 2011. Restoring Beaches for Atlantic Coast Piping Plovers (*Charadrius melodus*): A Classification and Regression Tree Analysis of Nest-Site Selection. Restoration Ecology, 19(201): 194-203.

To effectively restore wildlife habitat, ecological research must be easily translated into practical design criteria. Clear directives from research can support arguments that promote more appropriate restoration strategies. For the federally threatened piping plover (*Charadrius melodus*), beach stabilization practices often accelerate the degradation of suitable breeding habitat and could be revised to provide more advantageous conditions. Several studies of piping plover habitat selection have been conducted, yet useful and detailed design directives remain undeveloped. In this study, we use classification and regression tree analysis to (1) identify microhabitat characteristics and important variable interactions leading to nest establishment and (2) develop target, trigger, and threshold values for use in effective design and adaptive management of piping plover habitat. We found that nests primarily occur in three distinct habitat conditions defined by percent shell and pebble cover, vegetative cover, and distance to nearest dunes and the high tide line. Nest-site characteristics vary depending on where in the landscape a nest is initiated (backshore, overwash fan, or primary dune). We translate these results into the following pragmatic target design parameters: (1) vegetative cover: less than 10% (backshore), 13% (primary dune); (2) shell/pebble cover: 17–18%; (3) dune height: ≤1.1 m; and (4) dune slope: ≤13%. We also recommend threshold values for adaptive management to maintain habitat that is attractive to plovers. This technique can be applied to many other wildlife habitat restorations. Future studies on niche parameters driving chick survival are necessary to realize the full potential of habitat restoration in increasing overall reproductive success.

Maurer, D., Keck, R.T., Tinsman, J.C., and Leathem, W.A. 1981. Vertical Migration and Mortality of Benthos in Dredged Material: Part I- Mollusca. Marine Environmental Research, 4: 299-319.

Benthic invertebrates have many characteristics, which make them prime candidates for burial studies in dredged material. A major concern in dredging and disposal projects is the effect of burial on the survival of benthic invertebrates. The purpose of the research reported in this paper was to determine the ability of estuarine benthos - in particular three species of molluscs (*Mercenaria mercenaria, Nucula proxima* and *Ilyanassa obsoleta*) - to migrate vertically in natural and exotic sediments and to determine the survival o/benthos when exposed to particular amounts of simulated dredged material. Mortalities generally increased with increased sediment depth, with increased burial time and with overlying sediments whose particle size distribution differed from that of the species' native sediment. Temperature affected mortalities and vertical migration. It was concluded that vertical migration is a viable process which can significantly affect rehabilitation of a dredged disposal area. Under certain conditions, vertical migration should be considered, together with larval settling and immigration from outside impacted areas, as a mechanism of recruiting a dredge-dump site.

Maurer, D., Keck, R.T., Tinsman, J.C., and Leathem, W.A. 1981. Vertical Migration and Mortality of Benthos in Dredged Material: Part II- Crustacea. Marine Environmental Research, 5: 301-317.

A major concern in dredging and disposal projects is the effect of burial on the survival of benthic invertebrates. The purpose of the research described in this paper was to determine the ability of benthos (mud crab, *Neopanope sayi*; haustoriid amphipod, *Parahaustorius longimerus*) to migrate vertically in natural and exotic sediments and to determine the survival of benthos when exposed to particular amounts of simulated dredged material. Mortalities generally increased with increased sediment depth, burial time and exotic sediment type. Temperature also affected vertical migration and mortalities. As a taxonomic group, crustaceans showed considerable virtuosity in burrowing. Even though *N. sayi* and *P. longimerus* cannot be included among the deepest crustacean burrowers, their performance in laboratory experiments indicates that they may be capable of recolonisation of disposal sites under certain conditions.

Maurer, D., Keck, R.T., Tinsman, J.C., and Leathem, W.A. 1982. Vertical Migration and Mortality of Benthos in Dredged Material: Part III- Polychaeta. Marine Environmental Research, 6: 49-68.

The survival of benthic invertebrates from dredging and disposal activities is a major environmental concern in such projects. The purpose of the research described in this paper was to determine the ability of benthos (polychaetes, *Scoloplos fragilis* and *Nereis succinea*) to migrate vertically in natural and exotic sediments and to determine the survival of benthos when exposed to particular amounts of simulated dredged material. Mortalities generally increased with increased sediment depth, exotic sediment and burial time. Temperature also affected vertical migration and mortalities. These experiments, together with other experiments conducted by us and other workers, indicate that polychaetes in particular, and benthos in general, can survive dredging and disposal projects. Under certain conditions several major taxa (polychaetes. molluscs, crustaceans) can be expected to successfully recolonise disposal sites by vertical migration.

Maurer, D., Keck, R.T., Tinsman, J.C., and Leathem, W.A., Wethe, C., Lord, C., and Church, T.M. 1986. Vertical Migration and Mortality of Marine Benthos in Dredged Material: A Synthesis. International Review of Hydrobiology, 71(1): 49-63.

This account describes the comparative response of four species of benthic invertebrates to burial in terms of vertical migration and mortality, and provides a synthesis of studies and recommendations upon which to assess future impacts. The species featured were the bivalve *Mercenaria mercenaria*, the amphipod crustacean *Parahaustorius longimerus*, and the polychaetes *Scoloplos fragilis* and *Nereis succinea*. There was evidence of synergistic effects on burrowing activity and mortality with changes in time of burial, sediment depth, sediment type and temperature. In sediment with silt-clay, *N. succinea* was the most resistant species followed by *M. mercenaria, S. fragilis* and *P. longimerus*. In sediment without silt-clay the order of percent mortality was reversed. Studies of surface water chemistry and sediment geochemistry showed that dissolved oxygen decreased significantly and ammonia and sulfide increased significantly between the surface and below 2.0 cm within a 15-day period. Based on these results and physiological tolerances from the literature it was concluded that *M. mercenaria* and *N. succinea* would be relatively resistant to chemical effects of spoil disposal, whereas *S. fragilis* and *P. longimerus* would be less resistant to such effects. Vertical migration of benthic invertebrates through dredge disposal can be a viable mechanism of recolonization under certain conditions. Some effects of burial of benthos can be predicted based on morphology, behavior and physiology. These biological features were discussed with examples dealing with molluiscs, crustaceans, and polychaetes. Finally, recommendations were made concerning the type of studies to provide additional data to aid management agencies in decision making about future dredging and disposal practices.

McDougall, W.G., Sturtevant, M.A., and Komar, P.D. 1987. Laboratory and Field Investigations of the Impact of Shoreline Stabilization Structures on Adjacent Properties. Coastal Sediments '87, American Society of Civil Engineers: New York, 961-973.

The impact of shoreline stabilization structures on adjacent unprotected properties is a key consideration in the evaluation of construction permits. To address this issue a project has been initiated consisting of two elements; hydraulic model studies and a field monitoring program. Results indicate that the impacts increase as the structure length increases. It was observed in both the experimental results and the field data of Walton and Sensabaugh (1978) that the depth of excess erosion is approximately 10% of the seawall length. The laboratory data also revealed that the along-coast length of erosion from each end of the structure is approximately 70% of the structure length.

McGinnis, B.A. 2004. Late Holocene Evolution of a Retrograding Barrier: Hutaff Island, North Carolina. [M.S. thesis]: Wilmington, North Carolina, University of North Carolina Wilmington, 92 p.

Hutaff Island is a 6.0-km (3.7-mile) long undeveloped barrier located in southwestern Onslow Bay, North Carolina. The barrier is bordered by New Topsail Inlet to the northeast and Rich Inlet to the southwest, and has historically been influenced by several adjacent tidal inlets with contrasting behaviors. Severe storm events have frequently impacted the barrier throughout the

1938 – 2002 study period, resulting in dramatic erosion and overtopping of the barrier. The development of major washover terraces coupled with storm-induced dune erosion has dramatically lowered the barrier's topography. Consequently, the island is poised to migrate landward at accelerated rates during future high-energy storm events. The shoreface that fronts the barrier consists of a thin veneer of modern sand and gravelly sand. The mobile surface veneer is generally less than 1.0 m thick and overlies an easily eroded Oligocene siltstone unit that frequently crops out on the inner shoreface forming low-relief hardbottoms. Vibracore sequences recovered from the estuary contain inter-bedded clean and muddy sand units. The sand-rich intertidal and shallow subtidal sequences recovered near the barrier reflect the role of the numerous inlets that have cycled through the area. Long-term shoreline change rates showed that Hutaff Island had experienced an average net loss of ~ 2.1 m/year (7.0 ft/year) between 1938 and 2002. A dramatic lowering of the barrier profile accompanied this landward translation. The relatively high erosion rates and increased washover susceptibility appear to be attributable to a combination of variables, including the region's low sediment supply and the persistent presence of unstable inlets. An understanding of the processes influencing Hutaff Island's evolution can be used as a model in formulating management decisions on nearby barriers where it is often difficult to assess the active processes and changes taking place as a result of dense coastal development and its associated anthropogenic effects.

McLachlan, A. 1996. Physical Factors in Benthic Ecology: Effects of Changing Sand Particle Size on Beach Fauna. Marine Ecology Progress Series, 131: 205-217.

This paper reports on the disposal of diamond mine tailings on a Namibian sandy beach. Coarse sand in the tailings greatly increases the grain size of the affected parts of the beach and thereby provides the opportunity to assess the effects of changing sand grain size on a beach when other physical variables are kept constant. Elizabeth Bay (Namibia) is 4 km long and was originally composed of fine sand which, exposed to moderate to heavy wave action, produced a log spiral bay with a dissipative beach. Tailings disposal in the centre of the bay has increased mean sand particle size from original values of 110 to 160 pm to present values of 500 to 800 μm with a concomitant conversion of beach morphodynamic state from dissipative to intermediate. Surveys of the 2 ends of the bay, which are relatively unaffected by disposal, and of an undisturbed similar bay nearby revealed intertidal benthic macrofauna communities with 15 to 20 species occurring in high abundance (24,120 to 129,276 m^{-1}). In 3 transects in the affected area, species richness was 8 to 12 per transect and abundance was 640 to 4710 m^{-1}. Beds of the large sand mussel *Donax serra* have disappeared from the affected sector of the bay and peracarids typical of finer sands have been replaced by a more robust species. Regression analysis revealed significant correlations between community parameters (species richness and abundance) and both beach slope and particle size; ANOVA confirmed the significantly lower abundances of fauna in the affected areas. Smothering effects appeared to be localised and limited. This study has supported the hypothesis that an increase in sand particle size (on a beach where tide range and wave energy have remained constant) results in a change in beach state and a decrease in species richness and abundance.

McLean, M.R.W. 2009. Effects of Inlet Migration on Barrier Island Planform and Oceanfront Change: New Topsail Inlet, N.C. [M.S. thesis]: Wilmington, North Carolina, University of North Carolina Wilmington, 127 p.

New Topsail Inlet, located 40 km northeast of Wilmington, NC, separates Topsail Island, a developed barrier from Hutaff Island, an undeveloped barrier. Since the inlet opened in the late 1720's the inlet has migrated ~11 km to the southwest. A GIS based analysis of 61 sets of historic aerial photographs (1938-2006) provided data on migration rates, the morphologic changes, the periodicity of ebb delta breaching events and oceanfront changes associated with migration. Since 1938, New Topsail Inlet has migrated southwest at an average rate of 26 m/yr. Migration rates have varied from 95 m/yr (1945-49), to 11m/yr (1956-62). Four ebb delta-breaching events occurred between 1978 and 2007. During the largest event (1978-1986) the outer segment of the ebb channel was repositioned by 68°. Prior to channel reorientation, the inlet was migrating at 62 m/yr. Immediately prior to the breaching event, the ebb channel briefly reversed its direction of movement, migrating at 23m/yr to the northeast. Subsequent to shoal breaching, migration accelerated to 73 m/yr to the southwest due to the large volume of material by-passed to the updrift Topsail Beach shoulder. As a consequence of the southwesterly migration and ebb channel deflection, the southern portion of Topsail Beach has been characterized by complex temporal and spatial oceanfront changes. Increased rates of accretion (34 m/yr) and erosion (-15 m/yr) were common. This is due in part to the development and movement of a large shoreline protrusion and in part to the truncation of the trailing shoreline as the inlet moves south. The shoreline bump, which develops when the inlet is oriented to the north, accretes rapidly as bypassed shoals weld to the updrift beach. However, when the channel switches, the large bump soon becomes an erosion hotspot. Both the shoreline bump and the erosion hotspots migrate with the inlet, leaving behind a beach with typical erosion rates.

McNamara, D.E., Murray, A.B., and Smith, M.D. 2011. Coastal Sustainability Depends on how Economic and Coastline Responses to Climate Change Affect Each Other. Geophysical Research Letters, 38: L07401.

Human-induced climate change is predicted to accelerate sea level rise and alter storm frequency along the US east coast. Rising sea level will enhance shoreline erosion, and recent work indicates changing storm patterns and associated changes in wave conditions can intensify coastal erosion along parts of a coastline. Investigations of coastal response to climate change typically consider natural processes in isolation-neglecting repeated changes to the coastline from human actions, primarily through shoreline nourishment projects, which add sand to the shoreline to counteract erosion. In a model coupling economically driven shoreline nourishment with wave- and sea level rise-driven coastline change, and accounting for dwindling sediment resources for nourishment, coastline response depends dramatically on the relationship between patterns of property value and erosion. Simulations show that when nourishment costs rise with depletion of sand resources, coastline change is tied to the interaction between patterns of erosion and property value. Simulations show that when high property values align with highly erosive locations, sand resources are depleted rapidly and nourishment in lower property value towns is quickly abandoned. Although our model simulates a particular coastal morphology, the result that future behavior of the coastline and the economic viability of nourishment in a given town depend on the regional interaction between patterns of property value and erosion is likely applicable to many coastal configurations. More broadly, coupling economic and physical models reveals equity and sustainability implications of coastal climate adaptation as well as patterns of coastline change that a physical model alone would overlook.

McNamara, D.E., Gopalakrishnan, S., Smith, M.D., and Murray, A.B. 2015. Climate Adaptation and Policy-Induced Inflation of Coastal Property Value. PLoS ONE, 10(3): e0121278.

Human population density in the coastal zone and potential impacts of climate change underscore a growing conflict between coastal development and an encroaching shoreline. Rising sea-levels and increased storminess threaten to accelerate coastal erosion, while growing demand for coastal real estate encourages more spending to hold back the sea in spite of the shrinking federal budget for beach nourishment. As climatic drivers and federal policies for beach nourishment change, the evolution of coastline mitigation and property values is uncertain. We develop an empirically grounded, stochastic dynamic model coupling coastal property markets and shoreline evolution, including beach nourishment, and show that a large share of coastal property value reflects capitalized erosion control. The model is parameterized for coastal properties and physical forcing in North Carolina, U.S.A. and we conduct sensitivity analyses using property values spanning a wide range of sandy coastlines along the U.S. East Coast. The model shows that a sudden removal of federal nourishment subsidies, as has been proposed, could trigger a dramatic downward adjustment in coastal real estate, analogous to the bursting of a bubble. We find that the policy-induced inflation of property value grows with increased erosion from sea level rise or increased storminess, but the effect of background erosion is larger due to human behavioral feedbacks. Our results suggest that if nourishment is not a long-run strategy to manage eroding coastlines, a gradual removal is more likely to smooth the transition to more climate-resilient coastal communities.

McQuarrie, M. and Pilkey, O.H. 1998. Evaluation of Alternative or Non-Traditional Devices for Shoreline Stabilization. Journal of Coastal Research, SI 26: 269-272.

Traditional stabilization devices such as seawalls, groins and breakwaters have a number of disadvantages including high cost, difficulty of removal and damage to the fronting and adjacent beaches. A large number of non-traditional or alternative devices have come on the market, and often are permitted by coastal management authorities because they do not appear to be the traditional types. These devices are relatively low-cost and are removable, however, in the stabilizing function, they generally behave like traditional seawalls, groins and breakwaters. Some of the more visible non-traditional devices are reviewed by category, manufacturers' claims, and cautions to buyers.

Miller, H.C., William A. Dennis, W.A., and Wutkowski, M.J. 1996. A Unique Look at Oregon Inlet, NC USA. Proceedings of the 25th Conference on Coastal Engineering, American Society of Civil Engineers: New York, 25: 4517-4530.

Oregon Inlet (OI) in North Carolina (NC), the only inlet along a 170 km stretch of coast, supports an active commercial fishing and recreational boating industry. Severe erosion, because of the ongoing migration of 01, resulted in NC constructing a terminal groin to prevent the highway from being severed from the south side of the OI bridge. Construction of this structure provided a unique opportunity to monitor and assess project impacts which could be directly related to the twin jetties which are proposed for this site. The monitoring program included a directional wave gauge, aerial photography, and semi-annual sled-surveys extending 6 km north and south of the inlet. The terminal groin returned the shoreline to its pre-1986 position and has successfully protected the highway abutment to the bridge through many severe storms. This paper presents the results of 6 years of monitoring the morphologic changes. The results document how the coast has adjusted to the construction, a multi-year wave climate reversal, and placement of 1.5 million m3 of dredged material on the beach. The surveyed area generally lost material both on the up and downdrift sides, much of which apparently has been deposited in the inlet. The effect of these changes on the coast and the inlet's stability are discussed.

Moffatt & Nichol. 2010. Terminal Groin Study: Final Report. Raleigh, North Carolina, 450 p., 5 Append.

This report details the findings of the consultant team portion of the North Carolina Coastal Resources Commission Terminal Groin Study. The study was initiated by the legislature under House Bill 709 (HB709) and mandated by Session Law 2009-479. It directed the Coastal Resources Commission (CRC) in consultation with the Division of Coastal Management (DCM), Division of Land Resources, and the Coastal Resources Advisory Council (CRAC) to study the use and applicability of a terminal groin as an erosion control device. The CRC is to present a report to the Environmental Review Commission (ERC) and the General Assembly by April 1, 2010. The CRC through DCM has contracted with a consultant team to perform the technical review portion of the study. This report focuses on the data gathering and analysis performed by the consultant team for this study. The team selected was led by Moffatt & Nichol (M&N) and supported by Dial Cordy & Associates (Environmental Consultants), Dr. Christopher Dumas (Professor of Economics, University of North Carolina, Wilmington), and Dr. Duncan FitzGerald (Professor of Department of Earth Sciences – Coastal Marine Geology, Boston University). The M&N team gathered data and performed analysis with respect to the tasks outlined in HB709. Members of the Science Panel on Coastal Hazards, which advises the CRC and DCM with matters of scientific data pertaining to coastal topics and recommendations, provided input into the scoping of the study and selection of study sites; and reviewed and commented on the study methodology and reports.

Mohanty, P.K., Patra, S.K., Bramha, S., Seth, B., Pradhan, U., Behera, B., Mishra, P., and Panda, U.S. 2012. Impact of Groins on Beach Morphology: A Case Study Near Gopalpur Port, East Coast of India. Journal of Coastal Research, 28(1): 132-142.

Gopalpur Port is being developed as an all-weather open seaport from a fair-weather port which has existed since 1987. Two groins, a 530-m south groin and a 370-m north groin, were constructed during the periods from August 2007 to November 2009 and October 2007 to September 2008, respectively, on the north and south of the 500-m jetty which existed earlier. Port authorities are planning to construct a southern breakwater and a series of seven northern groins. Therefore, it is essential to assess the impacts of coastal structures on beach morphology and shoreline change in the present context and to predict future trends. To achieve this, a long-term observational programme has been conducted since May 2008. Observations include beach profile, shoreline change (berm position), littoral environment observations, and sedimentological characteristics at monthly intervals north and south of the port, covering a total distance of about 5 km. From the analysis of results, erosion is observed north of the northern groin, particularly during the monsoon season. From October to January, deposition is observed mostly in the foreshore which replenishes the erosive environment observed during monsoon. On the other hand, a constant depositional trend is noticed south of the southern groin for 1.5 km. To assess the impacts of the present groins, beach profile and sediment characteristics were compared with observations made from February 2002 to February 2003. The comparison distinctly shows the impact of groins on erosion and deposition on the north and south beaches of the port. Volume, beach width, and beach area estimates indicate that the rate of deposition on the south beach is much faster than the rate of erosion on the north.

Montague, C.L. 1993. Ecological Engineering of Inlets in Southeastern Florida: Design Criteria for Sea Turtle Nesting Beaches. Journal of Coastal Research, SI 18: 267-276.

