APPENDIX 1

Appendix 1a. Best Management Practices for Shoreline Stabilization to Avoid and Minimize Adverse Environmental Impacts[1]

Prepared for the USFWS, Panama City Ecological Services Field Office

Tracy Monegan Rice
Terwilliger Consulting, Inc.
November 2009

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.

SECTION I: DUNES

Artificial dunes should not be constructed by heavy equipment (i.e., bulldozers) by scraping the beach for sediment or through the addition of beach fill material mined elsewhere and pumped or hauled to the beach. Artificial dunes are typically constructed in continuous ridges that act like levees or dikes to protect inland areas from flooding and overwash, but they do not function like natural dunes or possess the same ecological services.

Wherever and whenever possible, new dunes should be created through the planting of native vegetation to trap natural windblown sediment. In undeveloped areas especially, vegetation alone should be used so that the resulting dunes are the most natural in size, shape and location, and to mimic natural dune development and growth processes (e.g., upward and lateral growth over time). Vegetation builds better dunes in the long-term (albeit after a short time lag) and maintenance is nearly nonexistent, avoiding environmental impacts after the initial installation.

---

[1] *Suggested citation*:
Rice, T. M. 2009. Best management practices for shoreline stabilization to avoid and minimize adverse environmental impacts. Prepared for USFWS, Panama City Ecological Services Field Office by Terwilliger Consulting, Inc., Locustville, Virginia. 21 p.

In highly developed areas and on a small scale, the judicious use of sand fencing could be used as long as appropriate maintenance and removal provisions are undertaken and enforced. For example, fencing should be raised periodically to keep pace with incipient dune growth and should be removed once the new dunes are a few feet tall (e.g., less than 3 feet) or after 18 months have passed so that damage caused by the removal to the surrounding environment is minimized; native plants can then be planted at grade to facilitate further dune growth. Sand fencing materials should never be left on the beach, buried under dunes, as it poses a hazard during storms and will become exposed as dunes migrate or are eroded by storms. Multiple rows of sand fencing should not be used, as they do not mimic natural dune development and growth processes, hinder the movement of wildlife and people, and limit the fetch with which supplemental rows can trap windblown sand.

Sand fencing should not be continuous but should be intermittent to allow passage for people, nesting and hatchling sea turtles, unfledged shorebird and waterbird chicks, and other wildlife that move between the dune line and the rest of the beach. Fencing should be placed perpendicular to prevailing wind directions to best trap naturally blowing sediments. Protective buffers of at least 100 – 180 meters (m) should be maintained around known locations of sensitive or listed wildlife and at least 10 m around sensitive or listed plant species so that fencing and the installation process does not trample or harm nests or vulnerable plant species. Sand fencing should not use materials that create perches for avian predators near known bird nesting areas and should be configured and oriented in accordance with existing guidelines to protect listed species such as sea turtles.

Vegetation plantings on existing or new dunes should consist of native species that reflect the local plant communities for the planting zone (e.g., foredune, dune face, dune crest, back of dune). Botanical surveys should be taken prior to the planting of any vegetation to identify the local plant community assemblages, and where possible historical records should be reviewed to ensure that only plants native to a specific barrier island or beach are used. For example, if historic records indicate that a threatened or endangered species used to occur on a particular beach and is now locally extirpated, it could be reintroduced.

Vegetation should be locally grown, where possible, and not harvested from wild stock unless the plants are being transplanted from an area where they would otherwise be destroyed by a development or construction project or where harvesting will not adversely affect local populations. Plantings should not be a monoculture but instead a diverse assemblage that reflects the local plant community type(s). Plants should not be planted on a regular spacing with rows but instead should be more random and reflect their natural spacing(s), which should be identified during the botanical survey. Long-term fertilization with nitrogen should not be conducted in order to avoid long-term alterations to species diversity, composition and density (Day et al. 2004).

When using sand fencing or vegetation to restore or create new dunes on a large scale, a geomorphological survey of the barrier island or beach (or a nearby undeveloped, natural area if the project beach is developed) should be conducted prior to action in order to identify the existing, undisturbed dune morphology for replication. The dune length, height, and width; number of dune ridges and their spacing(s); whether wetland swales are present; and the spacing of natural gaps should all be identified. These factors should guide the design of fencing and/or vegetation placement so that any restored or created dunes should blend seamlessly with the existing environment. If the project area is developed and a nearby natural area is utilized as a design model, the surveys should utilize areas in a state as close to the project area as possible; for example, a natural area of heavily vegetated, mature dunes would not be appropriate as a model for a project area devoid of any dunes or vegetation. Rather, incipient dunes and pioneering vegetation would be the more appropriate model.

In all cases, overwash should be allowed to continue unimpeded, including in dune gaps. Off-road vehicle (ORV) traffic should be prohibited on and in between dunes.

Pedestrian traffic should be encouraged to use dune crossovers or designated pedestrian paths to avoid disturbing the dune ecosystem, particularly in areas that host vulnerable species such as nesting birds, beach mice and listed plants.

Beach access points should not be cut into existing dunes but should utilize dune crossovers and boardwalks that avoid disturbing the dune system. Access points should not be located in areas with known wildlife nesting or breeding areas, such as remnant early successional habitats, dune blowouts and overwash areas, in order to avoid impacts to vulnerable or sensitive wildlife and vegetation. Access points should not align with streets or driveways that are perpendicular to the beach, as they can funnel flooding and overwash farther inland than would naturally occur, potentially damaging property and facilitating island breaches.

SECTION II: BEACHES

Hard stabilization should only be used in cases where extreme development has occurred on a shoreline, such as in highly urban areas like Manhattan. Where hard stabilization (e.g., seawalls, bulkheads, revetments, riprap, sandbags, groins) is installed, the eventual loss of the beach and its associated habitats is virtually assured. Therefore, if and when new hard stabilization is justified, a thorough environmental impact statement (EIS) should be prepared and mitigation for the loss of ecosystem services and habitat should be incorporated into the project design. Mitigation measures can include the removal of hard stabilization structures in other nearby locations, the relocation of buildings and structures that are impeding the natural landward migration of the beach system as sea levels rise, or the restoration of beaches where they have been historically lost to shoreline stabilization.

Soft stabilization (i.e., "beach nourishment") causes significant adverse environmental impacts and likewise should only be undertaken after a thorough EIS has been prepared. The design of a beach fill project should incorporate empirical evidence on the performance of other nearby beach fill or dredged material disposal projects; for example, if a nearby beach fill project typically 'disappears' or erodes within 3 years, the engineering design of a new project should not realistically assume that the new project will last 5 to 7 years before requiring "maintenance" with more "renourishment." Emergency "berms" should be considered beach fill projects and be subject to the same BMPs or conservation measures as a planned fill or dredge disposal project; the only difference between an emergency berm project and a planned beach nourishment project is the level of planning and consultation involved.

Where a beach fill or dredged material disposal project is proposed, the new sediment must be compatible with the native sediment on the existing beach. Visitors and wildlife should not be able to distinguish the fill material from the existing native beach material in color, grain size, mineralogy, compaction, or any other characteristic. The native beach sediments should be sampled and analyzed at the dune, across the berm, in the surf zone, and the nearshore before any project is undertaken. The fill material should also be sampled periodically during construction, especially in areas with sensitive plants or wildlife, to catch any incompatible or unexpected material as soon as possible. Comparison of the native sediments to the proposed fill material should be conducted prior to construction, with compatible material defined as:

1. Material consisting solely of natural sediment and shell material, containing no construction debris, toxic material or other foreign matter;
2. Material consisting predominantly of quartz, carbonate (i.e., shell, coral) or similar material with a particle size distribution ranging between 0.0625 millimeters (mm) and 4.76 mm, classified as sand by either the Unified Soils or Wentworth classification systems;

3. Material similar in color and grain size distribution (sand grain frequency, mean and median grain size and sorting coefficient) to the native material in the project area;
4. Material containing less than or equal to 2 % fine-grained sediment (< 0.0625 mm, considered silt, clay and colloids) by weight, unless sufficient sampling of the project area indicates that the native sediment grain size distribution contains > 2 % fine-grained material, in which case compatible material should be considered the percentage of fine-grained native material plus no more than an additional 2 % by weight;
5. Material containing coarse gravel, cobbles or material retained on a ¾ inch sieve in a percentage or size not greater than found on the native beach;
6. Material that does not result in cementation of the beach; and
7. Material that does not contain carbonate (i.e., shell) material that exceeds the average percentage of carbonate material on the native beach by more than 15% by weight.

The overall volume of fill material to be added to the beach in any fill episode should not exceed 50% of the estimated annual net sediment transport for the beach in order to minimize the magnitude of the disturbance to the ecosystem and to prevent large-scale alterations of the local coastal processes.

The beach fill design that avoids the most adverse environmental impacts to the beach is probably the one begun in 2004 at Assateague Island National Seashore in Maryland, where sand bypassing at the adjacent inlet is conducted by using a shallow hopper dredge to place fill only in the nearshore environment, as close to the beach as possible. As the hopper slowly dumps its fill, the dredge moves closer to shore as its load lightens. No fill is placed on the subaerial portions of the beach, avoiding impacts to those habitats and their resident and migratory wildlife and plants. Impacts will still occur on nearshore habitats, however.

Where beach fill is proposed for the subaerial portions of the beach, the design template should replicate the natural, existing beach profile, including any bar and trough morphology. Several small-scale fill projects minimize adverse impacts when compared to a single, large-scale project. Fill should not be placed in a continuous section of beach, but should be divided into several short sections where every other section is filled. This design leaves undisturbed refugia for fish and wildlife resources, which then can enhance the recovery of invertebrates within the fill sections by having source populations scattered throughout the project length instead of only at the ends. Sediment will naturally move from the fill sections into the unfilled sections on the littoral drift, increasing the beach width in unfilled sections over time but without direct burial of the benthic ecosystem. Subsequent 'renourishment' episodes can alternate which sections receive fill. Individual sections should not exceed 2000 feet in length unless scientifically rigorous monitoring indicates that this length is too long to facilitate benthic recovery or that benthic recovery occurs relatively fast and the length may be increased. The timing of the deposition (e.g., the season – fall, winter, spring or summer) should avoid the most biologically productive seasons, including spawning and recruitment periods for benthic invertebrates; this should enhance recovery rates following deposition of the fill material. For the eastern and southeastern United States, the best construction window is generally from November to February.

Beach fill should be of the thinnest depth possible (Defeo et al. 2009 recommend repeated application of layers of sediment, none thicker than 30 centimeters (cm)) to facilitate the repopulation of fill areas with benthic invertebrates. Some invertebrate species may survive shallow burial, minimizing mortality of these resources. The berm height should not be uniform but should vary along the beach fill, allowing waves, tides and overwash to penetrate the beach to varying degrees and creating a diversity of topographical microhabitats while maintaining necessary beach profiles for successful sea turtle nesting. If necessary, contract specifications should explicitly prohibit overfill so that these conservation measures are implemented as intended.

Heavy equipment use should not leave ruts on the beach. Storage of heavy equipment and pipe on the beach should be avoided to the extent possible, using staging areas off of the beach wherever available.

Construction schedules should avoid the most productive biological seasons, typically the nesting season for sea turtles, shorebirds and waterbirds but in some areas also may include migration or overwintering periods where fauna are present in high concentrations.

Construction should avoid sensitive habitats and areas with high ecological value such as migratory bird staging sites, aquatic spawning areas, and colonial waterbird nesting sites. Buffers of 100 m should be maintained around wading bird colonies, 200 m around mixed tern / skimmer colonies, and 100 - 200 m around solitary bird nests and larger for species with precocial chicks. Buffers of at least 10 m should be maintained around sensitive plants. In project areas where construction will be conducted 24 hours a day, 7 days a week, with multiple pieces of heavy equipment, buffers may need to be enlarged since the disturbance would be continuous (versus periodic disturbances with pedestrians). During non-breeding periods, buffers may be needed around roosting sites or migratory staging areas for sensitive bird species.

Renourishment episodes should only be conducted after all of the ecological monitoring (e.g., invertebrate, avian, fisheries, listed species) shows that the beach ecosystem has fully recovered (100% as compared to control areas) for a duration of at least one year, preferably two or three, in order to avoid permanent perturbations to the system. Disturbances should be episodic and their ecological impacts should not overlap between fill episodes (i.e., a renourishment episode should not take place before the impacts from the previous fill event have completely abated).

Scientifically rigorous pre-project, during construction, and post-project monitoring should be conducted according to the design protocols recommended by Peterson and Bishop (2006).

Beaches should not be raked or mechanically cleaned; wrack material should be left in place with the exception of marine litter or human trash, which should be collected by hand. Wrack materials are an essential component of the food web of sandy beach ecosystems, as well as a source of organic material and traps for windblown sediment to create foredunes.

In areas where beach nourishment creates a beach seaward of existing hard stabilization or heavy development, where the beach has been lost due to erosion and/or sea level rise, associated ecosystem functions such as nesting habitat for shorebirds, waterbirds or sea turtles, may be restored. Future renourishment episodes should then follow the aforementioned BMPs (e.g., protective buffers) for protection of ecological resources that have returned to or colonized the re-created beach.

SECTION III: NEARSHORE

The nearshore environment, which for ecological purposes can be defined as the active littoral or surf zone, contains a variety of ecological resources, including foraging fish and benthic invertebrates. In some areas, reefs and hard bottoms or other geologic outcrops may be present. These resources and habitats may be directly or indirectly impacted by shoreline stabilization projects.

Significant buffers should be maintained around all reefs (natural or artificial), hard bottoms, submerged aquatic vegetation (SAV) and other high value habitats, including areas designated as Essential Fish Habitat (EFH) or Habitat Areas of Particular Concern (HAPC). Buffers should be delineated prior to construction so that the design and construction planning can incorporate avoidance measures in advance. Buffers should be at least 500 m surrounding these sensitive and valuable habitats.

If beach fill sediment for a dredge disposal or nourishment project is compatible with the native material, nearshore communities should not be adversely affected by raised turbidity levels as the fill material dewaters and the sediment is reworked by wave and tidal action. Some turbidity is likely, however, and should be monitored with appropriate instrumentation and monitoring protocols. Where water quality standards are exceeded, work should cease and appropriate mitigative measures incorporated into the construction methods and design. Similarly, if introduced fill material contains too much coarse material, the benthic fauna may be adversely affected in their ability to burrow into the sediment and predators such as fish and birds may be less able to locate benthic prey; if such a situation occurs, post-construction mitigation should occur, including the removal of excess coarse material where warranted and the avoidance of that sediment source for future fill projects.

Long-term monitoring should also be conducted where geologically limited habitats such as reefs and hardbottoms are present near the work area to ensure that fill material does not move off of the artificially constructed beach / berm and bury or smother these fragile habitats. If such burial is documented, post-construction mitigation should be pursued and any renourishment episodes should increase protective measures such as buffer size.

Nearshore areas including sandbars and tidal shoals should not be used as a sediment source for beach fill projects. Removal of nearshore material for beach placement can increase wave energy reaching the beach by altering the nearshore bathymetry, defeating the purpose of an "erosion control project" and exacerbating the need for shoreline stabilization project(s).

Hard stabilization structures such as breakwaters and rubble mounds should not be constructed in nearshore areas due to their significant adverse environmental impacts. Artificial reefs may have ecological value if designed, installed and monitored properly and if they are located in appropriate areas.

SECTION IV: OFFSHORE

Similar to the BMPs for nearshore areas, offshore areas may also contain rare and valuable habitats like hardbottoms and reefs that should be protected with large buffers (at least 500 m). Offshore areas are typically used as the source for sediment for beach fill projects, which mine suitable materials from the seafloor and transport the material to the beach via dredges, barges and/or pipelines. Mine sites also should be located away from significant spawning areas or other habitats valuable to local fishery or benthic resources, including areas designated as EFH, HAPC or Marine Protected Areas (MPA).

Mine sites for beach fill material should not be excavated such that large depressions or holes are left on the seafloor, significantly altering the local bathymetry (and thus coastal processes and ecological habitats). Excavation should use a series of shallow, staggered cuts (furrows) that limit the area of disturbance and allow undisturbed areas in between cuts to serve as refugia and a source for repopulation of benthic resources; this method also limits alterations to the seafloor bathymetry, which may have regional and long-term adverse effects. Dredging should leave a sufficient layer of sediment that matches as closely as possible the original surface layer to avoid exposing a dissimilar sediment on the surface.

SECTION V: INLETS

Inlets are particularly valuable ecosystems, as they provide foraging, spawning, nesting, staging, roosting and migratory habitat for countless shorebirds and waterbirds, anadromous and catadromous fish, crabs, shrimp, invertebrates, waterfowl and other fish and wildlife resources. The highly dynamic nature of inlets creates a complex assemblage of habitats, including bare and sparsely vegetated spits; subaerial, intertidal and submerged shoals; sandbars; overwash and tidal flats; and passageways for aquatic resources. The constantly shifting nature of inlets creates a cycle of emergence, growth and renewal of these habitat types that is self-sustaining when left undisturbed.

Due to their incredible ecological significance and the significant adverse environmental impacts that hard stabilization generates, inlets should not be stabilized with jetties, terminal groins, revetments, riprap, geotubes, sandbags or any other hard structure. The cumulative impacts of inlet management and manipulation along the Atlantic and Gulf coasts of the U.S. already are significant and adverse and should preclude any undisturbed or relatively undisturbed inlet from being stabilized, mined or otherwise managed.

The flood and ebb tidal deltas of an inlet should not be mined for sediment for use in beach fill projects or to re-align channels away from threatened structures. Shoals are spawning areas for crab and shrimp, roosting and foraging habitat for birds, shelter for SAV, and an essential element of the inlet ecosystem. Mining shoals for sediment unbalances the natural equilibrium of coastal processes, disturbing and displacing fish and wildlife resources and leading to habitat loss and fragmentation. Removal of material from inlet shoals typically leads to increased erosion on adjacent shorelines as the system attempts to fill the sediment deficit, which can increase hazards to private property and infrastructure in developed inlet hazard zones. In some areas, protection of subaerial shoals (e.g., restricting boater access and activities such as parties, fires and dogs) may be a form of mitigation for increased recreational or development activity facilitated by shoreline stabilization projects on nearby beaches.

Dredging of new navigational channels through previously undisturbed inlets should be discouraged as this process removes sediment from the system much like shoal mining does. Undisturbed inlets naturally bypass sediment from one side of the inlet to the other, and navigational channels can become sediment sinks, depriving downdrift beaches and habitats of their sediment supply. Deep channels may have regional impacts as sediment is continuously removed via maintenance dredging from the channels and moved elsewhere, generally outside of the inlet and nearby coastal system. Excessively deep channels may also alter the salinity regime in adjacent estuaries by increasing the tidal prism and altering the hydrodynamics of the inlet, resulting in adverse ecological impacts well beyond the actual inlet area.

For existing navigational channels, dredged material should be disposed of within the inlet system, placed where it can bypass to downdrift beaches on wave and tidal processes. Nearshore placement of dredged material would avoid impacts to the beach and dune ecosystem and most closely replicate natural sand bypassing processes, which are subaqueous at inlets. Channel maintenance activities should occur on more frequent small scales instead of infrequent large scales in order to minimize the magnitude of the disturbance to the coastal ecosystem.

Restoration of inlet complexes provides an opportunity for mitigation required by other disturbance projects. Hard structures can be removed, dredged channels abandoned, and buildings and infrastructure relocated away from inlet shoulders. Preservation (e.g., conservation easements, fee title) of undisturbed inlet complexes with large buffers along each shoreline to allow natural movement of the inlet over time should be encouraged and pursued wherever possible.

ORVs should not be allowed in inlet areas during periods of nesting or migration, or if significant overwintering populations of wildlife are present.

SECTION VI: ESTUARINE

Estuaries should not provide a sediment source for oceanfront beach fill projects due to sediment compatibility issues and the adverse impacts sediment removal would have on the estuarine ecosystem. Where dredging is necessary, dredge disposal materials should stay within the local system as close to the project area as possible. Dredged materials disposal should not occur in areas with significant benthic resources where burial is likely to occur. Disposal should not bury marshes, tidal flats, SAV, oyster reefs, clam beds, or other valuable benthic or fishery resources occur; buffers of at least 500 m should be maintained around such areas.

In some cases, dredged material can be beneficially used to restore or enhance habitat. Dredge disposal islands in certain areas have become valuable bird nesting areas and their creation and/or maintenance with compatible material may offset the adverse impacts of dredging (albeit with out-of-kind services). The beneficial use of dredged material may also aid in the restoration of SAV, or where the material is rocky, in the restoration of oyster reefs. In areas where hard stabilization along the estuarine shoreline has led to the loss of intertidal habitat, dredged material may potentially restore such habitat through localized, small-scale fill projects in front of the hard structures or where such structures can be removed. Restoration of intertidal estuarine shoreline habitats may benefit nesting horseshoe crab and diamondback terrapin as well as foraging waterbirds and shorebirds. New canals or channels should not be dredged to reach habitat restoration project areas, nor should adjacent marsh, SAV, oyster reefs, etc., be disturbed during the construction phase. Any beneficial use of dredged material project should include appropriate post-construction monitoring to determine if the intended benefits are realized, and the project should be adaptively managed to incorporate the results of such monitoring in future operations and maintenance activities.

Overwash material should not be removed from estuarine areas or habitats; overwash fans and flats are a natural component of the coastal ecosystem and a necessary process to aid in the migration of estuarine habitats during rising sea levels. As these habitats (both on barrier island and mainland shorelines) are naturally maintained with raised elevations from overwash, adjacent mainland development should benefit from enhanced storm protection in the long-term as the risk of inundation is lessened with higher elevations.

Finger canals should not be dredged in estuarine areas or on the bayside of barrier islands or spits; these canals increase the naturally shallow bathymetry, lead to the loss of intertidal and shallow bottom habitats such as marsh and SAV, and serve as a conduit for storm surge during severe storms.

Hard stabilization structures should not be constructed along estuarine shorelines, including bulkheads for new marinas and personal boat slips. Riprap and rubble debris should not be placed along the estuarine shoreline. All hard stabilization structures lead to the loss of intertidal habitat over time, and prevent the migration (and thus maintenance) of estuarine shoreline habitats (i.e., tidal marshes and flats, beaches) during rising sea levels.

The cumulative impacts of personal docks and piers (which are often associated with bulkheads) should be carefully considered prior to the permitting or rebuilding of new docks and piers. Docks, piers and similar structures built over estuarine waters are generally demolished during severe storms, leading to significant amounts of debris following the storm. This debris should be carefully and quickly removed so that estuarine resources and habitats are not permanently harmed or buried by these materials.

SECTION VII: CLIMATE CHANGE AND RISING SEA LEVEL

Given the current trends and predictions for climate change and continuously rising sea levels, shoreline stabilization projects should utilize an adaptive management approach that allows for designs to be modified with changing conditions over time. Beach nourishment of the seaward shoreline, for instance, will not allow a barrier island or mainland beach to migrate to higher ground as sea level rises higher and higher. Instead, beachfront structures should be relocated away from the beach and the beach system (including dunes) should be allowed to migrate landward in space over time. After severe storm events where beachfront structures are heavily damaged, they should not be rebuilt in place but rebuilt significantly farther landward where feasible or not rebuilt at all where not feasible. Hard stabilization structures such as jetties should be removed to facilitate the long-term natural maintenance of tidal inlets as sea level rises and inlets shift in space along with the adjacent barrier islands. Similarly, navigational channels should shift in location over time to accommodate migrating islands and inlets.

In highly developed areas where beach fill is maintained (at ever increasing costs) in the long-term, the frequency of beach fill “renourishment” or “maintenance” episodes should be determined by the actual performance of the initial fill material (as documented by long-term monitoring) instead of the predicted performance based on engineering and mathematical modeling. Hard stabilization structures are not consistent with an adaptive management approach, nor are they practical in the long-term as sea levels rise an estimated one meter or more by 2100.

Shoreline stabilization projects should include pre-project (identifying baseline conditions), construction, and post-project monitoring that is scientifically rigorous and incorporates control areas and other features as recommended by Peterson and Bishop (2006). The results of ecological monitoring should guide the “maintenance” of shoreline stabilization projects, with design features or construction methods modified to avoid or minimize any adverse effects documented by the monitoring.

Some level of monitoring should persist for the entire lifespan of a shoreline stabilization project (often 50 years for a beach fill project), but the monitoring protocols may be modified over time as warranted by previous monitoring results. Shoreline stabilization projects such as beach fill should not disturb the ecosystem more than a severe storm would disturb the system, so that the faunal recovery period is similar to that of a natural disturbance. For example, the individual pulse perturbation to a sandy beach ecosystem from a single beach fill episode should not decrease or depress essential ecosystem functions by more than 50% so that the perturbation does not permanently alter the ecosystem; monitoring may indicate that the 50% perturbation threshold may not sufficiently minimize adverse impacts to critical resources such as threatened or endangered species, Important Bird Areas, critical habitat for listed species, or migration or overwintering staging sites. In such a case, the adaptive management approach would incorporate these monitoring findings and lower the perturbation threshold for future fill events. Likewise, if monitoring determines that a fill episode had no significant, lengthy adverse impacts on critical ecosystem functions, the perturbation threshold could be raised for future fill events.

The distribution of microhabitats within the coastal ecosystem, including beaches, dunes, inlets and estuaries, are shifting in location as sea level rises at an accelerating rate and climate change alters sea surface temperatures and other oceanographic processes. A hands-off approach to shoreline management would best avoid the permanent loss of coastal ecosystem habitats. As a result, overwash materials should not be removed from the interior or bayside of islands or spits (including roads and driveways), dune ridges should not be built to function as levees, and inlets and shorelines should not be locked in place by hard structures. Where buildings are damaged and left exposed in intertidal areas following severe storm events, they should be removed and not rebuilt instead of rebuilt and protected in place with shoreline stabilization projects. If these BMPs can be incorporated into shoreline stabilization projects, habitat loss, fragmentation and degradation may be minimized in a period of changing climate and rising seas.