With appropriate design criteria modern inlet engineering can restore habitat for nesting sea turtles. Past inlet modifications in southeastern Florida have resulted in erosion of beaches and threats to beach front property. Hence beach restoration is now an inlet management imperative. Southeastern Florida beaches, however, are also among the world's most important nesting habitats for sea turtles. Features that make these beaches attractive to sea turtles can be produced when beaches are restored. Good nesting beaches near Jupiter Inlet, Florida have a uniform moderate beach slope (~1:10) without obstructions. Good beaches also possess a soft sand berm of sufficient thickness (> 1.5 m) and low enough compaction (< 35 kg cm^{-2}) to allow excavation by nesting sea turtles and their subsequent hatchlings. Moreover, less nest washout occurs on more stable beaches. To annually produce such a beach in the vicinity of managed inlets, annual or continuous beach nourishment is recommended with sand no finer than found naturally on nearby nesting beaches. A special engineering challenge is to provide a stable beach in the vicinity of jetties that reflect wave energy. Curved jetties that trap sand along their flanks may minimize nest washout in the vicinity of inlets. Ecological design criteria based on features of good nesting beaches can take the process of beach nourishment beyond a tool for mitigating losses ascribed to inlet management-it can a proactive tool for sea turtle managers.

Montague, C.L. 2008. Recovering the Sand Deficit from a Century of Dredging and Jetties along Florida's Atlantic Coast: A Reevaluation of Beach Nourishment as an Essential Tool for Ecological Conservation. Journal of Coastal Research, 24(4): 899-916.

A sand deficit on Florida's Atlantic coast affects sea turtle nesting, dune ecosystems, and storm protection. Ecological benefits of restoring very large deficits could exceed ecological costs. Dredging and beach nourishment databases revealed sand disposal dynamics and deficit size. Dredge-and-fill activities increased after 1950, peaked in the 1980s, then declined somewhat. Most sand disposal accompanied channel and harbor deepening; little was primarily for beach nourishment. Until the 1970s most dredged material was placed outside the coastal sand-sharing system (off-shore and upland). After 1970, beach and nearshore disposal rapidly increased, but generally involved sand already within the system. Moreover, offshore and upland disposal did not immediately decline. To date, little sand has been returned. By 2003, net removal totaled ~130×10^6 m^3. Channels and harbors increased by ~70×10^6 m^3, leaving 60×10^6 m^3 of standing sand deficit. Jetties could have redistributed another 70×10^6 m^3 from beaches and dunes to inlet shoals. Overall, loss of beaches and dunes could approach 130×10^6 m^3. Engineering responses to past objections have improved both habitat suitability and longevity of nourished beaches. Through field trials and adaptive management principles, ecologists could now develop beach nourishment into a management tool to rebuild lost habitat, restore the sand deficit, and stockpile additional sand before nonessential channels and harbors are allowed to refill. With large projects, sand from offshore, upland, and ebb shoal sites and natural wave energy for stable beach building, beach and dune habitat can be restored within decades, better preparing threatened animals for rising sea level.

Mosier, A.E. 1998. The Impact of Coastal Armoring Structures on Sea Turtle Nesting Behavior at Three Beaches on the East Coast of Florida. M.S. Thesis. St. Petersburg, Florida, University of South Florida. 112 p.

The purpose of this study was to investigate sea turtle nesting behavior in the presence of armoring structures. Armoring structures include a wide variety of rigid structures such as seawalls, rock piles, and wooden retaining walls designed to control beach erosion. Three beaches on the east coast of Florida were surveyed to compare the nesting behavior of loggerhead turtles *(Caretta caretta)* in front of armoring structures to that on adjacent, non-armored beaches. Beach profile data were used to examine spatial relationships of turtle nests and armoring structures, and to describe physical changes in the beach during the nesting season. A total of 252 turtle emergences were documented over a 25-day survey period. Significantly fewer emergences occurred in front of seawalls than on adjacent, non-walled beaches. Of the turtles that did emerge in front of seawalls, significantly more returned to the water without nesting than did turtles that emerged on beaches without seawalls. The lower number of emergences on beaches with seawalls suggests that nest site selection was made by some turtles before emerging on the beach. Of the 52 turtle tracks recorded in front of the seawalls, 37 (71 %) came into contact with the walls. Of those 37 turtles, 32 (86%) returned to the water without nesting. Beach profiles showed that turtle nesting habitat in front of the seawalls was lower in elevation than that on adjacent, non-armored beaches. Seawalls appeared to block the turtle's access to higher elevations, and resulted in an increase in abandoned nesting attempts. As coastal armoring becomes more prevalent on a given stretch of beach, the probability of a turtle emerging in front of the structure increases, thereby increasing the probability of non-nesting emergences. A simulation model was derived using data from this study to show the cumulative effect of increased shoreline armoring on turtle nesting emergences. These models can be used to forecast changes in turtle nesting activity on armored beaches around the state.

Nascimentot, L. and Lavenere-Wanderley, A.A. 2006. Effect of Shore Protection Structures (Groins) on Sao Miguel Beach, Ilheus Bahia Brazil. Journal of Coastal Research, SI 39: 858-862.

Measurements of beach profiles associated with granulometric analysis of beach sediments were made to determinate the morphological evolution of Sao Miguel beach (north coast of Ilheus - Bahia - Brazil), the coastline state and its response to the construction of four transverse groins as shore-protection structures. The results showed that the beach continued quite susceptible to the erosion in most of the coastline except for the first sector of the beach, between the groins 1 and 2. The curvature in planview of the beach sectors results from the wave refraction at the groins, which generates a longshore sediment transport causing deposition at both extremes of the beach sectors; as well as the action of rip currents in the central part of the sector, which carries sand seaward from the beach. The groin spacing on Sao Miguel beach varies from around

500m to 770m and groin lengths from 57m to 190m. This variability can be the reason for the failure of the shore-protection structures because it doesn't respect the relation of 1:3 recommended for this case. The predominant sediment deposited on Sao Miguel beach is fine sand, except for profile 8, where the predominant sediment is medium sand, corresponding to the higher energy sector of the beach. The variation of energy level along the beach can be a consequence of the shade zone of the Port of Malhado breakwater that modifies the intensity of the incident waves in the south part of the study area.

National Marine Fisheries Service [NMFS] and U.S. Fish and Wildlife Service [USFWS]. 1991. Recovery Plan for U.S. Population of Loggerhead Turtle. National Marine Fisheries Service, Washington, D.C. 64 p.

The loggerhead is federally listed as threatened worldwide. Nesting in the United States occurs primarily along North Carolina (1.0 percent), South Carolina (6.5 percent), Georgia (1.5 percent), and Florida (91 percent) beaches and accounts for approximately one third of the world population. Nesting trends are declining in Georgia and South Carolina, unknown in North Carolina and appear stable in Florida. Coastal development threatens nesting habitat and populations while commercial fisheries and pollution pose significant threats in the marine environment.

Naylor, E. and Kennedy, F. 2003. Ontogeny of Behavioural Adaptations in Beach Crustaceans: Some Temporal Considerations for Integrated Coastal Zone Management and Conservation. Estuarine, Coastal and Shelf Science, 58S: 169-175.

So-called "typical" behavioural responses of coastal animals to particular stimuli have previously been shown often to vary cyclically in phase with diel or tidal cycles in the environment. Less well-studied are differences in the behaviour of adults and juveniles of the same species at the same time of day or tidal state, or in response to the same stimulus. Experimental studies of such differences in behaviour are reviewed and compared for three species of beach crustaceans, namely, the crab *Carcinus maenas*, the isopod *Eurydice pulchra* and the amphipod *Orchestoidea tuberculata*. Juvenile, but not adult, *Carcinus* will entrain circatidal rhythmicity after exposure to artificial tidal cycles of immersion/emersion; juvenile, but not adult, *Eurydice* express pronounced freerunning circatidal swimming rhythms at neap tides as well as at springs; and, in *Orchestoidea*, juveniles and adults express patterns of daily locomotor activity that are complementary, both on the shore and in the laboratory. These ontogenetic differences are discussed in relation to distributional and behavioural differences between adults and juveniles in each species, drawing attention to their adaptive significance and wider implications for coastal management and conservation.

Nel, R., Campbell, E.E., Harris, L., Hauser, L., Schoeman, D.S., McLachlan, A., du Preez, D.R., Bezuidenhout, K., and Schlacher, T.A. 2014. The Status of Sandy Beach Science: Past Trends, Progress, and Possible Futures. Estuarine, Coastal and Shelf Science, 150: 1-10.

Open-ocean sandy beaches are coastal ecosystems with growing relevance in the face of global change. They provide key ecosystem services, such as storm buffering, nutrient cycling, water purification, nursery habitats for resource species, and feeding-breeding habitats for focal species (e.g. endangered sea turtles and shorebirds), and have also become nodes for economic development and cultural use. As a result, beaches face a range of threats, primarily from extractive use, habitat modification and development, sea-level rise and coastal squeeze. Consequently, balancing conservation of the ecosystem and sustainable use of the goods and services is particularly important for sandy shores. Thus, the only way to ensure their protection and continued provision of their valuable services, especially in a period of rapid global change, will be to apply knowledge generated from sound science in beach conservation and management. Here we aim to (1) identify and outline the broad ecological paradigms in sandy beach science; (2) report on a citation analysis of the published literature of the past 63 years (1950-2013) to provide context regarding the topics and location of research, the size and institutional composition of the research teams; and (3) investigate whether beach ecology can and has been incorporated into integrated coastal zone management practices. Past research was framed by specific paradigms (chiefly the Swash Exclusion Hypothesis and derivatives), which can be identified with distinct principles and concepts unique to beaches. Most of the sandy beach literature comes from only a few countries (dominated by USA, South Africa, Brazil and Italy), published by small research teams (<4 authors), mostly from single institutes. The field has yet to establish large multi-disciplinary teams to undertake rigorous experimental science in order to contribute to general ecological theory. Despite the constraints, beach science is responding to new challenges, with increasing use of the latest techniques. However, research in conservation and management specifically remains limited, with stronger focus on anthropogenic impacts, in turn leading to management of people on beaches rather than conservation of the ecosystem itself. We conclude with a look to the future for sandy beach science, and a summary of the contributions to this Special Issue.

Nelson, W.G. 1988. An Overview of the Effects of Beach Nourishment on the Sand Beach Fauna. *In:* Tait, L.S. (editor), Beach Preservation Technology 88. Problems and Advancements in Beach Nourishment. Florida Shore and Beach Preservation Association, Tallahassee, Florida: 295-310.

A general review of data on the effects of beach restoration on the main components of the sand beach macrofauna suggests that minimal biological effects result from beach nourishment for most animal groups. Some mortality of organisms may occur where grain size is a poor match to existing sediments; however, recovery of the beach system appears to be rapid. Turtle nesting may be negatively affected due to sand compaction for a period of about one year. Therefore, experimental work should be done to determine methods which can counteract compaction in turtle nesting areas following nourishment. Because available studies specifically analyzing biological effects of beach nourishment are few and often have design or analysis flaws, further biological monitoring of beach nourishment should be continued until adequate data for deciding whether monitoring is necessary can be made.

Nelson, W.G. 1993. Beach Restoration in the Southeastern US: Environmental Effects and Biological Monitoring. Ocean & Coastal Management, 19: 157-182.

In the coastal region of the southeastern US, beach restoration has become the method of choice for alleviating threats to property arising from erosion. This method remains somewhat controversial, due to both economic and environmental concerns. Many of the existing studies of biological impacts of beach restoration have deficiencies of sampling design that make clear interpretation of results difficult. The goal of this paper is to offer guidelines for sampling and analytical methods that will substantially improve the study of beach restoration impacts. Towards this end, an overview of the biological composition of sandy beaches of the southeastern US, in the context of beach restoration, is provided first. Then, specific recommendations for the design, execution and analysis of beach restoration monitoring programs to receive the maximum return for effort invested are described.

Nelson, W.G. 1993. Beach-inlet Ecosystems of Southeastern Florida: A Review of Ecological Research Needs and Management Issues. Journal of Coastal Research, SI 18: 257-266.

Beach-inlet ecosystems of southeastern Florida are a complex, interacting mosaic of ecological subsystems. Major habitat components include near-shore hard and soft bottoms, sand beaches, rubble structure habitats, seagrass beds, and the pelagic zone. The biotic components of beach inlet ecosystems are briefly described and major research and management needs within each biotic system are proposed. It is proposed that future management plans within these systems need to reflect a more integrated view of the system if biotic integrity is to be adequately maintained.

Nordstrom, K.F., Allen, J.R., and Gares, P.A. 1979. The Effect of Groin Removal on Shoreline Stability. Coastal Structures '79, American Society of Civil Engineers: New York, 904-920.

One of the principal recreation beaches at Sandy Hook, N.J. is located immediately downdrift of a groin field. Episodes of accretion and erosion occur on this beach which considerably reduce the reliability of the beach for high intensity recreational use. Management options include the removal or alteration of the groins to reduce shoreline variability and thus to facilitate long-term planning. An identification of the groin effects on beach change, including beach stability and sediment transport, is required to determine whether groin alteration will have the desired effect. Offshore controls include a large tidal shoal, which affects wave refraction, and a longshore bar about 50 meters off the beach face which acts as a filter for onshore wave energies. Analysis of maps and aerial photographs indicates that beach change is correlated with changes in these offshore controls as well as changes in the highly mobile updrift beach and with the creation of inlets at the proximal end of the spit. It is felt that groin removal will achieve the desired stability of the downdrift beach without adversely affecting projected uses of the updrift beach. However, further investigation is warranted.

North Carolina Department of Environment and Natural Resources (NCDENR). 2011. North Carolina Beach and Inlet Management Plan (BIMP) Final Report. Raleigh, N.C., 1005 p.

North Carolina is renowned for its 326 miles of ocean shoreline, barrier islands and 19 active inlet complexes. North Carolina beaches and inlets have tremendous economic value and serve as important habitat for fish and wildlife resources. Beaches and inlets support millions of recreational visitors every year, provide billions of dollars in economic value through business and tourism, provide ocean access for commercial and recreational fishermen, and are an integral part of the state's history, culture, identity, and way of life. However, without effective planning and management, the future of the state's coastal communities and a significant part of the state's economic base could be adversely affected by storms, sea-level rise, shifting shorelines, and erosion. The North Carolina Department of Environment and Natural Resources (DENR) is committed to the long-term conservation and management of the state's beaches and inlets. As part of this commitment, the Beach and Inlet Management Plan (BIMP) was developed by the Division of Water Resources (DWR) and the Division of Coastal Management (DCM) in order to provide the necessary information to address the natural resources, funding mechanisms and strategies for the comprehensive management of the state's ocean and inlet shorelines. The BIMP is the first statewide compilation of data and issues related to managing the beaches and inlets.

North Carolina Department of Transportation (NCDOT). 1989. Environmental Assessment and Finding of No Significant Impact, Construction of a Terminal Groin and Revetment at Pea Island, Protection of the Herbert C. Bonner Bridge and North Carolina Highway 12 Dare County, North Carolina, 97 p.

This EA/FONSI addresses the proposed construction and maintenance of a terminal groin and revetment on the north end of Pea Island by the North Carolina Department of Transportation (NCDOT). The purpose of the structure is to prevent the severance of the Bonner Bridge-N.C. Highway 12 transportation route as a result of shoreline erosion. No significant adverse effects to biological resources, endangered and threatened species, recreation, cultural resources, water quality, and aesthetic resources are expected to occur either in the project area or up- or down coast from the project area as a result of the proposed terminal groin and revetment. A principal factor in the conclusions of the EA/FONSI is that the groin will not affect natural shoreline processes other than the position of the north point of Pea Island will be stabilized and restored to its approximate April 1988 position and the ocean shoreline of the northern end of Pea Island to its approximate 1985 position through the formation of a 60 acre accretion fillet. This will end a long-term trend of southern migration of the tip of Pea Island and associated erosion losses in the project area. Natural sand bypassing at Oregon Inlet will continue unimpeded. Six alternatives to the proposed action were evaluated. These were not selected primarily because they failed to offer optimum protection for the important transportation route.

Overton, M.F., Fisher, J.S., Dennis, W.A., and Miller, H.C. 1992. Shoreline Change at Oregon Inlet Terminal Groin. Proceedings of the 23rd International Conference on Coastal Engineering, American Society of Civil Engineers: New York, 2332-2343.

The Oregon Inlet Terminal Groin was completed in 1991. The groin was built to provide protection to the bridge crossing the inlet. A detailed monitoring program has analyzed shoreline position with the use of aerial photographs collected every two months. To date, no adverse impacts of the groin have been found on the shoreline within a 6 mile distance downdrift of the groin.

Park, J.-Y. and Wells, J.T. 2005. Longshore Transport at Cape Lookout, North Carolina: Shoal Evolution and the Regional Sediment Budget. Journal of Coastal Research, 21(1): 1-17.

The Cape Lookout cuspate foreland has undergone significant offshore accretion since the first

Rudimentary field studies were conducted in the 1800s. Despite the wave-dominated setting, however, little is known about littoral processes under the wide range of wave conditions that impact the complicated coastal geometry at the cape. In this study we examined littoral processes, driven by longshore currents, using a numerical wave refraction/diffraction model (Ref/Dif1) and through use of aerial photographs and nautical charts. Results show that longshore current direction and speed, as expected, are highly variable and depend primarily on incoming wave direction. Southerly longshore currents on Core Banks predominate under northeast and east wave approaches, whereas weaker northerly currents are generated under southeast and south wave approaches. The result of these patterns provides a source of sediments to Cape Lookout Shoal. Results show the sediment input from Core Banks to the shoal is of the order 512,000t o 581,000m^3/yr. The western limb of the system receives a portion of these sediments, which are released from the shoal and transported north by waves that approach from the southeast, south, and southwest. Predicted longshore currents on the shoal indicate that repeated extension and retreat of Cape Lookout Point would result from the imbalance between southerly longshore currents on the east side of the shoal and northerly longshore currents on the west side. Cape Lookout Shoal may play a role in protecting sections of adjacent barrier islands by interfering with shoreward wave propagation and by allowing waves to focus energy onto their offshore subaqueous areas. It is still unclear, however, how sediments on the northern proximal regions of the shoal are transported to the distal regions farther south.

Park, J.-Y. and Wells, J.T. 2007. Spit Growth and Downdrift Erosion: Results of Longshore Transport Modeling and Morphologic Analysis at the Cape Lookout Cuspate Foreland. Journal of Coastal Research, 23(3): 553-568.

This study examined geomorphologic changes, littoral processes and sediment budget along the west side of the Cape Lookout, North Carolina, cuspate foreland, where a prograding spit at right angles to an eroding barrier island forms prominent features. Progradation of the spit is of interest geologically because it occurs within a transgressive, sediment-starved coastal setting in which adjacent barrier island limbs are eroding and in which immediate sediment sources and transport mechanisms are not obvious. Results indicate that as the spit extends to the north, it also widens to the west through swash bar attachment, leaving a well-defined record of dune ridges that mark former shoreline positions. Although northerly longshore transport occurs only under SW wave conditions, the average rate, ~0.18×10^6 m^3/y, is considered high given the sheltered position of the spit within the cuspate foreland. Results of modeling and development patterns of a series of ridge and runnel systems along the spit indicate that sediments are derived from the eastern limb of the cape or, under certain conditions, from sediments stored in Cape Lookout Shoal by longshore currents. Because the spit forms the distal end of a terminal littoral cell, it has an important effect on the regional sediment budget. Shackleford Banks, oriented at right angles and located immediately downdrift of Power Squadron Spit, is sheltered by the spit at its eastern end but suffers high erosion rates in its central section from lack of sediment input from the updrift direction. This result suggests that change in the input sediment budget can be a major factor in controlling coastal geomorphologic change under uniform physical conditions.

Parsons, J.R. and M. Powell. 2001. Measuring the Cost of Beach Retreat. Coastal Management, 29: 91-103.

We estimate the cost over the next 50 years of allowing Delaware's ocean beaches to retreat inland. Since most of the costs are expected to be land and capital loss, especially in housing, we focus our attention on measuring that value. We use a hedonic price regression to estimate the value of land and structures in the region using a data set on recent housing sales. Then, using historical rates of erosion along the coast and an inventory of all housing and commercial structures in the threatened coastal area, we predict the value of the land and capital loss assuming that beaches migrate inland at these historic rates. We purge the losses of any amenity values due to proximity to the coast, because these are merely transferred to properties further inland. If erosion rates remain at historic levels, our estimate of the cost of retreat over the next 50 years in present value terms is about $291 million (2000$). The number rises if we assume higher rates of erosion. We compare these estimates to the current costs of nourishing beaches and conclude that nourishment make economic sense, at least over this time period.

Pereira da Silva, C. 2006. Landscape Perception and Coastal Management: A Methodology to Encourage Public Participation. Journal of Coastal Research, SI 39: 930-934.

The increase in coastal tourism over the last 30 years has altered the quality and types of recreational activity that are both expected and required. Intensive usage, in some coastal areas, has been a principal cause of degradation, and in turn, of subsequent intervention to re-establish the human-environment equilibrium. This intervention is almost always reactive rather than proactive and was often poorly understood by those at whom it was directed. Traditional and negative planning that prohibits and restricts without indicating clear alternatives is always resented and often only unwillingly accepted by the target groups. In Portugal although public participation in the planning process has been increasing, it was often no more than a final-phase charade; a show of public consultation put on simply to 'rubberstamp' non-negotiable proposals put forward by consultants and politicians. Perception studies can help to alleviate some of these problems. By sounding out relevant groups such studies can establish how people live an area, perceive it, and what their expectations are. By understanding attitudes and being able to anticipate reactions, it becomes easier to make and implement sound management policies. Through the analyses of questionnaires with visitors to an exhibition held at Sines, Portugal, during the summer of 1998, this paper explores the perceptions of beach users, with a view to utilising an understanding of their behaviour and attitudes more closely in the planning process. It carefully considers how the ideas of beach users can be integrated into the broader process of Coastal Zone Management in the region.

Peterson, C.H. 1985. Patterns of Lagoonal Bivalve Mortality after Heavy Sedimentation and Their Paleoecological Significance. Paleobiology, 11(2): 139-153.

Field experiments with bivalve molluscs at Mugu Lagoon, California (USA), during an intense rainstorm in February 1978 provided tests of the selectivity of mortality during catastrophic sedimentation. In a high-current sand channel, sedimentation was slight, the effects on sediment grade short-lived, and the effects on survival of two suspension-feeding bivalves, *Protothaca staminea* and *Chione undatella*, undetectable. In a lower-energy, muddy-sand environment, the storm deposited 10 cm of silts and clays, which substantially increased mortality of both species. Mortality rate in muddy sand varied significantly with (1) trophic group (the two suspension feeders > the deposit feeders, *Macoma nasuta* and *Apolymetis biangulata*), (2) species identity within the suspension feeders (*Chione* > the longer-siphoned *Protothaca*), (3) body size within the two suspension feeders (larger > smaller), and (4) *Protothaca* density (high density > lower density). A 15-day simulation of the effects of addition of 10 cm of the storm sediments to clams in laboratory aquaria tested and confirmed the species and size dependency of mortality. Smaller *Protothaca* survived by moving high up into the top 5 cm of new deposits, while larger individuals were found dead on the initial sediment surface, apparently physically incapable of achieving their customary living position in the flocculent sediments. The unanticipated enhancement of mortality from sedimentation at higher field densities may be a consequence of the combined action of increased energy costs from cleaning silt-clogged gills and local food depletion from competition observed at higher densities. Because several population and community traits vary greatly with density in marine soft-bottom communities, density dependence of mortality during sedimentation could lead to biases in the fossil record. Catastrophic burial clearly does not produce an unbiased instantaneous snapshot of past conditions, but rather requires taphonomic considerations of trophic group, species type, size, and also density dependence prior to accurate paleoecological reconstructions.

Peterson, C.H. and Bishop, M.J. 2005. Assessing the Environmental Impacts of Beach Nourishment. BioScience, 55: 887-896.

With sea levels rising under global warming, dredge-and-fill programs are increasingly employed to protect coastal development from shoreline erosion. Such beach "nourishment" can bury shallow reefs and degrade other beach habitats, depressing nesting in sea turtles and reducing the densities of invertebrate prey for shorebirds, surf fishes, and crabs. Despite decades of agency-mandated monitoring at great expense, much uncertainty about the biological impacts of beach nourishment nonetheless exists. A review of 46 beach monitoring studies shows that (a) only 11 percent of the studies controlled for both natural spatial and temporal variation in their analyses, (b) 56 percent reached conclusions that were not adequately supported, and (c) 49 percent failed to meet publication standards for citation and synthesis of related work. Monitoring is typically conducted through project promoters, with no independent peer review, and the permitting agencies exhibit inadequate expertise to review biostatistical designs. Monitoring results are rarely used to scale mitigation to compensate for injured resources. Reform of agency practices is urgently needed as the risk of cumulative impacts grows.

Peterson, C.H. and Manning, L. 2001. How Beach Nourishment Affects the Habitat Value of Intertidal Beach Prey for Surf Fish and Shorebirds and Why Uncertainty Still Exists. Proceedings of the Coastal Ecosystems and Federal Activities Technical Training Symposium, Abstract, 2 p.

Our research on ecological impacts of beach nourishment in North Carolina has involved monitoring of projects in the field, conducting process-oriented experiments on the beach and in unique wave tank mesocosms, and reviewing the statistical adequacy of sampling designs of beach nourishment monitoring studies. This work has led to tentative answers to long-standing questions and insight into why uncertainty over the ecological impacts still persists.

Peterson, C.H. and Peterson, N.M. 1979. The Ecology of Intertidal Flats of North Carolina: A

Community Profile. U.S. Fish and Wildlife Service, Office of Biological Services. FWS/OBS-79/39. 73 p.

We have developed this community profile to serve as an introduction to the ecology of intertidal sand and mud flats. Our main goal is to describe the ecological processes that characterize a habitat which, at first glance, appears barren and almost devoid of life. We emphasize and draw all our examples from the intertidal flats of coastal North Carolina with which we are most familiar. To the degree that we are successful in describing general processes of ecosystem function on an intertidal flat, what we have to say can be widely applied to the intertidal shorelines of sounds, lagoons, estuaries, and river mouths in temperate zones throughout the world. We trust that our descriptions of the ecology of intertidal mud and sand flats will be useful to scientists and informed laymen alike. We especially hope that our text will provide much of the background needed by coastal planners and environmental scientists whose decisions will influence the future of many of our coastal systems. Intertidal mud and sand flats are classified as habitat types by the National Wetlands Inventory of the U.S. Fish and Wildlife Service and designated as E2FL3 and E2FL2, respectively. Our text is organized on a taxonomic and a functional basis. After an introductory description of the physical environment of the intertidal soft-sediment habitat (Chapter 1), we describe the plants, the primary producers of most marine systems (Chapter 2). In succeeding chapters we discuss the benthic infauna and the mobile epibenthic invertebrates (Chapter 3), the fishes (Chapter 4), and the birds (Chapter 5). This progression is clearly taxonomic, but to a great extent it is also functional, reflecting the major pathways of energy flow through the intertidal flat system. The benthic infauna are largely herbivorous or detritivorous and form the prey of the mobile epibenthic invertebrates. Bottom-feeding fishes and shorebirds feed extensively on these mobile invertebrates, as well as on the benthic infauna. Some of the fishes fall victim to wading or diving birds. Consequently, our progression of chapters roughly corresponds to the flow of energy up the food chain of a coastal flat. In our final chapter (6), we address some specific applied problems that emerge in managing man's activities in the vicinity of intertidal flats.

Peterson, C.H., Hickerson, D.H.M., and Johnson, G.G. 2000. Short-Term Consequences of Nourishment and Bulldozing on the Dominant Large Invertebrates of a Sandy Beach. Journal of Coastal Research, 16: 368-378.

Biological responses of the dominant beach macro-invertebrates to beach nourishment and bulldozing, two widely practiced structure-free methods of responding to shoreline erosion, were evaluated along Bogue Banks, North Carolina. Sediments taken from maintenance dredging of a channel in Bogue Sound and used for beach nourishment in a replicated design were substantially finer (3.67 vs 2.33 ϕ) than those of untreated beaches and contained large concentrations of shell hash. In response to nourishment, densities of *Emerita talpoida* and *Donax* spp. were lower by 86-99% on nourished beaches in early-mid July, 5-10 weeks after cessation of the nourishment project. Beach bulldozing done to augment the primary dune reduced the width of the intertidal beach by about 7 m and replaced it with a wedge of coarser, shellier sand taken from the lower beach. In late July-early August about 3 months after termination of bulldozing, counts of active burrows of ghost crabs *Ocypode quadrata* were 55-65% lower on bulldozed beaches, with most of the reduction occurring on the 7 m of high beach occupied by the newly formed dune face. Despite no detectable difference in slope of the lower beach, *Emerita talpoida* densities were 35-37% lower on bull-dozed beach segments of 0.5- and 3-km, and, while *Donax* spp. exhibited no consistent residual response to bulldozing, two of three contrasts showed increased abundances of >100% on bulldozed segments. Failure of *Emerita* and *Donax* to recover from nourishment by mid summer when they serve as a primary prey base for important surf fishes, ghost crabs, and some shorebirds may be a consequence of the poor match in grain size and high shell content of source sediments and/or extension of the project too far into the warm season. Effects of bulldozing on ghost crabs may conceivably be mitigated by measures to stabilize the dune face after bulldozing, but the effects on *Emerita* and *Donax* are not easily interpreted so potential mitigation measures for mole crabs and bean clams are unclear.

Peterson, C.H., Summerson, H.C., Thomson, E., Lenihan, H.S., Grabowski, J., Manning, L., Micheli, F., and Johnson, G. 2000. Synthesis of Linkages between Benthic and Fish Communities as a Key to Protecting Essential Fish Habitat. Bulletin of Marine Science, 66: 759-774.

Several essential fish habitats lack the protections necessary to prevent degradation because of failure to integrate the scientific disciplines required to understand the causes of the degradation and failure to integrate the fragmented state and federal management authorities that each hold only a piece of the solution. Improved protection of essential habitat for demersal fishes requires much better synthesis of benthic ecology, fisheries oceanography, and traditional fisheries biology. Three examples of degraded habitat for demersal fishes and shellfishes are high-energy intertidal beaches, subtidal oyster reefs, and estuarine soft bottoms. In each case, both scientific understanding of and management response to the problem require a holistic approach. Intertidal beach habitat for surf fishes could be protected by constraints on the character of sediments used in beach nourishment and restriction of nourishment activity to biologically inactive seasons. Subtidal oyster-reef habitat for numerous crabs, shrimps, and finfishes could be protected and restored by reduction of nitrogen loading to the estuary and elimination of dredge damage to reefs. Estuarine soft-bottom habitat for demersal fin- and shellfishes could also be protected by reduction of the nutrient loading of the estuary, which could prevent associated problems of nuisance blooms and low dissolved oxygen. Although a broad general understanding of the nature of habitat degradation exists for each of these three examples, the interdisciplinary science needed to sort out the separate and interactive contributions of all major contributing factors is incomplete. Adopting the holistic approach embodied in the principles of ecosystem management sets a course for addressing both the scientific inadequacies and the management inaction.

Peterson, C.H., Bishop, M.J., Johnson, G.A., D'Anna, L.M., and Manning, L.M. 2006. Exploiting Beach Filling as an Unaffordable Experiment: Benthic Intertidal Impacts Propagating Upwards to Shorebirds. Journal of Experimental Marine Biology and Ecology, 338: 205-221.

Cold-season filling using much coarser sediments than the native caused dramatic suppression of beach macroinvertebrates, demonstrably degrading habitat value for foraging shorebirds. As a dual consequence of persistent steepening of the foreshore, which translated to reduction in habitat area by 14–29%, and disturbance-induced depression of invertebrate densities on filled beaches, abundances of *Donax* spp. and haustoriid amphipods averaged less than 10% of control levels. *Donax* spp. is the biomass dominant and a key prey for higher trophic levels. Haustoriids lack pelagic larvae. Recovery on filled beaches was not initiated by either taxon during the March–November sampling. Emerita talpoida, an order of magnitude less abundant than Donax spp. on control beaches, exhibited a pattern of initial depression on filled beaches but recovered by mid summer. Polychaetes, mostly the small *Scolelepis squamata*, experienced a warm-season bloom of equal magnitude on filled and control beaches. Summertime recruitment of predatory ghost crabs appeared inhibited on filled beaches, perhaps by persistent shell hash. Intertidal shell cover on filled beaches averaged 25–50% in mid summer as compared to 6–8% on control beaches. Largely in response to prey depression, but perhaps also to surface shell armoring and/or coarsening of sediments, shorebird (mostly sanderling) use plummeted by 70– 90% on filled beaches until November. Thus, despite likely adaptations to natural sediment dynamics, the high intensity of sediment deposition, cumulative spatial scope (10.8 km), and unnaturally coarse shelly character of the Bogue Banks beach nourishment resulted in a perturbation that exceeded biotic resistance and degraded the trophic transfer function of this highly productive habitat for at least one warm season.

Peterson, C.H., Bishop, M.J., D'Anna, L.M., and Johnson, G.A. 2014. Multi-year Persistence of Beach Habitat Degradation from Nourishment Using Coarse Shelly Sediments. Science of the Total Environment, 487: 481-492.

Beach nourishment is increasingly used to protect public beach amenity and coastal property from erosion and storm damage. Where beach nourishment uses fill sediments that differ in sedimentology from native beach sands, press disturbances to sandy beach invertebrates and their ecosystem services can occur. How long impacts persist is, however, unclear because monitoring after nourishment typically only extends for several months. Here, monitoring was extended for 3–4 years following each of two spatially separated, replicate nourishment projects using unnaturally coarse sediments. Following both fill events, the contribution to beach sediments of gravel-sized particles and shell fragments was enhanced, and although diminishing through time, remained elevated as compared to control sites at the end of 3-4 years of monitoring, including in the low intertidal and swash zones, where benthic macroinvertebrates concentrate. Consequently, two infaunal invertebrates, haustoriid amphipods and *Donax* spp., exhibited suppressed densities over the entire post-nourishment period of 3-4 years. *Emerita talpoida*, by contrast, exhibited lower densities on nourished than control beaches only in the early summer of the first and second years and polychaetes exhibited little response to nourishment. The overall impact to invertebrates of nourishment was matched by multi-year reductions in abundances of their predators. Ghost crab abundances were suppressed on nourished beaches with impacts disappearing only by the fourth summer. Counts of foraging shorebirds were depressed for 4 years after the first project and 2 years after the second project. Our results challenge the view that beach nourishment is environmentally benign by demonstrating that application of unnaturally coarse and shelly sediments can serve as a press disturbance to degrade the beach habitat and its trophic services to shorebirds for 2–4 years. Recognizing that recovery following nourishment can be slow, studies that monitor impacts for only several months are inadequate.

Pezzuto, P.R., Resgalla, Jr., C., Abreu, J.G.N., and Menezes, J.T. 2006. Environmental Impacts of the Nourishment of Balneario Camboriu Beach, SC, Brazil. Journal of Coastal Research, SI 39: 863-868.

From June to August 2002 the municipality of Balneario Camboriu developed a nourishment program in the southern sector of the beach using sediments dredged from Camboriu River mouth. Ecotoxicological, sedimentological and biological samplings were conducted in order to detect environmental impacts related to the project. The interstitial water at the mine site as well as in the pipeline opening showed chronic toxicity suggesting a poor chemical quality of the sediment used in the program. Sediments at the mine site were 30% silt/clay and 7.2% gravel while the native sediments on the nourished beach was 99.8% sand (mainly fine sand) and 0.2% gravel. After the nourishment, beach sediments were composed by 90.2% of medium sands and 9.6% of gravel. Most of the silt and clay was transported to the nearshore-offshore zones within the Balneario Camboriu bay, modifying its surface sedimentolgy. Before the beach nourishment, shallower zones were mainly sandy, with high silt percents found only at the northern and deeper stations. After the beach restoration, up to 27% of silt could be found from the shallower stations to the middle of the bay, while the percent of clay increased from a maximum of 2% before the project to 97% at the northern and deeper stations, suggesting a transport of sediments from the nourished zone towards the north along the depth gradient. More than 2.3 t of biological material was dispersed on the beach around the pipeline on a single day, mostly corresponding to shell hash (58%). Vegetal debris were the second item, with 18.7% of the total weight. The bivalves *Tagelus plebeius, Anomalocardia brasiliana* and *Crassostrea rhizophorae*, pertaining to a rich benthic community inhabiting the mine site, summed nearly 21%. Expressive and continuous mortalities of the beach-dwelling suspension-feeding bivalve *Tivela mactroides* occurred along 2003. The strandings occurred from the south to the north, and were observed even during periods of low wave energy. No similar mortalities were registered in neighboring beaches. It is suspected that these events should be a response to the suffocation by the drift of fine sediments and organic matter from the nourished zone towards the north. The municipality is considering the nourishment of all beach extension as an alternative to counteract its erosional tendency as well as to enlarge the beach area available to the increasing population. We expect that specific environmental protection protocols be considered before the start of a new restoration program, in order to minimize its negative impacts on the local ecosystem.

Pietrafesa, L.J. 2012. On the Continued Cost of Upkeep Related to Groins and Jetties. Journal of Coastal Research, 28(5): iii-ix.

So-called terminal groins, which are actually jetties at the terminus of barrier islands where inlets are located, have been the subject of controversy for half a century in North Carolina. Coastal scientists have opposed these hardened structures and point to their destructive effects upon downstream beaches, requiring ever increasing and costly beach renourishment projects. Meanwhile, some coastal engineers have claimed that they can he used to "stabilize" migrating inlets. Local politicians, in response to real estate interests, have argued for the construction of the hardened structures and, in contrast to the claims of the scientists on the ground, have cited examples of success in North Carolina and at other locales on the U.S. eastern seaboard. So what are the facts? This Editorial presents the documented facts for North Carolina and the other U.S. east coast locales.

Pietrafesa, L.J. and Janowitz, G.S. 1988. Physical Oceanographic Processes Affecting Larval Transport around and through North Carolina Inlets. American Fisheries Society Symposium, 3: 34-50.

Atlantic croaker *Micropogonias undulatus,* flounders *Paralichthys* spp., spot *Leiostomus xanthurus,* and Atlantic menhaden *Brevoortia tyrannus* all spawn in the continental shelf waters of North Carolina during late fall to early winter. The juveniles use the bays and tributaries adjoining estuaries such as Pamlico Sound and the Cape Fear River as nurseries during their first winter and spring. In previous studies of recruitment into the estuaries through barrier island inlets or estuarine mouths, it was assumed that both larvae and juveniles entered the estuaries at the bottom of the water column and moved upstream thereafter. The mechanisms were presumed to be tidal. Larvae can enter Pamlico Sound through Oregon, Hatteras, and Ocracroke inlets not only during flood stages of the tide but also in the presence of favorable ocean-to-estuary sea-level pressure gradients. The Cape Fear River has strong semidiurnal flood and ebb tidal flows and also responds vigorously to one-sided divergences and convergences of the adjacent coastal ocean. Facing seaward, flow at the river mouth is in at the left and out on the right. We conclude that, in addition to flooding tides, nonlocal forcing at the estuary mouths can effect transport of larval fish through the estuary mouths, throughout the entire water column.

Pilkey, O.H. 2001. Beach nourishment: Two sides to every story. Proceedings of the Geological Society of America 50th Annual Meeting (Raleigh, North Carolina, GSA). A-8, Abstract 4295.

Beach nourishment is now the preferred erosion control alternative for most U.S. open shorelines. The popularity of beach nourishment stems from the wide recognition that construction of seawalls leads to beach loss. The immediate reason for most nourishment projects is erosion-endangered beachfront property. The actual justification stated for public consumption is the need to provide a wide recreational beach. In fact, if the buildings are either moved or demolished, a wide beach will always be present as the shoreline retreats. A typical major nourishment project amounts to a cost of around $10,000 per beachfront building per year. The proposed North Carolina Outer Bank nourishment project is predicted to cost in excess of $30,000 per property per year. The point is that the erosion problem and the resulting need for nourishment is caused by imprudently sited buildings. No threatened buildings-no erosion problems, an important consideration in determining who should pay. There are many other considerations. Prediction of beach durability for first time beaches has proven to be unsuccessful because of, among other things, the random occurrence of storms. Mathematical models have been particularly unsuccessful in prediction, and have proven to be vulnerable to political manipulation to justify favorable cost ratios of projects. Ecological damage caused by beach nourishment is poorly understood - long term studies on sandy coasts are lacking. Eventually, sea level rise can be expected to increase the rates of nourished beach loss. By 2050, it may well be that the huge costs of beach nourishment will cause societal priorities to shift from open ocean recreational property to the protection of major coastal cities, such as Manhattan and Miami.

Pilkey, O.H. and Clayton, T.D. 1987. Beach Replenishment: The National Solution? Fifth

Symposium on Coastal and Ocean Management. Coastal Zone 1987, American Society of Civil Engineers: New York, 1408-1419.

The records of more than 90 replenished beaches and more than 200 sand-pumping operations on East Coast barrier island shorelines, while fragmentary, reveal a wide range of experiences, with a definite trend towards over-optimism in predicting the cost and performance of replenished beaches. Models and assumptions used to predict the fate of replenished barrier island beaches need careful reevaluation. Until sounder theoretical models are developed, a purely empirical approach is the best for predicting beach behavior.

Pilkey, O.H. and Clayton, T.D. 1989. Summary of Beach Replenishment Experience on U.S. East Coast Barrier Islands. Journal of Coastal Research, 5(1): 147-159.

This paper summarizes data on the occurrence of beach replenishment on the U.S. East Coast, listing the length, and cost of each emplacement operation as well as funding source. Approximately 90 replenished beaches were identified, including 260 federal-, state-, and locally-funded individual pumping operations. The amount of data available on the various beaches is quite variable; much information is lacking. A "broad brush" overview of these data has previously been published (PILKEY and CLAYTON, 1987),[1] and more detailed analyses are presently in preparation.