GLOSSARY

Adaptive management	An iterative process where monitoring or learning by doing better informs future management decisions when precise information is lacking or uncertainty remains as to the extent, intensity and duration of effects resulting from a set of actions (e.g., shoreline stabilization or management); subsequent management decisions are improved through the incorporation of new information obtained by monitoring the effects of previous actions
Aeolian	Of or pertaining to the wind, in this case windblown (aeolian) sediment transport or movement of sand
Beach	The area of unconsolidated sediments, stretching from the dunes to the intertidal zone; the underwater portion of the beach profile is sometimes referred to as the shoreface
Beach nourishment	The placement of sediments mined or transported from another location on a beach in order to temporarily reverse or slow down long-term erosion and protect structures located behind the beach
Benthic	Living on the bottom, in this case animals that live on the sea, bay or estuary floor and generally remaining submerged at all times
Best management practice (BMP)	Methods or techniques that can be used to avoid or minimize environmental harm or impacts in land management or construction activities
Breakwater	An engineering structure built in the water off of a shoreline with the intention of slowing down waves before they strike the beach, sheltering the adjacent shoreline
Bulkhead	A wall, typically built on the estuarine shoreline, to protect adjacent structures from erosion or storm flooding, or to allow for deep water immediately next to the shoreline for the mooring of boats
Downdrift	The direction in which the littoral drift or longshore sediment transport is moving sediment
Dune	A mound or ridge of unconsolidated sediment, usually sand-sized particles, that is built through the accumulation of windblown sand
Ebb tidal delta or shoals	Bodies (shoals) of sediment formed by the interaction of ebb, or falling, tides with incoming waves at a tidal inlet; ebb tidal shoals are generally smaller than flood tidal shoals and remain submerged during all tidal periods
Estuary	A semi-enclosed body of water which has open connections to the ocean and within which marine waters are diluted or mixed with freshwater, forming a body of water with lower salinity than the ocean and higher salinity than rivers
Fetch	The distance over which wind or waves can move unobstructed

Flood tidal delta or shoals	Bodies (shoals) of sediment formed by the interaction of flood, or rising, tides with the relatively calmer waters of a bay or estuary at a tidal inlet; flood tidal shoals are generally larger than ebb tidal shoals and can be exposed at periods of low tide
Geomorphology	The topography, or landforms, of a given area
Geotube	A very large sandbag, generally about one meter in diameter and tens of meters in length; geotubes can be stacked on top of each other to form a wall or mound to protect structures from the encroaching ocean and are sometimes buried under sediment to reinforce artificial dunes
Groin	An engineering structure perpendicular to the beach, typically constructed of wood pilings, sheet metal, large rocks, or concrete, with the intention of trapping sediment in the littoral drift and slowing local erosion rates
Infauna	Invertebrate animals that live within the sediment near the surface, such as mole crabs, polychaete worms and clams
Inlet	A water passageway between barrier islands or spits that connects the ocean with estuaries, bays or freshwater rivers
intertidal	The area of a shoreline that is alternately exposed to air and submerged under water with changing positions of the daily tide
Jetty	An engineering structure, typically constructed out of large stone, concrete or sheet metal that is built perpendicular to the shoreline along an inlet shoulder in order to hold or stabilize the inlet and its channels in place
Littoral drift, or longshore sediment transport	The current formed by waves striking a shoreline at an angle which moves sediment along a shoreline, predominantly in one direction (from updrift to downdrift)
Marsh	An area of partially submerged vegetation, typically saltmarsh reed grasses such as *Spartina* spp. or *Juncus* spp. along a shoreline or in an estuary, which may be exposed at low tide and mostly submerged at high tide
Nearshore	The active littoral, or surf, zone where wave action moves significant amounts of sediment on a daily basis
Offshore	The area of the seafloor or ocean that is farther away from the beach or shoreline, seaward of the surf zone
Revetment	An engineering structure, typically a sloping wall constructed of large rocks, installed along a shoreline to protect adjacent structures from erosion and encroaching waters
Riprap	Material or debris such as rock, brick, concrete block or similar hard materials that is placed along a shoreline to slow down local erosion rates

Rubble mound	A mound or ridge of rubble debris (rock, concrete, etc.) placed in the water off of a shoreline that acts like a breakwater to slow down waves and shelter adjacent shorelines
Sandbar	An underwater mound or ridge of sediment in the outer surf zone portion of a beach profile, typically noticed by the area where waves are breaking before striking the beach
Seawall	A wall, typically built of sheet metal or concrete, that is installed parallel to and on the landward side of the beach in order to protect structures from tidal flooding and wave action
Sediment supply	The volume of sediment moved annually along a beach by the littoral drift, or longshore sediment transport
Shoal	A body of sediment that rises in elevation from the surrounding sea or bay floor and that may be exposed during periods of low tide; shoals are generally found near or within tidal inlets
Subaerial	The portion of the beach that remains dry and not submerged during periods of high tide
Subaqueous	The portion of the beach, estuary or ocean that remains submerged under water during all tidal periods
Submerged	Under water
Surf zone	The area adjacent to a shoreline in which waves are breaking and running up on to the beach
Terminal groin	A groin that is placed at the end of an island adjacent to an inlet
Tidal flat	A marshy, muddy or sandy, nearly flat, landform that is alternately exposed and submerged during periods of low and high tides
Trough	A shallow, straight depression on the landward side of a sandbar
Updrift	The direction from which the predominant littoral drift or longshore sediment transport is moving; jetties and groins can trap this sediment on their updrift sides, blocking its movement to downdrift beaches
Wrack	Organic materials such as seaweed, marsh grass and other vegetation that is deposited on a beach by waves and tides

REFERENCES

Day, F. P., C. Conn, E. Crawford, and M. Stevenson. 2004. Long-Term Effects of Nitrogen Fertilization on Plant Community Structure on a Coastal Barrier Island Dune Chronosequence. *Journal of Coastal Research* 20(3):722-730.

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

Peterson, C.H., and M. J. Bishop. 2005. Assessing the Environmental Impacts of Beach Nourishment. *Bioscience* 55(10):887-896.

Whitfield, D. P., M. Ruddock, and R. Bullman. 2008. Expert Opinion as a Tool for Quantifying Bird Tolerance to Human Disturbance. *Biological Conservation* 141(2008):2708-2717.

BIBLIOGRAPHY

Ackerman, R. A. 1980. Physiological and Ecological Aspects of Gas Exchange by Sea Turtle Eggs. *American Zoologist* 20:575-583.

Alexander, R. R., R. J. Stanton Jr., and J. R. Dodd. 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.

Baker, V. R. 2000. Saving the Appearances of Beach Behavior. *Journal of Coastal Research*. 16(1):iii-iv.

Barnard, W. D. 1978. *Prediction and control of dredged material dispersion around dredging and open-water pipeline disposal operation*. Technical Report DS-78-13, U.S. Army Corps of Engineers Waterways Experiment Station, Vicksburg, Mississippi.

Beaches and Shores Research Center (BSRC). 2007. *Coastal Construction Control Line Review Study, Gulf County – St. Joseph Spit (Ranges R75-R108), Florida*. Beaches and Shores Resource Center, Institute of Science and Public Affairs, Florida State University, Tallahassee, FL. 28 p. + appendices.

Beatley, T., D. J. Brower, and A. K. Schwab. 1994. *An Introduction to Coastal Zone Management*. Washington, D.C.: Island Press. 210 p.

Bilodeau, A. L., and R. P. Bourgeois. 2004. Impact of Beach Restoration on the Deep-burrowing Ghost Shrimp, *Callichirus islagrande*. *Journal of Coastal Research* 20(3):931-936.

Bishop, M. J., C. H. Peterson, H. C. Summerson, H. S. Lenihan, and J. H. Grabowski. 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.

Blott, S. J., and K. Pye. 2004. Morphological and Sedimentological Changes on an Artificially Nourished Beach, Lincolnshire, UK. *Journal of Coastal Research* 20(1):214-233.

Bowen, P. R. and G. A. Marsh. 1988. *Benthic Faunal Colonization of an Offshore Borrow Pit in Southeastern Florida*. Miscellaneous Paper D-88-5. U. S. Army Corps of Engineers, Waterways Experiment Station. Vicksburg, Mississippi.

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

Browder, A. E. 2002. Sand search and beach restoration at Pensacola Beach, Florida. *Proceedings, 15th Annual National Conference on Beach Preservation Technology*, Biloxi, MS. pp. 251-264.

Brown, S., C. Hickey and B. Harrington (eds). 2000. *United States Shorebird Conservation Plan*. Manomet, Massachusetts: Manomet Center for Conservation Sciences. Various paginations.

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.

Bureau of Beaches and Coastal Systems (BBCS). 2009. *Critically Eroded Beaches in Florida, Updated, June 2009*. Division of Water Resource Management, Department of Environmental Protection, State of Florida. 77 p.

Burger, J., M. A. Howe, D. C. Hahn, and J. Chase. 1977. Effects of Tide Cycles on Habitat Selection and Habitat Partitioning by Migrating Shorebirds. *The Auk*. 4: 743-758.

Bush, D. M., N. J. Longo, W.J. Neal, L.S. Esteves, O.H. Pilkey, D.F. Pilkey, and C.A. Webb. 2001. *Living on the Edge of the Gulf: The West Florida and Alabama Coast*. Durham, NC: Duke University Press. 340 p.

Bush, D. M., O. H. Pilkey, Jr., and W. J. Neal. 1996. *Living by the Rules of the Sea*. Duke University Press. Durham, North Carolina. 179 pp.

Chapman, D. J., and B. E. Julius. 2005. The Use of Preventative Projects as Compensatory Restoration. *Journal of Coastal Research* SI #40:120-131.

Clark, J. S. 1986. Dynamism in the Barrier-Beach Vegetation of Great South Beach, New York. *Ecological Monographs* 56(2):97-126.

Cleary, W. J., and D. M. Fitzgerald. 2003. Tidal Inlet Response to Natural Sedimentation Processes and Dredging-Induced Tidal Prism Changes: Mason Inlet, North Carolina. *Journal of Coastal Research* 19(4):1018-1025.

Climate Change Science Program (CCSP). 2009. *Coastal Sensitivity to Sea-Level Rise: A Focus on the Mid-Atlantic Region*. A report by the U.S. Climate Change Science Program and the Subcommittee on Global Change Research. [James G. Titus (Coordinating Lead Author), K. Eric Anderson, Donald R. Cahoon, Dean B. Gesch, Stephen K. Gill, Benjamin T. Gutierrez, E. Robert Thieler, and S. Jeffress Williams (Lead Authors)], U.S. Environmental Protection Agency, Washington D.C., USA. Available at http://www.climatescience.gov/Library/sap/sap4-1/final-report/default.htm.

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

Conaway, C. A., and J. T. Wells. 2005. Aeolian Dynamics along Scraped Shorelines, Bogue Banks, North Carolina. *Journal of Coastal Research* 21(2):242-254.

Connors, P. G., J. P. Myers, C. S. W. Connors, and F. A. Pitelka. 1981. Interhabitat Movements by Sanderlings in Relation to Foraging Profitability and the Tidal Cycle. *The Auk* 98:49-64.

Crain, D. A., A. B. Bolten, and K. A. Bjorndal. 1995. Effects of Beach Nourishment on Sea Turtles: Review and Research Initiatives. *Restoration Ecology*. 3(2):95-104.

Croft, A., and L. A. Leonard, 2001. Effects of Dredged Material Disposal on Tidal Marsh Processes. *Geological Society of America Southeastern Section Annual Meeting, 2001 Abstracts with Program*. P. A-71.

Davison, A. T., R. J. Nicholls, and S. P. Leatherman. 1992. Beach Nourishment as a Coastal Management Tool: An Annotated Bibliography on Developments Associated with the Artificial Nourishment of Beaches. *Journal of Coastal Research*. 8(4): 984-1022.

Dean, C. 1999. *Against the Tide: The Battle for America's Beaches*. Columbia University Press. New York. 279 pp.

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

Diaz, H. 1980. The Mole Crab *Emerita talpoida* (Say): A Case Study of Changing Life History Pattern. *Ecological Monographs* 50(4):437-456.

Dixon, K. L., and O. H. Pilkey, Jr. 1991. Summary of Beach Replenishment on the U.S. Gulf of Mexico Shoreline. *Journal of Coastal Research* 7(1):249-256.

Donnelly, C., N. Kraus, and M. Larson. 2006. State of Knowledge on Measurement and Modeling of Coastal Overwash. *Journal of Coastal Research* 22(4):965-991.

Donoghue, C. R. 1999. The Influence of Swash Processes on *Donax variabilis* and *Emerita talpoida*. Ph.D. Dissertation, Univ. of Virginia. Department of Environmental Sciences. 197 p.

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

Dugan, J. E., D. M. Hubbard, M. D. McCrary, and M. O. Pierson. 2003. The Response of Macrofauna Communities and Shorebirds to Macrophyte Wrack Subsidies on Exposed Sandy Beaches of Southern California. *Estuarine, Coastal and Shelf Science* 58S(2003):25-40.

Erwin, R. M. 1989. Responses to Human Intruders by Birds Nesting in Colonies: Experimental Results and Management Guidelines. *Colonial Waterbirds* 12(1):104-108.

Erwin, R. M., B. R. Truitt, and J. E. Jimenez. 2001. Ground-Nesting Waterbirds and Mammalian Carnivores in the Virginia Barrier Island Region: Running Out of Options. *Journal of Coastal Research*, 17(2):292-296.

Everhart, S. H., R. F. Soots, Jr., J. F. Parnell, and P. D. Doerr. 1980. *Natural and Dredged Material Nesting Habitats of Gull-billed Terns, Common Terns and Black Skimmers in North Carolina*. University of North Carolina Sea Grant Publication UNC-SG-79-05. 39 p. + appendices.

Fish, M. R., I. M. Côté, J. A. Horrocks, B. Mulligan, A. R. Watkinson, and A. P. Jones. 2008. Construction Setback Regulations and Sea-level Rise: Mitigating Sea Turtle Nesting Beach Loss. *Ocean & Coastal Management* 51(2008):330-341.

Fonseca, M. S., W. J. Kenworthy, and G. W. Thayer. 1998. *Guidelines for the Conservation and Restoration of Seagrasses in the United States and Adjacent Waters*. NOAA Coastal Ocean Program Decision Analysis Series No. 12. NOAA Coastal Ocean Office, Silver Spring, MD. 222 p.

Gabriel, A. O., and T. A. Terich. 2005. Cumulative Patterns and Controls of Seawall Construction, Thurston County, Washington. *Journal of Coastal Research* 21(3):430-440.

Gheskiere, T., V. Magda, P. Greet, and D. Steven. 2006. Are Strandline Meiofaunal Assemblages Affected by a Once-Only Mechanical Beach Cleaning? Experimental Findings. *Marine Environmental Research* 61(2006):245-264.

Giles, R. T., and O. H. Pilkey, 1965. Atlantic Beach and Dune Sediments of the Southern United States: *Journal of Sedimentary Petrology*, 35(4):900-910.

Godfrey, P. J. 1970. *Oceanic Overwash and its Ecological Implications on the Outer Banks of North Carolina*. Office of Natural Sciences Studies. National Park Service. Department of the Interior. Washington, DC. 44 pp.

Godfrey, P. J. and M. M. Godfrey. 1976. *Barrier Island Ecology of Cape Lookout National Seashore and Vicinity, North Carolina*. U.S. Department of the Interior, National Park Service, Scientific Monographic Series, 9. 160pp.

Godschalk, D. R., D. J. Brower, and T. Beatley. 1989. *Catastrophic Coastal Storms: Hazard Mitigation and Development Management*. Durham, NC: Duke University Press. 275 p.

Goldberg, W. M. 1988. Biological effects of beach restoration in South Florida: the good, the bad, and the ugly. *In* Tait, L. S. (ed). 1988. *Beach Preservation Technology '88: Problems and Advancements in Beach Nourishment - Proceedings*. Florida Shore and Beach Preservation Association, Inc., Tallahassee, Florida.

Goss-Custard, J. D., P. Triplet, F. Sueur, and A. D. West. 2006. Critical Thresholds of Disturbance by People and Raptors in Foraging Wading Birds. *Biological Conservation* 127(2006):88-97.

Hackney, C. T., M. R. Posey, S. W. Ross, and A. R. Norris. (eds.). 1996. A Review and Synthesis of Data on Surf Zone Fishes and Invertebrates in the South Atlantic Bight and the Potential Impact from Beach Renourishment. Report to the Wilmington District, U. S. Army Corps of Engineers. Wilmington, North Carolina. 109 pp.

Heinz Center (The). 2000. Evaluation of Erosion Hazards. Report prepared for the Federal Emergency Management Agency (Contract EMW-97-CO-0375) by The H. John Heinz III Center for Science, Economics and the Environment. Washington, DC. 205 pp.

Hurme, A. K. and E. J. Pullen. 1988. Biological Effects of Marine Sand Mining and Fill Placement for Beach Replenishment: Lessons for Other Uses. *Marine Mining* 7:123-136.

Ikuta, L. A., and D. T. Blumstein. 2003. Do Fences Protect Birds from Human Disturbance? *Biological Conservation* 112(2003):447-452.

Ince, R., G. A. Hyndes, P. S. Lavery, and M. A. Vanderklift. 2007. Marine Macrophytes Directly Enhance Abundances of Sandy Beach Fauna Through Provision of Food and Habitat. *Estuarine, Coastal and Shelf Science* 74(2007):77-86.

Inman, D. and R. Dolan. 1989. The Outer Banks of North Carolina: Budget of Sediment And Inlet Dynamics Along a Migrating Barrier System. *Journal of Coastal Research* 5(2):192-237.

Intergovernmental Panel on Climate Change (IPCC). 2007. *Climate Change 2007: The Physical Science Basis*. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M. Tignor, and H.L. Miller (eds.)]. Cambridge University Press, Cambridge, UK, and New York, 996 pp.

Jackson, N. L., D. R. Smith, R. Tiyarattanachai, and K. F. Nordstrom. 2007. Evaluation of a Small Beach Nourishment Project to Enhance Habitat Suitability for Horseshoe Crabs. *Geomorphology* 89(2007):172-185.

Johnson, R. O. and W. G. Nelson. 1985. Biological Effects of Dredging in an Offshore Borrow Area. *Florida Scientist*. 48:166-188.

Jordan, L. K. B., K. W. Banks, L. E. Fisher, B. K. Walker, and D. S. Gilliam. 2010. Elevated Sedimentation on Coral Reefs Adjacent to a Beach Nourishment Project. *Marine Pollution Bulletin* 60(2)261-271.

Jorgenson, T., and C. Ely. 2001. Topography and Flooding of Coastal Ecosystems on the Yukon-Kuskokwim Delta, Alaska: Implications for Sea-Level Rise. *Journal of Coastal Research* 17(1):124-136.

Kaldy, J. E., K. H. Dunton, J. L. Kowalski, and K. Lee. 2004. Factors Controlling Seagrass Revegetation onto Dredged Material Deposits: A Case Study in Lower Laguna Madre, Texas. *Journal of Coastal Research* 20(1):292-300.

Kaufman, W. and O. H. Pilkey, Jr. 1983. *The Beaches are Moving*. Duke University Press. Durham, North Carolina. 336 pp.

Kenny, A. J., and H. L. Rees. 1994. The Effects of Marine Gravel Extraction on the Macrobenthos: Early Post-Dredging Recolonization. *Marine Pollution Bulletin* 28(7):442-447.

Klein, R. J. T., R. J. Nicholls, S. Ragoonaden, M. Capobianco, J. Aston, and E. N. Buckley. 2001. Technological Options for Adaptation to Climate Change in Coastal Zones. *Journal of Coastal Research* 17(3):531-543.

Lafferty, K. D. 2001. Disturbance to Wintering Western Snowy Plovers. *Biological Conservation* 101(2001):315-325.

Lankford, T. E., and B. J. Baca. 1993. Comparative Environmental Impacts of Various Forms of Beach Nourishment. *Proceedings of Coastal Zone '93.* American Society of Civil Engineers, New York, NY. Pp. 2046-2059.

Lastra, M., H. M. Page, J. E. Dugan, D. M. Hubbard, and I. F. Rodil. 2008. Processing of Allochthonous Macrophyte Subsidies by Sandy Beach Consumers: Estimates of Feeding Rages and Impacts on Food Resources. *Marine Biology* 154(2008):163-174.

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

Lindeman, K. C. 1997. *Development of Grunts and Snappers of Southeastern Florida: Cross-shelf Distribution and Effects of Beach Management Alternatives*. Ph.D. dissertation. Univ. Miami. Coral Gables, FL. 419 pp.

Lindeman, K. C. 1997. *Comparative Management of Beach Systems of Florida and the Antilles: Applications using Ecological Assessment and Decision Support Procedures*. UNESCO Coastal Region and Small Island Reports #1, pp. 134-164.

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

Lindquist, N., and L. Manning. 2001. *Impacts of Beach Nourishment and Beach Scraping on Critical Habitat and Productivity of Surf Fishes*. Final Report to the North Carolina Fisheries Resource Grant Program. 41 pp + figures.

Lord, A., J. R. Waas, J. Innes, and M. J. Whittingham. 2001. Effects of Human Approaches to Nests of Northern New Zealand Dotterels. *Biological Conservation* 98(2001):233-240.

Lucrezi, S., T. A. Schlacher, and W. Robinson. 2009. Human Disturbance as a Cause of Bias in Ecological Indicators for Sandy Beaches: Experimental Evidence for the Effects of Human Trampling on Ghost Crabs. *Ecological Indicators* 9(2009):913-921.

Maa, J. P. Y., C. H. Hobbs III, and C. S. Hardaway, Jr. 2001. A Criterion for Determining the Impact on Shorelines Caused by Altering Wave Transformation. *Journal of Coastal Research* 17(1):107-113.

Manning, L. 2003. *Ecology of Ocean Beaches: The Importance of Human Disturbance and Complex Biological Interactions within a Physically Rigorous Environment*. Ph.D. Dissertation, University of North Carolina at Chapel Hill. Department of Biology.

Marques, M. A., N. P. Psuty, and R. Rodriguez. 2001. Neglected Effects of Eolian Dynamics on Artificial Beach Nourishment: The Case of Riells, Spain. *Journal of Coastal Research* 17(3):694-704.

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

Matias, A., O. Ferreira, I. Mendes, J. A. Dias, and A. Vila-Concejo. 2005. Artificial Construction of Dunes in the South of Portugal. *Journal of Coastal Research* 21(3):472-481.

McArdle, S. B. and A. McLachlan. 1992. Sand Beach Ecology: Swash Features Relevant To The Macrofauna. *Journal of Coastal Research* 8(2):398-407.

McLachlan, A., and A. Dorvlo. 2007. Global Patterns in Sandy Beach Macrobenthic Communities: Biological Factors. *Journal of Coastal Research* 23(5):1081-1087.

McLachlan, A., I. G. Eliot and D. J. Clarke. 1985. Water Filtration through Reflective Microtidal Beaches and Shallow Sublittoral Sands and its Implications for an Inshore Ecosystem in Western Australia. *Estuarine, Coastal and Shelf Science* 21(1985):91-104.

McLachlan, A., E. Jaramillo, O. Defeo, J. Dugan, A. de Ruyck and P. Coetzee. 1995. Adaptations of Bivalves to Different Beach Types. *Journal of Experimental Marine Biology and Ecology* 187:147-160.

McNinch, J. E., and J. T. Wells. 1992. Effectiveness of Beach Scraping as a Method of Erosion Control. *Shore and Beach* (January 1992):13-20.

Meadows, P. S., and J. Tait. 1989. Modification of Sediment Permeability and Shear Strength by Two Burrowing Invertebrates. *Marine Biology* 101(1989):75-82.

Michener, W. L., E. B. Blood, K. L. Bildstein, M. M. Brinson, and L. R. Gardner. 1997. Climate Change, Hurricanes and Tropical Storms, and Rising Sea Level in Coastal Wetlands. *Ecological Applications* 7(1997):770-801.

Miller, D. L., M. Thetford, and L. Yager. 2001. Evaluation of Sand Fence and Vegetation for Dune Building Following Overwash by Hurricane Opal on Santa Rosa Island, Florida. *Journal of Coastal Research* 17(4):936-948.

Morton, R. A. 2008. Historical Changes in the Mississippi-Alabama Barrier-Island Chain and the Roles of Extreme Storms, Sea Level, and Human Activities. *Journal of Coastal Research* 24(6):1587-1600.

National Research Council (NRC). 1995. *Beach Nourishment and Protection*. National Academy Press. Washington, D.C. 334 pp.

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

Nordstrom, K. F. 1994. Developed coasts. Chapter 13, pp. 477-509. in R.W.G. Carter and C. D. Wooddroffe. (eds.) *Coastal Evolution - Late Quaternary Shoreline Morphodynamics*. Cambridge University Press. Cambridge, United Kingdom.

Nordstrom, K. F., N. L. Jackson, A. H. F. Klein, D. J. Sherman, and P. A. Hesp. 2006. Offshore Aeolian Transport across a Low Foredune on a Developed Barrier Island. *Journal of Coastal Research* 22(5):1260-1267.

Otvos, E. G., and G. A. Carter. 2008. Hurricane Degradation – Barrier Development Cycles, Northeastern Gulf of Mexico: Landform Evolution and Island Chain History. *Journal of Coastal Research* 24(2):463-78.

Peterson, C. H., and M. J. Bishop. 2005. Assessing the Environmental Impacts of Beach Nourishment. *Bioscience* 55(10):887-896.

Peterson, C. H., D. H. M. Hickerson, and G. G. Johnson. 2000. Short-term Consequences of Nourishment and Bulldozing on the Dominant Large Invertebrates of the Sandy Beach. *Journal of Coastal Research*16(2):368-378.

Peterson, C. H., M. J. Bishop, G. A. Johnson, L. M. D'Anna, and L. M. Manning. 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.

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

Pilkey, O. H. 1992. Another View of Beachfill Performance. *Shore and Beach*. Pp. 20-25.

Platt, R. H. 1999. *Disasters and Democracy: The Politics of Extreme Natural Events*. Washington, D.C.: Island Press. 320 p.

Platt, R. H., S. G. Pelczarski, and B. K. R. Burbank (eds). 1987. *Cities on the Beach: Management Issues of Developed Coastal Barriers*. Chicago, IL: Dept. of Geography, University of Chicago. 324 p.

Posey, M. H., and T. D. Alphin. 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.

Pullen, E. J. and S. M. Naqvi. 1983. Biological Impacts on Beach Replenishment and Borrowing. *Shore and Beach* (April 1983):27-31.

Quammen, M. L. 1984. Predation by Shorebirds, Fish, and Crabs on Invertebrates in Intertidal Mudflats: An Experimental Test. *Ecology* 65:529-537.

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

Reed, A. J., and J. T. Wells. 2000. Sediment Distribution Patterns Offshore of a Renourished Beach: Atlantic Beach and Fort Macon, North Carolina. *Journal of Coastal Research* 16(1):88-98.

Reilly, F. J., Jr., and V. J. Bellis. 1978. *A Study of the Ecological Impact of Beach Nourishment with Dredged Materials on the Intertidal Zone*. East Carolina University Institute for Coastal and Marine Resources, Technical Report No. 4., Greenville, North Carolina. 107 pp.

Reilly, F. J., D. M. Landy Cobb and V. J. Bellis. 1980. Biological Implications of Beach Replenishment: *in* N.P. Psuty and D. McArthur, eds, *Proceedings of the Sixth Annual Conference of The Coastal Society*, pp. 269-280.

Riggs, S. R., W. G. Ambrose Jr., J. W. Cook, Scott W. Snyder, and Stephen W. Snyder. 1998. Sediment Production on Sediment-Starved Continental Margins: The Interrelationship between Hardbottoms, Sedimentological and Benthic Community Processes, and Storm Dynamics. *Journal of Sedimentary Research*. 68(1):155-168.

Rodgers, J. A., and H. T. Smith. 1995. Set-back Distances to Protect Nesting Bird Colonies from Human Disturbance in Florida. *Conservation Biology* 9(1):89-99.

Rodil, I. F., C. Olabarria, M. Lastra, and J. López. 2008. Differential Effects of Native and Invasive Algal Wrack on Macrofaunal Assemblages Inhabiting Exposed Sandy Beaches. *Journal of Experimental Marine Biology and Ecology* 358(2008):1-13.