Pilkey, O.H. and Cooper, J.A.G. 2014. Are natural beaches facing extinction? *In:* Green, A.N. and Cooper, J.A.G. (eds.), Proceedings 13th International Coastal Symposium (Durban, South Africa) Journal of Coastal Research, SI 70: 431-436.

On a generational scale, on developed shorelines, the world's recreational beaches are doomed. This is largely because of the widespread assumption that preservation of buildings is a higher priority than preservation of beaches in response to sea level rise. Continuing beach degradation will be inevitable through active or passive processes. Active degradation means the actual removal of the beach, mostly as a result of shoreline engineering or mining. By far, the most important cause of beach loss in this category will be hard structures, especially seawalls. The incorrectly but widely perceived panacea of each replenishment will become economically impossible because of raised sea levels. Replenishment leads to intensified beachfront development and this ironically and inevitably will increase the future construction of seawalls. Passive degradation refers to reduction of the quality of the beach to the point that human usage drops, along with political support for costly beach preservation by nourishment. Passive degradation includes trash accumulation, oil spills, beach driving and most importantly, pollution, which is increasing rapidly apace with population growth and remains largely unrecognized by the beach-using public.

Pilkey, O.H. and Wright, H.L., III. 1988. Seawalls versus Beaches. Journal of Coastal Research, SI 4: 41-64.

It is widely assumed that hard shore-parallel structures on the beach are damaging to recreational beaches. Virtually all state coastal management programs assume this to be true. While there is broad agreement that walls are detrimental to adjacent beaches and that walls are passively responsible for narrowing of the beaches in front of them, controversy still remains over the question of whether seawalls play an active role in beach degradation. Coastal management initiatives should not be delayed on account of the technical argument regarding sea wall behavior. From the standpoint of the general public, the important question is whether seawalls negatively impact beaches, rather than exactly how it happens. It is argued in this paper that there are a number of mechanisms by which seawalls can accelerate erosion of the beach in front of them and that, until research proves otherwise, active beach degradation remains a real possibility. In this investigation, we have also compared the dry beach width on selected stabilized and unstabilized East Coast shorelines and note that dry beach width is consistently and significantly narrower in front of walls. The more dense the hard stabilization, the narrower the beach. Future research on seawall effects must take into account the fact that beach destruction may take place over several decades and study of single events or short-term changes may be of limited value in understanding effects of seawalls.

Pilkey, O.H. and Dixon, K.L. 1996. The Corps and the Shore. Island Press, Washington D.C., 272 p.

In the following chapters, we tell the story of the Corps at the beach on the local level. Through a series of case studies from the U.S. Atlantic, Great Lakes, and Gulf of Mexico coasts, we examine several Corps districts' interactions with local citizens and scientists. We also discuss beach replenishment and the mathematical models that increasingly serve as underpinning for replenishment design. In each case, we criticize the Corps' use of science but do not attempt an exhaustive scientific critique of their work. Rather, we are interested in revealing the scientific and engineering fallacies that pervade the statements the districts make to the public and through the media. We also describe the dismissive way that district engineers treat local scientists.

Posey, M. and Alphin, T. 2002. Resilience and Stability in an Offshore Benthic Community: Responses to Sediment Borrow Activities and Hurricane Disturbance. Journal of Coastal Research, 18(4): 685-697.

Placement of sand on coastal beaches (nourishment) has been used to reduce losses from storm erosion and barrier island movement, with sediment coming from a variety of potential sources including offshore borrow areas. We examined recovery of benthic fauna in an offshore borrow area as well as long-term patterns of community dominance and responses to storm disturbance. Benthic fauna were sampled in a borrow and a control site 2 years before and 2 years after sediment removal (1995-1999). Video surveys from an ROV were used to examine potential burial effects on hardbottom communities. Less than 30% of taxa exhibited differences between borrow and control sites at any time and only 2 of 29 numerically dominant species showed site differences after sediment removal. Strongest effects were related to temporal variations in abundance with some species exhibiting seasonal variations in abundance, some taxa exhibiting single periods of higher abundance, and other taxa exhibiting more variable patterns. Three hurricanes affected the sites during the study, but there was little evidence of acute changes associated with storm disturbance. Shifts in abundance corresponding to the time of sediment removal occurred for some taxa, but were present in both borrow and control areas. The data suggest relatively quick recovery from borrow activities with interannual variability explaining more of the observed differences than sediment removal effects. Limited effects of sediment removal may be related to timing of activities (in fall and winter before peak infaunal recruitment), small size of the area affected, and the opportunistic nature of many of the infaunal species.

Quammen, M.L. 1982. Influence of Subtle Substrate Differences on Feeding by Shorebirds on Intertidal Mudflats. Marine Biology, 71: 339-343.

Shallow-feeding shorebirds, dowitchers *(Limnodromus griseus* and *L. scolopaceus),* western sandpipers *(Calidris mauri),* dunlin *(C. alpina)* and American avocets *(Recurvirostra americana),* reduced the density of their prey in mudflats with little sand but not in mudflats with a moderate admixture of sand. An experiment in Upper Newport Bay, Southern California, during October and November 1979 to explain the difference in density is described. The effect of sand on shorebird feeding was compared in the field by measuring the times spent feeding in plots where sand had or had not been added, respectively. Increasing the sand content to 14% from 2% in the top centimeter decreased the time spent in treated plots by all species compared to adjacent untreated plots. The prey species were small polychaete and oligochaete worms (0.25 to 1.25 mm wide) similar in diameter to sand grains (0.5 to 1.0 mm). In plots where sand had been added, avocets fed by pecking at the surface in addition to scything, the more common method of feeding on muddy substrates. The results suggest that sand interferes with the detection and or capture of prey that are similar in diameter to small sand grains and explains the differences in the effects of predation by these birds seen on mudflats with a moderate admixture of sand compared to the effects on mudflats with little sand. Differential success in prey capture between one microhabitat and the next (rather than a reduction in competition, as suggested by some authors) might explain the different use of such habitats.

Rakocinski, C.F., Heard, R.W., LeCroy, S.E., McLelland, J.A., and Simons, T. 1996. Responses by Macrobenthic Assemblages to Extensive Beach Restoration at Perdido Key, Florida, U.S.A. Journal of Coastal Research, 12(1): 326-353.

In this study, we examine complex responses by macrobenthic assemblages to extensive beach restoration affecting 7 km of open shoreline at Perdido Key, Florida. Beach restoration consisted of two phases, beach nourishment and profile nourishment, each phase lasting roughly one year. We examined macrobenthic responses using an optimal impact study design incorporating ten macrobenthic surveys completed over a three-year period. This study is important because of its geographical region, its relatively large spatial scale, its long duration, and its consideration of both nearshore assemblages from high energy sandy beaches and diverse assemblages from stable offshore habitats. The physical environment was altered by beach restoration through changes in depth profiles and sediment composition as well as through sediment dynamics. Various macrobenthic responses attributable to beach restoration included: decreased species richness and total density, enhanced fluctuations in those indices, variation in abundances of key indicator taxa, and shifts in macrobenthic assemblage structure. One long-term impact of beach nourishment at nearshore stations included the development of macrobenthic assemblages characteristic of steep depth profiles. Two long-term negative impacts of beach restoration at offshore stations included one from beach nourishment and another from profile nourishment. After beach nourishment, the macrobenthic assemblage structure changed markedly across a considerable offshore area in concert with increased silt/clay loading. Macrobenthic impacts from silt/clay loading were still evident at the end of the study, more than two years after beach nourishment. Macrobenthic populations fluctuated widely at the farthest seaward stations from apparent sediment disturbance, both during and after profile nourishment. These fluctuations involved total densities, species richness, and densities of key indicator taxa. Macrobenthic fluctuations continued through the end of the study, although profile nourishment was completed for more than one year prior to that time. Considerable macrobenthic recovery was apparent during the study, although macrobenthic recovery remained indeterminate in some places. Long-term macrobenthic impacts at several offshore stations supported the hypothesis that diverse offshore assemblages may be less resilient than contiguous nearshore sandy-beach assemblages.

Reed, D.J., Hijuelos, A.C., and Fearnley, S.M. 2012. Ecological Aspects of Coastal Sediment Management in the Gulf of Mexico. Journal of Coastal Research, SI 60: 51-65.

Water and sediment resource planning is a vital facet of natural resource management. There have been many ecologically disruptive consequences from conventional resource management plans. In the northern Gulf of Mexico (GOM) nearby communities depend on water and sediment resources both ecologically as well as economically. The value of these resources is determined by habitat structure and ongoing sediment dynamics. This article explores how human activities have changed sediment dynamics in relation to the ecology of the habitats present in the northern GOM. It further presents ideas to prevent future problems through sediment management plans that account for natural processes. The northern GOM contains several habitats that are affected by sediment/water resource management plans such as the shoreface (beaches and dunes), barrier islands, hardbottom (coral and oyster reefs), bays, marshes, and forested wetlands. Many common techniques for water/sediment resource management have been used in these areas such as dredging, hard structures (jetties, groins, sea walls, and breakwaters), dams, diversions, levees, and coastal development. The implications of these different management techniques can lead to extensive changes in coastal habitats. Dredging causes disturbances to both borrow and placement sites and can change natural community structure at both sites. The installation of hard structures can cause severe changes in habitat structure that can lead to losses of species diversity. The impacts of river management structures (dams, levees, and diversions) alter the delivery of sediment needed by coastal habitats for growth and sustainability. Anthropogenic development in coastal regions prevents those areas from maturing naturally. Because of the importance of sediments to the ecology of the northern GOM coast and its vulnerability to natural and anthropogenic disturbances, several recommendations are made for holistic future sediment management plans.

Reilly, F.J. and Bellis, V.J. 1983. The Ecological Impact of Beach Nourishment with Dredged Materials on the Intertidal Zone at Bogue Banks, North Carolina. U.S. Army Corps of Engineers, Coastal Engineering Research Center, Misc. Rept. No. 83-3, 73 p.

During the winter and spring of 1977-78 approximately 1600 meters of high energy sandy ocean beach at Fort Macon State Park was nourished with sediments dredged from Morehead City State Port Harbor. This report is the result of a 20-month study of the nourished beach and a comparable unnourished beach. Shannon-Weaver's Species Diversity Indexes ranged from 0.00 to 0.64 on both beaches during the 6 months before nourishment. Generally, Shannon-Weaver values were higher on the nourishment beach before nourishment due to the higher numbers of species present. High species number is attributed to the close proximity of the nourishment beach to Beaufort Inlet. After nourishment began the unnourished beach maintained the same diversity and density patterns that both beaches had displayed before nourishment although there was seasonal variation. The species diversity on the nourished beach became undefined at the onset of nourishment because the density of all species dropped to zero. This situation remained at the nourished beach until nourishment activities ceased. During the nourishment activities, the Fort Macon beach was subdivided into two segments (the area already nourished and the area not yet nourished). While all organisms in the nourished area disappeared, no increased population densities were noted from the adjacent unnourished area. Near the end of nourishment activities this unnourished area showed both a drastic reduction in diversity and a change in species composition, thus indicating a certain edge effect of nourishment. A special transect designed to monitor rate of recovery after nourishment indicated that a speedy recovery largely depended on recruitment from pelagic larval stocks. It also seemed to indicate that high turbidities associated with nourishment can prevent this recruitment. Lastly it showed that those species unable to recolonize through pelagic larval recruitment returned to the area much more slowly. A comparison of the before-and-after nourishment data at Fort Macon showed little evident change in the densities of the most dominant secondary producer the mole crab, *Emerita talpoida;* however, when comparing before-and-after size class data with the comparison beach the effects of nourishment are obvious. While a complex age and size class array was evident before nourishment at Fort Macon and after nourishment at the comparison beach, only young of the year age classes were observed for any intertidal species present at Fort Macon. This lack of older and larger individuals and consequently biomass was reflected in lower densities of important migrating consumers at the study site. Although the populations of these consumers were probably not affected, they were noticeably absent from the nourished area during and after nourishment; they probably had moved to adjacent areas. The beach showed signs of recovery. Only *Emerita talpoida* returned in near-normal density; all other numerically important species also returned but in significantly lower density.

Rice, E. and Cameron, S. 2008. Final Report: Bogue Inlet Waterbird Monitoring and Management 2003 -2008. Prepared for Town of Emerald Isle, NC. 31 p.

Along our coastline the dynamic barrier islands and associated inlets on which many waterbirds depend are being severely altered by attempts to stabilize beaches. If we are to retain habitat for migrating, wintering and breeding waterbirds, it is imperative that we manage remaining habitat in the face of these changes. Habitats associated with inlets are particularly valuable to coastal birds (Harrington 2008) and as such should be afforded extra protection. According to the US Shorebird Conservation Plan (Brown et al. 2001), data from several shorebird inventory programs in North American in the past two decades strongly suggest that populations of the majority of species are declining, some at rates exceeding 5% per year. The Plan also states that coastal development and human activities in coastal zones have grown enormously and have reduced intertidal habitats and prey base and have usurped high tide resting areas used by shorebirds. Populations of many species of colonial waterbirds are also showing declines and coastal development, coastal protection, dredging and human disturbance are listed as actions that can significantly affect the ability of coasts and intertidal waters to sustain waterbirds (Kushlan et al. 2002). The Bogue Inlet channel relocation project has the potential to negatively impact the quality and quantity of habitat available to breeding and non-breeding colonial waterbirds and shorebirds. As a result, NCWRC and the United States Fish and Wildlife Service (USFWS) have worked with the Town of Emerald Isle to develop a Waterbird Management Plan and a monitoring schedule for Bogue Inlet. Channel relocation projects are relatively new and there is a need to monitor changes within inlet complexes. This project afforded us the opportunity to study the waterbird and shorebird communities at Bogue Inlet and monitor changes in response to the project. Pre-project monitoring was conducted by CZR, Incorporated for one year prior to channel relocation. NCWRC conducted during-project and post-project monitoring and management beginning in the winter of 2005. This report provides some information from 2008, the final year of monitoring, as well as a summary of data collected from 2003-2008. Detailed results from each year of during and post-project monitoring from 2005-2007 can be found in the Annual Reports.

Rice, T.M. 2009. Best Management Practices for Shoreline Stabilization to Avoid and Minimize Adverse Environmental Impacts. Prepared for the USFWS, Panama City Ecological Services Field Office, 22 p.

Shoreline stabilization projects can cause significant adverse environmental impacts to the coastal ecosystem. By incorporating conservation measures into a project during the planning, design, construction, and post-construction phases, many of the potential adverse environmental impacts can be avoided and minimized. This paper outlines best management practices (BMPs) that can be utilized as conservation measures to avoid, minimize, and mitigate adverse environmental impacts from shoreline stabilization projects. The first approach that best avoids and minimizes adverse environmental impacts from shoreline management is to "do nothing" and retreat roads and structures away from the shorelines as sea level rises and climate changes, and to prevent new development in naturally hazardous or migrating areas. Where shoreline stabilization *is* proposed, BMPs are presented in sections for dune, beach, nearshore, offshore, inlet and estuarine habitats, and an adaptive management framework is presented for project management (i.e., operations and maintenance) and issues relating to climate change and rising sea level. A glossary is included for key words and an extensive bibliography summarizes the scientific literature that provided scientific background and data in the development of these BMPs as conservation measures.

Rice, T.M. 2012. Inventory of Habitat Modifications to Tidal Inlets in the Coastal Migration and Wintering Range of the Piping Plover (*Charadrius melodus*). Appendix 1B *in* Draft Comprehensive Conservation Strategy for the Piping Plover (*Charadrius melodus*) Coastal Migration and Wintering Range, U.S. Fish and Wildlife Service, 35 p.

The U.S. Fish and Wildlife Service's (USFWS's) 5-Year Review for the piping plover (*Charadrius melodus*) recommends developing a state-by-state atlas for wintering and migration habitat for the overlapping coastal migration and wintering ranges of the federally listed (endangered) Great Lakes, (threatened) Atlantic Coast and Northern Great Plains piping plover populations (USFWS 2009). The atlas should include data on the abundance, distribution, and condition of currently existing habitat. This assessment addresses this recommendation by providing this data for one habitat type – sandy, tidal inlets within the migration and wintering range of the southeastern continental United States (U.S.). Inlets are a highly valuable habitat for piping plovers and other shorebirds and waterbirds for foraging, loafing, and roosting and have been documented to be preferentially used over other habitat types during the wintering period (Harrington 2008, Lott et al. 2009, Maddock et al. 2009). While some information is available for the number of inlets stabilized with jetties, revetments, and other hard structures, these data have not been combined with other information that is available for navigational dredging, inlet relocations, shoal mining, and artificial opening and closing of inlets. Altogether this information can provide an assessment of the cumulative impacts of habitat modifications at tidal inlets for piping plovers and other shorebirds and waterbirds. This assessment does not, however, include habitat disturbances at tidal inlets such as off-road vehicle (ORV) usage, pet and human disturbance, or disturbance to dunes or vegetation on inlet shoulders.

Riggs, S.R. and Ames, D.V. 2009. Impact of the Oregon Inlet Terminal Groin on Downstream Beaches of Pea Island, NC Outer Banks. A White Paper. East Carolina University, Greenville, North Carolina, 19 p.

The basic function of the terminal groin and rock revetment at Oregon Inlet (Fig. 1) was to 1) stop the southward migration of Oregon Inlet and 2) keep the north end of Pea Island from abandoning the Oregon Inlet bridge within the inlet (NCDOT, 1989). Both structures were built in the period from October 1989 to March 1991 and have been successful in carrying out their original design function. Whether the terminal groin at Oregon Inlet has had a negative impact on the downstream shoreline of Pea Island beaches is a totally different question. In order to answer this question, NCDOT contracted Overton and Fisher in October 1989 (report 1 in 1990 to report 27 in March 2005) and Overton (reports 28 to 31 in June 2007) to carry out a monitor study of the adjacent six miles of Pea Island beaches, the northern half of Pea Island. Fisher, Overton, and Jarrett (2004) summarized the monitor data from 1989-2003 and utilized it as a basis for developing cost estimates for building and maintaining the new Highway 12 across Pea Island over the next 100 years for NCDOT. The NCDOT (1989) stated that the "severe ocean shoreline erosion that is taking place along the two mile stretch of shoreline south of the Oregon Inlet Coast Guard Station, a result of the inlet's inefficient sand bypassing, will continue. The problems associated with the severe ocean shoreline erosion.....can only be addressed by a separate corrective measure. The most desirable solution for this problem would be to undertake a program of periodic beach nourishment to offset the sediment deficit imposed by Oregon Inlet." Thus, to minimize negative impacts of the Oregon Inlet terminal groin on the downstream Pea Island shoreline, the USACE agreed to place the sediment from routine Oregon Inlet channel dredging either directly on the Pea Island beach or in the shallow near-shore of the northernmost 3 miles of Pea Island. According to the NCDOT (1989) report, the purpose of the monitor program is "to document the changes in the shoreline on the northern end of Pea Island, within six miles of the terminal groin....a known area of high shoreline erosion. It is anticipated that the groin will reduce this erosion and serve to stabilize the down-drift shoreline." However, NCDOT "agreed to provide (additional) beach nourishment if it can be shown that there is a significant increase in erosion rates with the construction of the groin...(based upon) the determination of the historical rates of erosion." "If the monitoring program determines that there is an increase in shoreline erosion above the background historical rates, then two thresholds for corrective beach nourishment have been established."

Riggs, S.R. and Ames, D.V. 2011. Consequences of Human Modifications of Oregon Inlet to the

Down-drift Pea Island, North Carolina Outer Banks. Southeastern Geology, 48(3): 103-128.

Oregon Inlet is a highly dynamic inlet-outlet system through the northern North Carolina Outer Banks that opened in 1846, separating Bodie and Pea Islands. Bodie Island extends northward from the inlet (about 9.3 miles) to the Nags Head-Kitty Hawk urbanized barriers and includes part of Cape Hatteras National Seashore (CHNS). South of the inlet is the 12 mile-long Pea Island National Wildlife Refuge (PINWR). By 1989, Oregon inlet had migrated southward about 2.9 miles to its southernmost location when it was pushed back north and hardened with a terminal groin and rock revetment along the south side in 1989-1991. In 1962-63 a 2.4 mile-long bridge, with a fixed navigational span, was constructed across the southward migrating Oregon Inlet, which led to immediate conflicts. In order to maintain the main inlet channel under the navigation span, dredging was initiated with offshore, deep-water disposal of the dredged sand. During the post-terminal groin period (1991-present), the northern Oregon Inlet shoreline continued to migrate southward into the inlet channel driven by the dominant energy of nor'easter storms. This necessitated a further increase in frequency and volume of dredging to "hold the channel" under the fixed navigation span. The groin and rock-revetment secured the southern Oregon Inlet shoreline. This stabilization, however, also prevented the natural southward sediment transport system from replenishing the rapidly eroding Pea Island beaches. Consequently, between 1983 to 2009, over 12 million cubic yards of sand were dredged from Oregon Inlet and artificially by-passed to the Pea Island beaches between mileposts 1 and 3. Additionally, NCDOT spent a minimum of $100 million from 1983-2009 to maintain NC Highway 12 due to persistent ocean shoreline recession of the down-drift Pea Island beaches. Portions of the Pea Island ocean shoreline still have average rates of shoreline recession up to 13 ft/yr resulting in a constant and expensive battle to maintain NC Highway 12. Today, in spite of all the nourishment, regular reconstruction of barrier dune ridges, construction of sand-bag walls, and the almost constant work of a fleet of bulldozers, NC Highway 12 is not a reliable road across Pea Island. Frequently, segments of this road flood with a spring tide, an extra high wind tide, or even just a heavy rainfall, to say nothing about major storm events. These Pea Island road segments are all in jeopardy today, so what will happen in the next 5, 10, or 25 years as sea level rises and storms continue to strike the coast? In addition, similar problem areas for NC Highway 12 exist further south at Avon to Buxton, Frisco to Hatteras, and on northeastern Ocracoke Island. Is it possible that we could be building a new $250 million dollar Oregon Inlet bridge to a fixed road system that cannot be maintained on a shifting pile of sand?