Roessler, R. S., and J. T. Wells. 2001. Beach Changes along Eastern Bogue Banks, North Carolina, Resulting from the 1996 Hurricane Season. *Journal of Coastal Research* 17(4):964-975.

Rosati, J. D. 2005. Concepts in Sediment Budgets. *Journal of Coastal Research* 21(2):307-322.

Rosati, J. D., and G. W. Stone. 2009. Geomorphic Evolution of Barrier Islands along the Northern U.S. Gulf of Mexico and Implications for Engineering Design in Barrier Restoration. *Journal of Coastal Research* 25(1):8-22.

Ross, S. W., and J. E. Lancaster. 1996. *Movements of Juvenile Fishes Using Surf Zone Nursery Habitats and the Relationship of Movements to Beach Nourishment along a North Carolina Beach: Pilot Project*. Final Report to NOAA Office of Coastal Resource Management and the U.S. Army Corps of Engineers. 31 p.

Saloman, C. H. and S. P. Naughton. 1984. *Beach Restoration with Offshore Dredged Sand: Effects on Nearshore Macrofauna*. U.S. Dept. of Commerce, National Oceanic and Atmospheric Association, NOAA Tech. Memorandum NMFS-SEFC-133. 20 pp.

Schlacher, T. A., and J. M. Morrison. 2008. Beach Disturbance Caused by Off-Road Vehicles (ORV) on Sandy Shores: Relationship with Traffic Volumes and a New Method to Quantify Impacts Using Image-based Data Acquisition and Analysis. *Marine Pollution Bulletin* 56(2008):1646-1649.

Schlacher, T. A., and L. M. C. Thompson. 2008. Physical Impacts Caused by Off-Road Vehicles to Sandy Beaches: Spatial Quantification of Car Tracks on an Australian Barrier Island. *Journal of Coastal Research* 24(2B):234-242.

Sellers, J. D., and C. L. Jolls. 2007. Habitat Modeling for *Amaranthus pumilus*: An Application of Light Detection and Ranging (LIDAR) Data. *Journal of Coastal Research* 23(5):1193-1202.

Skidaway Institute of Oceanography. 1981. Saving the American Beach: A Position Paper by Concerned Coastal Geologists. Results of the First Skidaway Institute of Oceanography Conference on America's Eroding Shoreline. 12 p.

Skidaway Institute of Oceanography. 1985. National Strategy for Beach Preservation. Results of the Second Skidaway Institute of Oceanography Conference on America's Eroding Shoreline. 11 p.

Smith, C. G., S. J. Culver, S. R. Riggs, D. Ames, D. R. Corbett, and D. Mallinson. 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.

Snyder, R. A., and C. L. Boss. 2002. Recovery and Stability in Barrier Island Plant Communities. *Journal of Coastal Research* 18)3):530-536.

Steinitz, M. J., M. Salmon and J. Wyneken. 1998. Beach Renourishment and Loggerhead Turtle Reproduction: A Seven Year Study at Jupiter Island, Florida: *Journal of Coastal Research*, 14(3):1000-1013.

Thayer, G. W., and M. E. Kentula. 2005. Coastal Restoration: Where have We Been, Where are We Now, and Where Should We be Going? *Journal of Coastal Research* SI #40:1-5.

Thieler, E. R., A. L. Brill, W. J. Cleary, C. H. Hobbs III, and R. A. Gammisch. 1995. Geology of the Wrightsville Beach, North Carolina Shoreface: Implications for the Concept of Shoreface Profile of Equilibrium. *Marine Geology* 126:271-287.

Thieler, E. R., W. C. Schwab, R. P. Signell, P. T. Gayes, and M. S. Harris, 2001. The shoreface as a source and sink for beach nourishment. *Geological Society of America Southeastern Section Annual Meeting, 2001 Abstracts with Program*. P. A-20.

Thom, R. M., G. Williams, A. Borde, J. Southard, S. Sargeant, D. Woodruff, J. C. Laufle, and S. Glasoe. 2005. Adaptively Addressing Uncertainty in Estuarine and Near Coastal Restoration Projects. *Journal of Coastal Research* SI#40:94-108.

Titus, J. G. 1990. Greenhouse Effect, Sea Level Rise, and Barrier Islands: Case Study of Long Beach Island, New Jersey. *Coastal Management* 18(1990):65-90.

Titus, J. G. and V. Narayanan. 1995. *The Probability of Sea Level Rise.* Washington, D.C.: U.S. Environmental Protection Agency, EPA 230-R95-008, 186 pp.

Trembanis, A. C., H. R. Valverde, and O. H. Pilkey. 1998. Comparison of Beach Nourishment along the U.S. Atlantic, Great Lakes, Gulf of Mexico and New England Shorelines. *Journal of Coastal Research* Special Issue #26. Pp. 246-251.

U.S. Minerals Management Service (US MMS). 1996. *Marine Mining Technologies and Mitigation Techniques: A Detailed Analysis With Respect to the Mining of Specific Offshore Mineral Commodities*. OCS Report MMS 95-0003.

______. 1999. *Environmental Report – Use of Federal Offshore Sand Sources for Beach and Coastal Restoration in New Jersey, Maryland, Delaware, and Virginia*. OCS Study MMS 99-0036. Office of International Activities and Marine Minerals. Prepared by The Louis Berger Group, Inc., Contract Number 1435-01-98-RC-30820. Various paginations.

______. 2001. *Final Report: Development and Design of Biological and Physical Monitoring Protocols to Evaluate the Long-term Impacts of Offshore Dredging Operations on the Marine Environment*. OCS Study MMS 2001-089. 116 pages + appendices.

Valverde, H. R., A. C. Trembanis and O. H. Pilkey. 1999. Summary of Beach Nourishment Episodes on the U.S. East Coast Barrier Islands. *Journal of Coastal Research*. 15(4):1100-1118.

Van der Wal, D. 2004. Beach-Dune Interactions in Nourishment Areas along the Dutch Coast. *Journal of Coastal Research* 20(1):317-325.

Van Dolah, R. F., P. H. Wendt, R. M. Martore, M. V. Levisen, W. A. Roumillat. 1992. *A Physical and Biological Monitoring Study of the Hilton Head Beach Nourishment Project*. Marine Resources Research Institute, South Carolina Marine Resources Division, Charleston, S.C. 159 pp.

Van Dolah, R. F., R. M. Martore, and M.V. Levisen. 1993. *A Physical and Biological Monitoring Study of the Hilton Head Beach Nourishment Project.* Supplemental report prepared by the South Carolina Marine Resources Research Institute for the Town of Hilton Head, South Carolina.

Van Dolah, R. F., Martore, R. M., Lynch, A. E., Wendt, P. H., Levisen, M. V., Whitaker, D. J., and W. D. Anderson. 1994. *Final Report. Environmental Evaluation of the Folly Beach Nourishment Project*. South Carolina Department of Natural Resources, Marine Resources Division, Charleston, SC. Prepared for the United States Army Corps of Engineers, Charleston District, Charleston, SC.

Wang, P., J. H. Kirby, J. D. Haber, M. H. Horwitz, P. O. Knorr, and J. R. Krock. 2006. Morphological and Sedimentological Impacts of Hurricane Ivan and Immediate Poststorm Beach Recovery along the Northwestern Florida Barrier-Island Coasts. *Journal of Coastal Research* 22(6):1382-1402.

Weinstein, M. P., and L. L. Weishar. 2002. Beneficial Use of Dredged Material to Enhance the Restoration Trajectories of Formerly Diked Lands. *Ecological Engineering* 19(2002):187-201.

West, A. D., J. D. Goss-Custard, R. A. Stillman, R. W. G. Caldow, S. E. A. le V. Dit Durell, and S. McGrorty. 2002. Predicting the Impacts of Disturbance on Shorebird Mortality Using a Behaviour-based Model. *Biological Conservation* 106(3):319-328.

Weston, M. A., and M. A. Elgar. 2007. Responses of Incubating Hooded Plovers (*Thinornis rubricollis*) to Disturbance. *Journal of Coastal Research* 23(3):569-576.

Wilber, D. H., D. G. Clarke, and M. H. Burlas. 2006. Suspended Sediment Concentrations Associated with a Beach Nourishment Project on the Northern Coast of New Jersey. *Journal of Coastal Research* 22(5):1035-1042.

Williams, S. J., and B. T. Gutierrez. 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.

Appendix 1b. Inventory of Habitat Modifications to Tidal Inlets in the Continental U.S. Coastal Migration and Wintering Range of the Piping Plover (*Charadrius melodus*)[1]

Tracy Monegan Rice
Terwilliger Consulting, Inc.
October 2012

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 these data for one habitat type – namely sandy tidal inlets within the migration and wintering range of the southeastern United States (U.S.). Inlets are a highly valuable habitat for piping plovers, 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).

Although 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 birds. 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.

A description of the different types of stabilization structures typically constructed at or adjacent to inlets – jetties, terminal groins, groins, seawalls, breakwaters and revetments – can be found in Appendix 1a (Rice 2009) as well in the *Manual for Coastal Hazard Mitigation* (Herrington 2003, online at http://www.state.nj.us/dep/cmp/coastal_hazard_manual.pdf) and in *Living by the Rules of the Sea* (Bush et al. 1996).

METHODS

This assessment was compiled by examining many disparate sources of information regarding tidal inlets within the piping plover's migration and wintering range into one central Microsoft Excel database. Sources include peer-reviewed literature, books, gray literature (e.g., conference presentations, project applications, or proposals), government reports and files, maps such as Google Earth, U.S. Geological Survey (USGS) topographic maps, nautical charts and state Gazetteers, and on-line databases and government websites (federal, state, county, and municipal).

Google Earth imagery (using the most recent dates available, generally from 2010 and 2011 at inlet locations) and the Federal Inlet Aerial Photo Database (http://www.oceanscience.net/inletsonline/map/map.html) were used to create a database of inlets within

[1] *Suggested citation*:
Rice, T. M. 2012. Inventory of Habitat Modifications to Tidal Inlets in the Continental U.S. Coastal Migration and Wintering Range of the Piping Plover (*Charadrius melodus*). Appendix 1b *in* Comprehensive Conservation Strategy for the Piping Plover (*Charadrius melodus*) in its Coastal Migration and Wintering Range in the Continental United States, U.S. Fish and Wildlife Service, East Lansing, Michigan.

the migration and wintering range of the piping plover, namely those within the states of North Carolina, South Carolina, Georgia, Florida, Alabama, Mississippi, Louisiana, and Texas. Zooming in to each inlet allowed identification of existing hard structures and whether the land ownership on the inlet shoulders was developed or undeveloped. Viewing publicly posted digital photographs linked to each location within Google Earth allowed further verification of the existence and type of hard structures or absence thereof.

An inlet, sometimes called a "pass" or a "cut," is defined as an opening between barrier islands, spits, or peninsulas that allows ocean and bay water to freely exchange and that contains an inlet throat (the main channel) and a series of shoals (Leatherman 1988; Figure 1). Inlets are influenced by sediment supply, the wave climate, the tidal prism (the volume of water passing through the inlet on a tidal cycle), the longshore sediment transport system, sea level rise, and human modifications of the inlet, estuary, river discharging through the inlet, and adjacent shorelines (Leatherman 1988, Davis and Gibeaut 1990, Bush et al. 1996). These various coastal processes and variables are connected with feedback loops, producing inlet features and behavior that are in a state of dynamic equilibrium. Thus the wildlife habitat associated with inlets is constantly changing due to natural processes.

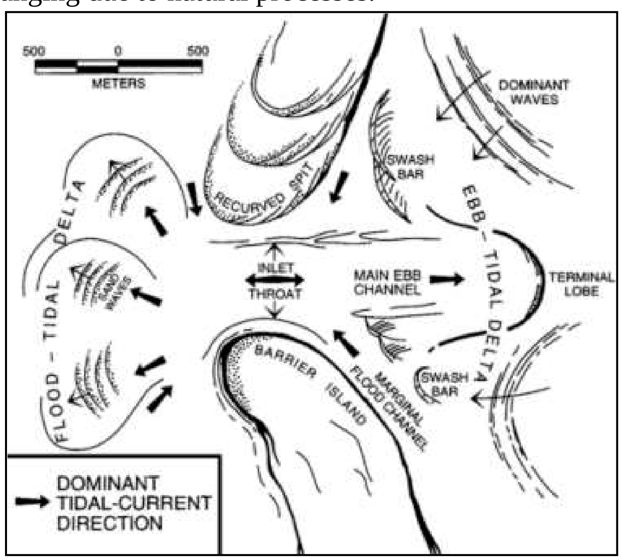

Figure 1. Schematic diagram of a typical tidal inlet with its morphological features. The ocean or Gulf is to the right in the diagram and the lagoon, bay or estuary is on the left. The net longshore sediment transport is from the top of the diagram to the bottom, the same direction as the dominant waves. Marine waters from the ocean freely exchange with brackish water from the bay, lagoon, sound, or estuary through the inlet on the incoming (flood) and outgoing (ebb) tides. From Schrader et al. (2000).

Davis and Gibeaut (1990, p. 2) characterize tidal inlets in the following manner:

> *Tidal inlets are geologically ephemeral environments which act as dynamic conduits between the sea and coastal bays and which divide the coast into barrier-island segments. Inlets may close and open, migrate or become stable on the order of tens of years in response to changing sediment supply, wave climate and tidal regime, rate of sea level rise, and back-bay filling or dredging. In turn, the associated sediment bodies, ebb- and flood-tidal deltas, may rapidly change character. Because most material making up the inlet sand bodies is taken from the littoral-drift system which feeds adjacent beaches, changes in inlet behavior are reflected by changes in adjacent shorelines and overall barrier-island morphologies ….Tidal inlets are very dynamic and commonly show major changes in inlet size and shape, in some*

cases even without intervention by man's activities. Changes in wave climate, sediment availability, and nearshore bottom configuration can cause perturbations in coastal processes, and therefore, in the morphology of the inlet or inlets.

An inlet shoal complex, which consists of both ebb and flood tidal shoals, is the group of sand bodies within and near an inlet that is created by an interaction between the tides, waves and sediment supply (Figure 1). Individual shoals are separated by tidal channels. Ebb shoals are on the ocean side of an inlet and are more influenced by waves, whereas flood shoals are on the bay or estuarine side of the inlet and may be emergent during low tide or even maintain some dry (subaerial) lands that could become vegetated over time. A group of ebb tidal shoals is also referred to as an ebb tidal delta, and a group of flood tidal shoals as the flood tidal delta (Leatherman 1988, Bush et al. 1996). Shoals may become relict when an inlet closes, allowing the ebb tidal shoals to weld to the new beach and the flood shoals to stabilize and possibly become vegetated over time. Along deltaic coasts such as in Louisiana, shoals may become relict if sea level rise outpaces the sediment supply allowing the inlets essentially to drown in place, thus converting the shoals into subaqueous (submerged) sand bodies and some inlets into open bay mouths. Wide, open bay or sound entrances (e.g., East Cote Blanche Bay in Louisiana, St. George Sound in Florida) were not categorized as inlets in this assessment due to their width and the absence of active inlet shoal complexes.

Inlets along deltaic coasts in Louisiana are distinct from the tidal inlets typically seen along non-deltaic coasts in the southeastern U.S. The Mississippi and Atchafalaya delta coasts are river-dominated instead of the wave- or tide-dominated inlets and coasts elsewhere in the range (Suter 1994). In Texas, the Rio Grande and Brazos River deltas are relatively small and wave-dominated, with most of their distributary streams discharging into estuaries as "bayhead deltas" (Suter 1994, p. 109); as a result, inlets along some Texas coastal segments more closely resemble tidal inlets along the non-deltaic coasts . The flats and shoals associated with the bayhead deltas within the lagoons provide valuable habitat for piping plovers and other birds. In the absence of human intervention, the deltaic coast of Louisiana would consist of a series of active distributaries, delta plains, extensive wetlands, distributary-mouth bars, and abandoned deltas in which marine processes may have reworked the coarser deltaic sediments into barrier islands or spits, producing sections of coast that are wave-dominated rather than river-dominated. Abandoned distributary channels may convert into brackish estuaries, as the Bayou Lafourche has done since it ceased to be an active distributary of the Mississippi River roughly 300 years ago (Suter 1994). "The natural geomorphology of a given delta is the result of complex interactions between sediment supply, relative sea-level changes, and marine reworking. Human interference with any of these factors inevitably alters the form and evolution of the delta. … [On the Mississippi delta,] through the construction of the levees, the natural processes of the delta were drastically altered. … Depleted sediment supply from overbanking has accelerated the long-term degradation of the deltaic plain" (Suter 1992, pp. 112-3). As a result, the tidal inlets along the current Louisiana deltaic coast have a very limited sediment supply, preventing them from being self-sustaining without additional sediment input from coastal restoration projects. Where sandy shorelines are present along the Louisiana deltaic coast, tidal inlets were included in this assessment when they exhibited features generally similar to inlets elsewhere in the range (as in Figure 1).

Ephemeral breaks or breaches in shorelines or islands were considered inlets in this assessment if they appeared to maintain a tidal exchange of water from the ocean to the bayside; conversely, inlets were considered closed if they did not appear to allow the free flow of water at low tide. This assessment represents a snapshot in time of the inlets open along the southeastern and Gulf coasts of the U.S., using the most recent imagery, publications and personal knowledge available. Inlets are very dynamic, however, and some ephemeral breaches or smaller inlets may have shifted in space or closed and others opened after the publication date of this assessment. Overwash-dominated barrier islands or coasts are especially dynamic, their inlets and breaches repeatedly opening and closing naturally; these areas are included in this survey as a snapshot assessment of the condition of inlet habitats valuable or potentially valuable to the piping plover on its migration and wintering range. The database can be updated by contacting the author via email at tracymrice@yahoo.com to report any modifications to the current status or new habitat modifications to inlets contained within the geographic area covered in this assessment. Updated copies of the database will be posted on-line at the Program for the Study of Developed Shorelines website (http://www.wcu.edu/1037.asp).

Where barrier islands exist offshore of the mainland, entrances or passes that are located on a mainland shoreline are not included as they are geomorphologically distinct from inlets between sandy barrier islands or spits and are estuarine in nature. The mainland coast of Mississippi, for example, provides habitat for the piping plover, but its bay entrances are not included in this assessment because Petit Bois, Horn, Ship and Cat Islands are located offshore and separated by inlets. When the mainland coast does **not** have offshore barrier islands, and the mainland coast is sandy and has direct ocean or Gulf exposure, then mainland passes or inlets are included when they are geomorphologically similar to inlets between barrier islands. Some of these inlets may have been artificially created to provide access to inland water bodies, whereas others may be river drainages. Examples of such areas include the Matagorda Peninsula in Texas, the Holly Beach area of Louisiana, and the Grand Strand area of South Carolina.

Mainland areas lacking sandy coastlines are excluded. Thus, for example, only two sandy coastlines qualify on the western Florida coast: one located in the Northwest Barrier Chain, eastward from the Alabama state line to Ochlockonee Bay in Franklin County, and the other the West-Central Barrier Chain, from Anclote Key south to Cape Romano. Specifically excluded are the "plant-dominated, sediment-starved, low-wave energy and tide-dominated coastlines" that are "natural geologic boundaries" of the Big Bend Marsh Coast between the two barrier island chains and the Ten Thousand Islands Mangrove Coast to the south (Hine et al. 2003, p. 2; Davis and Gibeaut 1990, Morton and Peterson 2003a, 2003b, 2004). Bush et al. (2001, p. 171) characterize the Big Bend Marsh Coast as an area where "barrier islands are absent and sandy beaches and dunes are rare." Critical Habitat Unit FL-14 at Hagens Cove in Taylor County, therefore, is excluded from consideration because it contains no true tidal inlets.

Outlets that discharge freshwater or brackish water from lagoons or lakes of the Gulf Coast in the Florida panhandle, Louisiana and Texas were also omitted from this assessment because they generally have no visible tidal deltas, their channels are generally narrow and meandering, and they are not tidally flushed but merely allow outflows from inland bodies of water. The Florida Keys were also excluded from this inventory, specifically those from Soldier Key south due to their geologic nature. These islands, or keys, are "a different kind of island chain" that "are quite different from the beach and barrier island systems of East Florida" (Bush et al. 2004, p. 232). They are composed of limestone, are often fringed by mangroves, and natural beaches are rare and limited in length (Bush et al. 2004). The area of Atlantic Florida included in this assessment, therefore, stretches from the Georgia state line to Cape Florida on Key Biscayne south of Miami Beach.

Maps in other published sources (e.g., the *Living with the Shore* series of books for individual state coastlines, government reports, journal publications) were then used to confirm the number and geographic location of currently open tidal inlets, thereby adding non-federally maintained inlet data to the inventory (e.g., inlets dredged by state or local agencies). These map sources were also used to identify the proper political boundaries (i.e., county) in which each inlet is located. News reports and information supplied by relevant public officials and academic sources were consulted to identify the location of new inlets formed within the past few years, typically as a result of storms. History and geology books, literature and government files were referenced to identify inlets that have been relocated or artificially opened or closed since the late 1800s.

In determining the ownership of the inlet shorelines, available maps and on-line directories were searched to identify and verify public properties such as National Wildlife Refuges, National Seashores, state parks and refuges, state wildlife management areas, county and municipal parks and preserves, and lands owned by non-governmental conservation organizations (e.g., Audubon, The Nature Conservancy). Where no records of public ownership were found, the lands were assumed to be privately owned and were recorded as such. Notations were made as to whether the private land was developed or undeveloped; land with low-density development such as a small number of structures with no significant infrastructure (e.g., a few fishing cottages) were considered undeveloped due to their dominant land use as being natural.

The primary data source for stabilized inlets was the Coastal Inlets Research Program (CIRP) prepared by the U.S. Army Corps of Engineers (USACE), which maintains an on-line database of 156 federally-maintained tidal inlets of the U.S. (available at http://cirp.usace.army.mil/wiki/Inlet_Database). This Federal Inlets Database provides information on stabilization structures including jetties as well as physical characteristics such as tidal prism, inlet dimensions and wave conditions (where data are available). USACE construction history reports, often available for federal structures maintained at inlets included in the database (accessible through http://www.oceanscience.net/inletsonline/map/map.html), provide details on the dates of construction (and thus dates of habitat modification).

These data were combined within a centralized Microsoft Excel database containing the following data fields for each inlet: inlet name, state, north / east land ownership, south / west land ownership, county where the inlet occurs, type of hard structure, location of the structure, structure ownership, date built, dredging (yes or no), dredging maintenance agency, location(s) of dredged material disposal, sand bypassing (yes or no), shoal mining (yes or no), mining sponsor, date mined, fill location, other miscellaneous but relevant details, and data sources.

A separate Microsoft Excel database was created to catalog the number and location of inlets that have been relocated either naturally or artificially opened or closed since the 1890s. Relocated inlets are those in which the inlet has been physically moved to a new location – typically hundreds to thousands of feet away – and the old inlet closed with sediment or other materials and the new inlet excavated through land. An inlet generally is relocated as an erosion control measure to protect property or infrastructure from loss due to inlet migration. An inlet that was moved to a new location but where the old inlet was allowed to remain open was categorized as artificially created and not as a relocated inlet. If the old inlet subsequently closed naturally, that inlet was categorized as naturally closed. Inlets that have opened or closed due to natural processes include those that were created during storm events or filled in and closed by natural sediment transport processes. Artificially created inlets include those cut through barrier islands or spits where previously no channel existed; these have been created predominantly for navigational purposes but less frequently for water quality or fish passage purposes.

Inlets that have been artificially closed tend to be those opened during a storm event (e.g., Hurricanes Hugo (1989), Katrina (2005) or Irene (2011)) in a location where property owners, governing agencies or politicians consider them undesirable; closure of these new inlets is oftentimes considered a storm recovery endeavor, particularly where it is necessary to restore a road that has been severed by the new inlet. Artificially closed inlets provide a different mosaic of habitats than those that have closed naturally. Naturally closed inlets tend to be low in elevation, to have no or sparse vegetation initially, and are wide, especially if the tidal deltas or shoals have welded to the island. Artificially closed inlets, on the other hand, have higher elevations, tend to have a substantial constructed berm and dune system tying in to the adjacent beach and dune systems, and are manually planted with dune grasses and/or other vegetation to stabilize the area. The materials used to fill the inlet and construct the berm and dune ridge typically are mined nearby, often disturbing the local sediment supply and transport system. The overwash occurring periodically at a naturally closed inlet is prevented at an artificially closed inlet by the constructed dune ridge, or in some cases by additional hard structures or sandbags such as those installed at the Rodanthe

Breach in North Carolina when it was artificially closed in the fall of 2011. However, inlets that have been artificially closed in Louisiana as part of coastal restoration projects are purposefully designed to approximate the natural system and to allow overwash in the future (B. Firmin, USFWS, personal communication, March 9, 2012). Katrina Cut in Alabama is considered an existing inlet in this assessment (see Table 7) despite its closure with a rock dike during Deepwater Horizon oil spill response efforts because the dike was permitted as a temporary structure (but now, in 2012, is undergoing review to remain in place as a permanent structure).

Shoal mining is defined as a project that intentionally mines sediment from a tidal shoal within an inlet complex, typically for nourishment of nearby beaches. These projects tend to target ebb shoals, are located outside of any authorized and/or maintained navigational channels, and tend to require new permits or environmental review. Dredging activities that have occurred within authorized and/or maintained navigational channels with the dredged materials placed on nearby beaches to address erosion are not considered mining projects within this assessment. Such types of projects may be considered by the USACE as "beneficial use of dredged material" or as Section 933 projects under the Water Resources Development Act (as amended) but do not create new areas of disturbance to the seafloor as a true mining project does. Both dredging of channels and shoal mining create similar geological and ecological impacts, however, in that they disrupt the sediment transport system within and around inlets, creating sediment sinks within the inlet which can lead to increased erosion rates of adjacent shorelines and shoals.

Data on each inlet were confirmed with information from multiple sources wherever possible and the sources for each inlet's data recorded.

The data in both databases were then compiled, sorted and analyzed using common assessment techniques (e.g., the proportion of inlets modified in a particular way within individual states and the range) to identify trends and patterns. Numerous USFWS staff members within the range have reviewed a draft of this assessment in order to verify and correct details, where necessary.

RESULTS

Of the 221 tidal inlets that were open in December 2011 within the migration and wintering range of the piping plover, 30 (14%) had been artificially created (i.e., cut where there was previously no inlet or dredged open after closing naturally), 8 (4%) had been relocated to entirely new positions, 89 (40%) have been stabilized with one or more hard structures, 97 (44%) had been dredged at least once, and at least 20 (9%) had been mined as a sediment source for beach nourishment. Altogether 119 (54%) of the 221 inlets currently open have been significantly modified in one or more of these ways. Furthermore, at least 64 inlets have been closed artificially and thus are not included in the 221 total inlets that are presently open (Table 1).

The states with the highest proportion of inlets modified by any means are North Carolina (85%), Atlantic Florida (90%) and Alabama (100%). In fact only two states (Georgia and Louisiana) have modified fewer than 45% of their inlets. Florida has modified a 43 of 69 inlets (62%). In sum, over half (54%) of all the sandy inlets within the migration and wintering range of the piping plover have been modified in one way or another.

Of the 89 inlets with at least one hard structure, 6 (7%) have one jetty, 45 (49%) have two jetties, 28 (31%) have terminal or other groin structures, 24 (27%) have revetments (sandbag or rock) or seawalls, and 4 (4%) have offshore breakwaters (NOTE: the numbers total more than 89 because many inlets have more than one type of structure). The highest number of inlets with structures is found along the Gulf coast of Florida (20) but the highest proportion of inlets stabilized with hard structures is along the Atlantic coast of Florida (90%), where 19 inlets of 21 have been stabilized (Table 1).

Table 1. The number of open tidal inlets, inlet modifications, and artificially closed inlets in each state as of December 2011.

State	Existing Inlets							Artificially closed
	Number of Inlets	Total Number of Modified Inlets	Habitat Modification Type					
			structures†	dredged	relocated	mined	Artificially opened	
NC	20	17 (85%)	7	16	3	4	2	11
SC	47	21 (45%)	17	11	2	3	0	1
GA	23	6 (26%)	5	3	0	1	0	0
FL – *Atlantic*	21	19 (90%)	19	16	0	3	10	0
FL – *Gulf*	48	24 (50%)	20	22	0	6	7	1
AL	4	4 (100%)	4	3	0	0	0	2
MS	6	4 (67%)	0	4	0	0	0	0
LA	34	10 (29%)	7	9	1	2	0	46
TX	18	14 (78%)	10	13	2	1	11	3
TOTAL	221	119 (54%)	89 (40%)	97 (44%)	8 (4%)	20 (9%)	30 (14%)	64 (N/A)

† Structures include jetties, terminal groins, groin fields, rock or sandbag revetments, seawalls, and offshore breakwaters.

The state with the highest proportion of unmodified (natural) inlets is Georgia (74%). The highest number of adjacent (or consecutive), unmodified inlets is the 15 inlets between Little Tybee Slough at Little Tybee Island Nature Preserve (GA) and the entrance to Altamaha Sound at the south end of Wolf Island National Wildlife Refuge (GA), a distance of approximately 54 miles. The longest stretch of adjacent, unstabilized inlets is in Louisiana, where 17 inlets between a complex of breaches on the West Belle Pass barrier headland in Lafourche Parish and Beach Prong, located just to the west of the western boundary of the state Rockefeller Wildlife Refuge, have no stabilization structures. One of these inlets, however, has been dredged, namely the Freshwater Bayou Canal. South Carolina also has a lengthy section of coast with no stabilization structures, i.e., the 16 inlets from a small unnamed inlet separating the Tom Yawkey Wildlife Center Heritage Preserve from the Santee Coastal Reserve Wildlife Management Area in Georgetown County to Dewees Inlet in Charleston County (although 1 of them has been modified by dredging: Clarks Creek Channel within Bulls Bay). Mississippi is the only state to have no stabilization structures at any of its 6 inlets; all are within Gulf Islands National Seashore where all of the barrier islands are undeveloped (4 of the 6 inlets are dredged, however).

The highest number of inlets that have been modified is along the Atlantic coast of Florida, where 17 of 19 stabilized inlets are adjacent to one another, extending from the St. John's River in Duval County to Norris Cut in Miami-Dade County, a distance of approximately 341 miles; a shorebird would have to travel about 344 miles between unstabilized inlets along this stretch of coast.

State-specific Results

North Carolina

Twenty tidal inlets currently are open in North Carolina, of which 7 (35%) have been stabilized with hard structures along at least one shoulder (Table 2). Of the inlets with hard structures, 2 have jetties (one with a single jetty and one with dual jetties), one has a terminal groin, one has a landlocked groin, one has a sandbag groin field, one has a non-functional / submerged breakwater, and 2 have sandbag revetments (one of which also has sheet piling). Sixteen (80%) inlets have been or continue to be periodically dredged for navigation or erosion control purposes to redirect channels away from buildings or infrastructure. Three inlets (Masonboro Inlet in 1947, Tubbs Inlet in 1970, and Mason Inlet in 2002) have been relocated, with artificial closures of existing inlets and openings of new inlets nearby, whereas another inlet (Bogue Inlet) has had its main channel relocated in 2006 (Masterson et al. 1973, Cleary and Marden 1999, Erickson et al. 2003, Cleary and Fitzgerald 2003, USACE 2004). New inlets have been cut artificially in two locations (Carolina Beach Inlet in 1953, New Drum Inlet in 1971), but neither has been hardened with structures (Pilkey et al. 1998, Mallinson et al. 2008). The shoal complexes of at least 4 inlets have been mined to supply sediment for beach nourishment projects (Shallotte Inlet in 2001, Bogue Inlet in 2005, Barden Inlet in 2006, and Rich Inlet in 1996, 1999 and 2002); two additional inlets have been proposed for mining – Mason Inlet (for Figure Eight Island) and New River Inlet (for Onslow Beach).

At least 11 inlets or breaches have been closed artificially after having been opened by storm events (Mary's Inlet in the early 1950s, an unnamed breach in Long Beach on Oak Island in 1958, Masonboro Inlet South in 1959, Buxton Inlet in 1963, Moore's Inlet in 1965, Isabel Inlet in 2003, and unnamed breaches on Topsail Island in 1996 and 3 on Hatteras Island near Rodanthe in 2011), while at least 8 inlets were allowed to close as a result of natural coastal processes (New Inlet in 1945, an unnamed inlet on Long Beach in 1956, Mad Inlet in 1997, Old Topsail Inlet in 1998, New / Corncake Inlet in 1999, Old Drum Inlet in 1910, 1971 and 1999, New Drum Inlet in 2008-09, and New-Old Drum Inlet in 2009) (Pilkey et al. 1998, Cleary and Marden 1999, Wamsley and Kraus 2005, Mallinson et al. 2008, Google Earth 2012). Hurricane Isabel in 2003 opened a large new inlet on Hatteras Island near the village of Hatteras, south of Cape Hatteras and within the Cape Hatteras National Seashore, severing North Carolina Highway 12 (Mallinson et al. 2008, Morgan 2009a). The USACE, on behalf of the North Carolina Department of Transportation (NC DOT) and Federal Emergency Management Agency filled in the inlet with material dredged from nearby in 40 days, allowing vehicular traffic to be restored in near record-time (Wamsley and Kraus 2005, Mallinson et al. 2008). Hurricane Irene in August 2011 opened at least 2 inlets and other breaches near Rodanthe on Hatteras Island, north of Cape Hatteras and within or adjacent to the Pea Island National Wildlife Refuge and Cape Hatteras National Seashore; of these breaches, all but one were filled manually within two months while the most significant new inlet (the Pea Island Breach) was temporarily bridged by the NC DOT while long-term alternatives are being evaluated (NC DOT, http://www.ncdot.gov/travel/nc12recovery/). On the undeveloped Cape Lookout National Seashore, 2 inlets have opened since 1999 (New-Old Drum and Ophelia Inlets) and three have naturally closed (Old Drum Inlet, New-Old Drum, and New Drum Inlet – the last of which merged with Ophelia Inlet in 2008-09). Recent studies forecast that the North Carolina Outer Banks will continue to see a series of new inlets open as sea level rises and climate changes (Riggs and Ames 2003, Mallinson et al. 2008).

Table 2. Open tidal inlets from north to south along the North Carolina coast as of December 2011 with actual (X) and proposed (P) habitat modification(s) at each. Note that an X in the Jetties column indicates one jetty is present and a D indicates two (dual) jetties.

Inlet	Type of Habitat Modification							
	Artificially created	Jetties	Terminal groins / groin field	Seawalls / revetments	Breakwaters	Dredging	Relocation of channel or inlet	Mined for beach fill
Oregon Inlet			X			X		
Pea Island Breach				X				
Hatteras Inlet						X		
Ocracoke Inlet						X		
Ophelia Inlet								
Barden Inlet					X	X		X
Beaufort Inlet		X	X			X		
Bogue Inlet				X		X	X	X
Bear Inlet								
Brown's Inlet								
New River Inlet						X		P
New Topsail Inlet			P			X		
Rich Inlet						X	P	X
Mason Inlet						X	X	P
Masonboro Inlet		D				X	X	
Carolina Beach Inlet	X					X		
Cape Fear River			X			X		
Lockwood's Folly Inlet						X		
Shallotte Inlet						X		X
Tubbs Inlet						X	X	

South Carolina

South Carolina currently has 47 tidal inlets open, of which 17 (36%) have been stabilized with hard structures along at least one shoreline (Table 3). Of the inlets with hard structures, 10 have some form of groins (adjacent groins, terminal groins, and/or groin fields), 4 have dual jetties, and 6 have rock revetments and/or seawalls. Eleven (23%) inlets have been or continue to be dredged for navigation or erosion control purposes (i.e., to redirect channels away from buildings or infrastructure). One inlet (Captain Sam's Inlet) has been relocated twice (in 1983 and 1996), with artificial closures of the existing inlet and opening of a new inlet in a nearby location (Kana et al. 1987, Lennon et al. 1996). In addition, an unnamed inlet near Stono Inlet was relocated in 2006 and mined material from the adjacent lower beach was used as beach fill on Kiawah Island to the west (USFWS 2006). No new inlets have been artificially created in South Carolina (except for those that have been relocated). One inlet or breach on Pawley's Island was closed artificially after creation by Hurricane Hugo in 1989 (Lennon et al. 1996). Eleven new inlets or breaches have opened as a result of storms since 1989, with Hurricane Irene in August 2011 opening three new breaches on Cape Island at Cape Romain NWR most recently (Lennon et al. 1996, Sarah Dawsey, USFWS Cape Romain NWR pers. comm.). At least 3 inlets have closed naturally, one in Cherry Grove in the late 1950s (Lennon et al. 1996) and two at Cape Romain NWR around 1992 and 2006 (Sarah Dawsey, USFWS, pers. comm.). The shoal complexes of at least 3 inlets have been mined to supply sediment for beach nourishment projects (Hog Inlet in 1989/1990, Murrell's Inlet in 1989/1990, and Fripp Inlet in 1975).

Table 3. Open tidal inlets from north to south along the South Carolina coast as of December 2011 with actual (X) habitat modification(s) at each. Note that an X in the Jetties column indicates one jetty is present and a D indicates two (dual) jetties.

Inlet	Type of Habitat Modification							
	Artificially created	Jetties	Terminal groins / groin field	Seawalls / revetments	Breakwaters	Dredging	Relocation of channel or inlet	Mined for beach fill
Little River Inlet		D				X		
Hog Inlet				X		X		X
Murrell's Inlet		D				X		X
Midway Inlet								
Pawleys Inlet			X					
North Inlet								
Winyah Bay Entrance		D				X		
small unnamed inlet separating Cat or Sand Island from South Island								
North Santee River								
South Santee River								
small unnamed inlet into a lagoon on the north end of Murphy Island adjacent to South Santee River mouth								
Cape Romain Harbor (between Murphy and Cape Islands)								
Unnamed inlet 1 at south end of Cape Island								
Unnamed inlet 2 at south end of Cape Island								
Unnamed inlet 3 at south end of Cape Island								
Unnamed inlet separating Cape Island from Lighthouse Island								
Key Inlet								
Unnamed inlet 1 on Raccoon Key								
Unnamed inlet 2 on Raccoon Key								
Bulls Bay						X		
Price Inlet								
Capers Inlet								
Dewees Inlet								
Breach Inlet			X	X				
Charleston Harbor Entrance		D				X		
Lighthouse Inlet			X					
Stono Inlet						X		
small unnamed inlet into tidal lagoon on east end of Kiawah Island						X	X	
Captain Sams Inlet						X	X	

Inlet	Type of Habitat Modification							
	Artificially created	Jetties	Terminal groins / groin field	Seawalls / revetments	Breakwaters	Dredging	Relocation of channel or inlet	Mined for beach fill
North Edisto River Inlet								
South Creek Inlet								
Frampton Inlet								
Jeremy Inlet				X				
St. Helena Sound Entrance			X					
Johnson Creek			X					
Fripp Inlet			X			X		X
Skull Inlet			X	X				
Price Creek								
Pritchards Inlet								
small unnamed inlet on Little Capers Island								
Trenchards Inlet								
Morse Creek								
Port Royal Sound Entrance			X			X		
Folly Creek			X					
Calibogue Sound Entrance				X				
Mungen Creek			X	X				
Wright River								

Georgia

There are 23 tidal inlets currently open in Georgia, of which 5 (22%) are stabilized with hard structures along at least one shoulder (Table 4). Of the inlets with hard structures, 2 have terminal groins, 2 have adjacent groin fields, 1 has dual jetties, 1 has an offshore breakwater, and 4 have rock revetments and/or seawalls. Three (13%) inlets have been dredged for navigation or erosion control purposes. No inlets have been relocated, artificially opened or artificially closed in Georgia. The inlet separating Williamson Island from Little Tybee Island opened naturally sometime between 1957 and 1960 (Clayton et al. 1992), but no other inlets have naturally opened or closed since then. The shoal complex of at least one inlet has been mined to supply sediment for a beach nourishment project (Hampton River Inlet in 1990).

Table 4. Open tidal inlets from north to south along the Georgia coast as of December 2011 with actual (X) habitat modification(s) at each. Note that an X in the Jetties column indicates one jetty is present and a D indicates two (dual) jetties.

Inlet	Type of Habitat Modification							
	Artificially created	Jetties	Terminal groins / groin field	Seawalls / revetments	Breakwaters	Dredging	Relocation of channel or inlet	Mined for beach fill
Savannah River Entrance		D			X	X		
Savannah River South Channel			X	X				
Tybee Inlet			X	X				
Little Tybee Slough								
Little Tybee Creek								
Wassaw Sound Entrance								
Ossabaw Sound Entrance								
Bradley Slough								
Unnamed slough on middle of Ossabaw Island								
Big Slough								
Saint Catherine's Sound Entrance								
Seaside Inlet (at Fish Creek)								
McQueen Inlet								
Sapelo Sound Entrance								
Cabretta Inlet								
Big Hole (between Cabretta and Sapelo Islands)								
Doboy Sound Entrance								
Altamaha Sound Entrance								
Hampton River Inlet						X		X
Gould's Inlet				X				
Saint Simons Sound Entrance				X		X		
Saint Andrews Sound Entrance								
Christmas Creek								

Florida Atlantic Coast

Twenty-one tidal inlets currently are open on Florida's Atlantic coast from the Georgia state line south to Key Biscayne, of which 19 (90%) have been stabilized with hard structures along at least one shoulder (Table 5). Of the inlets with hard structures, 2 have terminal groins, 16 have jetties (all 16 with 2 jetties), 1 has a rock revetment, 2 have offshore breakwaters and 1 has an adjacent groin field. Sixteen (76%) inlets have been dredged for navigation or erosion control purposes. No inlets have been relocated, but new inlets have been cut artificially in 10 (48%) locations for various purposes (St. Augustine, Sebastian, Fort Pierce, St. Lucie, Lake Worth, Boynton, Boca Raton, Port Everglades, Haulover, and Government Cut Inlets); all of these inlets were cut where no inlets existed at the time except for Boca Raton Inlet, which has been repeatedly reopened following natural closures by storms from 1966-1969; all of the new inlets have jetties (Sargent 1988, Bush et al. 2004, Palm Beach County 2003). No inlets have been closed artificially after having been opened by storms , but four inlets have closed as a result of natural coastal processes: old St. Augustine Inlet, Sebastian Inlet in 1941, an inlet near Lake Worth in 1919, and Boca

Raton Inlet several times from 1966-1969. Old St. Augustine Inlet between Villano Beach and Conch Island and the one near Black Rocks near Lake Worth were allowed to remain closed, with the other two being reopened artificially. A nor'easter in 1973 opened a small breach near Ponce Inlet, which presumably closed shortly thereafter (Bush et al. 2004). An ephemeral inlet periodically opens and closes in the Summer Haven area south of Matanzas Inlet; it is currently closed (John Milio, USFWS, pers. Communication 3/8/12). The shoal complexes of at least three inlets have been mined to supply sediment for a beach nourishment project (Boca Raton Inlet in 1985, Jupiter Inlet in 1995, and St. Augustine Inlet in 1996;Cialone and Stauble 1998, Bush et al. 2004).

Table 5. Open tidal inlets from north to south along the east Florida coast as of December 2011 with actual (X) habitat modification(s) at each. Note that an X in the Jetties column indicates one jetty is present and a D indicates two (dual) jetties.

Inlet	Type of Habitat Modification							
	Artificially created	Jetties	Terminal groins / groin field	Seawalls / revetments	Breakwaters	Dredging	Relocation of channel or inlet	Mined for beach fill
St. Mary's Entrance		D				X		
Nassau Sound Entrance			X					
Fort George Inlet								
St. John's River		D				X		
St. Augustine Inlet	X	D				X		X
Matanzas Inlet				X	X			
Ponce de Leon Inlet		D				X		
Port Canaveral		D				X		
Sebastian Inlet	X	D				X		
Fort Pierce Inlet	X	D				X		
St. Lucie Inlet	X	D			X	X		
Jupiter Inlet		D				X		X
Lake Worth Inlet	X	D				X		
Boynton Inlet (aka South Lake Worth Inlet)	X	D				X		
Boca Raton Inlet	X	D				X		X
Hillsboro Inlet		D				X		
Port Everglades Channel	X	D				X		
Haulover Inlet	X	D	X			X		
Government Cut	X	D				X		
Norris Cut			X					
Bear Cut								

Florida Gulf Coast

There are 48 tidal inlets currently open along Florida's Gulf coast between the Alabama state line on the panhandle and Cape Romano, of which 20 (42%) have been stabilized with hard structures along at least one shoulder (Table 6). Of the inlets with hard structures, 7 have some sort of groin (adjacent groins, terminal groins and/or groin fields), 11 have jetties (3 inlets with 1 jetty and 8 inlets with dual jetties), 1 has an offshore breakwater, and 5 have rock revetments and/or seawalls. At least 22 (46%) inlets have been or continue to be dredged periodically for various purposes. No inlets have been relocated along the Gulf coast of Florida, although two new inlets have been opened artificially to replace existing inlets which subsequently closed naturally – new East Pass (Destin Pass) and West Pass (Panama City).

New inlets have been cut artificially (either in new locations or to reopen an inlet that closed naturally) in 8 locations (5 of which now have hard structures): East Pass (Destin Pass) in 1926, West Pass (Saint Andrews Bay - Panama City Harbor) in 1933-1934, Venice Inlet before 1937, Bob Sikes Cut in 1954, Clam Pass in 1976 and again in 1981, Midnight Pass in 1983, Blind Pass (Lee County) in 2000 and again in 2009, and St. Andrew Pass on Crooked Island in 2001; a ninth inlet, Big Hickory Inlet, was reopened artificially in 1976 but it closed naturally in 1979 and then has reopened naturally since (Sargent 1988, Davis and Gibeaut 1990, Bush et al. 2001, Antonini et al. 2002). Mexico Beach Canal, also artificially created, has been stabilized on both shorelines, and requires dredging to remain open. However, it was not included in this assessment because it is a manmade canal with no discernible tidal inlet geomorphology. At least one inlet (Philips Inlet) was closed artificially to block oil spilled in the Deepwater Horizon disaster, and at least 17 inlets were allowed to close as a result of natural coastal processes (Sargent 1988, Davis and Gibeaut 1990, Bush et al. 2001, Antonini et al. 2002, Dezember 2010). At least 12 inlets have been opened naturally by storms along the Florida Gulf coast (Sargent 1988, Davis and Gibeaut 1990, Antonini et al. 1999, Bush et al. 2001, Antonini et al. 2002). The shoal complexes of at least 6 inlets have been mined to supply sediment for beach nourishment projects: Pass-a-Grille Channel in the 1980s, Redfish Pass in 1981 and 1988, Johns Pass in 1988, Longboat Pass in 1993, New Pass (Sarasota County) in 1993, and Caxambas Pass in 1990, 1997, 2006 and proposed again for 2012 (Davis and Gibeaut 1990, Cialone and Stauble 1998, Bush et al. 2001, Antonini et al. 2002, Coastal Engineering Consultants 2012). Altogether, 24 of the 48 (50%) west Florida inlets have been modified in some manner.

Table 6. Open tidal inlets from north (west) to south (east) along the west Florida coast as of December 2011 with actual (X) habitat modifications at each. Note that an X in the Jetties column indicates one jetty is present and a D indicates two (dual) jetties.

Inlet	Type of Habitat Modification							
	Artificially created	Jetties	Terminal groins / groin field	Seawalls / revetments	Breakwaters	Dredging	Relocation of channel or inlet	Mined for beach fill
Pensacola Pass			X			X		
East Pass (aka Destin Pass)	X	D				X		
West Pass (St. Andrew's Bay - Panama City)	X	D				X		
St. Andrew Sound Entrance								
Indian Pass								
West Pass (between St. Vincent and Little St. George Islands)								
Bob Sikes Cut	X	D				X		
East Pass (between eastern St. George Island State Park and Dog Islands)								
Unnamed pass between Anclote Key and Anclote Bar to the north								
Unnamed pass between Three Rooker								

Inlet	Type of Habitat Modification							
	Artificially created	Jetties	Terminal groins / groin field	Seawalls / revetments	Breakwaters	Dredging	Relocation of channel or inlet	Mined for beach fill
Bar and Anclote Key								
Unnamed pass between Three Rooker Island and Three Rooker Bar								
St. Joseph Sound (between Honeymoon and Three Rooker Islands)								
Hurricane Pass								
Clearwater Pass		D				X		
Johns Pass		X		X		X		X
Blind Pass (Pinellas County)		D						X
Pass-a-Grille Channel		X				X		X
Bunces Pass								
Unnamed inlet into lagoon on Mullet Key at Fort De Soto Park								
Egmont Channel				X		X		
Southwest Channel								
Passage Key Inlet								
Longboat Pass		X				X		X
New Pass (Sarasota County)			X	X		X		X
Big Sarasota Pass				X				
Venice Inlet	X	D				X		
Stump Pass						X		
Gasparilla Pass								
Boca Grande Pass			X			X		
Captiva Pass								
Redfish Pass			X			X		X
Blind Pass (Lee County)	X		X			X		
Matanzas Pass						X		
Big Carlos Pass								
New Pass (Lee County)								
Unnamed breach in Big Hickory Island								
Big Hickory Pass	X[†]		X			X		
Wiggins Pass						X		
Clam Pass	X					X		
Doctors Pass		D				X		
Gordon Pass		D				X		
Little Marco Pass								
Big Marco Pass								
Caxambas Pass			X	X	X	X		X
Unnamed breach between Dickman's and Kice Islands								
Blind Pass (Collier County)								
Unnamed pass between Big Morgan Island and the island to the north								
Morgan Pass								

† Big Hickory Inlet closed naturally and was reopened artificially in 1976, but the inlet closed again in 1979; the existing Big Hickory Inlet naturally opened since that time.

Alabama

All 4 tidal inlets currently open in Alabama have been stabilized with hard structures along at least one shoulder (Table 7): one has a groin field, one has dual jetties, one is "temporarily" closed with a rock berm, and 3 have rock or sheet pile revetments and/or seawalls. Three (75%) inlets have been or continue to be dredged periodically. No inlets have been relocated. No new inlets have been cut artificially , but West Pass (aka Little Lagoon Pass) was temporarily closed with a sand dike during the Deepwater Horizon oil spill response effort in May 2010 and then was artificially reopened in September 2010 (Dezember 2010). At least two inlets created by hurricanes were allowed to close on Dauphin Island as a result of natural coastal processes (Bush et al. 2001). Hurricane Ivan in 2004 opened a new inlet at Pine Beach in the Bon Secour National Wildlife Refuge (Morgan 2009a), but the inlet appear to be closed in 2009 Google Earth imagery. The shoal complexes of no inlets have been mined to supply sediment for beach nourishment projects in Alabama.

Dauphin Island has had several inlets cut across the island by hurricanes, including a 5-mile wide shallow inlet cut by an early 20th century hurricane (which had closed by 1942), a September 1948 hurricane, and Hurricane Katrina in 2005 (Bush et al. 2001, USACE 2011). Katrina Cut, opened on the western end of Dauphin Island by Hurricane Katrina, was "temporarily" closed with a rock berm or dike in 2010-2011 with the original purpose to block oil from the Deepwater Horizon spill from reaching Mississippi Sound. Alabama has since requested that the USACE allow the berm to remain as a permanent structure (USACE 2011).

Table 7. Open tidal inlets from west to east along the Alabama coast as of December 2011 with actual (X) habitat modification(s) at each. Note that an X in the Jetties column indicates one jetty is present and a D indicates two (dual) jetties.

Inlet	Type of Habitat Modification							
	Artificially created	Jetties	Terminal groins / groin field	Seawalls / revetments	Breakwaters	Dredging	Relocation of channel or inlet	Mined for beach fill
Katrina Cut†								
Mobile Pass			X	X		X		
West Pass‡				X		X		
Perdido Pass		D		X		X		

† Katrina Cut was "temporarily" closed with a rock dike as part of the Deepwater Horizon oil spill response efforts in 2010 but the state is currently seeking permission from the USACE to make the structure permanent (USACE 2011).

‡ West Pass (aka Little Lagoon Pass) was temporarily closed with a sand dike from in May 2010 as part of the Deepwater Horizon oil spill response efforts but was artificially reopened in September 2010 (Dezember 2010).

Mississippi

Six tidal inlets currently are open in Mississippi, none of which has been stabilized with hard structures (Table 8). Four (67%) are dredged for navigation (Morton 2008). No new inlets have been cut artificially in barrier islands, been closed artificially after having been opened by storms, been relocated, or naturally closed in recent years. At least 7 inlets have been opened by storms, including Camille Cut opened by Hurricane Camille in 1969 on Ship Island, thereby creating West and East Ship Islands (Bowden 1994, Otvos 2006, Otvos and Carter 2008). At least 7 breaches or inlets have closed naturally since 1952 (Otvos and Carter 2008, Stockdon et al. 2010).

The Mississippi Coastal Improvements Program (MsCIP) comprehensive plan for coastal Mississippi proposes the use of dredged material from the Horn Island ship channel to provide beach fill for a portion of West Ship Island within Gulf Islands National Seashore (NPS 2010) and to close Camille Cut between West and East Ship Islands with sediment mined from Sand Island (USACE 2009, Paul Necaise, USFWS, pers. Communication 3/6/12). No inlet shoal complexes have been mined to supply sediment for beach nourishment projects in Mississippi.

Table 8. Open tidal inlets from west to east along the Mississippi coast as of December 2011 with actual (X) habitat modifications at each.

Inlet	Type of Habitat Modification							
	Artificially created	Jetties	Terminal groins / groin field	Seawalls / revetments	Breakwaters	Dredging	Relocation of channel or inlet	Mined for beach fill
Ship Island Pass						X		
Camille Cut†								
Dog Keys Pass						X		
Unnamed inlet between Sand Island and Horn Island								
Horn Island Pass						X		
Petit Bois Pass						X		

†Camille Cut is proposed to be artificially closed as part of the MsCIP comprehensive plan.