Riggs, S.R., Ames, D.V., Culver, S.J., Mallinson, D.J., Corbett, D.R., and Walsh, J.P. 2009. Eye of a human hurricane: Pea Island, Oregon Inlet, and Bodie Island, northern Outer Banks, North Carolina, *in* Kelley, J.T., Pilkey, O.H., and Cooper, J.A.G., eds., America's Most Vulnerable Coastal Communities: Geological Society of America Special Paper 460: 43-72.

Pea Island, Oregon Inlet, and Bodie Island, North Carolina, are severely human modified barrier-island segments that are central to an age-old controversy pitting natural barrier-island dynamics against the economic development of coastal North Carolina. Bodie Island extends for 15 km from the Nags Head–Kitty Hawk urban area to the north shore of Oregon Inlet and is part of Cape Hatteras National Seashore. Pea Island extends 19.3 km from the southern shore of Oregon

Inlet to Rodanthe Village and is the Pea Island National Wildlife Refuge. Bodie and Pea Islands evolved as classic inlet- and overwash-dominated (transgressive) simple barrier islands that are now separated by Oregon Inlet. The inlet was opened in 1846 by a hurricane and subsequently migrated 3.95 km past its present location by 1989. With construction of coastal Highway 12 on Bodie and Pea Islands (1952) and the Oregon Inlet bridge (1962–1963), this coastal segment has become a critical link for the Outer Banks economy and eight beach communities that occur from Rodanthe to Ocracoke. The ongoing natural processes have escalated efforts to stabilize these dynamic islands and associated inlet in time and space by utilizing massive rock jetties and revetments, kilometers of sand bags and constructed dune ridges, and extensive beach nourishment projects. As the coastal system responds to ongoing processes of rising sea level and storm dynamics, efforts to engineer fixes are increasing and now constitute a "human hurricane" that pits conventional utilization of the barriers against the natural coastal system dynamics that maintain barrier-island integrity over the long term.

Riggs, S.R., Cleary, W.J., and Snyder, S.W. 1995. Influence of Inherited Geologic Framework on Barrier Shoreface Morphology and Dynamics. Marine Geology, 126: 213-234.

Passive margin coastlines with limited sand supplies, such as much of the U.S. Atlantic margin, are significantly influenced by the geologic framework of older stratigraphic units that occur beneath and seaward of the shoreface. Many U.S. east coast barrier islands are *perched barriers* in which the underlying, pre-modern sediments determine the morphology of the shoreface and strongly influence modern beach dynamics and composition. Perched barriers consist of varible layers of beach sand on top of older, eroding stratigraphic units with highly variable compositions and geometries. Along many parts of the coastal system, stratigraphically-controlled bathymetric features on the inner shelf modify waves and currents and thereby effect patterns of sediment erosion, transport, and deposition on the adjacent shoreface. It is essential to understand this geologic framework before attempting to model the large-scale behavior of these types of coastal systems. In North Carolina, most shoreline features are controlled by the pre-Holocene stratigraphic framework of the shoreface; the beaches are perched on top of pre-existing Pleistocene, Tertiary, and Cretaceous sediments. The surficial geology of the coastal zone is subdivided into two distinct provinces resulting in different stratigraphic controls of the shoreface. North of Cape Lookout the geological framework consists of a Quaternary sequence that fills a regional depositional basin called the Albemarle Embayment. The coastal zone south of Cape Lookout is dominated by Tertiary and Cretaceous units that crop out across the coastal plain and continental shelf, with very thin Quaternary units only locally preserved. Superimposed upon this regional stratigraphy is an ancient drainage system resulting in a series of fluvial valleys filled with younger coastal sediments separated by large interfluve areas of older stratigraphic units. This results in a coastal system in which the shoreface is either nonheadland or headland dominated, respectively. Headland dominated shorefaces are further divided into subaerial and submarine categories. Nonheadland dominated shorefaces are further divided into those influenced primarily by transgressive or regressive processes, or channel-dominated depositional processes (i.e., inlet migration or stream valley fill). Examples of each of these six types of shorefaces are presented to demonstrate the control that the geologic framework exhibits on shoreface morphologies and processes.

Riggs, S.R., Culver, S.J., Ames, D.V., Mallinson, D.J., Corbett, D.R., and Walsh, J.P. 2008.

North Carolina's Coasts in Crisis: A Vision for the Future. A White Paper. East Carolina University, Greenville, North Carolina, 28 p.

The coastal zone of North Carolina that we know today is not permanent. It has evolved throughout its history. These changes, which can be both imperceptibly gradual or sudden and violent, continue today and will do so into the future. Humans are moving into this environment in ever increasing numbers accompanied by towns, industry, tourism, and the supporting infrastructure of services such as roads, bridges, water, power, and waste disposal. The changing coastal system is not fragile. It is the fixed human infrastructure that can easily be destroyed by natural processes. This is the coastal conflict that we must examine closely and then manage. The climate is changing; tropical storms and hurricanes will continue to strike our coast as will nor'easters, and sea level is rising at an increasingly rapid rate. We must accept these changes as inevitable but we seem reluctant to do so. This is why our coasts are in crisis.

Rizkalla, C.E. and Savage, A. 2011. Impact of Seawalls on Loggerhead Sea Turtle *(Caretta caretta)* Nesting and Hatching Success. Journal of Coastal Research, 27(1): 166-173.

As coastal development becomes increasingly threatened by erosion, installation of armoring such as seawalls has been applied to protect property by permanently relocating the position of a dune. The physical impact of seawalls to beach ecosystems is relatively well-understood, but the impact to sea turtle nesting remains unclear. We investigated the impact using observations of loggerhead sea turtle nesting in Florida at a seaward wall over 7 years, and a more landward wall over 3 years. Nesting patterns indicated that passive erosion at seawalls likely caused fewer turtles to attempt to nest on armored beach when compared with unarmored beach. Nests placed in front of seawalls were more likely to be washed away in storms. Placement of walls further from the shoreline may only delay the impact to nesting turtles by a few years. Armoring is expected to multiply as sea levels rise and storms become more frequent; thus, the availability of appropriate nesting habitat for loggerhead sea turtles remains at risk.

Rocha, M.V.L., Coelho, C., and Fortes, C.J.E.M. 2013. Numerical Modeling of Groin Impact on Nearshore Hydrodynamics. Ocean Engineering, 74: 260-275.

Groins are cross shore structures built to promote shoreline stabilization. However, the specific impact of these structures on the wave conditions and velocity field nearshore (and hence, on sediment transport) is still poorly understood. Therefore, this study wishes to extend this knowledge using a numerical model, COULWAVE, previously validated with field data. For that, a typical bar-trough profile is considered and different groin lengths and orientations are tested, under the influence of different significant incident-wave heights and sea-surface levels. The hydrodynamics factors are found to have a greater impact on the nearshore wave conditions than the groin geometry. The variation of significant incident-wave height imparts the greater changes in wave height nearshore, where the groin would be located. The typical tidal range is also important, since a 2 m change in sea surface level can cause great depth changes over bathymetric features and thus influence wave propagation. Although less important, the geometry of the groin should also be considered. The greater the length, the greater the sheltering effect expected, extending further to the lee-side of the groin. The impact will also reach a broader region. With a smaller impact verified, the best orientation of the groin is hard to unravel.

Rolet, C., N. Spilmont, D. Davoult, E. Goberville and C. Luczak. 2015. Anthropogenic impact on macrobenthic communities and consequences for shorebirds in Northern France: A complex response. Biological Conservation 184: 396-404.

Shorebird populations are declining worldwide due to the combined effect of climate change and anthropogenic forcing, the ongoing coastal urbanisation amplifying the alteration of their habitat in both rate and magnitude. By focusing on a highly anthropogenically-influenced region in Northern France, we studied the impact of a seawall construction on wintering shorebird populations through potential alterations in the abundance and availability of their food resources. We concurrently investigated changes in the spatial distribution of muddy-sand beach macrobenthic communities between two periods of contrasting anthropogenic impacts and examined year-to-year trends of wintering shorebirds. Our study reveals that the seawall construction led to a major spatial reorganisation of the macrobenthic communities with a drastic reduction of the muddy-sand community. However, no relation between macrobenthic changes and shorebird abundances was detected. Fluctuations in shorebird abundances appeared to be congruent with flyway population trends. This result suggests that the response of shorebirds to human-induced perturbations is much more complex than expected. While an assessment of potential disturbances induced by coastal engineering constructions is needed, the pathways by which alterations could propagate through an ecosystem are not linear and as such difficult to determine. Ecosystems appear as complex adaptive systems in which macroscopic dynamics emerge from non-linear interactions at entangled smaller/larger scales. Our results confirm that an in-depth knowledge of the local, regional and global factors that influence trends of shorebirds and their habitat use is essential for accurate and effective management and conservation strategies.

Ross, S.W. and Lancaster, J.E. 2002. Movements and Site Fidelity of Two Juvenile Fish Species Using Surf Zone Nursery Habitats along the Southeastern North Carolina Coast. Environmental Biology of Fishes, 63: 161-172.

We examined the extent of movements of juvenile Florida pompano, *Trachinotus carolinus*, and gulf kingfish, *Menticirrhus littoralis*, along an open ocean beach. Fishes were collected by seine at three sites along Masonboro Island and Carolina Beach, NC between 7 June and 7 July 1995. All specimens >40mm standard length (SL) were tagged with coded wire tags and released at the capture sites. Between 7 July and 9 August and on 15–16 September Masonboro Island and northern Carolina Beach were surveyed for tagged fish. A controlled tag mortality/retention study was conducted for both species. Overall, 1569 Florida pompano (40–135mm SL) were tagged. Sixty-one (3.9%) of these were recaptured, and only eight moved away from the original tagging sites. The largest movements by two Florida pompano were 2.1 and 10.5 km. Many fish remained at their original tagging sites for 21–27 days. Of 488 gulf kingfish (36–158mm SL) tagged, 16 (3.3%) were recaptured. Gulf kingfish also exhibited little movement away from tagging sites during the study, with individuals remaining at original tagging sites up to 21 days. Stock size estimates for Florida pompano ranged from 3354 to 4670 among the tagging sites, with densities ranging from 1.9 to 2.6 fish m^{-2}. The remarkable site fidelity exhibited by these two species suggests that resources were not limiting or that predation pressure was not high enough to cause large scale movements during the study. This implies that local disturbances could impact behavior or survival of juvenile fishes in the surf zone.

Rumbold, D.G., Davis, P.W., and Perretta, C. 2001. Estimating the Effect of Beach Nourishment on *Caretta caretta* (Loggerhead Sea Turtle) Nesting. Restoration Ecology, 9(3): 304-310.

Caretta caretta (loggerhead sea turtle) nesting activity was recorded daily during three seasons prior to and two seasons immediately following a beach nourishment (replenishment) project in Palm Beach County, Florida. Surveys were done at the nourished beach (Jupiter/Carlin) and at two natural beaches (Juno and Tequesta). The size of the nourishment effect on nesting activity was estimated using Before-After-Control-Impact Paired Series (BACIPS) models. Nesting declined by 4.4 to 5.4 nests km^{-1} day^{-1} on the nourished beach compared to the two natural beaches in the first season after nourishment. At the same time, false crawls (FC, non-nesting crawls) increased by 5.0 to 5.6 FC km^{-1} day^{-1} on the nourished beach. In the second season following nourishment, nesting was reduced by 0.5 to 1.6 nests km^{-1} day^{-1} on the nourished beach compared to the two natural beaches. The increase in false crawl frequency in the second season following nourishment was 0.7 to 0.9 FC km^{-1} day^{-1}. These results suggest that beach nourishment significantly decreased loggerhead sea turtle nesting during the first season following the project. However, the size of the effect, in terms of nesting frequency and false crawl frequency, was much reduced by the second season following nourishment.

Sampaio, L.C. 2011. A Comparison of Inlet-Induced Geomorphic Changes Related to Unmodified Inlets along a Sand Rich Coastal System. [M.S. thesis]: Wilmington, North Carolina, University of North Carolina Wilmington, 130 p.

Bear and Brown's Inlets are small barrier island systems located in the northeastern sector of Onslow Bay along the shoreline reach characterized by high relief, sand-rich barrier islands. Bear Inlet (BEI) separates Bear Island to the northeast from Brown's Island to the southwest while Brown's Inlet (BRI) borders Brown's Island on its southern margin and separates the barrier island from Onslow Beach to the southwest. Due to their unmodified nature they are exemplary sites to study the linkage between inlet changes and the response of the adjacent oceanfront shorelines. Both inlets are relatively stable systems having been confined to narrow migration pathways since 1872. This study utilizes and evaluated two Geographic Information System (GIS) software extensions (DSAS and AMBUR) that are specifically designed to measure shoreline change. Since 1938 the BEI throat has migrated southwestward 592 m at an average rate of 8.5 m/yr while the BRI has migrated to the southwest a distance of 355 m at an average rate of 5 m/yr. The net migration direction is opposite the inferred direction of sediment transport. While the position of the throat segment of the ebb channel of both inlets have changed comparatively little (BRI: 137 m; BEI: 700 m) from 1938 to 2008, the outer bar segment of the channel shifted across a comparatively wider zone that ranged from 700 m (BEI) to 1,100 m (BRI). Since 1934 a minimum of six cycles of channel deflection and reorientation have occurred. Consequently the ebb-tidal deltas have undergone significant shape changes, which in turn have altered the ebb delta's breakwater effect along the opposing oceanfront shorelines. The decadal long accretion and erosion patterns are responses to the above-mentioned changes. Generally speaking, for a given period of time, the oceanfront shorelines along the adjacent barriers are characterized by opposing shoreline change patterns. From this study, the measurements obtained from both DSAS and AMBUR GIS extensions were very comparable and show that although each GIS extension package had slightly different operating assumptions, the results of shoreline change from 1934 to 2008 for Brown's and Bear Inlets evaluated by these methods were very similar.

Schlacher, T.A., Noriega, R., Jones, A., and Dye, T. 2012. The Effects of Beach Nourishment on Benthic Invertebrates in Eastern Australia: Impacts and Variable Recovery. Science of the Total Environment, 435-436: 411-417.

Beach erosion is likely to accelerate, driven by predicted consequences of climate change and coastal development. Erosion is increasingly combated by beach nourishment, adding sand to eroding shores. Because a range of engineering techniques exists to nourish beaches, and because these techniques differ in their environmental effects, assessments of ecological impacts need to be tailored and specific. Here we report on impacts and recovery of benthic invertebrates impacted by beach nourishment operations undertaken at Palm Beach (SE Queensland, Australia). Assessments are made based on a beyond-BACI design, where samples were taken once before nourishment and twice afterwards at the impact and two control sites. Because almost all of the sand was deposited on the upper beach and later moved with bulldozers down-shore, we specifically examined whether the effects of nourishment varied at different heights of the beach—a little-studied question which has management implications. Impacts on the fauna were massive on the upper and middle levels of the beach: samples collected two days after the conclusion of nourishment were entirely devoid of all invertebrate life ('azoic'), whereas weaker effects of nourishment were detectable on the lower shore. Recovery after five months also varied between shore levels. The sediment of the upper level near the dunes remained azoic, the fauna of the middle shore had recovered partially, and the lower level had recovered in most respects. These findings indicate that the height and position of sand placement are important. For example, rather than depositing fill sand on the intertidal beach, it could be placed in the shallow subtidal zone, followed by slow up-shore accretion driven by hydrodynamic forces. Alternatively, techniques that spread the fill sand in thin layers (to minimize mortality by burial) and leave unfilled intertidal refuge islands (to provide colonists) may minimize the ecological impacts of beach nourishment.

Schlacher, T.A., Dugan, J., Schoeman, D.S., Lastra, M., Jones, A., Scapini, F., McLachlan, A., and Defeo, O. 2007. Sandy Beaches at the Brink. Diversity and Distributions, 13: 556-560.

Sandy beaches line most of the world's oceans and are highly valued by society: more people use sandy beaches than any other type of shore. While the economic and social values of beaches are generally regarded as paramount, sandy shores also have special ecological features and contain a distinctive biodiversity that is generally not recognized. These unique ecosystems are facing escalating anthropogenic pressures, chiefly from rapacious coastal development, direct human uses-mainly associated with recreation-and rising sea levels. Beaches are increasingly becoming trapped in a 'coastal squeeze' between burgeoning human populations from the land and the effects of global climate change from the sea. Society's interventions (e.g. shoreline armouring, beach nourishment) to combat changes in beach environments, such as erosion and shoreline retreat, can result in severe ecological impacts and loss of biodiversity at local scales, but are predicted also to have cumulative large-scale consequences worldwide. Because of the scale of this problem, the continued existence of beaches as functional ecosystems is likely to depend on direct conservation efforts. Conservation, in turn, will have to increasingly draw on a consolidated body of ecological theory for these ecosystems. Although this body of theory has yet to be fully developed, we identify here a number of critical research directions that are required to progress coastal management and conservation of sandy beach ecosystems.

Schlacher, T.A., Weston, M.A., Schoeman, D.S., Olds, A.D., Huijbers, C.M., and Connolly, R.M. 2015. Golden Opportunities: A Horizon Scan to Expand Sandy Beach Ecology. Estuarine, Coastal and Shelf Science, 157: 1-6.

Robust ecological paradigms and theories should, ideally, hold across several ecosystems. Yet, limited testing of generalities has occurred in some habitats despite these habitats offering unique features to make them good model systems for experiments. We contend this is the case for the ocean-exposed sandy beaches. Beaches have several distinctive traits, including extreme malleability of habitats, strong environmental control of biota, intense cross-boundary exchanges, and food webs highly reliant on imported subsidies. Here we sketch broad topical themes and theoretical concepts of general ecology that are particularly well-suited for ecological studies on sandy shores. These span a broad range: the historical legacies and species traits that determine community assemblages; food-web architectures; novel ecosystems; landscape and spatial ecology and animal movements; invasive species dynamics; ecology of disturbances; ecological thresholds and ecosystem resilience; and habitat restoration and recovery. Collectively, these concepts have the potential to shape the outlook for beach ecology and they should also encourage marine ecologists to embrace, via cross-disciplinary ecological research, exposed sandy beach systems that link the oceans with the land.

Schwartz, R.K. and Birkemeier, W.A. 2004. Sedimentology and Morphodynamics of a Barrier Island Shoreface Related to Engineering Concerns, Outer Banks, NC, USA. Marine Geology, 211: 215-255.

Forty-nine vibracores were collected from a barrier island shoreface following 12.4 years of biweekly profile surveying. The sedimentologic architecture of the shoreface was linked to time-series elevation change and profile shape to determine relationships between morphodynamics, facies development, erosional processes, profile closeout, and cross-shore transport. The modern shoreface mass, which erosionally overlies a tidal inlet-associated complex, attains a maximum thickness of 3–4 m below the beach to middle profile before pinching out seaward between 9 and 12 m depth. Concave erosional surfaces overlain by cross-stratified fine to medium sand and gravel make up most of the lower half of the shoreface prism below the beach through middle profile reflecting longshore trough incision and subsequent current-dominated aggradation. At the landward margin, gravel-rich laminae record episodic seaward progradation of beach surfaces over coarse inner-trough settings. Seaward, a parallel-laminated fine-sand facies dominates the upper part of the prism recording intermittent shoal zone buildup, including trough filling, under high-velocity plane-bed conditions. Similarly, a bioturbated parallel-laminated, fine- to very fine sand facies makes up the entire prism below the outermost lower ramp sector, again indicating buildup under high-velocity conditions. However, accretion of the lower ramp results from major storms that cause trough scour along landward locations and simultaneous displacement of fine sand onto the lower ramp. Conversely, lower ramp erosion typically occurs during less energetic conditions as sediment is slowly returned shoreward causing inner-shoreface buildup. Close spacing of major storms during some years led to net progradation of the shoreface. The upper and lower limits of surveyed elevation change (ULe and LLe) repeatedly develop similar limit-profile shapes over shoreface accretion–erosion cycles. The ULe reflects accretion maxima resulting from beach, bar, and lower ramp buildup. The LLe and lower sedimentologic limit (LLs) along the inner 250 to 300 m of the active shoreface are a product of storm-trough scour down to a maximum depth of ~5.5 m. Below the lower ramp facies, the LLe and LLs are primarily products of less energetic wave erosion down to ~5 m (shoreward) and 9 m (offshore) depths. The LLe closely matches the LLs documenting that >90% of the shoreface prism was reworked during the 12.4-year period whereas actual ages for erosional events indicate a potential of 2 to 4 years for complete reworking of the shoreface mass. Textural distribution indicates net long-term transport direction and loci of deposition for different sized material. The coarsest material is concentrated at landwardmost locations and well-sorted fine to very fine sand at seaward locations. Medium sand to gravel tends to remain within the trough zone, even during extreme storm events. The ULe and LLe also represent the upper and lower limits for profile closure events. A location of about 4.5 m depth at 300 to 350 m from shoreline marks the boundary between inner profile- and lower ramp-associated closure events, the boundary between trough-associated and lower ramp facies, and the lower ramp morphologic break, all of which correspond to the juncture between longshore-current- and shoaling wave-dominated zones. The lower-ramp zone of closure is a zone of seaward decreasing storm transport in which fine to very fine sand is the typical bedload material.