Louisiana

At least 34 tidal passes (inlets) with sandy shorelines are currently open along the deltaic coast of Louisiana. This total does not include passes without sandy shorelines and counts the Chandeleur Island chain and the West Belle Pass barrier headland as one inlet complex each. The Chandeleur Island chain was fragmented with 44 inlets by Hurricane Katrina in 2005 but roughly 11 inlets were closed by the state during the Deepwater Horizon oil spill response effort, resulting in a highly dynamic and uncertain series of islets and inlets. As of September 2011 approximately 7 breaches were present along the West Belle Pass barrier headland shoreline (none of which existed in 2010), but a federally-funded beach restoration project scheduled for 2012 would close any of these breaches that remain open at the time of construction. The vast majority of passes or inlets in Louisiana are connected to extensive wetland complexes and are not inlets separating barrier islands as typically are found throughout the rest of the range (and as described in Figure 1); nevertheless, these delta-influenced and sediment-starved inlets often provide valuable shorebird and waterbird habitat.

Of the 34 passes open in 2011, 7 (21%) have been stabilized with hard structures along at least one shoreline. Of these, 7 have jetties (2 inlets with 1 jetty and 5 inlets with dual jetties), 1 has a groin, and 1 has a rock revetment or seawall (Table 9). At least 9 (26%) sandy passes in Louisiana that have been dredged for navigation or other purposes: Calcasieu Pass, Mermentau River, Freshwater Bayou, Belle Pass (Bayou Lafourche), Barataria Pass, Pass La Mer, Chaland Pass, Fontanelle Pass, and South Pass of the Mississippi River; Southwest Pass of the Mississippi River is also federally maintained with dredging, but as of 2011 does not have sandy shorelines adjacent to the distributary channel and thus was not included in this analysis. One inlet channel (Bayou Lafourche) was relocated in 1968, with artificial closure of the existing navigational channel and the opening of a new channel 300 feet to the west (Sargent and Bottin 1989a). No new inlets have been cut artificially (not including oil and gas industry canals).

Breaches cut by Hurricane Andrew (1992) on Raccoon Island were closed artificially (Louisiana Department of Wildlife and Fisheries, http://www.wlf.louisiana.gov/refuge/terrebonne-barrier-islands-refuge). Several projects funded under the Coastal Wetlands Planning, Protection and Restoration Act (CWPPRA) have artificially closed inlets while restoring Louisiana's coast, with 3 breaches having been closed on the Chaland headland in 2006 (CWPPRA Project BA-38), approximately 8 breaches on East Timbalier Island in 1999-2000 (CWPPRA Projects TE-25 and TE-30), 3 breaches on Trinity Island in 1998 (CWPPRA Project TE-24), and the Coupe Nouvelle breach on Whiskey Island in 1998 (CWPPRA Project TE-27) (Louisiana Office of Coastal Protection and Restoration, http://www.lacoast.gov). Approximately 29 inlets were closed in response to the Deepwater Horizon oil spill, including 2 on Elmer's Island in Jefferson Parish, approximately 11 in the Chandeleur Island chain, approximately 6 on Scofield Island, approximately 6 on Pelican Island, and approximately 4 on Shell Island as part of Louisiana's sand berms building project (National Commission 2011, Google Earth 2012, Louisiana Office of Coastal Protection and Restoration (http://coastal.louisiana.gov/index.cfm?md=pagebuilder&tmp=home&pid=131 and http://www.lacoast.gov). In addition, any of the 7 breaches on the West Belle Pass barrier headland that are open at the time of construction will be closed as part of a barrier island restoration project funded by the National Oceanic and Atmospheric Administration in October 2011 (NOAA, http://www.habitat.noaa.gov/hlbarrierislandrestoration.html). Altogether at least 46 inlets (including those on the Chandeleur Island chain) have been closed artificially in Louisiana in recent years and 7 more likely to be closed in 2012.

Hurricanes Katrina, Rita and others created several dozen new inlets and breaches along the Louisiana coast, most notably within the Chandeleur Island chain of Breton National Wildlife Refuge, where the island was segmented into 45 islets and 44 inlets/breaches following Hurricane Katrina (Stockdon et al. 2007, Sallenger et al. 2009). An unknown number of inlets have closed as a result of natural coastal processes but the number is likely small as the natural closure of storm breaches during poststorm recovery periods is limited by a restricted supply of sandy sediments in coastal Louisiana and the relatively short period between storms in recent years. At least 2 inlet shoal complexes have been mined to supply sediment for beach nourishment projects (Pass La Mer in 2009 and Chaland Pass in 2009).

Table 9. Open tidal inlets from west to east along the Louisiana coast as of December 2011 with actual (X) habitat modification(s) at each. Note that an X in the Jetties column indicates one jetty is present and a D indicates two (dual) jetties. Also note that the Chandeleur Island complex is listed here as one entry due to its recent disintegration into dozens of islets, closure of numerous inlets during Deepwater Horizon oil spill response efforts, and uncertain stability.

Inlet	Type of Habitat Modification							
	Artificially created	Jetties	Terminal groins / groin field	Seawalls / revetments	Breakwaters	Dredging	Relocation of channel or inlet	Mined for beach fill
Unnamed breach in sandbar/spit adjacent to eastern jetty at Sabine Pass								
Calcasieu Pass		D				X		
Mermentau River Navigation Channel		D				X		
Beach Prong (west of the western boundary of Rockefeller Refuge)								
Joseph Harbor Bayou								
Little Constance Bayou								
Pigeon Bayou								
East Little Constance Bayou								
Rollover Bayou								
Freshwater Bayou Canal						X		
Mosquito Bayou								
Oyster Bayou								
Goreau River								
Bayou de West								
Jack Stout Bayou								
Fish Bayou								
Turtle Bayou								
Whiskey Pass								
Small inlet complex at eastern end of East Timbalier Island								
West Belle Pass barrier headland breaches†								
Belle Pass (i.e., Bayou Lafourche)		D				X	X	
Caminada Pass		X						
Barataria Pass		X		X		X		
Pass Abel								
Bayou Quatre Pass								
Pass Ronquille								
Unnamed breach two west of Pass La Mer								
Unnamed breach immediately west of Pass La Mer								
Pass La Mer						X		X
Chaland Pass						X		X
Fontanelle Pass (i.e., Empire Waterway)		D	X			X		
Scofield Bayou								
South Pass		D				X		
Chandeleur Island complex								

† Any breaches open along the West Belle Pass barrier headland are proposed to be closed in 2012 as part of a federally-funded restoration project (NOAA, http://www.habitat.noaa.gov/hlbarrierislandrestoration.html).

Texas

Eighteen tidal inlets currently are open in Texas, of which 10 (56%) have been stabilized with hard structures along at least one shoulder (Table 10). Of the latter, 9 have dual jetties, one has groins and one has sheet pile revetments. At least 13 (72%) inlets have been or continue to be dredged periodically for navigation or other purposes; 8 inlets are federally maintained as navigation channels and 4 have been dredged only once (Sargent and Bottin 1989b, USACE 1992, Kraus 2007). [Corpus Christi Pass, now closed and therefore not included in the above count of 13, was dredged in 1928 and 1938 before its 1943 closure (the inlet opens and closes intermittently due to storms; USACE 1992)]. The mouth of the Brazos River was relocated 5 miles to the south in 1929 for flood control purposes, but the old river mouth was not closed and currently exists as the Freeport Ship Channel (Sargent and Bottin 1989b, Kraus 2007). The San Bernard River mouth and Bolivar Roads (Galveston Bay) inlets have been relocated (Woody Woodrow, USFWS, pers. Communication 3/6/12). New inlets have been cut artificially in 11 locations for fish passage, flood relief and other purposes in Texas: the Brazos River (Diversion Channel) in 1929, the Colorado River Navigation Channel in 1934, Yarbrough Pass in 1952, Mansfield Pass in 1957 and 1962, Rollover Fish Pass in 1954-55, Matagorda Ship Channel in the 1962, Mustang Island Fish Pass in 1972, McCabe Cut in 1983, Cedar Bayou most recently in 1988 (also in 1939 and 1959), Mitchell's Cut in 1989, and Packery Channel in 2003-06. Four of the artificially created inlets have jetties today. The artificial cuts at both Mustang Island Fish Pass and Yarborough Pass were unsuccessful and both passages have closed naturally, although jetties still exist on the Gulf beach side of Mustang Island Fish Pass (Sargent and Bottin 1989b, USACE 1992, Wamsley and Kraus 2005, Kraus 2007, Williams et al. 2007, Thomas et al. 2011).

Table 10. Open tidal inlets from west (south) to east (north) along the Texas coast as of December 2011 with actual (X) and proposed (P) habitat modification(s) at each. Note that an X in the Jetties column indicates one jetty is present and a D indicates two (dual) jetties.

Inlet	Type of Habitat Modification							
	Artificially created	Jetties	Terminal groins / groin field	Seawalls / revetments	Breakwaters	Dredging	Relocation of channel or inlet	Mined for beach fill
Rio Grande River Mouth								
Brazos-Santiago Pass		D	X			X		
Mansfield Pass	X	D				X		
Packery Channel	X	D				X		
Aransas Pass		D				X		
Pass Cavallo						X		
Matagorda Ship Channel	X	D				X		
Colorado River Mouth	X	D				X		
Mitchell's Cut	X					X		
San Bernard River Mouth						X	X	
Brazos River Diversion Channel	X							
Bryan Beach Cut								
Quintana Beach Cut								

Inlet	Type of Habitat Modification							
	Artificially created	Jetties	Terminal groins / groin field	Seawalls / revetments	Breakwaters	Dredging	Relocation of channel or inlet	Mined for beach fill
Freeport Ship Channel		**D**				**X**		
San Luis Pass								**P**
Bolivar Roads (Galveston Bay)		**D**				**X**	**X**	**X**
Rollover Pass	**X**			**X**		**X**		**X**
Sabine Pass		**D**				**X**		

Three inlets have been closed artificially: Boca Chica Pass in 1868, Cedar Bayou in 1979 as part of IXTOC oil spill response efforts, and McCabe Cut in 1989 after Mitchell's Cut was opened nearby (USACE 1992). At least 14 inlets have been allowed to close as a result of natural coastal processes: Bryan Beach Cut 2, Wolf Island Cut, Cedar Lakes Pass, Matagorda Peninsula Cut, Brown Cedar Cut, 3-mile Cut, Greens Bayou, Cedar Bayou, Mustang Island Fish Pass, Corpus Christi Pass, Newport Pass, Yarborough Pass, Mansfield Pass and Boca Chica Pass (Sargent and Bottin 1989b, USACE 1992, Bates 2004, Kraus 2007, Google Earth 2012, Jennifer Wilson, USFWS, pers. Communication 3/7/12). A permit has been issued to reopen Cedar Bayou artificially as a fish pass, but the project has not been constructed yet (Robyn Cobb, USFWS, pers. Communication 3/7/12). At least 5 inlets are hurricane overwash channels that open and close naturally in response to storms, including Brown Cedar Cut, Greens Bayou, Cedar Bayou, Corpus Christi Pass and Newport Pass (USACE 1992, 2003); Cedar Lakes Pass is also a hurricane overwash channel that is influenced by river flows from the San Bernard River but is currently closed (Woody Woodrow, USFWS, pers. communication 3/7/12). Hurricane Allen reportedly cut 42 breaches across South Padre Island in 1980 (St. John 1991), Hurricane Bret opened a dozen breaches on Padre Island in 1999, and Hurricane Camille opened numerous breaches on Matagorda Island in 1969 (Robyn Cobb, USFWS, pers. Communication 3/7/12). Several overwash breaches appear in Google Earth imagery from 2011 on southern North Padre, South Padre and Brazos Islands from more recent storm events.

Bolivar Roads (Galveston Bay) has been mined to supply sediment for beach nourishment projects and the flood tidal delta of San Luis Pass has been proposed for mining as a source for a beach restoration project (Woody Woodrow, USFWS, pers. communication 3/6/12; Robyn Cobb, USFWS, pers. communication 3/7/12). The USACE (1992) reported that 6 of the 8 federally maintained navigation channels contained suitable material for mining as a source for beach fill.

DISCUSSION

Over half (54%) of the sandy tidal inlet habitats within the U.S. continental migration and wintering range of the piping plover that existed in 2010-2011 has been modified within the last century or so by human actions, such as the construction of hard stabilization structures, dredging activities, sediment mining, and the artificial relocation, opening and closing of inlets. The Atlantic coast of Florida has the most contiguously modified habitat; by contrast, significant sections of the South Carolina, Georgia and Louisiana coasts have remained unmodified. Two-thirds or more of the inlets of North Carolina, eastern Florida, Alabama, Mississippi and Texas have been modified (Table 1).

The adverse direct and indirect impacts of hard stabilization structures, dredging, inlet relocations and mining can be significant. The impacts that jetties have on inlet and adjacent shoreline habitat have been described by Cleary and Marden (1999), Bush et al. (1996, 2001, 2004), Wamsley and Kraus (2005), Thomas et al. (2011) and many others. The maintenance of navigation channels by dredging, especially deep ship channels such as those in Alabama and Mississippi, can significantly alter the natural coastal processes on adjacent inlet shorelines, as described by Otvos (2006), Morton (2008), Otvos and Carter (2008), Beck and Wang (2009), and Stockdon et al. (2010). The relocation of inlets or the creation of new inlets often leads to immediate widening of the new inlet cut and loss of adjacent habitat, amongst other impacts; these responses have been described by Mason and Sorenson (1971), Masterson et al. (1973), USACE (1992), Cleary and Marden (1999), Cleary and Fitzgerald (2003), Erickson et al. (2003), Kraus et al. (2003), Wamsley and Kraus (2005) and Kraus (2007). Cialone and Stauble (1998) describe the impacts of mining ebb shoals within inlets as a source of beach fill material at 8 locations and provide a recommended monitoring protocol for future mining events; Dabees and Kraus (2008) also describe the impacts of ebb shoal mining. In brief, mining of ebb shoals disrupts the dynamic equilibrium of the inlet and its natural processes and can alter tidal currents and circulation, increase erosion of adjacent shorelines, expose adjacent shorelines to higher wave energy, modify the longshore sediment transport system, impair sediment bypassing across the inlet, and result in the migration of tidal channels and shoals (Cialone and Stauble 1998, Dabees and Kraus 2008).

The cumulative effects of the habitat modifications to sandy tidal inlets within the migration and wintering range of the piping plover are appreciable and significant. The cumulative effects catalogued herein are regional, covering all eight states of the U.S. continental mainland range of the wintering piping plover. Range-wide, over half (54%) of the inlets and their associated habitats have been modified. The cumulative environmental consequences are adverse, major and long-term.

The artificial opening and closing of inlets modifies this type of habitat in the most extreme manner, resulting in the artificial conversion of habitat types and alteration of their abundance and distribution. A high number of inlets (30) have been artificially created within the migration and wintering range of the piping plover, including 10 of the 21 inlets along the eastern Florida coast (Table 1). These artificially created inlets tend to need hard structures to remain open or stable, with 20 of the 30 (67%) of them having hard structures at present. An even higher number of inlets (64) have been artificially closed, the majority in Louisiana; artificial closure of inlets results in complete loss of inlet habitat. One inlet in Texas was closed in response to the IXTOC oil spill in 1979, and 32 others in 2010-2011 because of the Deepwater Horizon oil spill. Of the latter, 29 are located in Louisiana, 2 in Alabama and 1 in Florida. To date only one of these inlets, West (Little Lagoon) Pass in Gulf Shores, Alabama, has been reopened, and the rest remain closed with no current plans for them to be reopened. The other inlets that have been artificially closed in Louisiana tend to be barrier island restoration projects because many of the state's barrier islands are disintegrating (Otvos 2006, Morton 2008, Otvos and Carter 2008).

The dredging of navigation channels or to relocate inlet channels for erosion control purposes also contributes to the cumulative effects by removing or redistributing the local and regional sediment supply; the maintenance dredging of deep ship channels can convert a natural inlet that normally bypasses sediment from one shoreline to the other into a sediment sink in which sediment no longer bypasses the inlet. Of the dredged inlets included in this analysis, dredging efforts began as early as the 1800s and continue to the present, generating long-term and even permanent effects on inlet habitat; at least 11 inlets have been dredged since the 19th Century, with the Cape Fear River (NC) having been dredged as early as 1826 and Mobile Pass (AL) since 1857. Dredging conducted every year or every 2 to 3 years results in continual perturbations and modifications to inlet and adjacent shoreline habitat. The volumes of sediment removed can be major, with 2.2 million cubic yards of sediment being removed on average every 1.9 years from the Galveston Bay Entrance (TX) and 3.6 million cubic yards of sediment removed from Sabine Pass (TX) on average every 1.4 years (USACE 1992). The mining of inlet shoals also removes massive amounts of sediment, with 1.98 million cubic yards mined for beach fill from Longboat Pass (FL) in 1998, 1.7 million cubic yards from Shallotte Inlet (NC) in 2001 and 1.6 million cubic yards from Redfish Pass (FL) in 1988 (Cialone and Stauble 1998, USACE 2004). This mining of material from inlet shoals for use as beach fill is not equivalent to the natural sediment bypassing that occurs at unmodified inlets for several reasons, most notably for the massive volumes involved that are "transported" virtually instantaneously instead of gradually and continuously and for the placement of the material outside of the immediate inlet vicinity, where it would naturally bypass. All of these dredging and mining impacts are range-wide and are being conducted in every state.

The hard stabilization of inlets is another contributor to the appreciable cumulative adverse effects to inlet habitat along the southeastern Atlantic and Gulf coasts. The construction of jetties, groins, seawalls and revetments leads to habitat loss and both direct and indirect impacts to adjacent shorelines. Habitat modifications resulting from the construction of hard structures are long-term and permanent; at least 13 inlets across 6 of the 8 states containing have hard structures dating from the 19th Century. These effects are on-going, cumulative, and increasing in intensity, as hard structures continue to be built as recently as 2011 and others proposed for 2012. With sea level rising and global climate change altering storm dynamics, the pressure to modify the remaining half of sandy tidal inlets will only increase. Thus, the adaptation management strategies recommended by the USFWS climate change strategy (USFWS 2010), CCSP (2009), Williams and Gutierrez (2009), Pilkey and Young (2009), and many others will increasingly be difficult to implement.

Indeed, Otvos (2006, p. 1587) found that "[a]ccelerating trends of island destruction have brought delta-fringing Louisiana islands to the verge of extinction." A typical cycle along much of the coast of the migration and wintering range of the piping plover is for storms to open a new inlet or breach in a barrier island; then the inlet closes naturally as littoral drift slowly fills the breach within a small number of years. In this way islands are alternately segmented and joined as inlets naturally open and close (Davis and Gibeaut 1990, Otvos and Carter 2008, Stockdon et al. 2010). But many sections of coast are disintegrating and in some cases face extinction due to insufficient sediment in the system to support the natural post-storm reconstruction (sometimes due to dredging of nearby channels that act as sediment sinks), more intense and/or frequent storms due to climate change, and a rising sea level, all of which perturb the natural cycle of inlet opening and closing. This pattern is being observed along the North Carolina Outer Banks (Riggs and Ames 2003, Mallinson et al. 2008, Smith et al. 2008), western Dauphin Island in Alabama (Otvos 2006, Morton 2008), the Mississippi barrier islands of Gulf Islands National Seashore (Morton 2008, Stockdon et al. 2010), and much of the Louisiana coast (Otvos 2006, Morton 2008, Otvos and Carter 2008).

The cumulative effects of the existing habitat modifications to 119 of the 221 inlets, as described in this assessment, should be addressed in current and future proposals that would affect sandy tidal inlets within the U.S. continental wintering range of the piping plover. Rising sea level and climate change are likely to continue to increase the number of inlets in the near future. Whether these new inlets will provide additional favorable habitat to the piping plover and other wildlife, however, will depend on the human responses to their formation and whether decisions will be made to close or modify an inlet or allow natural processes to operate. The NC DOT and its partners, for example, are currently evaluating long-term solutions to the transportation corridors along the Outer Banks and whether to bridge, stabilize or close new inlets such as the ones opened in 2011 by Hurricane Irene. Large-scale plans to restore the Louisiana (Coast 2050 plan) and Mississippi (MsCIP Project) coasts also have been proposed. Although these plans would eliminate a significant number of current inlets, they would restore local sediment supplies to maintain beach and inlet habitats and improve their resilience to climate change and rising sea level (Louisiana Coastal Wetlands Conservation and Restoration Task Force and the Wetlands Conservation and Restoration Authority 1998, USACE 2009). Finally, opportunities exist to restore and/or mitigate adverse impacts to existing inlets through the removal of hard structures, elimination of dredging and mining activities, reducing the frequency of dredging cycles, and the beneficial use of dredged material.

REFERENCES

Antonini, G. A., D. A. Fann, and P. Roat. 1999. A historical geography of southwest Florida waterways. Volume 1 – Anna Maria to Lemon Bay. Florida Sea Grant Program. FLSGP-M-99-004. 80 pp. Available at http://nsgl.gso.uri.edu/flsgp/flsgpm99004/flsgpm99004index.html.

Antonini, G. A., D. A. Fann, and P. Roat. 2002. A historical geography of southwest Florida waterways. Volume 2 – Placida Harbor to Marco Island. Florida Sea Grant Program. FLSGP-M-02-003. Available at http://nsgl.gso.uri.edu/flsgp/flsgpm02003/flsgpm02003index.html.

Barnes, J. 1998. North Carolina's hurricane history, revised and updated edition. University of North Carolina Press, Chapel Hill, North Carolina. 256 pp.

Bates, R. E. 2004. A Brief History of the Laguna Madre area. Port Isabel, Texas, Rio Bravo Gallery. 2 pp. Available at http://portisabel-texas.com/blog/wp-content/uploads/2010/04/brief_history.pdf.

Beck, T. M., and P. Wang. 2009. Influences of channel dredging on flow and sedimentation patterns at microtidal inlets, west-central Florida, USA. Proceedings of Coastal Dynamics 2009: Impacts of Human Activities on Coastal Processes, Paper No. 98. Tokyo, Japan. 15 pp.

Bowden, J. E. 1994. Gulf Islands: The sands of all time, preserving America's largest national seashore. Pace Printing Company, Pensacola, Florida. 143 pp.

Bush, D. M., O. H. Pilkey, Jr., and W. J. Neal. 1996. Living by the rules of the sea. Duke University Press, Durham, North Carolina. 179 pp.

Bush, D. M., N. L. Longo, W. J. Neal, L. S. Esteves, O. H. Pilkey, D. F. Pilkey, and C. A. Webb. 2001. Living on the edge of the Gulf: The west Florida and Alabama coast. Duke University Press, Durham, North Carolina. 340 pp.

Bush, D. M., W. J. Neal, N. J. Longo, K. C. Lindeman, D. F. Pilkey, L. Slomp Esteves, J. D. Congleton, and O. H. Pilkey. 2004. Living with Florida's Atlantic beaches: Coastal hazards from Amelia Island to Key West. Duke University Press, Durham, North Carolina. 338 pp.

Cialone, M. A., and D. K. Stauble. 1998. Historical findings on ebb shoal mining. Journal of Coastal Research 14(2):537-563.

Clayton, T. D., L. A. Taylor, Jr., W. J. Cleary, P. E. Hosier, P. H. F. Graber, W. J. Neal, and O. H. Pilkey, Sr. 1992. Living with the Georgia shore. Duke University Press, Durham, North Carolina. 188 pp.

Cleary, W. J., and D. M. FitzGerald. 2003. Tidal inlet response to natural sedimentation processes and dredging-induced tidal prism changes: Mason Inlet, North Carolina. Journal of Coastal Research 19(4):1018-1025.

Cleary, W. J., and T. Marden. 1999. Shifting shorelines: A pictorial atlas of North Carolina inlets. North Carolina Sea Grant Publication UNC-SG-99-4. 51 pp.

CCSP (Climate Change Science Program). 2009 "Coastal Sensitivity to Sea-Level Rise: A Focus on the Mid-Atlantic Region." A report by the U.S. Climate Change Science Program and the Subcommittee on Global Change Research. [James G. Titus (Coordinating Lead Author), K. Eric Anderson, Donald R. Cahoon, Dean B. Gesch, Stephen K. Gill, Benjamin T. Gutierrez, E. Robert Thieler, and S. Jeffress Williams (Lead Authors)]. U.S. Environmental Protection Agency, Washington D.C., USA. 320 pp.

Coastal Engineering Consultants. 2012. South Marco renourishment project application, attachment 1: project description. January 9, 2012. Submitted to Florida Department of Environmental Protection, Bureau of Beaches and Coastal Systems, Tallahassee, Florida. Available at http://bcs.dep.state.fl.us/env-prmt/collier/pending/0235209_South_Marco_Island/003_JC/Application/Attachment%20I%20-%20Project%20Description/11143Attachment_I-20120109.pdf.

Coburn, A. S., A. D. Griffith, and R. S. Young, 2010. Inventory of coastal engineering projects in coastal national parks. Natural Resource Technical Report NPS/NRPC/GRD/NRTR—2010/373. National Park Service, Fort Collins, Colorado.

Dabees, M. A., and N. C. Kraus. 2004. Evaluation of ebb-tidal shoals as a sand source for beach nourishment: General methodology with reservoir model analysis. Proceedings of the 17th National Conference on Beach Preservation Technology, Tallahassee, Florida. 21 pp. Available at http://cirp.usace.army.mil/Downloads/PDF/dabees-kraus-FSBPA04.pdf.

Dabees, M. A., and N. C. Kraus. 2008. Cumulative effects of channel and ebb shoal dredging on inlet evolution in southwest Florida, USA. Proceedings of the 31st International Conference on Coastal Engineering 2008, Hamburg, Germany, pp. 2303-2315.

Davis, R. A., Jr., and J. C. Gibeaut. 1990. Historical morphodynamics of inlets in Florida: Models for coastal zone planning. Florida Sea Grant Program, Technical Paper 55. FLSGP-T-90-001 C3. 81 pp. Available at http://nsgl.gso.uri.edu.

Davis, R. A., Jr., A. C. Hine, and M. J. Bland. 1987. Midnight Pass, Florida: Inlet instability due to man-related activities in Little Sarasota Bay. Proceedings Coastal Sediments '87, New Orleans, Louisiana. 16 pp. Available at http://nsgl.gso.uri.edu/flsgp/flsgpr87003.pdf.

Dean, R. G. 1988. Recommendations for placement of dredged sand on Perdido Key, Gulf Islands National Seashore. Report prepared for the National Park Service, Atlanta, Georgia. University of Florida Publication UFL/COEL-88/016. 51 pp. Available at http://ufdc.ufl.edu/UF00076128/00001/1j.

Dezember, R. 2010. "Crews begin reopening Gulf Shores' Little Lagoon Pass." The Press-Register, September 10, 2010. Available at http://blog.al.com/live/2010/09/crews_begin_reopening_gulf_sho.html.

Erickson, K. M., N. C. Kraus, and E. E. Carr. 2003. Circulation change and ebb shoal development following relocation of Mason Inlet, North Carolina. Proceedings Coastal Sediments '03, World Scientific Publishing Corp. and East Meets West Productions, Corpus Christi, Texas. 13 pp.

Florida Department of Environmental Protection (FL DEP). 1997. Hillsboro Inlet management study implementation plan, certificate of adoption. 7 pp. Available at http://bcs.dep.state.fl.us/bchmngmt/hillsbor.pdf.

FL DEP. 2010. Permit number BA-850 E to the Florida Park Service. Tallahassee, Florida. 12 pp. Available at http://www.dep.state.fl.us/deepwaterhorizon/files/authorizations/071310_ba_850e.pdf.