Scyphers, S.B., Picou, J.S., and Powers, S.P. 2015. Participatory Conservation of Coastal Habitats: The Importance of Understanding Homeowner Decision Making to Mitigate Cascading Shoreline Degradation. Conservation Letters, 8(1): 41-49.

Along densely populated coasts, the armoring of shorelines is a prevalent cause of natural habitat loss and degradation. This article explores the values and decision making of waterfront homeowners and identifies two interlinked and potentially reversible drivers of coastal degradation. We discovered that: (1) misperceptions regarding the environmental impacts and cost-effectiveness of different shoreline conditions was common and may promote armoring; and (2) many homeowners reported only altering their shorelines in response to damage caused by armoring on neighboring properties. Collectively, these findings suggest that a single homeowner's decision may trigger cascading degradation along a shoreline, which highlights the necessity of protecting existing large stretches of natural shoreline. However, our study also found that most homeowners were concerned with environmental impacts and preferred the aesthetics of natural landscapes, both of which could indicate nascent support and pathways for conservation initiatives along residential shorelines.

Smith, C.G., Culver, S.J., Riggs, S.R., Ames, D., Corbett, D.R., and Mallinson, D. 2008. Geospatial Analysis of Barrier Island Width of Two Segments of the Outer Banks, North Carolina, USA: Anthropogenic Curtailment of Natural Self-sustaining Processes. Journal of Coastal Research, 24(1): 70-83.

A comparison of two sections of the Outer Banks, North Carolina, USA (Pea Island and Avon-Buxton areas), reveals the importance of the interplay between oceanic and estuarine shoreline dynamics to long-term changes in barrier island width. From 1852 to 1998, the northern portion of Pea Island experienced an average net increase in width of 431 m (3 m/y); this area experienced low to moderate rates of oceanic shoreline erosion and high rates of back-barrier land accretion via overwash and formation of flood tidal delta islands. In contrast, between 1852 and 1998, the width of the southern portion of Pea Island and the Avon-Buxton area decreased an average of 515 m (4 m/y) and 594 m (4 m/y), respectively, because of high rates of oceanic shoreline erosion and variable changes in estuarine shoreline accretion and erosion. Net gain or net loss of barrier island width is strongly dependent on the natural depositional processes of overwash and flood tide delta formation. Anthropogenic modifications to the barrier island, such as construction of barrier dune ridges, planting of stabilizing vegetation, and urban development, can curtail or even eliminate the natural, self-sustaining processes of overwash and inlet dynamics.

Smith, M.D., Slott, J.M., McNamara, D., and Murray, A.B. 2009. Beach Nourishment as a Dynamic Capital Accumulation Problem. Journal of Environmental Economics and Management, 58: 58-71.

Beach nourishment is a common coastal management strategy used to combat erosion along sandy coastlines. It involves building out a beach with sand dredged from another location. This paper develops a positive model of beach nourishment and generates testable hypotheses about how the frequency of nourishment responds to property values, project costs, erosion rates, and discounting. By treating the decision to nourish as a dynamic capital accumulation problem, the model produces new insights about coupled economic geomorphological systems. In particular, determining whether the frequency of nourishment increases in response to physical and economic forces depends on whether the decay rate of nourishment sand exceeds the discount rate.

South Atlantic Fishery Management Council (SAMFC). 2014. Policies for the Protection and Restoration of Essential Fish Habitats from Beach Dredging and Filling and Large-scale Coastal Engineering. South Atlantic Fishery Management Council, Charleston, South Carolina, 7 p.

This document establishes the policies of the South Atlantic Fishery Management Council (SAFMC) regarding protection of the essential fish habitats (EFH) and habitat areas of particular concern (EFH-HAPCs) impacted by beach dredge-and-fill activities, and related large-scale coastal engineering projects. The policies are designed to be consistent with the overall habitat protection policies of the SAFMC as formulated and adopted in the Habitat Plan (SAFMC, 1998a) and the Comprehensive EFH Amendment (SAFMC, 1998b). The findings presented below assess the threats to EFH potentially posed by activities related to the large-scale dredging and disposal of sediments in the coastal ocean and adjacent habitats, and the processes whereby those resources are placed at risk. The policies established in this document are designed to avoid, minimize and offset damage caused by these activities, in accordance with the general habitat policies of the SAFMC as mandated by law.

Speybroeck, J., Bonte, D., Courtens, W., Gheskiere, T., Grootaert, P., Maelfait, J., Mathys, M., Provoost, S., Sabbe, K., Stienen, E., VanLancker, V., Vincx, M., and Degraer, S. 2006. Beach Nourishment: An Ecologically Sound Coastal Defence Alternative? A Review. Aquatic Conservation: Marine and Freshwater Ecosystems, 16: 419-435.

1. Even though beach nourishment is generally considered as an environment-friendly option for coastal protection and beach restoration, sizeable impacts on several beach ecosystem components (microphytobenthos, vascular plants, terrestrial arthropods, marine zoobenthos and avifauna) are described in the literature, as reviewed in this paper.
2. Negative, ecosystem-component specific effects of beach nourishment dominate in the short to medium term, with the size of the impact being determined by (1) activities during the construction phase, (2) the quality and (3) the quantity of the nourishment sand, (4) the timing, place and size of project, and (5) the nourishment technique and strategy applied. Over the long term the speed and degree of ecological recovery largely depend on the physical characteristics of the beach habitat, mainly determined by (1) sediment quality and quantity, (2) the nourishment technique and strategy applied, (3) the place and the size of nourishment and (4) the physical environment prior to nourishment.
3. The limited information available on indirect and cumulative ecological effects indicates that these effects cannot be neglected in an overall impact assessment. Hence, for ecologically good practice of beach nourishment it is advised (1) to choose nourishment sands with a sediment composition comparable to that of the natural sediment, (2) to avoid short-term compaction by ploughing immediately after construction, (3) to execute the nourishment in a period of low beach use by birds and other mobile organisms, (4) to choose a number of smaller projects rather than a single large nourishment project and (5) to select the nourishment technique with respect to the local natural values.
4. In order to allow an objective, scientifically sound, ecological adjustment of future nourishments, research should aim at (1) taking into account the full sandy beach ecosystem, (2) avoiding strategic imperfections in experimental design and (3) elucidating the biological processes behind impact and recovery of all ecosystem components.

Steinitz, M.J., Salmon, M., and Wyneken, J. 1998. Beach Renourishment and Loggerhead Turtle Reproduction: A Seven Year Study at Jupiter Island, Florida. Journal of Coastal Research, 14(3): 1000-1013.

The effects of beach renourishment on a major marine turtle nesting beach (Jupiter Island) in Florida were studied over seven years. This made possible a long-term comparison between reproductive activity on several beaches, renourished at different times, and a control beach composed of natural sand. Our goal was to determine if renourishment resulted in a nesting beach that, from the turtles' perspective, was equivalent to a natural beach. Equivalence was based upon two criteria: the number of nests placed by females on an equal length of beach (nest "density"), and by the proportion of eggs that developed into hatchlings that left those nests. Nests deposited on the renourished and natural beaches did not differ statistically in the proportion of eggs that developed into departing hatchlings. But females placed significantly fewer nests on the renourished beaches than on the control beach. There were several correlates.

When renourished beaches were narrowed by erosion, fewer turtles nested there. After renourishment, more turtles tried to nest but a large proportion of them abandoned these attempts. Abandoned nesting attempts were positively correlated with the greater surface hardness of the renourished beach. Berms tended to form after each renourishment project and these probably prevented some females from crawling to preferred nesting sites. After two years, surface hardness decreased, berms were rarely present, nesting attempts were more often successful, and nesting densities on the renourished beach were comparable to those on the control beach. But in subsequent years, nesting densities declined again as erosion narrowed the renourished beach. Thus at Jupiter Island, less nesting occurred on renourished beaches because these sites cycled between relatively long and unattractive, and relatively short and attractive, "states". To the extent that other renourished beaches mimic these cycles, they also represent inferior nesting habitats. It is therefore imperative to reduce beach-front armoring and associated development (which accelerates erosion), and to protect the few remaining natural nesting beaches used by sea turtles in Florida.

Taylor, J.C., Miller, J.M., Pietrafesa, L.J., Dickey, D.A., and Ross, S.W. 2010. Winter Winds and River Discharge Determine Juvenile Southern Flounder (*Paralichthys lethostigma*) Recruitment and Distribution in North Carolina Estuaries. Journal of Sea Research, 64: 15-25.

Retrospective analyses of a 23 year data set on abundance of Age 0 southern flounder in 105 estuarine nursery areas in the coastal region of North Carolina showed that discernible temporal and spatial patterns exist among clusters of stations. Furthermore, these patterns could be quantitatively related to certain meteorological and hydrological variables, namely winds from the east–southeast (E–SE) and from the north–northeast (N–NE) sectors and river runoff, which explained up to 83% of the interannual variability in numbers. We developed a regression model using recent catch data (1987–2002) and used the model to hindcast an earlier segment of the time series (1979–1986). The model was found to be quite robust, and could predict year class strength within 1 to 80% in the test set of data. We interpret these results to mean that hydrodynamic factors are principally responsible for the observed interannual recruitment variability in southern flounder in NC, since the interannual pattern in abundance of Age 0 fish persists for 2 more years of adult life. Finally, we discuss the implications of the variable spatial distribution patterns for estimates of year class strength from juvenile abundance data. It is possible that estimates of year class strength with a useful level of confidence could be obtained from meteorological data during the larval migration period.

Taylor, J.C., Mitchell, W.A., Buckel, J.A., Walsh, H.J., Shertzer, K.W., Martin, G.B. and Hare, J.A. 2009. Relationships between Larval and Juvenile Abundance of Winter-Spawned Fishes in North Carolina, USA. Marine and Coastal Fisheries: Dynamics, Management, and Ecosystem Science, 1: 12-21.

We analyzed the relationships between the larval and juvenile abundances of selected estuarine dependent fishes that spawn during the winter in continental shelf waters of the U.S. Atlantic coast. Six species were included in the analysis based on their ecological and economic importance and relative abundance in available surveys: spot *Leiostomus xanthurus*, pinfish *Lagodon rhomboides*, southern flounder *Paralichthys lethostigma*, summer flounder

Paralichthys dentatus, Atlantic croaker *Micropogonias undulatus*, and Atlantic menhaden *Brevoortia tyrannus*. Cross-correlation analysis was used to examine the relationships between the larval and juvenile abundances within species. Tests of synchrony across species were used to find similarities in recruitment dynamics for species with similar winter shelf-spawning life-history strategies. Positive correlations were found between the larval and juvenile abundances for three of the six selected species (spot, pinfish, and southern flounder). These three species have similar geographic ranges that primarily lie south of Cape Hatteras. There were no significant correlations between the larval and juvenile abundances for the other three species (summer flounder, Atlantic croaker, and Atlantic menhaden); we suggest several factors that could account for the lack of a relationship. Synchrony was found among the three southern species within both the larval and juvenile abundance time series. These results provide support for using larval ingress measures as indices of abundance for these and other species with similar geographic ranges and winter shelf-spawning life-history strategies.

Theuerkauf, E.J. and Rodriguez, A.B. 2014. Evaluating Proxies for Estimating Subaerial Beach Volume Change across Increasing Time Scales and Various Morphologies. Earth Surface Processes and Landforms, 39: 593-604.

Proxies, such as changes in beach profiles and shoreline positions, are commonly used in management and research for estimating changes in subaerial beach volume; however, the accuracy of these proxies across increasing time scales and complex morphologies is unclear. Volume changes associated with along-beach morphologic variability may not be captured well by changes in profiles, while volume changes associated with across-beach morphologic variability may not be captured well by measuring shoreline change. This study assesses the impacts of morphologic variations, associated with beach cusps and nourishment material, on volume change estimates from profiles and shoreline change at 0.5 to 3.5 year time periods. Results indicate that profiles spaced ≥150 m apart and the shoreline-change proxy will likely estimate volume change inaccurately over periods ≤1 year at beaches that are consistently eroding or accreting and contain cusps. However, over longer time periods (1–3.5 years), estimates of volume change from both proxies improved at those types of beaches. Volume changes at the edges of nourishment areas are not captured well by profiles. When the nourishment material is graded to a ramped morphology, which minimizes across-beach morphologic variability, the shoreline-change proxy does accurately estimate volume changes. Both proxies estimate volume changes inaccurately at beaches where volume changes oscillate between erosion and accretion on both short and long time scales because the magnitude of small-scale changes in volume from the formation and erosion of morphologic features, such as cusps and berms, will always be similar to the longer-term net volume change. This study suggests that decadal records of shoreline change, which are commonly developed using aerial photography, can be used to help identify the best proxy for estimating volume change; however, recent anthropogenic modifications that impact patterns of beach sedimentation, including nourishment, terminal groins, and inlet-channel dredging, makes decadal records less useful.

Thieler, E.R., Brill, A.L., William J. Cleary, W.J., Hobbs, C.H., III, and Gammisch, R.A. 1995. Geology of the Wrightsville Beach, North Carolina Shoreface: Implications for the Concept of Shoreface Profile of Equilibrium. Marine Geology, 126: 271-287.

Nearly 300 km of 3.5 kHz subbottom profile and 100 kHz sidescan-sonar data, a suite of over 100 short (~2 m) percussion cores and vibracores have been collected on the shoreface and inner continental shelf off Wrightsville Beach, North Carolina. Sidescan-sonar images were analyzed for acoustic backscatter to delineate the surface sediment distribution. Groundtruth data for the sidescan-sonar interpretations were provided by surface grab samples. Cross-shore sediment transport by combined waves and currents is the predominant sedimentologic signature on this shoreface. The shoreface is dominated by a shore-normal system of rippled scour depressions that begin in 3-4 m water depth and extend to the base of the shoreface about 1 km offshore, at 10 m depth. The depressions are 40-100 m wide, and up to 1 m deep. They are floored by coarse, rippled shell hash and gravel; some are separated by rock-underlain fine sand ridges. On the inner shelf, the bathymetric and sedimentary fabrics become shore-oblique, due to a series of relict ridges with 1-2 m of relief. The ridges are coarse on their landward sides and covered on their seaward flanks by thin veneers of fine sand. Field evidence from the Wrightsville Beach shoreface demonstrates that a shoreface equilibrium profile as defined by Dean (1991) and others does not exist here. For example: (1) the grain size varies widely and inconsistently over the profile; (2) shoreface profile shape is controlled predominantly by underlying geology, including Tertiary limestone outcrops and Oligocene silts; and (3) sediment transport patterns cannot be explained by simple diffusion due to wave energy gradients, and that transport occurs seaward of the assumed engineering "closure depth" of 8.5 m. This has several implications for the application of equilibrium profile-based numerical models used to investigate coastal processes and design coastal engineering projects at Wrightsville Beach. The most important practical implication is that a number of assumptions required by existing analytical and numerical models (e.g., Dean, 1991; GENESIS; SBEACH) used for the design of shore protection projects and large-scale coastal modeling over decadal time scales cannot be met.

Thrush, S.F., Hewitt, J.E., Norkko, A., Cummings, V.J., and Funnell, G.A. 2003. Macrobenthic Recovery Processes Following Catastrophic Sedimentation on Estuarine Sandflats. Ecological Applications, 13(5): 1433-1455.

Land use can exacerbate the rate of sediment delivery to estuaries. In particular, for catchments with steep terrain and heavy, sporadic rainfall, changes in land use can increase the risk of catastrophic deposition of terrestrial sediment. One of the key issues in assessing the ecological significance of catastrophic sedimentation events is determining the rate of recovery of the macrobenthic community and understanding how physical and biological processes influence the recovery rate in different locations. We conducted a field experiment over 212 days to assess the impact of terrestrial sediment deposits at six sites on the intertidal sandflats of Whitianga Harbour (New Zealand). Differences in the sedimentary habitat as a-result of the deposition of terrestrial sediment lasted for ~50 d, although these effects varied between different sediment properties and between sites. The deposition of terrestrial sediment had an immediate and negative effect on resident macrofauna, although complete defaunation of the experimental plots did not occur. Macrobenthic recovery lagged behind the recovery of the sediment properties. Based on multivariate analysis, three sites never recovered over the duration of the experiment, while based on univariate analysis four sites never recovered. Macrofaunal assemblages living deep (2-15 cm) within the sediment were generally slower to recover than those found in the top 2 cm. A meta-analysis of recovery rates for macrofauna was conducted on information generated in this study and in two similar experiments carried out in other New Zealand estuaries. This analysis revealed a consistent negative relationship between the magnitude of disturbance generated by the terrestrial sediment layer and the recovery of the macrobenthos. Measures of recovery at the community level emphasized the importance of site environmental factors reflecting increased wave disturbance, flow velocity, and the wetting and drying of the deposited terrestrial sediment in speeding recovery. Overall, our results indicate that the long-term effects of catastrophic sediment disturbance are influenced by local hydrodynamic conditions and the composition of resident macrofauna living in sediments adjacent to disturbed areas. Given the long time scale of recovery from these experiments they indicate the potential for catastrophic sediment deposition to result in broad-scale degradation of estuarine macrobenthic communities.

Traynum, S.B., Kana, T.W., and Simms, D.R. 2010. Construction and Performance of Six Template Groins at Hunting Island, South Carolina. Shore and Beach, 78(3): 1-12.

Hunting Island, South Carolina, a four-mile-long barrier-island state park, has one of the highest erosion rates in the United States, averaging over 20 ft/yr for the past ~50 years. After six federal and state nourishment projects (1968 to 2004) failed to keep pace with erosion, officials at the South Carolina Department of Parks, Recreation and Tourism (SCPRT) approved a beach stabilization project involving groins plus nourishment. The final plan called for construction of six groins in three clusters at strategic beach access locations along the largely undeveloped oceanfront. Nourishment was an integral and required part of the plan, because it provided a platform for land-based construction of the groins and a source of sand to accommodate sand trapping. In this mesotidal, moderate wave energy setting, the completed structures had to be ~450 ft long to provide a profile encompassing the design berm width and wet-sand beach to low water. Groin spacing in clusters was ~1,200 ft. The template profile followed design guidance by ASCE (1994) and is likely one of the first groin installations in the United States attempting this recommended configuration. The groins were constructed using ASTM A690 steel sheet pile with steel caps. Toe protection was limited to broad, armor-stone mats at the heads of each groin. The structures were designed for low reveal along their lengths. Post-project monitoring confirms that erosion rates have lessened within each groin cluster. However, excess nourishment sand has been lost mainly to the north spit (the principal transport direction in this setting). Downcoast areas have continued to receive sand during the first two years following construction. The quantities of sand retained by the structures are dwarfed by the volumes of sand in the adjacent ebb-tidal deltas.

Trembanis, A.C., Valverde, H.R., and Pilkey, O.H. 1998. Comparison of Beach Nourishment Along the U.S. Atlantic, Great Lakes, Gulf of Mexico and New England Shorelines. Journal of Coastal Research, SI 26: 246-251.

The U.S. national beach nourishment experience is summarized for the East Coast barrier islands, the Gulf of Mexico, New England and the Great Lakes. A total of 1305 nourishment episodes are recorded at a total estimated cost of approximately $1.4 billion ($2.5 billion in 1996 dollars). In terms of both volume and costs, nourishment has been the most extensive by far on the East Coast barrier islands. Between 65-85% of all nourishment projects have a federal funding component. Annual expenditures and sand volumes for beach nourishment are increasing especially on East coast barriers. At present, total annual national beach nourishment costs (excluding the Pacific coast) are on the order of $100 million per year. Surprisingly, cost per cubic yard of nourishment sand as expressed in 1996 dollars has remained more or less constant over time. Additionally, there is no indication of a reduced need of sand through time for episodes on individual beaches.