Froede, C. R., Jr. 2007. Elevated waves erode the western end of the recently completed sand berm on Dauphin Island, Alabama (U.S.A.). Journal of Coastal Research 23(6):1602-1604.

Google, Inc. 2012. Google Earth (Version 6.2) [Software]. Available from http://www.google.com/earth/index.html.

Harrington, B. R. 2008. Coastal inlets as strategic habitat for shorebirds in the southeastern United States. DOER Technical Notes Collection. ERDC TN-DOER-E25. Vicksburg, Mississippi: U.S. Army Engineer Research and Development Center. Available at http://el.erdc.usace.army.mil/dots/doer.

Herrington, T. O. 2003. Manual for coastal hazard mitigation. New Jersey Sea Grant College Program, Publication NJSG-03-0511. 108 p. Available at http://www.state.nj.us/dep/cmp/coastal_hazard_manual.pdf.

Hine, A. C., G. R. Brooks, R. A. Davis Jr., D. S. Duncan, S. D. Locker, D. C. Twichell, and G. Gelfenbaum. 2003. The west-central Florida inner shelf and coastal system: A geologic conceptual overview and introduction to the special issue. Marine Geology 200(2003):1-17.

Jaeger, J. M., A. Mehta, R. Faas, and M. Grella. 2009. Anthropogenic impacts on sedimentary sources and processes in a small urbanized subtropical estuary, Florida. Journal of Coastal Research 25(1):30-47.

Kana, T. W., J. E. Mason, and M. L. Williams. 1987. A sediment budget for a relocated tidal inlet. Proceedings Coastal Sediments ’87, New Orleans, Louisiana. Abstract available at http://nsgl.gso.uri.edu/cgi-bin/zgate?present+4932+Default+5+1+F+1.2.840.10003.5.1000.34.1+21.

Kraus, N. C. 2007. Coastal inlets of Texas, USA. Proceedings Coastal Sediments ’07. Reston, Virginia: ASCE Press. Pp. 1475-1488. Available at http://www.dtic.mil/cgi-bin/GetTRDoc?Location=U2&doc=GetTRDoc.pdf&AD=ADA481728.

Kraus, N. C., G. A. Zarillo, and J. F. Tavolaro. 2003. Hypothetical relocation of Fire Island Inlet, New York. Proceedings Coastal Sediments ’03. World Scientific Publishing Corp. and East Meets West Productions, Corpus Christi, Texas. Pp. 10-14.

Lennon, G., W. J. Neal, D. M. Bush, O. H. Pilkey, M. Stutz, and J. Bullock. 1996. Living with the South Carolina Coast. Duke University Press, Durham, North Carolina. 241 pp.

Lott, C. A., C. S. Ewell, Jr., and K. L. Volansky. 2009. Habitat associations of shoreline-dependent birds in barrier island ecosystems during fall migration in Lee County, Florida. Dredging Operations and Environmental Research Program Publication ERDC/EL TR-09-14. Engineer Research and Development Center, U.S. Army Corps of Engineers, Washington, D.C. 110 pp.

Louisiana Coastal Wetlands Conservation and Restoration Task Force and the Wetlands Conservation and Restoration Authority. 1998. Coast 2050: Toward a sustainable coastal Louisiana. Louisiana Department of Natural Resources, Baton Rouge, La. 161 pp. Available at http://www.coast2050.gov/2050reports.htm.

Machemehl, J. L., M. Chambers, and N. Bird. 1977. Flow dynamics and sediment movement in Lockwoods Folly Inlet, North Carolina. University of North Carolina Sea Grant Publication UNC-SG-77-11. 153 pp. Available at http://nsgl.gso.uri.edu/ncu/ncut77006.pdf.

Maddock, S., M. Bimbi, and W. Golder. 2009. South Carolina shorebird project, draft 2006-2008 piping plover summary report. Audubon North Carolina and U.S. Fish and Wildlife Service, Charleston, South Carolina. 135 pp.

Mallinson, D. J., S. J. Culver, S. R. Riggs, J. P. Walsh, D. Ames, and C. W. Smith. 2008. Past, present and future inlets of the Outer Banks Barrier Islands, North Carolina. Department of Geological Sciences, East Carolina University, Greenville, North Carolina. 43 pp. Available at http://core.ecu.edu/geology/riggs/Mallinson%20et%20al.%20inlet%20white%20paper%20with%20figures.pdf.

Mason, C., and R. M. Sorensen. 1971. Properties and stability of a Texas barrier beach inlet. Texas A&M University Sea Grant Program Publication No. TAMU-SG-71-217. 177 pp. Available at http://nsgl.gso.uri.edu/tamu/tamut71009.pdf.

Masterson, R. P., Jr., J. L. Machemehl, and V. V. Cavaroc. 1973. Sediment movement in Tubbs Inlet, North Carolina. University of North Carolina Sea Grant Report No. 73-2. 117 pp. Available at http://nsgl.gso.uri.edu/ncu/ncut73013.pdf.

McLaughlin, T. E. August 14, 2009. "Homeowners Work to Save Big Hickory Island Beach." Naples News. Available at http://www.naplesnews.com/news/2009/aug/14/videophotos-bonita-homeowners-work-save-beach/.

Morgan, K. L. M. 2009a. Coastal change during Hurricane Isabel 2003. U.S. Geological Survey Fact Sheet 2009-3025. 2 pp.

Morgan, K. L. M. 2009b. Coastal change during Hurricane Ivan 2004. U.S. Geological Survey Fact Sheet 2009-3026. 2 pp.

Morton, R. A. 2008. Historical changes in the Mississippi-Alabama barrier-island chain and the roles of extreme storms, sea level, and human activities. Journal of Coastal Research 24(6):1587-1600.

Morton, R. A., and R. L. Peterson. 2003a. Coastal classification atlas: West-Central Florida coastal classification maps - Anclote Key to Venice Inlet. Version 1.1. USGS Open File Report 03-227. Available online with maps at http://pubs.usgs.gov/of/2003/of03-227/.

Morton, R. A., and R. L. Peterson. 2003b. Coastal classification atlas: Southwestern Florida coastal classification maps - Venice Inlet to Cape Romano. Version 1.2. USGS Open File Report 03-322. Available online with maps at http://pubs.usgs.gov/of/2003/of03-322/.

Morton, R. A., and R. L. Peterson. 2004. Coastal classification atlas: Eastern panhandle of Florida coastal classification maps - Lighthouse Point to St. Andrew Bay Entrance Channel. USGS Open File Report 2004-1044. Available online with maps at http://pubs.usgs.gov/of/2004/1044/.

Morton, R. A., T. Miller, and L. Moore. 2005. Historical shoreline changes along the US Gulf of Mexico: A summary of recent shoreline comparisons and analyses. Journal of Coastal Research 21(4):704-709.

National Commission on the BP Deepwater Horizon Oil Spill and Offshore Drilling. 2011. The story of the Louisiana Berms Project. Staff Working Paper No. 8. 44 pp. Available at http://www.oilspillcommission.gov/sites/default/files/documents/Updated%20Berms%20Working%20Paper.pdf.

National Park Service. 2010. Finding of No Significant Impact (FONSI), proposed West Ship Island North Shore Restoration, Mississippi Sound, Harrison County, Mississippi. U.S. Department of the Interior, National Park Service, Gulf Islands National Seashore. 6 pp. Available at http://www.mscip.usace.army.mil.

North Carolina Department of Environment and Natural Resources (NC DENR). 2011. North Carolina beach & inlet management plan. Final report. Raleigh, North Carolina. Various paginations + appendices. Available at http://dcm2.enr.state.nc.us/BIMP/BIMP%20Final%20Report.html.

Otvos, E. G. 2006. Discussion of Froede, C. R., Jr., 2006. The impact that Hurricane Ivan (September 16, 2004) made across Dauphin Island, Alabama. Journal of Coastal Research, 22(2), 562-573. Journal of Coastal Research 22(6):1585-1588.

Otvos, E. G., and G. A. Carter. 2008. Hurricane degradation – Barrier island development cycles, northeastern Gulf of Mexico: Landform evolution and island chain history. Journal of Coastal Research 24(2):463-478.

Palm Beach County. 2003. A history of Palm Beach County inlets. Palm Beach County, Florida. 18 pp. Available at http://www.pbcgov.com.

Parchure, T. M. 1982. St. Marys Entrance, Glossary of Inlets Report #11. Florida Sea Grant College Report No. 44. 53 pp. Available at http://nsgl.gso.uri.edu/flsgp/flsgpt82002.pdf.

Pilkey, O. H., and R. Young. 2009. The rising sea. Island Press, Washington, D.C.. 203 pp.

Pilkey, O. H., W. J. Neal, S. R. Riggs, C. A. Webb, D. M. Bush, D. F. Pilkey, J. Bullock, and B. A. Cowan. 1998. The North Carolina shore and its barrier islands: Restless ribbons of sand. Duke University Press, Durham, North Carolina. 318 pp.

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. Terwilliger Consulting, Inc., Locustville, Virginia. 21 pp.

Riggs, S. R. and Ames, D. V., 2003. Drowning the North Carolina coast: Sea-level rise and estuarine dynamics, North Carolina Sea Grant College Program, Raleigh, NC, Pub. No. UNC-SG-03-04, 152 pp.

St. John, B. 1991. South Padre: The island and its people. Poseidon Press, Dallas, Texas. 281 pp.

Sallenger, A., W. Wright, J. Lillycrop, P. Howd, H. Stockdon, K. Guy, and K. Morgan. 2007. Extreme changes to barrier islands along the central Gulf of Mexico coast during Hurricane Katrina. Chapter 5 in Science and the storms: the USGS response to the Hurricanes of 2005, G. S. Farris, G. J. Smith, M. P. Crane. C. R. Demas, L. L. Robbins, and D. L. Lavois (eds.). U.S. Geological Survey Circular 1306. pp. 113-118.

Sallenger, A. H., Jr., Wright, C. W., Howd, P., Doran, K., and Guy, K. 2009. Chapter B. Extreme coastal changes on the Chandeleur Islands, Louisiana, during and after Hurricane Katrina. In Lavoie, D., ed., Sand resources, regional geology, and coastal processes of the Chandeleur Islands coastal system—an evaluation of the Breton National Wildlife Refuge. U.S. Geological Survey Scientific Investigations Report 2009–5252. pp. 27–36.

Sargent, F. E. 1988. Case histories of Corps breakwater and jetty structures. Report 2, South Atlantic Division. Technical Report REMR-CO-3. Waterways Experiment Station, Corps of Engineers, Vicksburg, Mississippi. 105 pp.

Sargent, F. E., and R. R. Bottin, Jr. 1989a. Case histories of Corps breakwater and jetty structures. Report 8, Lower Mississippi Valley. Technical Report REMR-CO-3. Waterways Experiment Station, Corps of Engineers, Vicksburg, Mississippi. 53 pp.

Sargent, F. E., and R. R. Bottin, Jr. 1989b. Case histories of Corps breakwater and jetty structures. Report 9, Southwestern Division. Technical Report REMR-CO-3. Waterways Experiment Station, Corps of Engineers, Vicksburg, Mississippi. 53 pp.

Schrader, R. J., M. O. Hayes, T. M. Montello, and E. A. Levine. 2000. Tidal inlets – a major hurdle to effectively protecting sensitive coastal resources. Site Remediation News, Vol. 12, No. 1, Article 03. Available at http://www.state.nj.us/dep/srp/news/2000/0007_03.htm.

Smith, C. G., S. J. Culver, S. R. Riggs, D. Ames, D. R. Corbett, and D. Mallinson. 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.

Stick, D. 1958. The Outer Banks of North Carolina, 1584-1958. University of North Carolina Press, Chapel Hill, North Carolina. 352 pp.

Stockdon, H. F., L. A. Fauver, A. H. Sallenger, Jr., and C. W. Wright. 2007. Impacts of Hurricane Rita on the beaches of western Louisiana. Chapter 6 in Science and the storms: the USGS response to the Hurricanes of 2005, G.S. Farris, G.J. Smith, M.P. Crane. C.R. Demas, L.L. Robbins, and D.L. Lavois (eds.). U.S. Geological Survey Circular 1306. pp. 119-123.

Stockdon, H. F., K. S. Doran, and K. A. Serafin. 2010. Coastal change on Gulf Islands National Seashore during Hurricane Gustav: West Ship, East Ship, Horn, and Petit Bois Islands. U.S. Geological Survey Open-File Report 2010-1090. 14 pp.

Suter, J. R. 1994. Deltaic coasts. Chapter 3 in R. W. G. Carter and C. D. Woodroffe (eds.), Coastal evolution: Late Quaternary shoreline morphodynamics, Cambridge University Press, pp. 87-120. 517 pp.

Thomas, R. C., K. B. Brown, and N. C. Kraus. 2011. Inlet stabilization: A case study at mouth of Colorado River, Texas. Proceedings of Coastal Sediments 2011, Miami, Florida. Vol. 1, pp. 533-545.

United States Army Corps of Engineers (USACE). 1992. Inlets along the Texas Gulf Coast. Planning Assistance to States Program, Section 22 Report. U.S. Army Engineer District, Galveston, Southwestern Division. 56 pp. Available at http://cirp.usace.army.mil/pubs/archive/Inlets_Along_TX_Gulf_Coast.pdf.

USACE. 2003. North Padre Island Storm Damage Reduction and Environmental Restoration Project, Nueces County, Texas, Volume 1. Final environmental impact statement. Galveston District, U.S. Corps of Engineers, Galveston, Texas. 297 pp. Available at http://www.swg.usace.army.mil/pe-p/.

USACE. 2004. Bogue Inlet Channel Erosion Response Project. Final environmental impact statement. Prepared for The Town of Emerald Isle by Coastal Planning & Engineering, Inc. Wilmington District, U.S. Army Corps of Engineers, Wilmington, North Carolina. Various paginations. Available at http://www.saw.usace.army.mil/wetlands/Projects/BogueInlet/.

USACE. 2009. Comprehensive plan and integrated programmatic environmental impact statement, Mississippi Coastal Improvements Program (MsCIP) Hancock, Harrison, and Jackson Counties, Mississippi. Mobile, Alabama. 417 pp. Available at http://www.mscip.usace.army.mil/.

USACE. 2011. Public notice no. SAM-2011-00780-SPG request for authorization to retain and maintain and existing sand-filled rock rubble berm, West end of Dauphin Island, Gulf of Mexico/Mississippi Sound, Mobile County, Alabama. Mobile District, Corps of Engineers, Mobile, Alabama. 26 pp.

U.S. Fish and Wildlife Service (USFWS). 2006. Biological opinion for the Kiawah Island Beach Nourishment Project, Charleston County, South Carolina. Charleston Ecological Services Field Office, Charleston, South Carolina. 59 pp.

USFWS. 2009. Piping plover (*Charadrius melodus*) 5-year review: summary and evaluation. Northeast Region, Hadley, Massachusetts. 206 pp.

USFWS. 2010. Rising to the urgent challenge: Strategic plan for responding to accelerating climate change. Washington, D.C. 32 pp.

Wamsley, T. V., and N. C. Kraus. 2005. Coastal barrier island breaching, part 2: Mechanical breaching and breach closure. U.S. Army Corps of Engineers Technical Note ERDC/CHL CHETN-IV-65. 21 pp.

Williams, S. J., and B. Gutierrez. 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, D. D., N. C. Kraus, and C. M. Anderson. 2007. Morphologic response to a new inlet, Packery Channel, Corpus Christi, Texas. Proceedings Coastal Sediments ’07 Conference, ASCE Press, Reston, VA. Pp. 1529-1542.

Appendix 1c. The Status of Sandy Oceanfront Beach Habitat in the Continental U.S. Coastal Migration and Wintering Range of the Piping Plover (*Charadrius melodus*)[3]

Tracy Monegan Rice
Terwilliger Consulting, Inc.
October 2012

The 5-Year Review of the U.S. Fish and Wildlife Service (USFWS) 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 information for one habitat type – namely, sandy oceanfront beaches within the migration and wintering range of the southeastern continental United States (U.S.). Sandy beaches are a valuable habitat for piping plovers, other shorebirds and waterbirds for foraging, loafing, and roosting.

METHODS

In order to evaluate the status of sandy oceanfront beaches along the coastlines of North Carolina (NC), South Carolina (SC), Georgia (GA), Florida (FL), Alabama (AL), Mississippi (MS), Louisiana (LA) and Texas (TX), several methods were used. Non-sandy oceanfront areas were excluded because they do not currently provide this habitat. These excluded areas occur along marshy sections of coast in Louisiana, the Big Bend Marsh coast of northwest Florida, the Ten Thousand Island Mangrove coast of southwest Florida, and the Florida Keys. The status of sandy oceanfront beaches was evaluated through an estimation of the length and proportions of shoreline that were developed, undeveloped, preserved, armored or with beach fill or dredge spoil placement. Mainland beaches, with the exception of those in Mississippi, were not included unless no barrier islands were located offshore and thus the mainland beaches were located directly on the Atlantic Ocean or Gulf of Mexico (e.g., Holly Beach, Louisiana).

The lengths of developed versus undeveloped sandy oceanfront beach were assessed primarily by using published reports such as the United States Geological Survey's (USGS's) *Coastal Classification Atlas* that was recently completed for most of the Gulf of Mexico coast. Existing data were thus located for the coasts of North Carolina, South Carolina, the Gulf coast of Florida, Alabama, Mississippi, and significant portions of Texas and Louisiana (sources are listed under the State-specific Results section). Data gaps were then identified where no existing data assessed these parameters. Google Earth was then used to calculate the lengths of sandy oceanfront beaches within the geographic data gaps as well as to distinguish the lengths that were developed versus undeveloped (see Table 1 for a list of the data gaps from Google Earth). A Microsoft Excel database of all data was created, with the data organized by geographic area. Wherever possible, data were compiled on a county-by-county or shoreline segment basis to facilitate updates and replication of the data.

---

[3] *Suggested citation*:
Rice, T. M. 2012. The Status of Sandy, Oceanfront Beach Habitat in the Continental U.S. Coastal Migration and Wintering Range of the Piping Plover (*Charadrius melodus*). Appendix 1c *in* Comprehensive Conservation Strategy for the Piping Plover (*Charadrius melodus*) in its Coastal Migration and Wintering Range in the Continental United States, U.S. Fish and Wildlife Service, East Lansing, Michigan.

For geographic areas where Google Earth was utilized to calculate the approximate lengths of beach shoreline that were developed versus undeveloped, no distinction was made as to the level of development. The USGS *Coastal Classification Atlas* categorized developed areas into low, medium, and high density development, but this assessment consolidated those categories into one developed category (for more detailed information on a particular area, consult the individual reports or topographic quadrangles produced by the Coastal Classification Mapping Project at http://coastal.er.usgs.gov/coastal-classification/). Undeveloped areas were those where no structures existed adjacent to the beach and that appeared natural in the Google Earth aerial imagery. Vacant lots that were surrounded by a high number of buildings were not counted as undeveloped areas unless they were of a sufficient size to measure (e.g., greater than 0.1 mile in oceanfront length). Golf courses adjacent to the beach were considered developed areas because the beach habitat has been modified or protected by armoring (e.g., Sea Island, GA) or inlet relocation and beach fill activities (e.g., Kiawah Island, SC). Parking lots and roads were not considered as developed areas developed on the landward side of the road and the road was close to the beach, preventing the sandy beach from migrating with rising sea level. Length measurements were made in miles using the "ruler" tool of Google Earth. The individual dates of Google Earth imagery and eye altitude from which measurements were made were recorded; the latter was typically 5,300-5,800 feet above ground level.

The shoreline lengths used in this report are approximations for several reasons. First, each state used its own methodology and a number of sources in determining the proportions of developed-to-undeveloped beaches. Also, some states conducted their estimates in 2001 but others in 2011, years of rapid development in some places but not others (Table 1). Furthermore, the imagery used by Google Earth was made between 2006 and 2011, creating further potential problems with estimations. The data sources for each geographic area are listed in Table 1.

The second reason why the shoreline lengths in this assessment are approximations is the dynamic nature of the habitat. Sandy oceanfront beaches shift in space over time and may grow (accrete) or recede (erode) on a daily, weekly, seasonal or annual basis. Thus, the measured lengths are snapshots in time and are not necessarily the same lengths that would be measured today or tomorrow. Third, only the ocean-facing segments of the inlet shorelines were included, and the demarcation lines were based on professional judgment. Finally, the measurements are approximations due to mathematical rounding to the nearest mile for statewide figures and nearest tenth of a mile for data within individual states.

The amount of preserved sandy oceanfront beach (protected to some degree from development) provides an approximation of how much of this habitat may be available as sea level continues to rise and climate changes. If an area is preserved then it is assumed that the habitat retains the potential to migrate inland with rising sea level and to continue to provide habitat for the piping plover and other shorebirds and waterbirds over time. Where sandy oceanfront beaches are developed, it is assumed that the habitat is highly susceptible to being lost or significantly degraded as sea level rises (through erosion or shoreline armoring), and thus of diminishing value to the piping plover. Currently undeveloped and unpreserved sandy oceanfront beaches were assumed to be developable.

Preserved lands in this assessment include the public lands of National Wildlife Refuges (NWRs) owned by the USFWS; National Seashores (NSs) owned by the National Park Service (NPS); National Estuarine Research Reserves (NERRs) owned by the National Oceanic and Atmospheric Administration (NOAA); lands owned by the Bureau of Land Management (BLM); state, county and local parks; state Wildlife Management Areas (WMAs); state wildlife refuges and heritage preserves, state recreation areas; and sometimes military bases (if landward areas are undeveloped). Sandy oceanfront beaches that have been protected by non-governmental conservation organizations, such as Audubon sanctuaries, or that are a part of research preserves such as the University of South Carolina (Beaufort)'s Pritchards Island, were also included. Finally, areas with known conservation easements (e.g., Dewees Island, SC) were included as preserved beaches. Properties that have habitat conservation plans were not included because these properties typically have some level of development and are not preserved, undeveloped spaces like refuges or parks. Data on the name, location, approximate shoreline length, and type of preserved land (e.g., wildlife refuge, park) were added to the Excel database. Shoreline lengths were obtained from published sources or websites of the individual lands wherever possible, and from Google Earth using the aforementioned methodology for measuring developed versus undeveloped areas. Preserved lands in Florida were measured using the State Parks, Conservation Lands, and Public Land data layers of the Florida Department of Environmental Protection (FL DEP) Beaches and Coastal Systems GIS database (http://ca.dep.state.fl.us/mapdirect/?focus=beaches); parcel lengths were measured at 1:12,000 scale and rounded to the nearest tenth of a mile. Due to their diminished habitat value from surrounding development, some preserved lands with less than one-tenth of a mile in beach length were excluded when they were not near other preserved parcels. Preserved lands that were included may also have diminished habitat value due to disturbance from recreational and other activities that can occur in parks, seashores, recreation areas, military bases, etc.

Table 1. Data sources used to determine the lengths of sandy oceanfront beach for each state of the wintering and migration range of the piping plover.

State	Shoreline segment	Data Sources
NC	Entire state	NC DENR (2011)
SC	Entire state	SC DHEC (2010)
GA	Entire state	Clayton et al. (1992), Google Earth (2010 imagery)
FL Atlantic Coast	Entire state	Bush et al. (2004), Google Earth (2010 and 2011 imagery)
FL Gulf Coast	Perdido Pass (AL) to St. Andrew Bay Entrance	Morton et al. (2004)
	St. Andrew Bay Entrance to Lighthouse Point	Morton and Peterson (2004)
	Anclote Key to Venice Inlet	Morton and Peterson (2003a)
	Venice Inlet to Cape Romano	Morton and Peterson (2003b)
AL	Entire state	Bush et al. (2001), Morton and Peterson (2005a), Google Earth (2008 imagery)
MS	Entire state	Morton and Peterson (2005a), Google Earth (2003, 2006 and 2007 imagery)
LA	Chandeleur Sound to Pass Abel	Google Earth (2010 imagery)
	Pass Abel to East Timbalier Island	Morton and Peterson (2005b)
	East Timbalier Island to Mermentau River Navigation Channel	Google Earth (2009 and 2010 imagery)
	Mermentau River Navigation Channel to Sabine Pass	Morton et al. (2005)
TX	Sabine Pass to Colorado River mouth	Morton and Peterson (2005c)
	Colorado River mouth to Aransas Pass	Google Earth (2011 imagery)
	Aransas Pass to Mansfield Channel	Morton and Peterson (2006a)
	Mansfield Channel to Rio Grande River mouth	Morton and Peterson (2006b)

Where readily available information existed, notations about habitat modifications within the preserved lands were noted in the database. These habitat modifications could include:

- the presence of jetties, groins or other shoreline armoring in or adjacent to the preserved land;
- dredging activities at an inlet in or near the preserved land;
- beach nourishment or dredge disposal activities on beaches in the preserved land;

- the presence of off-road vehicle (ORV) or recreational vehicle usage;
- campgrounds, recreational facilities, and/or camping allowed on the beach;
- the maintenance and protection of coastal highways (e.g., North Carolina Highway 12 in Cape Hatteras National Seashore or Texas Highway 87 within Sea Rim State Park);
- the artificial creation and/or maintenance of dunes;
- artificial opening or closure of inlets, including inlet relocations;
- vegetation plantings;
- the presence of feral horses, hogs or other animals that can damage vegetation and dunes;
- waterfowl impoundments;
- the presence of private inholdings or retained rights agreements that preclude some management options; and
- the presence of historic sites or structures (e.g., historic forts on the Fort Morgan peninsula in Alabama, Egmont Key NWR in Florida, or Fort Massachusetts in the Mississippi portion of Gulf Islands NS).

An assessment to estimate the length of each state's sandy oceanfront beach that has been armored with hard structures was conducted using data derived from published sources. Armoring structures are shore-parallel seawalls, revetments, riprap, geotubes and sandbags, but also may include groins, offshore breakwaters, and jetties. A description of the different types of stabilization structures typically constructed at or adjacent to sandy oceanfront beaches can be found in Appendix 1a (Rice 2009) as well in the *Manual for Coastal Hazard Mitigation* (Herrington 2003, online at http://www.state.nj.us/dep/cmp/coastal_hazard_manual.pdf) and in *Living by the Rules of the Sea* (Bush et al. 1996). The lengths of shoreline affected by armoring included in this report should be considered a minimum because the published sources are not necessarily current and short structures may protect only individual houses or buildings. Furthermore, Google Earth could not be readily used to update or fill data gaps due to the difficulty in identifying structures that may be hidden by vegetation, dunes, or beach fill. For example, the entire length of Miami Beach is armored with a seawall that is not readily visible due to a large-scale beach nourishment project that replaced the beach in front of the seawall (Bush et al. 2004).