Vallianos, L. 1975. A Recent History of Masonboro Inlet, North Carolina. *In:* Cronin, L.E. (ed.) Estuarine Research, Volume II: Geology and Engineering. New York: Academic Press, 151-166.

Masonboro Inlet is located along the southeastern ocean shoreline of North Carolina and, with respect to the general Atlantic coast of the United States, is located at a point approximately equidistant from Boston, Massachusetts, and the southern tip of the Florida peninsula. The morphology of the coastal margin of North Carolina (Fig. 1) is characterized by three cuspate forelands known as Cape Hatteras, Cape Lookout, and Cape Fear. The ocean shoreline is comprised of a narrow band of low, sandy barrier islands whose widths are generally on the order of 250 meters. These barrier islands are separated by a total of 22 inlets which couple the ocean with the interconnected estuarine waters of the State. Though a barrier island-inlet chain is typical of the entire coastline, there is a marked difference between the northern and southern halves of the State's coastal zone in terms of estuarine areas. In the northern half, the estuaries are expansive bodies of water known as Pamlico Sound and Albemarle Sound. These are the largest embayments on the Atlantic coast contained between a barrier island system and the continental land mass. The southern half of the State's coastal zone is characterized by narrow elongated lagoons comprised of salt marshes and circuitous networks of tidal-flow channels. The width of most of these elongated lagoons does not exceed 1.5 kilometers. The coastal setting at and in the vicinity of Masonboro Inlet embodies the general features of the southern half of the State's coastal zone, as evidenced by Figure 2.

Valverde, H.R. and Pilkey, O.H. 1996. Shoreline Stabilization in Onslow Bay. *In:* Environmental Coastal Geology: Cape Lookout to Cape Fear, NC. Cleary, W.J., (ed), Carolina Geological Society Field Guidebook, 59-63.

The shoreline along Onslow Bay is retreating landward toward an ever-increasing number of beach front buildings. Naturally, beach front property owners wish to preserve their buildings. There are basically 3 ways in which they may do this: (1) move buildings back, (2) armor the shoreline with seawalls and/or groins, or (3) nourish the beach. Of course, there are advantages and disadvantages to each of these approaches. The retreat option is the best way to preserve the recreational beach but could be costly and certainly is politically difficult. This is because people who own beach front property tend to be politically influential and are unwilling to move or demolish their structures. Armoring the shoreline is the best way to preserve buildings but this approach results in degradation, and even disappearance, of the recreational beach. For this reason, North Carolina prohibits all shoreline armoring with the exception of sandbags. Beach nourishment "improves" the quality of the recreational beach but is very costly and temporary as the long history of beach nourishment at Carolina Beach and Wrightsville Beach demonstrates.

Valverde, H.R., Trembanis, C., and Pilkey, O.H. 1999. Summary of Beach Nourishment Episodes on the U.S. East Coast Barrier Islands. Journal of Coastal Research, 15(4): 1100-1118.

This study documents that since 1923, approximately 350 million cubic yards of sand have been deposited on the US East Coast barrier island shoreline (from Long Island, New York to Fisher Island, Florida), by more than 573 beach nourishment episodes, at 154 locations. On East Coast barrier beaches, the use of beach nourishment to control coastal erosion has increased rapidly since the 1960's. Most of this volume (65%) has been placed by federally sponsored beach nourishment projects, either storm and erosion control projects or navigation projects with beach disposal of dredge spoil. However, the proportion of nourishment projects not involving federal funds (state/local and local/private nourishment projects) has been increasing.

Van Dolah, R.F., Calder, D.R., and Knott, D.M. 1984. Effects of Dredging and Open-Water Disposal on Benthic Macroinvertebrates in a South Carolina Estuary. Estuaries, 7(1): 28-37.

Approximately 28,475 m^3 of muddy sediments were dredged from a shoal in a South Carolina estuarine system and released near the surface at a nearby site having high tidal current velocities. Effects at the dredged sites included decreased macrofaunal abundance and changes in species composition. These effects appeared to be short term, with substantial recovery occurring within 3 months. Rapid recovery was primarily attributed to immigration through slumping of channel wall sediments similar to those dredged. Detrimental effects on benthic macrofauna in the area of open water disposal were minimal. Most differences noted in community structure between collection dates were attributed to sampling and seasonal variability. The absence of a major long-term disruption to the benthos in the disposal area was probably due to (1) strong tidal currents, which rapidly dispersed the moderate amount of mud sediments released; (2) surface disposal, permitting wider dispersal; and (3) disposal during late autumn, a period of low faunal recruitment.

Van Dolah, R.F., Wendt, P.H., Wenner, C.A., Martore, R.M., Sedberry, G.R., and Moore, C.J. 1987. Ecological Effects of Rubble Weir Jetty Construction at Murrells Inlet South Carolina Volume III: Community Structure and Habitat Utilization of Fishes and Decapods Associated with the Jetties. U.S. Army Corps of Engineers, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS, Technical Report EL-84-4, 164 p.

Quarrystone jetties at Murrells Inlet, South Carolina, were studied over a 1-year period to: (a) identify changes in the distribution, relative abundance, and composition of fish and crab assemblages, (b) characterize the food habits of most fish species collected, and (c) identify seasonal patterns in recreational fishing activities around the jetties. Fishes were assessed using gill nets, traps, and rotenone collections and by diver surveys; crabs were sampled using traps. Fish food habits were determined through stomach content analysis, and interview-count surveys were used to identify recreational fishing activities. Seventy-five species of fish representing 53 families were captured or observed around the jetty rocks. Distinct seasonal differences were observed in the community composition, as well as in the overall abundance of fishes collected or observed. The jetties generally attracted fish species that are normally associated with reef structures, species that are commonly found around estuarine inlets, and species that seasonally migrate along the coast. The jetties also appear to serve as nursery habitat for a variety of fish species. Stomach content analyses of 55 species identified three major trophic groups: fish that are mostly piscivorous, fish that feed primarily on sand bottom epifauna, and fish that feed primarily on jetty biota or zooplankton. Several of the recreationally important species feed directly on the jetty fauna, or on smaller fishes which consume jetty biota. Stone crabs were numerically dominant among the eight species of crabs captured by trap around the jetty rocks. Stone crab catches were greatest in spring and declined in all subsequent seasons. More stone crabs were captured on the exposed versus channel side of the jetty, and most were caught at night. The Murrells Inlet jetties do not appear to support more than an incidental stone crab fishery. Considerable recreational fishing was observed around both the north and south jetties, with most fishing activity observed on weekend days. Interviewed anglers primarily sought red drum, flounder, spot, bluefish, king mackerel, and sheepshead; however, black sea bass and smooth dogfish were the species most frequently caught. The numbers of fishes and fish species caught by fishermen were greatest during the summer, and more fish were captured around the jetty structures than in nonjetty areas.

Van Dusen, B.M., Fegley, S.R., Peterson, C.H. 2012. Prey Distribution, Physical Habitat Features, and Guild Traits Interact to Produce Contrasting Shorebird Assemblages among Foraging Patches. PLoS ONE, 7(12): e52694.

Worldwide declines in shorebird populations, driven largely by habitat loss and degradation, motivate environmental managers to preserve and restore the critical coastal habitats on which these birds depend. Effective habitat management requires an understanding of the factors that determine habitat use and value to shorebirds, extending from individuals to the entire community. While investigating the factors that influenced shorebird foraging distributions among neighboring intertidal sand flats, we built upon species-level understandings of individual-based, small-scale foraging decisions to develop more comprehensive guild- and community-level insights. We found that densities and community composition of foraging shorebirds varied substantially among elevations within some tidal flats and among five flats despite their proximity (all located within a 400-m stretch of natural, unmodified inlet shoreline). Non-dimensional multivariate analyses revealed that the changing composition of the shorebird community among flats and tidal elevations correlated significantly ($\rho_s = 0.56$) with the spatial structure of the benthic invertebrate prey community. Sediment grain-sizes affected shorebird community spatial patterns indirectly by influencing benthic macroinvertebrate community compositions. Furthermore, combining sediment and macroinvertebrate information produced a 27% increase in correlation ($\rho_s = 0.71$) with shorebird assemblage patterns over the correlation of the bird community with the macroinvertebrate community alone. Beyond its indirect effects acting through prey distributions, granulometry of the flats influenced shorebird foraging directly by modifying prey availability. Our study highlights the importance of habitat heterogeneity, showing that no single patch type was ideal for the entire shorebird community. Generally, shorebird density and diversity were greatest at lower elevations on flats when they became exposed; these areas are at risk from human intervention by inlet sand mining, construction of groins and jetties that divert sediments from flats, and installation of seawalls on inlet shorelines that induce erosion of flats.

van Rijn, L.C. 2011. Coastal Erosion and Control. Ocean & Coastal Management, 54: 867-887.

Coastal erosion is a problem at many coastal sites caused by natural effects as well as human activities. This paper explores the coastal cell concept to deal with coastal erosion by identifying and analyzing the sediment volumes accumulated in large-scale and small-scale coastal cells at various sites. Mechanisms causing chronic erosion and episodic erosion related to coastal variability are identified and discussed. The effectiveness of soft and hard remedial measures for sandy beaches are assessed based on laboratory, field and modelling experiences.

Van Tomme, J., Eede, S.V., Speybroeck, J., Degraer, S., and Vincx, M. 2013. Macrofaunal Sediment Selectivity Considerations for Beach Nourishment Programmes. Marine Environmental Research, 84: 10-16.

Nowadays, beach nourishment is widely considered as a better alternative compared to the construction of hard structures to protect a sandy coast against detrimental erosive effects, both from an ecological and an engineering perspective. The rare studies conducted on the ecological impact of beach nourishment are short-term, post hoc monitoring investigations of the benthic macrofauna. Little is known of the biological processes during and after nourishment. To allow swift recolonization after nourishment, the characteristics of the nourished beach have to match the habitat demands of the benthic macrofauna. The sediment preference of the key intertidal species *Scolelepis squamata*, *Eurydice pulchra*, *Bathyporeia pilosa* and *Bathyporeia sarsi*, which dominate many West European sandy beaches, was investigated through laboratory experiments, both in single-species as well as combined-species treatments. While the former aimed at developing guidelines for impact mitigation of beach nourishment, the latter aimed at elucidating the role of biotic interactions in sediment preference. Results of the experiments indicated that *B. pilosa* and *E. pulchra* prefer the finest sediment, while *B. sarsi* had a broader preference and also occurred in medium-coarse sediments. However, the sediment preference of *E. pulchra* for fine sediments was not confirmed by other field and experimental studies. The polychaete *S. squamata* had the broadest preference and even showed a high occurrence in coarse sediments that are not naturally occurring on the sandy beaches where the animals were caught for this experiment. However, this polychaete is a cosmopolitan species, not only occurring on fine-grained beaches, but also on coarse-grained beaches worldwide. The preferences imply that beach nourishment with coarse sediment will have a major effect on *B. pilosa* while effects of coarse sediments on *S. squamata* will be minor. Finally, interspecific competition with the sympatrically occurring amphipod *B. sarsi* was found to change the sediment selection of the amphipod *B. pilosa* towards the coarser sediments where *B. sarsi* occurred in lower frequencies.

Viola, S.M., Hubbard, D.M., Dugan, J.E., and Schooler, N.K. 2014. Burrowing Inhibition by Fine Textured Beach Fill: Implications for Recovery of Beach Ecosystems. Estuarine, Coastal and Shelf Science, 150: 142-148.

Beach nourishment is often considered the most environmentally sound method of maintaining eroding shorelines. However, the ecological consequences are poorly understood. Fill activities cause intense disturbance and high mortality and have the potential to alter the diversity, abundance, and distribution of intertidal macroinvertebrates for months to years. Ecological recovery following fill activities depends on successful recolonization and recruitment of the entire sandy intertidal community. The use of incompatible sediments as fill material can strongly affect ecosystem recovery. We hypothesized that burrowing inhibition of intertidal animals by incompatible fine fill sediments contributes to ecological impacts and limits recovery in beach ecosystems. We experimentally investigated the influence of intertidal zone and burrowing mode on responses of beach invertebrates to altered sediment texture (28-38% fines), and ultimately the potential for colonization and recovery of beaches disturbed by beach filling. Using experimental trials in fill material and natural beach sand, we found that the mismatched fine fill sediments significantly inhibited burrowing of characteristic species from all intertidal zones, including sand crabs, clams, polychaetes, isopods, and talitrid amphipods. Burrowing performance of all five species we tested was consistently reduced in the fill material and burrowing was completely inhibited for several species. The threshold for burrowing inhibition by fine sediment content in middle and lower beach macroinvertebrates varied by species, with highest sensitivity for the polychaete (4% fines, below the USA regulatory limit of 10% fines), followed by sand crabs and clams (20% fines). These results suggest broader investigation of thresholds for burrowing inhibition in fine fill material is needed for beach animals. Burrowing inhibition caused by mismatched fill sediments exposes beach macroinvertebrates to stresses, which could depress recruitment and survival at all intertidal zones. Our results suggest use of incompatible fine fill sediments from dredging projects creates unsuitable intertidal habitat that excludes burrowing macroinvertebrates and could delay beach ecosystem recovery. Through effects on beach invertebrates that are prey for shorebirds and fish, the ecological impacts of filling with mismatched fine sediments could influence higher trophic levels and extend beyond the beach itself.

Walker, R., Rudolph, G., and Rogers, S. 2011. Fort Macon Terminal Groin, Beaufort Inlet, North Carolina. Shore and Beach, 78(4): 75-83.

Beaufort Inlet is one of North Carolina's two deep-draft inlets and provides an important navigation path to the Morehead City Harbor. On the east side of the inlet sits the historic Fort Macon, which dates back to 1826 and is now a state park. Since the initial occupation of this area by federal forces, coastal erosion has continuously threatened the fort structure and associated park infrastructure. Beginning in 1831, a variety of groin configurations have been constructed to protect the site. The groins - which lined the ocean beach and continued around the inlet – managed to stabilize the site but not without a constant struggle with coastal processes and inlet dynamics, requiring an extensive long-term management scheme and constant re-evaluations and improvements to the structures. After a series of hurricanes in the 1950s threatened the historic fort, construction began in 1961 for a terminal groin on the east end of the barrier island to permanently stabilize the site. After several extensions, the terminal groin was finalized in 1970 and has continued to maintain the Fort Macon site in a stable condition.

Warrick, J.A. 2013. Dispersal of Fine Sediment in Nearshore Coastal Waters. Journal of Coastal Research, 29(3): 579-596.

Fine sediment (silt and clay) plays an important role in the physical, ecological, and environmental conditions of coastal systems, yet little is known about the dispersal and fate of fine sediment across coastal margin settings outside of river mouths. Here I provide simple physical scaling and detailed monitoring of a beach nourishment project near Imperial Beach, California, with a high portion of fines (~40% silt and clay by weight). These results provide insights into the pathways and residence times of fine sediment transport across a wave-dominated coastal margin. Monitoring of the project used physical, optical, acoustic, and remote sensing techniques to track the fine portion of the nourishment sediment. The initial transport of fine sediment from the beach was influenced strongly by longshore currents of the surf zone that were established in response to the approach angles of the waves. The mean residence time of fine sediment in the surf zone—once it was suspended—was approximately 1 hour, and rapid decreases in surf zone fine sediment concentrations along the beach resulted from mixing and offshore transport in turbid rip heads. For example, during a day with oblique wave directions and surf zone longshore currents of approximately 25 cm/s, the offshore losses of fine sediment in rips resulted in a 95% reduction in alongshore surf zone fine sediment flux within 1 km of the nourishment site. However, because of the direct placement of nourishment sediment on the beach, fine suspended-sediment concentrations in the swash zone remained elevated for several days after nourishment, while fine sediment was winnowed from the beach. Once offshore of the surf zone, fine sediment settled downward in the water column and was observed to transport along and across the inner shelf. Vertically sheared currents influenced the directions and rates of fine sediment transport on the shelf. Sedimentation of fine sediment was greatest on the seafloor directly offshore of the nourishment site. However, a mass balance of sediment suggests that the majority of the fine sediment moved far away (over 2 km) from the nourishment site or to water depths greater than 10 m, where fine sediment represents a substantial portion of the bed material. Thus, the fate of fine sediment in nearshore waters was influenced strongly by wave conditions, surf zone and rip current transport, and the vertical density and flow conditions of coastal waters.

Welsh, J.M. 2004. Characterization of the Evolution of a Relocated Tidal Inlet: Mason Inlet, North Carolina. [M.S. thesis]: Wilmington, North Carolina, University of North Carolina Wilmington, 99 p.

Between January and April 2002, Mason Inlet, situated between Figure Eight Island and Wrightsville Beach, N.C. was artificially relocated 2,800 ft updrift of its most recent position at the southern terminus of a migrating barrier spit. Relocation was chosen from several coastal management options due to increased backbarrier infilling and southerly migration of the inlet that imminently threatened a resort complex and infrastructure on northern Wrightsville Beach. The relocated Mason Inlet provides an ideal site to study the evolution and impacts of a recently relocated system from its inception while simultaneously assessing the relative success of the project. Techniques such as ADCP, RTK GPS, and GIS-based analyses served as tools in the collection of data pertaining to a variety of inlet parameters. Cumulative erosion measured along neighboring shoreline reaches was induced by inlet relocation and subsequent formation of the ebb-tidal delta coupled with channel migration. Key indicators suggest that the system remains flood dominant. Noticeable infilling of the backbarrier persists along with ebb durations exceeding flood durations and flood flow volumes exceeding ebb volumes. JARRETT's (1976) theoretical equation relating tidal prism (T_P) and cross-sectional area (A_C) appears to be a useful tool for estimation of the relocated Mason Inlet's T_P. However, ebb-tidal delta volume after 1.6 years remains well below the equilibrium volume predicted by WALTON and ADAMS' (1976) model. Future modification (e.g. dredging feeder channels) to the system will be needed in order to mitigate the infilling nature of the inlet that historically has led to increased migration to the southwest. Failure to contain the inlet within the proposed "inlet corridor" will result in an unsuccessful relocation effort.

Wilber, D.H. and Clarke, D.G. 2001. Biological Effects of Suspended Sediments: A Review of Suspended Sediment Impacts on Fish and Shellfish with Relation to Dredging Activities in Estuaries. North American Journal of Fisheries Management, 21: 855-875.

Objective assessment of the effects of increased concentrations of suspended sediment caused by human activities, such as navigation dredging, on estuarine fish and shellfish requires an integration of findings from biological and engineering studies. Knowledge is needed of (1) the suspended sediment characteristics typical of both ambient and dredging-induced conditions, (2) the biological responses of aquatic organisms to these suspended sediment dosages, and (3) the likelihood that organisms of interest will encounter suspended sediment plumes. This paper synthesizes the results of studies that report biological responses to known suspended sediment concentrations and exposure durations and relates these findings to suspended sediment conditions associated with dredging projects. Biological responses of taxonomic groups and life history stages are graphed as a function of concentration and exposure duration. The quality and taxonomic breadth of studies on which resource managers must rely when evaluating potential impacts from activities that resuspend sediments, such as dredging projects, are addressed. Review of the pertinent literature indicates that few data exist concerning biological responses of fish and shellfish to suspended sediment dosages commonly associated with dredging projects. Much of the available data come from bioassays that measured acute responses and required high concentrations of suspended sediments to induce the measured response, usually mortality. Although anadromous salmonids have received much attention, little is known of behavioral responses of many estuarine fishes to suspended sediment plumes. Likewise, the effects of intermittent exposures at periodicities that simulate the effects of tidal flushing or the conduct of many dredge operations have not been addressed.

Wilber, D.H. and Clarke, D.G. 2007. Defining and Assessing Benthic Recovery Following Dredging and Dredged Material Disposal. WODCON XVIII Conference, Lake Buena Vista, FL. 603-618.

Assessing the recovery of benthic habitats disturbed by dredging and dredged material disposal operations is an important and growing management issue throughout the world. Although many projects have been monitored and a substantial literature on the subject exists, few generalizations can be made about typical recovery rates because biological responses are influenced by numerous factors, including site-specific bathymetry, hydrodynamics, depth of deposited sediments, the spatial scale of the disturbance, sediment type, and the timing and frequency of the disturbance. Additionally, there is no accepted definition of what constitutes "recovery." In various studies, recovery has been defined as a return of benthic resources to a baseline (pre-impact) condition, a reference (neighboring unimpacted) condition and/or both. Infaunal macroinvertebrates are most commonly monitored to assess benthic recovery, ususally by sampling the substrate, preserving organisms in formalin, and identifying and enumerating the organisms in the laboratory. Methods used to analyze these data vary and may influence study conclusions just as much as the aforementioned physical factors. Study results are generally presented through some combination of three methods of data analysis, i.e., univariate statistics (very common and used almost exclusively in early studies), multivariate statistics (increasingly common), and benthic indices. We review benthic recovery rates reported for approximately 50 dredging-related (disposal and dredging sites) projects and explore the relative influence of both physical and analytical factors in the determinations of recovery status. Although early impact assessments relied heavily upon univariate diversity indices that were derived from species level identifications of macroinvertebrates, it has become increasingly apparent that multivariate analyses of the same data sets provide more sensitive measures of ecological status.