An estimate of the length of sandy oceanfront beaches that have received or continue to receive beach fill or dredge spoil placement was also compiled. This information serves two purposes: 1) a basis for cumulative effects to sandy oceanfront beaches resulting from soft stabilization and dredge disposal activities, and 2) an assessment of the length of coastline where sandy beaches will attempt to be "held in place" as sea level rises. The latter increases the risk of further degrading habitat quality over time as the adverse impacts of these activities continue, perhaps in perpetuity (for a discussion of the potential adverse ecological impacts of beach nourishment and dredge disposal activities, for which "there is little to no difference" (Bush et al. 2004, p. 90), see Peterson et al. 2000, Peterson and Bishop 2005, Defeo et al. 2009, and Rice 2009). Again, published sources were used to compile the lengths of shoreline affected by beach nourishment and dredge disposal placement activities in each state (e.g., Lott et al. 2009, FL DEP 2011). For the coast of Florida, the GIS database of Lott et al. (2009) was used for lengths of individual projects; where adjacent projects overlapped, their individual lengths were trimmed to eliminate overlapping areas. Where readily available published sources were absent for a geographic area, the beach nourishment database of the Program for the Study of Developed Shorelines (at http://www.wcu.edu/1038.asp) was consulted and an inventory of projects in that region was added to the Excel database.

RESULTS

At present, approximately 2,119 miles of sandy oceanfront beach lie within the U.S. continental wintering range of the piping plover (Table 2). Florida has the highest number of miles of this habitat and the Mississippi mainland and Florida coasts have the highest proportion of sandy oceanfront beaches that are currently developed (80% and 57%, respectively). By contrast, the barrier island coast of Mississippi (0%), Louisiana (6%), Texas (14%) and Georgia (17%) are the least developed. Altogether, 856 of 2,119 miles (40%) of sandy oceanfront beaches in the continental wintering range of the piping plover are developed. A slightly higher amount (901.5 miles, 43%) has been preserved, with Georgia (76%) and the barrier islands of Mississippi (100%) having the highest proportions of sandy oceanfront beach in preservation.

Table 2. The lengths and percentages of sandy oceanfront beach in each state that are developed, undeveloped and preserved as of December 2011.

State	Approximate Shoreline Length (miles)	Approximate Miles of Beach Developed (percent of total shoreline length)	Approximate Miles of Beach Undeveloped (percent of total shoreline length)[a]	Approximate Miles of Beach Preserved (percent of total shoreline length)[b]
NC	326	159 (49%)	167 (51%)	178.7 (55%)
SC	182	93 (51%)	89 (49%)	84 (46%)
GA	90	15 (17%)	75 (83%)	68.6 (76%)
FL	809	459 (57%)	351 (43%)	297.5 (37%)
- Atlantic	*372*	*236 (63%)*	*136 (37%)*	*132.4 (36%)*
- Gulf	*437*	*223 (51%)*	*215 (49%)*	*168 (38%)*
AL	46	25 (55%)	21 (45%)	11.2 (24%)
MS barrier island coast	27	0 (0%)	27 (100%)	27 (100%)
MS mainland coast	51[c]	41 (80%)	10 (20%)	12.6 (25%)
LA	218	13 (6%)	205 (94%)	66.3 (30%)
TX	370	51 (14%)	319 (86%)	152.7 (41%)
TOTAL	**2,119**	**856 (40%)**	**1,264 (60%)**	**901.5 (43%)**

[a] Beaches classified as "undeveloped" occasionally include a few scattered structures.
[b] Preserved beaches include public ownership, ownership by non-governmental conservation organizations, and conservation easements. The miles of shoreline that have been preserved generally overlap with the miles of undeveloped beach but may also include some areas (e.g., in North Carolina) that have been developed with recreational facilities or by private inholdings.
[c] The mainland Mississippi coast along Mississippi Sound includes 51.3 miles of sandy beach as of 2010-2011, out of 80.7 total shoreline miles (the remaining portion is non-sandy, either marsh or armored coastline with no sand). See the Mississippi state-specific results for details.

For nearly every state, data were located on the number of sandy oceanfront beaches that have been armored with hard erosion control structures (Table 3). The armoring data for North Carolina and South Carolina do not include shoreline length, but the total number of armoring structures is provided in their respective state summaries below. The length of armored shoreline on the Atlantic coast of Florida is uncertain, with only one county (Volusia) having complete data available. Therefore the total length of shoreline within the continental wintering range of the piping plover that has been armored is unknown but constitutes at least 230 miles (11% of the total shoreline length). Regardless of the missing data, the Florida coast has the greatest length of armored oceanfront beach.

At least 684.8 miles (32%) of sandy beach habitat in the continental wintering range of the piping plover have received artificial sand placement via dredge disposal activities, beach nourishment or restoration, dune restoration, emergency berms, inlet bypassing, inlet closure and relocation, and road reconstruction projects (Table 3). In some locations, such as in Louisiana, where sandy beach habitat has been lost due to erosion and sea level rise (see the Louisiana state-specific discussion below), "sediment placement projects are deemed environmental restoration projects by the USFWS, because without the sediment, many areas would erode below sea level" (USFWS 2009, p. 34). In most areas, however, sand placement projects are conducted in developed areas or adjacent to shoreline or inlet hard stabilization structures in order to address erosion, reduce storm damages, or ameliorate sediment deficits caused by inlet dredging and stabilization activities. The Atlantic coast of Florida has the highest proportion of sand placement activities on oceanfront beaches (at least 51%), but the mainland coast of Mississippi has had at least 85% of its sandy beaches modified with fill placement.

Table 3. Approximate shoreline miles of sandy beach that have been modified by armoring with hard erosion control structures and by sand placement activities for each state in the U.S. continental wintering range of the piping plover as of December 2011. Note that these totals are minimum numbers, given missing data for some areas.

State	Known Approximate Miles of Armored Beach	Known Approximate Miles of Beach Receiving Sand Placement
NC	Length Unknown (see state discussion below for numbers of structures)	91.3
SC	Length Unknown (see state discussion below for numbers of structures)	67.6
GA	10.5	5.5
FL Atlantic Coast*	58.1*	189.7
FL Gulf Coast	59.2	189.9
AL	4.7	7.5
MS barrier island coast	0	1.1
MS mainland coast	45.4	43.5
LA	15.9	60.4
TX	36.6	28.3
TOTAL	**230.4+**	**684.8+**

* The total lengths of coastal armoring for the Florida Atlantic coast are incomplete because no data are available from Brevard, Indian River, St. Lucie and Martin Counties. Only Volusia County has complete armoring data (Ecological Associates 2005); only partial data (Bush et al. 2004) are available from the remaining counties.

State-specific Results

North Carolina

Approximately 159 miles (49%) of the North Carolina sandy oceanfront beach are developed and 167 miles are undeveloped (NC DENR 2011). The beaches of Currituck and Brunswick Counties are the most developed, and those of Hyde and Carteret Counties are the least developed, due to the presence of Cape Hatteras and Cape Lookout National Seashores, respectively (Table 4).

Table 4. The approximate lengths of sandy oceanfront beach within each county of North Carolina and the proportions that are developed and undeveloped (NC DENR 2011).

County	Approximate shoreline length in miles	Developed shoreline miles (% of total)	Undeveloped shoreline miles (% of total)
Currituck	23	18 (78%)	5 (22%)
Dare	89	44 (49%)	45 (51%)
Hyde	17	3 (18%)	14 (82%)
Carteret	85	25 (29%)	60 (71%)
Onslow	27	14 (52%)	13 (48%)
Pender	14	9 (64%)	5 (36%)
New Hanover	31	16 (52%)	15 (48%)
Brunswick	40	30 (75%)	10 (25%)
TOTAL	**326**	**159 (49%)**	**167 (51%)**

Preserved sandy oceanfront beaches account for roughly 55% of the North Carolina coastline (Table 5). The longest of these is found in Cape Hatteras and Cape Lookout National Seashores, although the former has been extensively modified by the protection and maintenance of a coastal highway, several inholding communities, use by off road vehicles (ORVs), and the construction and maintenance of a continuous dune ridge. As a result of the inholding developed communities adjacent to the oceanfront in Cape Hatteras NS, the amount of land considered preserved in the state (55%) exceeds the amount undeveloped (51%).

The state of North Carolina prohibited the use of hardened erosion control structures on oceanfront beaches in 1985 but in 2011 authorized by legislation up to 4 terminal groins to be constructed (locations to be determined). However, sandbag revetments, constructed of very large geotextile bags several feet in length, are permitted for temporary protection of oceanfront property. The North Carolina Beach and Inlet Management Plan documents one jetty system in the state, 2 rock revetments, 2 sets of groins and 2 terminal groins. In addition approximately 350 sandbag revetments have been installed along the state's sandy oceanfront beaches, each of which is supposed to only be in place for 2 to 5 years. But most have been in place for much longer and their fate is controversial (NC DENR 2011). The total length of these armoring structures is unknown.

Table 5. Preserved sandy oceanfront beaches in North Carolina, the county in which each is located, and approximate shoreline length of each.

Preserved Land	County Location	Approximate Length in Miles
Swan Island Unit, Currituck NWR	Currituck	2
Monkey Island Unit, Currituck NWR	Currituck	1
Pine Island Sanctuary	Currituck	0.3
Pea Island NWR	Dare	12
Cape Hatteras NS	Dare	68
Cape Lookout NS	Carteret	56
Fort Macon State Park	Carteret	1.4
Hammocks Beach State Park (Bear Island)	Onslow	4
Brown's Island, Camp Lejeune	Onslow	3.3
Onslow Beach, Camp Lejeune	Onslow	7.3
Lea-Hutaff Island	Pender	3.8
Mason Inlet Waterbird Management Area	New Hanover	0.4
Masonboro Island NERR and Masonboro Island State Natural Area	New Hanover	7.7
Freeman Park	New Hanover	1.3
Fort Fisher State Recreation Area	New Hanover	6
Smith Island, Bald Head Island State Natural Area	Brunswick and New Hanover	3
Cape Fear Point, Bald Head Island State Natural Area	Brunswick	0.3
Bird Island NC Coastal Reserve	Brunswick	0.9
	TOTAL MILES	**178.7 (55% of state shoreline)**

As part of authorized beach nourishment or dredge disposal activities, approximately 28% (91.3 miles) of North Carolina's sandy oceanfront beaches have been or continue to receive beach fill, often multiple times (Table 6). The Wrightsville Beach beach fill project is one of the oldest in the country, beginning around 1939 and receiving renourishment approximately every 3 years.

Table 6. The approximate lengths of authorized constructed beach nourishment and dredge disposal placement projects on North Carolina beaches (from NC DENR 2011, PSDS 2012 and USFWS files).

Location	Project Length (miles)
Kitty Hawk	Unknown
Kill Devil Hills	Unknown
Nags Head	10.0
Pea Island	3.0
Hatteras Island	0.3
Hatteras Island, Isabel Inlet closure	0.3
Cape Hatteras	1.5
Ocracoke Island	0.6
Core Banks	2.0
Atlantic Beach / Fort Macon	7.4
Bogue Banks	16.8
Hammocks Beach State Park (Bear Island)	1.0

Location	Project Length (miles)
West Onslow Beach	1.6
Topsail Island	3.5
Figure Eight Island North	1.8
Figure Eight Island South (Mason Inlet)	2.8
Wrightsville Beach	3.0
Masonboro Island	2.5
North Carolina Beach (Carolina Beach Inlet dredge disposal)	0.8
Carolina Beach	3.0
Kure Beach	3.8
Bald Head Island	4.7
Oak Island	9.6
Long Beach Sea Turtle Habitat Restoration Project	2.3
Holden Beach	5.7
Ocean Isle Beach	3.3
TOTAL MILES	**91.3 (28% of state shoreline)**

South Carolina

The South Carolina *Adapting to Shoreline Change* report (SC DHEC 2010) found that 51% (93 miles) of the 182 miles of sandy oceanfront beach in the state has been developed. Approximately 89 miles (49%) are undeveloped, of which just over 13 miles are considered developable (SC DHEC 2010). No data are available comparing the level of development in individual counties or shoreline segments in South Carolina.

Preserved beaches account for 46% of the 182 miles of sandy oceanfront beach coastline in South Carolina (Table 7). The longest of these is found within Cape Romain NWR, which protects 22 miles of sandy oceanfront beaches.

In an inventory of armoring, SC DHEC (2010) found that 933 out of 3,850 (24%) habitable beachfront structures were fronted by erosion control structures constructed parallel to the shoreline. The lengths of these structures are unknown. Fripp Island had 100% and Folly Beach had 99% of its beachfront parcels armored. The Grand Strand area (North Myrtle Beach, Myrtle Beach, Surfside Beach and Garden City Beach) is also significantly armored. Dewees, Kiawah and Hunting Islands were the only developed areas without any shore parallel armoring structures, although the latter has shore perpendicular groins (SC DHEC 2010; Melissa Bimbi, USFWS, pers. communication, 4/20/12).

In addition to the 933 shore-parallel armoring structures (seawalls, revetments, etc.), in 2006 there were 165 oceanfront groins in South Carolina (SC DHEC 2010). Most (n = 125) are on Pawleys Island, Folly Beach, Edisto Beach and Hilton Head Island and six of them are terminal groins. Other armoring in South Carolina includes 6 jetty systems and one offshore breakwater. Finally, since 1985 111 Emergency Orders have been issued by the state and local governments, allowing sandbag revetments, beach scraping and minor nourishment projects using upland sand sources. SC DHEC (2010, p. 95) report that "the number of Emergency Orders has been increasing in recent years and may continue to increase if sea level continues to rise, storms become more frequent, and funding for renourishment becomes more intermittent."

Approximately 37% (67.6 miles) of South Carolina's sandy oceanfront beaches have been or continue to receive beach fill as part of authorized beach nourishment or dredge disposal activities, many of them multiple times (Table 8). For example, the Grand Strand has one of the longest lengths of beach nourishment in the country, with 26 miles of continuous beach fill modifying the sandy oceanfront beaches of the northern coast of the state.

Table 7. Preserved sandy oceanfront beaches in South Carolina, the county in which each is located, and approximate shoreline length of each (from Lennon et al. 1996, USFWS 2010a, and multiple online websites for individual preserved lands).

Preserved Land	County Location	Approximate Length in Miles
Waites Island	Horry	3.0
Briarcliffe Acres Conservation Area	Horry	0.7
SC Wildlife Sanctuary, Meher Spiritual Center	Horry	1.2
Myrtle Beach State Park	Horry	1.0
Huntington Beach State Park	Georgetown	3.0
Hobcaw Beach, Hobcaw Barony	Georgetown	2.3
North Island, Tom Yawkey Heritage Preserve	Georgetown	8.2
Sand and South Islands, Tom Yawkey Heritage Preserve	Georgetown	5.5
Cedar Island, Santee Coastal Reserve	Georgetown	3.0
Murphy Island, Santee Coastal Reserve	Charleston	6.0
Cape Romain NWR	Charleston	22.0
Capers Island Heritage Preserve	Charleston	3.3
Dewees Island, north end	Charleston	1.4
Isle of Palms County Park	Charleston	0.1
Morris Island	Charleston	4.0
Lighthouse Inlet Heritage Preserve	Charleston	0.4
Folly Beach County Park	Charleston	0.8
Bird Key Stono Seabird Sanctuary	Charleston	0.8
Kiawah Beachwalker Park	Charleston	1.2
Deveaux Bank Seabird Sanctuary	Charleston	2.3
Botany Bay Plantation WMA	Charleston	2.5
Edisto Beach State Park	Colleton	1.3
Hunting Island State Park	Beaufort	5.0
Pritchards Island	Beaufort	2.5
Turtle Island WMA	Jasper	2.5
TOTAL MILES		**84.0 (46% of state shoreline)**

Table 8. The approximate lengths of authorized constructed beach nourishment and dredge disposal placement projects on South Carolina beaches (from SCCC 1992, USFWS 2006c, SC DHEC 2010, PSDS 2012, and USFWS files).

Location	Project Length (miles)
Grand Strand (North Myrtle Beach, Myrtle Beach, Surfside Beach and Garden City Beach)	26.0
Huntington Beach	1.9
Pawleys Island	2.8
Debidue (Debordieu) Island	1.8
Isle of Palms	2.7
Sullivans Island	0.5
Folly Beach	5.3
Folly Beach County Park and Bird Key	0.5
Kiawah Island	2.5
Captain Sam's Inlet Relocation	0.6
Seabrook Island	3.4
Edisto Beach	3.5
Hunting Island	3.8
Hilton Head Island	8.8
Daufuskie Island	3.5
TOTAL MILES	**67.6 (37% of state shoreline)**

Georgia

In Georgia, only 17% of approximately 90 miles of sandy oceanfront beach has been developed (Table 9). Nine of 13 barrier islands are "uninhabited places of coastal wilderness" that are completely undeveloped, but others, such as St. Simons and Sea Islands, are 100% developed (Clayton et al. 1992, p. 1). Approximately 76% (68.6 miles) of the sandy oceanfront beaches in the state have been preserved (Table 10). The longest of these is the Little Cumberland Island – Cumberland Island NS complex with nearly 20 miles of preserved beach. Little St. Simons Island is virtually undeveloped but unpreserved at present, although its private ownership maintains a "commitment to sustainable-use ecotourism" with a small resort on the backside of the island (http://www.littlestsimonsisland.com/greenpractices.html).

Clayton et al. (1992) found that approximately 10.5 miles of the sandy oceanfront beaches of Tybee, Sea, St. Simons and Jekyll Islands in Georgia had been armored. Two islands have been or continue to receive beach nourishment or dredge spoil placement and a third has been proposed (Table 11).

Table 9. The approximate lengths of sandy oceanfront beach in each county of Georgia and the proportions that are developed and undeveloped (from Clayton et al. 1992, Google Earth 2010 imagery).

County	Approximate shoreline length in miles	Developed shoreline miles (% of total)	Undeveloped shoreline miles (% of total)
Chatham	24.6	3.5 (14%)	21.1 (86%)
Liberty	10	0 (0%)	10 (100%)
McIntosh	15.2	0 (0%)	15.2 (100%)
Glynn	20.7	11.6 (56%)	9.1 (44%)
Camden	19.5	0 (0%)	19.5 (100%)
TOTAL	**90**	**15.1 (17%)**	**74.9 (83%)**

Table 10. Preserved sandy oceanfront beaches in Georgia, the county in which each is located, and approximate shoreline length of each.

Preserved Land	County Location	Approximate Length in Miles
Little Tybee Island Nature Preserve	Chatham	5.0
Williamson Island	Chatham	1.5
Wassaw Island NWR	Chatham	5.5
Ossabaw Island Heritage Preserve	Chatham	9.1
Saint Catherine's Island	Liberty	10.0
Blackbeard NWR	McIntosh	6.4
Richard J. Reynolds State Wildlife Refuge (Cabretta Island)	McIntosh	2.0
Sapelo Island NERR	McIntosh	3.8
Wolf Island NWR	McIntosh	3.0
Jekyll Island State Park	Glynn	2.4
Little Cumberland Island	Camden	2.4
Cumberland Island NS	Camden	17.5
	TOTAL MILES	**68.6 (76% of state shoreline)**

Table 11. The approximate lengths of authorized constructed beach nourishment and dredge disposal placement projects on Georgia beaches (from PSDS 2012).

Location	Project Length (miles)
Tybee Island	3.5
Sea Island	2.0
St. Simons Island	Proposed
TOTAL MILES	**5.5 (6% of state shoreline)**

Florida

Of the approximately 809 miles of sandy oceanfront beach in Florida, roughly 57% has been developed and 43% is undeveloped, with the Atlantic Coast more developed (63%) than the Gulf Coast (51%; Tables 12 and 13). The most developed counties on the Atlantic coast are Flagler, Palm Beach, Broward and St. Johns, where 79% or more of linear beach of each has been developed. Along the Gulf Coast, the central and southern coasts are considerably more developed than the Panhandle coastline.

Preserved beaches account for 37% (300.4 miles) of Florida's sandy oceanfront beaches (Tables 14 and 15). The Atlantic Coast accounts for over 132 miles of the preserved beaches and the Gulf Coast the remaining 168 miles. The longest of the preserved beaches are the Gulf Islands National Seashore (23.5 miles) and Tyndall Air Force Base (AFB) on the Gulf coast (16.5 miles) and the Cape Canaveral National Seashore – Cape Canaveral Air Force Station complex (43.4 miles) and the Archie Carr NWR Partnership (20.5 miles altogether) on the Atlantic Coast.

Table 12. The approximate lengths of sandy oceanfront beach in each county along the Atlantic Coast of Florida and the proportions that are developed and undeveloped (from Bush et al. 2004, Google Earth 2010 and 2011 imagery).

County	Approximate shoreline length in miles	Developed shoreline miles (% of total)	Undeveloped shoreline miles (% of total)
Nassau	15	9.5 (63%)	5.5 (37%)
Duval	15	9 (60%)	6 (40%)
St. Johns	40	31.6 (79%)	8.4 (21%)
Flagler	19	15.9 (84%)	3.1 (16%)
Volusia	51	32.6 (64%)	18.4 (36%)
Brevard	72	32.3 (45%)	39.8 (55%)
Indian River	28	17.2 (61%)	10.9 (39%)
St. Lucie	21	9.1 (43%)	11.9 (57%)
Martin	24	12.2 (51%)	11.8 (49%)
Palm Beach	42	34.7 (83%)	7.3 (17%)

County	Approximate shoreline length in miles	Developed shoreline miles (% of total)	Undeveloped shoreline miles (% of total)
Broward	24	19.3 (80%)	4.7 (20%)
Miami-Dade	21	12.9 (61%)	8.3 (39%)
TOTAL	**372**	**236 (63%)**	**136 (37%)**

Table 13. The approximate lengths of sandy oceanfront beach in each segment of the Gulf Coast of Florida and the proportions that are developed and undeveloped (from Morton et al. 2004, Morton and Peterson 2003a, 2003b, and 2004).

Shoreline Segment	Approximate shoreline length in miles	Developed shoreline miles (% of total)	Undeveloped shoreline miles (% of total)
Perdido Pass to St. Andrew Bay Entrance (Escambia, Santa Rosa, Okaloosa, Walton and Bay Counties)	113.7	53.6 (47%)	60.1 (53%)
St. Andrew Bay Entrance to Lighthouse Point (Bay, Gulf and Franklin Counties)	129.2	38.7 (30%)	90.5 (70%)
Anclote Key to Venice Inlet (Pinellas, Hillsborough, Manatee and Sarasota Counties)	84.5	59.2 (70%)	25.3 (30%)
Venice Inlet to Cape Romano (Sarasota, Charlotte, Lee and Collier Counties)	110.0	71.3 (65%)	38.6 (35%)
TOTAL	**437.4**	**222.8 (51%)**	**214.6 (49%)**

Table 14. Preserved sandy oceanfront beaches along the Atlantic coast of Florida, the county in which each is located, and approximate shoreline length of each. Note that only lands that exceed 1 mile in length are listed here by name, but the contribution of 41 additional preserved areas with lengths less than 1 mile to the overall length of preserved beaches is included in the total (therefore the total listed is greater than the sum of the individual parcels listed).

Preserved Land	County Location	Approximate Length in Miles
Little Talbot Island State Park	Duval	4.2
Huguenot Memorial Park	Duval	1.3
Kathryn Abbey Hanna Park	Duval	1.5
Guana Tolomato Matanzas NERR	St. Johns	13.1
Anastasia State Park	St. Johns	3.6
North Peninsula State Park	Volusia	2.8
Cape Canaveral NS	Volusia and Brevard	24.0
Cape Canaveral Air Force Station	Brevard	19.4
Archie Carr NWR Partnership	Brevard and Indian River	20.5
Sebastian Inlet State Park	Brevard and Indian River	2.8

Preserved Land	County Location	Approximate Length in Miles
Avalon State Park	St. Lucie	1.4
John Brooks Park	St. Lucie	1.7
Blind Creek Natural Area	St. Lucie	1.4
St. Lucie Inlet Preserve State Park	Martin	2.4
Jupiter Island Tract, Hobe Sound NWR	Martin	3.5
Blowing Rocks Preserve	Martin	1.0
John D. MacArthur State Recreation Area	Palm Beach	1.6
Red Reef Park & South Beach Park	Palm Beach	1.2
John H. Lloyd State Park	Broward	2.2
Haulover Beach Park	Miami-Dade	1.4
Crandon Park	Miami-Dade	1.9
Bill Baggs Cape Florida State Recreation Area	Miami-Dade	1.4
	TOTAL MILES	**132.4 (36% of state shoreline)**

Table 15. Preserved sandy oceanfront beaches along the Gulf coast of Florida, the county in which each is located, and approximate shoreline length of each. Note that only lands that exceed 1 mile in length are listed here by name, but their contribution of 16 additional preserved areas with lengths of less than 1 mile to the overall length of preserved beaches is included in the total (therefore the total listed is greater than the sum of the individual parcels listed).

Preserved Land	County Location	Approximate Length in Miles
Perdido Key State Park	Escambia	1.6
Perdido Key Area, Gulf Islands NS	Escambia	6.7
Fort Pickens Area, Gulf Islands NS	Escambia	7.5
Santa Rosa Island Area, Gulf Islands NS	Escambia	9.3
Eglin Air Force Base†	Santa Rosa	17.0
Henderson Beach State Park	Santa Rosa	1.3
Topsail Hill Preserve State Park	Walton	3.3
Grayton Beach State Park	Walton	1.8
St. Andrews State Park	Bay	4.6
Tyndall Air Force Base	Bay	16.5
St. Joseph Peninsula State Park	Gulf	9.9
Eglin Air Force Base, Cape San Blas Satellite Property	Gulf	1.5
St. Vincent NWR (St. Vincent Island)	Franklin	8.7
Cape St. George State Preserve (Little St. George Island)	Franklin	9.6
St. George Island State Park	Franklin	8.8
Jeff Lewis Wilderness Preserve	Franklin	4.0
John S. Phipps Preserve	Franklin	1.5
Bald Point State Park	Franklin	1.8
Anclote Keys State Preserve State Park	Pasco and Pinellas	5.7
Honeymoon Island State Park	Pinellas	2.9
Caladesi Island State Park	Pinellas	2.2
Shell Key Preserve	Pinellas	2.3

Preserved Land	County Location	Approximate Length in Miles
Fort DeSoto Park	Pinellas and Hillsborough	2.8
Egmont Key NWR	Hillsborough	1.8
Coquina Gulfside Park	Manatee	1.0
North Lido Public Beach	Sarasota	1.4
Brohard Park	Sarasota	1.3
Caspersen Beach County Park	Sarasota	2.0
Stump Pass Beach State Park	Charlotte	1.2
Don Pedro Island State Park	Charlotte	1.2
Cayo Costa State Park	Lee	9.3
Bowman's Beach Regional Park	Lee	1.7
Lovers Key State Park	Lee	1.7
Barefoot Beach Preserve County Park	Collier	1.4
Delnor-Wiggins Pass State Park	Collier	1.1
Clam Pass Park	Collier	1.5
Rookery Bay NERR (Kice Island / Cape Romano complex)	Collier	11.6
	TOTAL MILES	**168 (38% of state shoreline)**

† Note that Eglin Air Force Base (AFB) contains several segments of shoreline that have been armored or developed, which is likely to result in those segments not providing high quality habitat as sea level rises.

Approximately 59.2 miles (14%) of the sandy oceanfront beach between Perdido Pass near the Alabama-Florida state line and Cape Romano on the Gulf coast of Florida are armored (Morton et al. 2004, Morton and Peterson 2003a, 2003b, 2004). Data on the length of armoring along the Atlantic Florida coast are incomplete, with Volusia County the only county with complete data (see Table 3 footnote). Using outdated data from 1991, 145 miles of the entire Florida coast were armored as of two decades ago (NMFS 1991a and b as cited within Ecological Associates 2005). Some communities are 100% armored, such as Miami Beach (Bush et al. 2004).