Wilber, D.H., Clarke, D.G., Ray, G.L., and M. Burlas, L. 2003. Response of Surf Zone Fish to Beach Nourishment Operations on the Northern Coast of New Jersey, USA. Marine Ecology Progress Series, 250: 231-246.

Surf zone fishes were captured by beach seine over the late summer and early fall of 5 yr (1995 to 1999), spanning pre-, during, and post-nourishment time periods along a 15 km expanse of the New Jersey shoreline. During the baseline years of sampling, silversides (primarily *Menidia menidia)* numerically dominated the surf-zone fish community. In 1997, coincident with beach nourishment operations, bluefish *Pomatomus saltatrix* became numerically dominant, increasing in abundance 10-fold. Bluefish were not captured near active beach nourishment sites and were significantly more abundant at reference stations than in the beach nourishment (treatment) area for 2 of 6 sampling dates in 1997. In contrast, northern kingfish *Menticirrhus saxatilis* were more abundant at treatment stations in 1997, and on one occasion congregated at the stations undergoing active sand replenishment. The feeding habits of Atlantic silversides and northern kingfish were consistent throughout the study period. In 1997, prey biomass was greater in fish caught at treatment stations when significant differences occurred. Prey consisted primarily of benthic invertebrates such as polychaetes and mole crabs. Amphipods and insects, which probably originated from groins and terrestrial sources respectively, were also common prey items and were present in plankton samples. Retrospective power analysis indicates that an approximate 3-fold difference in mean fish abundance was the minimum detectable effect size between reference and treatment areas. Beach nourishment impacts on the surf zone fish monitored in this study were restricted to localized attraction (northern kingfish) and avoidance (bluefish) responses to the beach nourishment operation.

Williams, S.J. and Gutierrez, B.T. 2009. Sea-level Rise and Coastal Change: Causes and Implications for the Future of Coasts and Low-lying Regions. Shore and Beach, 77(4): 13-21.

According to climate change assessment reports published in 2008 and 2009 by the U.S. Global Change Research Program and the U.S. Climate Change Science Program, observations show that recent increase in global temperature is unequivocal; and that warming and widespread environmental change primarily result from increase in greenhouse gas emissions from anthropogenic fossil fuel burning. Additional contributions to climate change are from land-use activities since the late 19th century. One of the most significant climate-change impacts is sea-level rise. Direct sea-level rise impacts include: increased coastal erosion, more frequent tidal and storm-surge flooding, inundation of low-lying areas, saltwater intrusion, wetland loss, and threats to human infrastructure in coastal zones. Climate-change assessments, such as the United Nation's Intergovernmental Panel on Climate Change Fourth Report, suggest that global sea level for this century will rise 18-59 cm (IPCC 2007). More recent modeling studies suggest that sea-level rise rates may be significantly higher in decades ahead due to climate processes that appear to be stronger than previously thought (e.g. Greenland and West Antarctica ice-sheet melting, ocean current disruption). These recent studies suggest that global sea-level rise could be 1 m or more by the year 2100 and continued accelerated melting in Greenland and West Antarctica could lead to 4 m to 6 m rise over the next several hundred years. Accelerated sea-level rise will have significant impacts on coastal and wetland systems, natural resources and habitats, and societies world-wide. Coastal scientists have developed conceptual and qualitative frameworks based on field studies and modeling to understand the primary factors and processes that drive coastal change. However, current techniques used to predict coastal change such as inundation modeling, historical shoreline-change analysis, and equilibrium-profile modeling can not yet provide reliable long-term predictions at spatial and temporal scales considered optimal for local coastal planning and decision making. With substantial acceleration of sea-level rise, some coastal management and engineering practices (i.e. maintaining shoreline position with hard structures, beach nourishment) will become more difficult for society and may not be economically or environmentally sustainable. Sea-level rise projections and implications need to be fully considered in coastal management plans and engineering design. Options such as relocation of infrastructures to higher elevations and conversion of low-lying developed areas to parks for open space conservation and recreation may be more appropriate for adapting to coming coastal change.

Williams, S.J., Dodd, K., and Gohn, K.K. 1991. Coasts in Crisis. Department of the Interior, U.S. Geological Survey Circular 1075, Washington, D.C.: United States Government Printing Office, 32 p.

Our coasts are reaching a crisis. Threats to coasts and to coastal communities are growing as development, recreation, and waste disposal activities increase, often in conflict with long-term natural processes. Other threats to our coasts, such as sea-level rise and reduction in sediment supply, result from global warming and the damming of rivers. The impending crisis of our coasts stems from misconceptions about what coasts are and from actions based on those misconceptions. Differences between our perceptions and the reality of coasts intensify the conflicts between people and nature. These conflicts will worsen as the coastal population expands and competing uses of the recreational, wildlife, shipping, and mineral resources of coasts increase.

Witherington, B., Hirama, S., and Mosier, A. 2011. Sea Turtle Responses to Barriers on Their Nesting Beach. Journal of Experimental Marine Biology and Ecology, 401: 1-6.

We experimentally studied the nesting behavior and nest-site choice of loggerhead sea turtles (*Caretta caretta*) that emerged to nest at night on a beach in southern Brevard County, Florida USA. Emerging turtles were divided between two paired treatments: wall and control. Intercepted turtles in the wall treatment were presented a portable wall that blocked their ascent of the beach. The position of the portable wall was shoreparallel and midway between the recent wrack line and the dune toe. Intercepted turtles in the control treatment ascended the beach and did not encounter a wall. We observed individual turtles in both wall and control treatments so that their nesting behavior could be measured. We observed 44 female loggerheads (22 paired samples). In the control treatment, 15 of 22 turtles completed a nest, and in the wall treatment, 14 of 22 turtles completed a nest. There was no significant difference in nesting success (nests/attempts) between treatments (Chi-square=0.10, p=0.75). However, effects from the wall resulted in wall-treatment nests being 3.5 m closer to the surf than control nests, on average. Although it was possible for turtles to nest within 0.5 m of the wall, mean distance of nests from the wall was 3.2 m (SD±2.0 m). Although the wall affected the location where nesting occurred, there was no observable effect on the effort turtles made to prepare the nest site, dig an egg chamber, fill it with eggs, cover the eggs, or camouflage the nest site. Egg survivorship did not differ significantly between treatments; however, the sample size was not large enough to detect biologically significant differences in hatching success amidst the high variation in the data. An additional factor that made our test of hatching success less rigorous was the absence of significant beach erosion during the study period. Erosion has been shown to be the principal cause of mortality for nests low on the beach and can cause 100% mortality in the region of beach where the wall-treatment nests were located.

Wood, D.W. and Bjorndal, K.A. 2000. Relation of Temperature, Moisture, Salinity, and Slope to Nest Site Selection in Loggerhead Sea Turtles. Copeia, 1: 119-128.

Nest site selection in reptiles can affect the fitness of the parents through the survival of their offspring because environmental factors influence embryo survivorship, hatchling quality, and sex ratio. In sea turtles, nest site selection is influenced by selective forces that drive nest placement inland and those that drive nest placement seaward. Nests deposited close to the ocean have a greater likelihood of inundation and egg loss to erosion whereas nest placement farther inland results in greater likelihood of desiccation, hatchling misorientation, and predation on nesting females, eggs, and hatchlings. To evaluate the role of microhabitat cues in nest site selection in Loggerhead Sea Turtles (*Caretta caretta*), we assessed temperature, moisture, salinity (conductivity), and slope along the tracks of 45 female loggerheads during their beach ascent from the ocean to nest sites in the Archie Carr National Wildlife Refuge in Florida on the beach with the greatest density of loggerhead nesting in the Atlantic. Of the four environmental factors evaluated (slope, temperature, moisture, and salinity), slope appears to have the greatest influence on nest site selection, perhaps because it is associated with nest elevation. Our results refute the current hypothesis that an abrupt increase in temperature is used by loggerheads as a cue for excavating a nest. Moisture content and salinity of surface sand are potential cues but may not be reliable for nest site selection because they can vary substantially and rapidly in response to rainfall and changes in the water table. Sea turtles may use multiple cues for nest site selection either in series with a threshold that must be reached for each environmental factor before the turtle initiates nest excavation or integrated as specific patterns of associations.

North Carolina
Coastal Federation
Working Together for a Healthy Coast

January 4, 2016

Via Electronic Email
Mr. Tancred Miller
Division of Coastal Management
400 Commerce Ave
Morehead City, NC 28557
Tancred.Miller@ncdenr.gov

RE: Legislative study to develop a strategy for preventing, mitigating and remediating the effects of beach erosion in North Carolina

Dear Mr. Miller:

Thank you for the opportunity to provide comments on the legislative study to develop a strategy for preventing, mitigating and remediating the effects of beach erosion. The North Carolina Coastal Federation supports the preservation and responsible use of our state's beautiful and productive beaches and inlets as public trust resources.

North Carolina's barrier island beaches and inlets are some of our state's most valuable environmental and economic assets. Our ability to use our beaches and inlets is a basic public trust right that we all share. Our state's constitution specifically says that preserving our beaches as part of our common heritage is the responsibility of state government (N.C. Constitution, Article XIV, Section 5).

Problems arise in some locations where public uses of our oceanfront beaches have been lost or reduced as efforts to protect oceanfront property have become more aggressive. Most oceanfront property owners will insist that their property be protected from erosion as long as they are exposed to significant financial losses if it erodes away. Currently, flood insurance pays for up to $250,000 in structural damages to buildings, and pays nothing for the lost value of eroded real estate. While existing coastal management efforts try to limit the damage done to the natural beaches by imposing restrictions on what can be done to mitigate erosion, these regulatory safeguards to preserve public trust rights become progressively less effective when erosion problems become more extreme and catastrophic.

In 2009 the federation and UNC Center for the Study of Natural Hazards and Disasters, with funding assistance from the N.C. Beach, Inlet & Waterway Association organized a Beach Management Summit. The goal of the summit was to discuss emerging threats to the public recreational beach and to evaluate existing oceanfront policies, programs, and regulations. Participants in the summit represented the diverse stakeholders in beach policy (full list of participants can be found in Appendix A).

The Summit participants determined that current beach policies were formulated with the priority of protecting the beach for the public. They agreed that this was the correct priority, and that efforts to protect private and public investments along the oceanfront should always be of secondary importance to the need to maintain our sandy, unobstructed beaches. While there were disagreements over whether or not to build terminal groins, all participants remained united in opposing any actions that would allow for seawalls along our oceanfront beaches.

Summit participants developed two sets of key management actions consistent with the priority to protect public trust rights along our beaches. They encouraged:

1. "Status quo" actions that protect existing development for as long as it is environmentally and economically feasible; and
2. "Adaptation" actions that are used when increases in sea level and storms mean that existing "status quo" management actions are no longer cost-effective.

The following specific management actions recommended by Summit participants are still applicable and should be incorporated into this report:

(a) Recommend the enactment of a Family Beach Act that places limits on high-rise buildings and other forms of high-density development on the oceanfront. This law should be patterned after the height limits adopted by most beach communities. This would prevent beach nourishment projects from encouraging increased building densities along the oceanfront, and give longer-term adaptation and relocation strategies more chance to succeed.
(b) Amend and seek federal approval of the North Carolina Coastal Management Plan to include a specific policy statement that prevents the loss of sand to the beach system as a result of navigational dredging projects.
(c) Devise a program for removing condemned and orphaned buildings from the public beach;
(d) Provide for adequate resources to enforce sand compatibility standards for all beach nourishment projects.
(e) Work with local governments to identify additional funding and innovative financing strategies for beach nourishment projects that are consistent with the state's strategy for allocating sand resources under the Beach and Inlet Management Plan.
(f) Explore the feasibility of adopting a new user-financed erosion insurance program that would protect oceanfront landowners from catastrophic economic losses when their oceanfront real estate is no longer buildable because of erosion. This type of program has been evaluated by Congress and deemed feasible but has never been acted upon.

Regarding the recommendation on erosion insurance (f), Summit participants were aware that in 1994 Congress requested a study to determine, among other issues, whether and how the existing federal programs such as National Flood Insurance Program (NFIP) might provide solutions to the problems caused by erosion.

That study was completed by the John H. Heinz III Center for Science, Economics and the Environment. It explored the dynamic relationship between flooding and erosion and their coverage under the NFIP. According to the study, while NFIP covers some erosion-related damages (i.e. flood-related erosion), it does not cover damages from erosion unrelated to flooding.

With the goal of accounting for accurate erosion risk, the study proposes a number of policy options and tools designed to influence coastal activities and land-use choices by discouraging or promoting certain developments and practices by legal, economic, or other informal means. One example is the Disclosure and Mapping provision. Under this measure, the state could institute a notification or disclosure law that would require that the information about flooding history, erosion risk, or other hazard exposure data for a particular structure or property be made available to a potential buyer or developer in a timely and understandable manner. Similarly, the state could develop and disseminate 60-year erosion maps to showcase the investments at risk.

Managing Coastal Erosion (National Research Council, 1990) is another report that examined similar issues and recommended that an erosion element of the NFIP incorporate the following objectives:

- Transfer economic costs of erosion losses from all federal taxpayers to the property owners at risk by charging premiums that approximate the risks of loss;
- Discourage inappropriate development from occurring in erosion zones as delineated by FEMA or the states;
- Promote the improvement of development and redevelopment practices in erosion-prone areas.

How the erosion insurance works

The Heinz Study found that one possible way to account for the erosion risks is to develop erosion maps similar to flood maps and charge policyholders different premiums based on erosion risk.

Figure 1 shows estimates of insurance rate increases (in 2000) for several alternative ways to charge policyholders for the cost of erosion damage. By spreading the costs over a newly created Coastal High Hazard Zone, rates for all policy holders in both High Hazard Flood Zones (V-zones) and the 60-year Erosion Hazard Area would rise roughly $.90/year per $100 of coverage and fully cover expected erosion damage rates in the new area. This would be in addition to current rates that vary by flood risk.

This mechanism would include:

- Creation of a coastal high hazard zone, including both high flood and erosion zones. This zone would encompass the current highest-risk flood zone (the "V-zone") and any additional areas highly susceptible to erosion. Insurance rates would increase to reflect both risks. The Heinz Study estimates that on the Atlantic coast, the combined region would be roughly 15 percent larger than the current high-hazard V-zone.

- Development of a 60 year Erosion Hazard Area that shows projections of how far inland the coastline may erode over the next 60 years and, where applicable, expected flood heights from a 1 percent chance ("100-year") storm today and in the future.

- Development of ocean hazard maps and their dissemination to public. These maps could help discourage development within high hazard areas.

TABLE S.6 Insurance Rate Increases[a]

	High Hazard Flood Zone, Not EHA[b]	Erosion Hazard Area	Subsidized Rate
Combined Flood and Erosion Coastal High Hazard Zone	\$0.90	\$0.90	\$0.35
Single Zone Erosion Hazard Area			
0- to 60-year EHA	No increase	\$2.45	\$0.95
Two Zone Erosion Hazard Area For New Structures			
0- to 20-year EHA	No increase	\$11.40	N.A.[c]
20- to 60-year EHA	No increase	\$1.75	N.A.

[a] Surcharges are given in dollars per year per \$100 of coverage for a 1-4 family residence. Rates for new structures and post-1981 structures are calculated to be revenue neutral within each zone. Assumptions: Federal Insurance Administration (FIA) pays for 85 percent of damage (remainder is wind damage paid for by private insurers); interest rate is 3 percent; FIA overhead is 35 percent; subsidized structures pay 38 percent of post-81 rates.
[b] Erosion hazard area
[c] Not applicable

Figure 1: Estimated insurance rate increases when risk of erosion is added. Source: The Heinz Center, Evaluation of Erosion Hazards, 2000.

If rate increases were confined to only those structures in the 60-year erosion hazard area, rates would have to rise by roughly \$2.45/year per \$100 of coverage to fully cover expected losses, or to \$0.95/year per \$100 if subsidized.

Incentives to build farther from the ocean could be given to new construction by charging higher rates closer to the shore and lower rates further inland. Figure 1 shows the different rates within 20-year ($11.40/year per $100 of coverage) and 60-year ($1.75/year per $100 of coverage) Erosion Hazard Areas.

Congress is unlikely to include erosion insurance as part of the NFIP. However, given the findings of these two feasibility studies, the federation recommends that the N.C. General Assembly explore providing erosion insurance in conjunction with the beach plan the North Carolina currently manages. The N.C. Insurance Underwriting Association provides a coastal property insurance pool that might be a model for how to set up such an erosion insurance program for beachfront property owners. The federation does not support taxpayer subsidies for erosion insurance. The cost of the program should be completely paid by policyholders.

A final method to mitigate against flood and erosion losses is to relocate buildings away from flood- and- erosion-prone locations. The NFIP standard flood insurance policy does not require the insured to repair the building on the same premises to qualify for loss settlement on a replacement cost basis. The erosion policy would work in the same way and thus provide a financial incentive to the insured to relocate and either repair a substantially damaged or rebuild a totally damaged building at the new location away from risk prone areas.

The federation suggests these recommendations be included in the Beach study required by the legislature.

Thanks you for considering these comments.

Sincerely,

Ana Zivanovic-Nenadovic
Senior Policy Analyst

Appendix A

2009 Beach Summit Participants

Dick Bierly, vice president N.C. Coastal Federation
Ray Burby, professor emeritus, Department of City and Regional Planning, UNC-Chapel Hill
Chris Canfield, executive director, Audubon North Carolina
Derb Carter, executive director, Southern Environmental Law Center
Matthew Converse, Bank of Currituck
Chris Dumas, associate professor Department of Economics and Finance, UNC-Wilmington
Bob Emory, chairman, N.C. Coastal Resources Commission
Dave Godschalk, Stephen Baxter professor emeritus, Department of City and Regional Planning, UNC-Chapel Hill
Jimmy Johnson, eastern regional field officer, N.C. Department of Environmental and Natural Resources
Charles Jones, retired director, N.C. Division of Coastal Management
Rick Luettich, director and professor, Institute of Marine Sciences, UNC-Chapel Hill
David Marlett, director, Brantley Risk and Insurance, Appalachian State University
Todd Miller, executive director, N.C. Coastal Federation
Charlotte Mitchell, K&L Gates
Pres Pate, retired director, N.C. Division of Marine Fisheries; retired associate director, N.C. Division of Coastal Management
Mark Paul, K&L Gates
Len Pietrafesa, director, Office of External Affairs, College of Physical & Mathematical Sciences, N.C. State University
Joe Ramus, Research Professor, Duke University Marine Lab
Dara Royal, chair, Coastal Resources Advisory Council
Greg Rudolph, manager, Carteret County Shore Protection Office
Harry Simmons, executive director, N.C. Beach and Inlet Waterway Association
Gavin Smith, executive director, Center for the Study of Natural Hazards and Disasters, UNC-Chapel Hill
Jim Stephenson, policy director, N.C. Coastal Federation
Doug Wakeman, economics professor, Meredith College
J.P. Walsh, assistant professor, Department of Geology, East Carolina University
Joan Weld, vice chairwoman. N.C. Coastal Resources Commission
Berry Williams, Berry A. Williams & Associates
Rob Young, director, Program for the Study of Developing Shorelines, Western Carolina University

Miller, Tancred

From: Allan Starr <ahstarresq@icloud.com>
Sent: Wednesday, December 16, 2015 10:23 PM
To: Miller, Tancred
Subject: Beach erosion and nourishment

Follow Up Flag: Follow up
Flag Status: Flagged

My wife and I live at 106 Gannet Cove in Duck. and have owned property in Duck since 1981. During that time we have seen both erosion and accretion of the beach—many times in the same stretch of beach. While we are not convinced of the efficacy and cost effectiveness of beach nourishment projects over the long run, we understand and respect the views of others who either strongly advocate or strongly object to beach nourishment projects.

We do ,however, strongly believe that if these projects are undertaken they should be paid for entirely by those in the project zone through one or more Municipal Service Districts—for both the initial project and the requisite periodic re nourishment projects. In our opinion it is both unfair and unwise to ask those outside the project areas to pay for the work. There is no benefit to those outside the project area. Anyone looking to rent or buy in the project zone is interested in what the beach is like in that area –not what the beach is like several miles away. The significant expense involved in these projects may also result in no funding availability down the road. It is unfair to ask folks to contribute to the first project—several miles away from them—and then tell them there is no money for a project in their area several years later This scenario is not fantasy but a very likely possibility as time goes on given the cost of these projects ,the limited availability of funds to pay for same and the unpredictability of when and where the next eroded beach will occur

Increasing ad valorem taxes for all is not a solution to funding shortfalls —not spending more than you have is what fiscal responsibility is all about. If those in the project zone want to move forward they need to pay for it 100%—any other approach is unfair and unwise.

Thank you for considering our position.

Allan and Donna Starr