More beach nourishment and dredge disposal activities have been conducted in Florida than in any other state in the continental wintering range of the piping plover. FL DEP (2011) states that over 218 miles of sandy beaches have been "restored" or "maintained" under the state Ecosystem Management and Restoration Trust Fund since 1998. For Fiscal Year 2011/2011, 81 projects requested state funding for feasibility, design and/or construction of beach nourishment projects and another 13 for inlet sand bypassing or inlet management plan activities (FL DEP 2011). Almost 51 contiguous miles from Boca Raton to Key Biscayne south of Miami Beach receive beach nourishment, by far the longest project area in the continental wintering range of the piping plover (FL DEP Beaches and Coastal System GIS Beach Nourishment Data Layer). Approximately 43% (over 189.9 miles) of the Gulf Coast in Florida has received beach nourishment or dredge spoil, and half (51% or at least 189.7 miles) of the Atlantic Coast has done so, many areas multiple times and with multiple types of projects (Tables 16 and 17).

These beach lengths with habitat modification are minimum distances, because other known sand placement projects do not have accurate location data (i.e., Florida R-Monuments) to be included without potentially overlapping with other project areas. The state of Florida utilizes a network of range monuments (R-Monuments) located along the entire coastline for survey, planning, and monitoring purposes; the monument numbers are sequential within each county, increasing in number from north to south, or west to east along the Panhandle. The distance between monuments varies. The lengths listed in Tables 16 and 17 are also minimum measurements because distances between R-Monuments did not include partial monuments but were calculated to the nearest R-Monument (e.g., if a project's start point was R-33.8, the measurement started at R-34; if its endpoint was R-101.5, the measurement ended at R-101).

Table 16. The approximate lengths of sand placement projects on Florida's Atlantic Coast beaches (from Lott et al. 2009, FL DEP 2011, PSDS 2012, USFWS files and the FL DEP Beaches and Coastal System GIS Beach Nourishment Data Layer). Projects are listed by county from north to south, and then by increasing R-Monument within each county. RM_Start refers to the known starting Florida R-Monument location and RM_End refers to the known endpoint R-Monument for the project; start and endpoints may have been trimmed to eliminate overlaps with immediately adjacent projects. Note that projects denoted with a P are currently proposed.

County	Project Name or Area	RM_Start	RM_End	Length (miles)
Nassau	Fernandina Harbor dredge disposal	R-1	R-9	1.52
Nassau	Nassau County (Amelia Island) Beach Erosion Control	R-9	R-34.5	4.30
Nassau	South Amelia Island Beach Restoration Project	R-50	R-80	3.40
Duval	Duval County Beach Erosion Control	R-31	R-80	8.99
Duval	Jacksonville Harbor Expansion	V-501	V-505	0.79 P
St. Johns	Vilano Beach and Summer Haven	R-109	R-117	1.61 P
St. Johns	St. Johns County Shore Protection Project at St. Augustine	R-132	R-152	3.80
St. Johns	Summer Haven	R-197	R-209	2.29
St. Johns	Anastasia State Park (St. Augustine Inlet dredge disposal)			3.79
Flagler	State Road AIA Shoreline Stabilization Project			unknown
Volusia	Volusia County	R-40	R-145	18.92
Volusia	Ponce de Leon Inlet dredge disposal	R-158	R-161	0.56
Volusia	Volusia County	R-161	R-208	8.50
Brevard	Brevard County Beach at Cape Canaveral	R-1	R-4	0.56
Brevard	Brevard County Shore Protection Project- (North Reach)	R-4	R-53	8.98
Brevard	Patrick Air Force Base	R-53	R-75	4.05
Brevard	Brevard County Shore Protection Project- (Mid Reach)	R-75	R-118	7.60
Brevard	Brevard County Shore Protection Project- (South Reach)	R-118	R-139	7.80
Indian River	Ambersand Beach (Indian River County Sectors 1 & 2)	R-3	R-17	2.63
Indian River	Indian River County, Sector 3 and Wabasso Beach	R-19	R-55	6.76
Indian River	Vero Beach	R-71	R-86	2.89

County	Project Name or Area	RM_Start	RM_End	Length (miles)
Indian River	South County Beach (Indian River County Sector 7)	R-97	R-115.7	3.40
St. Lucie	Avalon	R-1	R-10	1.69
St. Lucie	Fort Pierce Harbor Dredged Material Disposal	R-31	R-33	0.38
St. Lucie	Fort Pierce Shore Protection Project	R-33.8	R-46	2.27
St. Lucie	South St. Lucie County Beaches	R-88	R-90	0.38
St. Lucie	South St. Lucie County Beaches	R-97.7	R-115	3.18
Martin	Martin County Shore Protection Project - Hutchinson Island	R-1	R-25.6	4.20
Martin	Bathtub Beach Park	R-34.5	R-36	0.24
Martin	Sailfish Point Marina Channel dredging with beach placement	R-36	R-39	0.66
Martin	St. Lucie Inlet dredge disposal	R-59	R-69	1.69
Martin	Jupiter Island Beach Restoration Project	R-75	R-117	7.18
Palm Beach	Coral Cove Park	R-5	R-7.6	0.29
Palm Beach	Jupiter Inlet Bypassing	R-12	R-13	0.15
Palm Beach	Jupiter-Carlin Park Beach Nourishment Project	R-13	R-19	1.10
Palm Beach	Juno Beach Restoration Project	R-26	R-38	2.45
Palm Beach	Singer Island	R-60	R-69	1.91
Palm Beach	Palm Beach Harbor dredging with beach placement	R-76	R-79	0.65
Palm Beach	North End Palm Beach Restoration (Reach 2)	R-79	R-90	2.30 P
Palm Beach	Mid-Town Beach Restoration Project (Reaches 3 & 4)	R-90.4	R-101.4	2.40
Palm Beach	South of Mid-Town Beach Restoration Project	R-101.4	R-110	1.75 P
Palm Beach	Town of Palm Beach, Phipps Ocean Park and South End Palm Beach Reach 8	R-116	R-134	5.54
Palm Beach	Palm Beach County	R-135	R-138	0.68
Palm Beach	Palm Beach Harbor / South Lake Worth Inlet Bypassing	R-151	R-152	0.16
Palm Beach	Ocean Ridge Beach Restoration Project	R-152	R-160	1.58
Palm Beach	Delray Beach Restoration Project	R-175	R-188.5	2.71
Palm Beach	Boca Raton (North) Beach Restoration Project	R-205	R-212	1.42
Palm Beach	Boca Raton (Central) Beach Restoration Project	R-216	R-222.9	1.50

County	Project Name or Area	RM_Start	RM_End	Length (miles)
Palm Beach	South Boca Raton (South) Beach Restoration Project	R-223	R-227.9	1.00
Broward	Hillsboro Beach Restoration Project	R-6	R-12.5	1.40
Broward	Segment II Broward County Beach Erosion – Hillsboro Inlet to Port Everglades	R-25	R-72	8.87
Broward	Segment III Broward County Beach - John U. Lloyd SP, Dania Beach, Hollywood, and Hallandale Beach	R-86	R-128	8.11
Miami-Dade	Dade County Shore Protection Project - Sunny Isles	R-7	R-19	2.43
Miami-Dade	Dade County Shore Protection Project - Haulover Beach Park	R-19	R-26	1.35
Miami-Dade	Dade County Shore Protection Project - Bal Harbor	R-27	R-31	0.79
Miami-Dade	Dade County Shore Protection Project - Surfside	R-31	R-38	1.43
Miami-Dade	Dade County Shore Protection Project - Miami Beach	R-38	R-74	7.12
Miami-Dade	Fisher Island	R-75	R-78	0.52
Miami-Dade	Virginia Key Beach	R-79	R-88	1.75
Miami-Dade	Key Biscayne Beach Erosion Control	R-92.5	R-96	0.59
Miami-Dade	Key Biscayne Beach Erosion Control	R-99	R-101	0.38
Miami-Dade	Key Biscayne Shore Protection Project	R-101	R-113.7	2.32
			TOTAL	**189.7+**

Table 17. The approximate lengths of beach nourishment and dredge disposal placement projects on Florida's Gulf Coast beaches (from Lott et al. 2009, FL DEP 2011, PSDS 2012 and USFWS files). Projects are listed by county from west to east / north to south, and then by increasing R-Monument within each county. RM-Start refers to the known starting Florida R-Monument location and RM_End refers to the known endpoint R-Monument for the project; start and endpoints may have been trimmed to eliminate overlaps with immediately adjacent projects. Note that projects denoted with a P are currently proposed.

County	Project Name or Area	RM_Start	RM_End	Length (miles)
Escambia	Perdido Key	R-1	R-34	6.50
Escambia	Pensacola Navigation Channel (dredge disposal)	R-34	R-64	6.30
Escambia	Santa Rosa Island (dredge disposal)	R-85	R-107	4.19 P
Escambia	Pensacola Beach	R-107	R-151	8.20
Escambia	Navarre Beach	R-192.5	R-213.5	4.10
Santa Rosa/Okaloosa	Eglin Air Force Base	V-551	V-609 (selected sites)	5.00
Santa Rosa/Okaloosa	Eglin Air Force Base	V-608	V-512 (selected sites)	2.65
Okaloosa	Ft. Walton Beach	R-1	R-15	2.80
Okaloosa	Okaloosa County- Destin, Holiday Isle	R-17	R-32	3.06
Okaloosa/Walton	Destin - Walton County	R-39	R-49	2.13
Walton	Western Walton County- Beach Restoration	R-1	R-23	4.92
Walton	Walton County Beach Nourishment, Phase 2	R-41	R-67	5.20
Walton	Gulf Trace	R-67	R-68	0.21
Walton	Walton County- Beach Restoration	R-68	R-78	1.95 P
Walton	Walton County Beach Nourishment, Phase 2	R-78	R-98	3.86
Walton	Walton County- Beach Restoration	R-98	R-105	1.59 P
Walton	Walton County Beach Nourishment, Phase 2	R-105	R-127	3.86
Bay	Panama City Beaches	R-0.5	R-92	17.40
Bay	Panama City Harbor (dredge disposal)	R-92	R-97	0.85
Bay	Mexico Beach	R-127	R-138.2	2.45
Gulf	St. Joseph's Peninsula	R-67	R-105.5	7.50
Gulf	Stump Hole	R-105.5	R-112	1.56
Franklin	St. George Island State Park	R-106	R-128.5	4.26
Franklin	Alligator Point	R-210	R-225	0.47 P
Pinellas	Honeymoon Island	R-8	R-12	0.82
Pinellas	Sand Key - Bellair, Indian Shores, Redington Beach, N. Redington Beach	R-51	R-107	10.57
Pinellas	Treasure Island	R-126	R-143	9.50
Pinellas	Long Key	R-144	R-148	0.76
Pinellas	Mullet Key	R-173	R-179.5	1.16
Pinellas	Mullet Key (dredge disposal)	R-181	R-191	1.74

County	Project Name or Area	RM_Start	RM_End	Length (miles)
Hillsborough	Egmont Key	R-2	R-10	1.52
Manatee	North Anna Maria Island	R-1	R-2	0.11 P
Manatee	Anna Maria Island	R-2	R-41	4.20
Manatee/Sarasota	Longboat Key	R-44	R-29.5	9.92
Sarasota	Lido Key	R-31	R-44.2	2.31
Sarasota	North Siesta Key	R-46	R-48.4	0.36 P
Sarasota	South Siesta Key	R-64	R-77.2	2.46
Sarasota	Casey Key	R-81	R-96	2.93 P
Sarasota	Venice	R-116	R-133	3.30
Charlotte	Manasota Key	R-14.4	R-20	0.92
Charlotte	Charlotte County Shore Protection Project	R-22	R-25.5	0.46
Charlotte	Knight Island	R-27.5	R-40	2.20
Lee	Gasparilla Island	R-10	R-26A	3.20
Lee	North Captiva Island	R-81	R-81A (+208 ft)	0.23
Lee	Captiva Island	R-83	R-109	5.06
Lee	Northern Shore Sanibel Island	R-109	R-118	1.69
Lee	Gulf Pines, Sanibel Island	R-129	R-133	0.77
Lee	Sanibel Island	R-174A	Bay 1A	0.25
Lee	Estero Island	R-175	R-199	4.72
Lee	South Estero Island	R-208	R-210	0.41
Lee	Lover’s Key	R-214	R-222	1.54
Lee	Big Hickory Island	R-222.3	R-223.8	0.47
Lee	Little Hickory Island- Bonita Beach	R-225.5	R-230	0.80
Collier	Barefoot Beach (dredge disposal)	R-11.4	R-14.2	0.39 P
Collier	Delnor-Wiggins State Park	R-18	R-20.5	0.39 P
Collier	Vanderbilt Beach	R-21	R-37	3.12
Collier	Clam Bay (dredge disposal)	R-37	R-48	2.13
Collier	Park Shore	R-48	R-55	1.42
Collier	Naples	R-58	R-79	3.70
Collier	Naples (Gordon Pass dredge disposal)	R-79	R-83	0.83
Collier	Keewaydin Island (Gordon Pass dredge disposal)	R-90	R-93	0.76
Collier	Marco Island- Hideaway Beach (North)	R-135	R-139	0.83
Collier	Marco Island- Hideaway Beach (South)	R-143	R-148	0.90
			TOTAL	**189.9+**

Alabama

The approximately 46.3 miles of sandy oceanfront beach in Alabama is roughly 55% developed, with Dauphin Island (total shoreline in Mobile County) 42% developed and the Baldwin County shoreline of the Fort Morgan peninsula, Gulf Shores and Orange Beach 61% developed (Table 18). Dauphin Island was split into Dauphin Island West (0% developed) and Dauphin Island East (82% developed) by the Ivan/Katrina Cut, an inlet opened by Hurricane Ivan in 2004 and expanded to 2 kilometers wide by Hurricane Katrina in 2005. There are at least 4 preserved lands along the Alabama coast, totaling over 11 miles of sandy oceanfront beach (Table 19). The longest stretch of preserved sandy oceanfront beach is in Gulf State Park, although the park is partially developed with recreational facilities and public recreation appears to be the primary use of the land.

Table 18. The approximate lengths of sandy oceanfront beach within each county of Alabama and the proportions that are developed and undeveloped (Bush et al. 2001, Morton and Peterson 2005a, USFWS 2005a, Google Earth 2008 imagery).

County	Approximate shoreline length in miles	Developed shoreline miles (% of total)	Undeveloped shoreline miles (% of total)
Mobile	15.3	6.5 (52%)	8.8 (58%)
Baldwin	31	18.9 (61%)	12.1 (39%)
TOTAL	**46.3**	**25.4 (55%)**	**20.9 (45%)**

Table 19. Preserved sandy oceanfront beaches in Alabama, the county in which each is located, and the approximate shoreline length of each.

Preserved Land	County Location	Approximate Length in Miles
Dauphin Island Audubon Bird Sanctuary	Mobile	0.6
Fort Morgan State Historic Site / Bon Secour NWR, Fort Morgan Unit	Mobile	1.8
Perdue Unit, Bon Secour NWR	Baldwin	4
Gulf State Park	Baldwin	3.5
Bureau of Land Management	Baldwin	1.3
	TOTAL MILES	**11.2 (24% of state shoreline)**

Approximately 4.7 miles (10%) of the Alabama coast is armored with hard erosion control structures (Morton and Peterson 2005a). Dauphin Island, Gulf Shores, and Orange Beach have had beach nourishment projects, an unknown length of sandy oceanfront beaches near Perdido Pass have received dredge spoil, and up to 1,000 feet of littoral zone of adjacent beaches receive maintenance dredge spoil on an as-needed basis from Little Lagoon Pass (Table 20). Altogether at least 7.4 miles (16%) of Alabama's oceanfront coastline has received fill material, some areas multiple times.

Table 20. The approximate lengths of authorized constructed beach nourishment and dredge disposal placement projects on Alabama sandy oceanfront beaches (from Froede 2007, PSDS 2012, and USFWS files).

Location	Project Length (miles)
Dauphin Island	4
Gulf Shores	3.3
Perdido Pass area dredge disposal	Unknown
Little Lagoon Pass area dredge disposal	0.2
TOTAL MILES	**7.5 (16% of state shoreline)**

Mississippi

Barrier Island Shoreline

Mississippi's Gulf of Mexico shoreline consists of a series of offshore barrier islands that, with the exception of a dredge spoil island owned by the U.S. Army Corps of Engineers, are entirely within the Gulf Islands National Seashore. These islands currently have approximately 27.3 miles of sandy oceanfront beach, of which none is developed. Preserved beaches account for 100% of the barrier island coastline (Table 21). The longest of these (≈11.8 miles) is found on Horn Island in Gulf Islands National Seashore. The mainland coastline of Mississippi, landward of the barrier islands, includes many miles of sandy beaches that were assessed separately (see below) since these beaches include several critical habitat units and provide habitat for the piping plover; the mainland beaches front on Mississippi Sound and not the Gulf of Mexico, however, as they are located landward of the barrier islands.

Table 21. The approximate lengths of sandy oceanfront barrier island beach in each county of Mississippi and the proportions that are developed and undeveloped (from Morton and Peterson 2005a, Google Earth 2003, 2006, and 2007 imagery).

County	Approximate shoreline length in miles	Developed shoreline miles (% of total)	Undeveloped shoreline miles (% of total)
Harrison	8.1	0	8.1 (100%)
Jackson	19.2	0	19.2 (100%)
TOTAL	**27.3**	**0**	**27.3 (100%)**

Table 22. Preserved sandy oceanfront barrier island beaches in Mississippi, the county in which each is located, and approximate shoreline length of each. Note that private inholdings remain on some of the barrier islands, and therefore the NPS does not have full ownership of all the islands.

Preserved Land	County Location	Approximate Length in Miles
Petit Bois Island, Gulf Islands NS	Jackson	6.4
Sand Island	Jackson	1.0
Horn Island, Gulf Islands NS	Jackson	11.8
East and West Ship Islands, Gulf Islands NS	Harrison	4.5
Cat Island, Gulf Islands NS	Harrison	3.6
	TOTAL MILES	**27.3 (100% of state barrier island shoreline)**

There is no shoreline armoring of the barrier island beaches of Mississippi (Morton and Peterson 2005a). The Mississippi oceanfront coast has not received much beach nourishment or dredge spoil; only one small intermittent beach nourishment project to protect Fort Massachusetts on West Ship Island and dredge disposal activities on Sand Island has been reported. The Mississippi Coastal Improvements Program (MsCIP) Comprehensive Plan to protect and restore the Mississippi barrier island coast proposes to add fill material to East and West Ship Islands, to close the inlet that separates them, and to place nearshore fill deposits near the other islands of Gulf Shores NS (USACE 2009).

Table 23. The approximate lengths of authorized constructed beach nourishment and dredge disposal placement projects on Mississippi's sandy oceanfront barrier island beaches (from PSDS 2012).

Location	Project Length (miles)
Sand Island	0.9
West Ship Island	0.2
TOTAL MILES	**1.1 (4% of state barrier island shoreline)**

<u>Mainland Shoreline</u>

Approximately 51.3 miles of sandy, soundfront beaches are present along the 80.7 mile long mainland Mississippi coast (Table 24). USACE (2010a) states that there are 60 miles of sandy beach along the Mississippi Sound shoreline, but 2010 and 2011 Google Earth imagery records only 51.3 miles. The amount of sandy beach along the sound front, shoreline of mainland Mississippi fluctuates with the placement and subsequent erosion of beach fill and dredge disposal projects. Non-sandy shoreline segments were included in this area due to the presence of extensive shoreline armoring (i.e., seawalls, bulkheads and groins). Some of these shoreline segments currently have no sandy beaches in front of them, but beach fill and dredge disposal projects periodically recreate beaches in these locations. Highly irregular estuarine shorelines not directly facing Mississippi Sound were excluded in this assessment. With the exceptions of the approximately 6 miles of non-sandy shoreline in Hancock County Marshes Preserve and approximately 6.8 miles of non-sandy shoreline within Grand Bay NERR in Jackson County (Table 25), virtually the entire remaining 67.9 miles of soundfront coast could periodically have sandy beach habitat given the extensive degree of habitat modifications resulting from beach fill and dredge disposal activities (Table 26).

The soundfront shoreline is well developed in the communities of Waveland, Bay St. Louis, Pass Christian, Long Beach, Gulfport, Biloxi, Ocean Springs, Belle Fontaine, Gautier and Pascagoula. The precise shoreline length is difficult to calculate given the irregular shape of the non-sandy shorelines in the Hancock County Marshes Preserve and the Grand Bay NERR. When non-sandy and sandy shoreline segments are combined, 66% of the soundfront shoreline is developed and 34% is undeveloped (Table 24). Harrison County, stretching from Pass Christian to Biloxi, is the most developed (86%), with Deer Island just off the Biloxi shoreline the only undeveloped segment in the county. When just the sandy shoreline segments of the soundfront coast are considered, 80% of the sandy beaches are developed and 20% are undeveloped (Table 2).

Table 24. The approximate lengths of soundfront mainland shoreline in each county of Mississippi and the proportions that are developed and undeveloped (from Google Earth 2010 and 2011 imagery).

County	Approximate shoreline length in miles	Developed shoreline miles (% of total)	Undeveloped shoreline miles (% of total)
Hancock	15.0	7.0 (47%)	8.0 (53%)
Harrison	32.6	28.0 (86%)	4.6 (14%)
Jackson	33.2	18.2 (55%)	14.9 (45%)
TOTAL	**80.7**	**53.2 (66%)**	**27.5 (34%)**

Although several segments of the soundfront shoreline have been preserved, very little has sandy beaches, as of September 2010 (Table 25). Deer Island Coastal Preserve is a state-owned island near Biloxi that has been undergoing restoration using dredged material (Paul Necaise, USFWS, pers. communication, 4/17/12), and as of November 2011 4.6 miles of sandy beach habitat has been constructed. Grand Bay NERR has a few natural pocket beaches along its soundfront shoreline in Jackson County (Paul Necaise, USFWS, pers. communication, 4/17/12). The beneficial use of dredged material has been proposed to be added to create additional habitat to Round Island (Paul Necaise, USFWS, pers. communication, 4/17/12), and other areas are being proposed for preservation and ecosystem restoration under the MsCIP (USACE 2009). However, the amount of sandy beach habitat that would be constructed in those efforts is unknown.

Historically most of the shoreline of the Mississippi mainland had a narrow sandy strip, with freshwater inlets, grasses and trees along the water's edge (Cathcart and Melby 2009). Following a series of storms, the shoreline between Pass Christian and Biloxi was modified with a seawall constructed between 1923 and 1927, which later allowed the construction of U.S. Route 90 just landward of the seawall (Cathcart and Melby 2009). Altogether there are roughly 45.4 miles of armored shoreline along the soundfront coast, primarily consisting of seawalls and groins.

Table 25. Preserved sandy, soundfront beaches in mainland Mississippi, the county in which each is located, and approximate shoreline length of each. Note that the total of 25% is based upon the proportion of sandy beaches present in 2010 and 2011 Google Earth imagery (of 51.3 miles).

Preserved Land	County Location	Approximate Length in Miles
Hancock County Marshes Coastal Preserve	Hancock	0 (no sand)
Buccaneer State Park / Grand Bayou Coastal Preserve	Hancock	1.1[1]
Deer Island Coastal Preserve	Harrison	4.6[2]
Davis Bayou Coastal Preserve	Jackson	2.1[3]
Bellefontaine Marsh Coastal Preserve	Jackson	1.7[3]
Graveline Bay Coastal Preserve	Jackson	0.8
Pascagoula River Marshes Coastal Preserve	Jackson	0 (no sand)
Round Island Coastal Preserve	Jackson	1.6
Grand Bay NERR	Jackson	0.7 (sandy portion)
	TOTAL MILES	**12.6 (25% of state mainland shoreline)**

[1] Buccaneer State Park had only 0.2 miles of sandy beach as of 2010 but was scheduled for a federal beach fill project that would restore all 1.1 miles of its shoreline.
[2] Deer Island recently has had its sandy beaches restored using dredged material.
[3] Sandy beaches along these shorelines typically are narrow strips of intermittent pocket beaches.

The majority of the present soundfront shoreline is manmade, with 26 miles of artificially created beach between Pass Christian and Biloxi alone (Douglass 2002, Cathcart and Melby 2009). Approximately 85% (43.5 of 51.3 miles) of the sandy, soundfront coast has been modified with beach nourishment and dredge disposal placement projects (Table 26). The Hancock County Beach Dunes Project in Waveland and Bay St. Louis currently is placing 6.0 miles of beach fill and restoring 19 acres of dunes along the shoreline of the western sound (USACE Mobile District, http://www.sam.usace.army.mil/mscip/Hancock_County_Beach_Dunes.htm). With the completion of the federal Hancock County Beach Dunes Project, virtually the entire soundfront shoreline of mainland Hancock County (apart from the Hancock County Marshes Coastal Preserve) will have received beach fill or dredge spoil. Similarly, the entire Harrison County soundfront shoreline has received beach fill.

The MsCIP has proposed to modify and restore many habitats along the mainland Mississippi shoreline, including on roughly 30 of 60 miles of beach and dune (USACE 2010a). The interim Pascagoula Beach Boulevard Restoration Project recently repaired a seawall, reconstructed 7,700 feet of geotubes, placed beach fill excavated from the Pascagoula federal navigation channel along 7,700 feet of Pascagoula shoreline, and installed riprap and vegetation to protect the beach fill and geotubes from erosion (USACE 2010b). However, the addition of the riprap and tidal marsh vegetation along the toe, or waterfront, edge of the beach fill limits its potential for becoming valuable sandy beach habitat.

Table 26. The approximate lengths of authorized constructed beach nourishment and dredge disposal placement projects on the soundfront shoreline of mainland Mississippi (from USACE 2010b, PSDS 2012, and the USACE Mobile District website).

Location	Project Length (miles)
Hancock County Beach Dunes Project[1]	6.0
City of Bay St. Louis[2]	2.7
Harrison County (Pass Christian to Biloxi)	26.0
Deer Island	4.6
Ocean Springs, Front Beach	1.1
Ocean Springs, East Beach	1.1
Pascagoula Beach Boulevard Restoration Project	1.5
Pascagoula, Front Beach	0.5
TOTAL MILES	**43.5 (85% of state mainland shoreline)**

[1] The federal Hancock County Beach Dunes Project overlaps with previous beach fill projects along Hancock County Beach and Waveland.
[2] A segment of the 6.0 mile long Bay St. Louis area previously receiving beach fill overlaps with the Hancock County Beach Dunes Project and has been subtracted to obtain the length listed here.

Louisiana

The Louisiana coast is a mix of sandy and non-sandy oceanfront beaches. There are currently roughly 217.5 miles of sandy beaches, but they are not continuous and large sections of coastline are characterized by a series of small pocket beaches interspersed with non-sandy and often marshy shoreline. Of the sandy beaches, only 6% are developed (Table 27), primarily the areas of Holly Beach, Constance Beach, and Grand Isle. Preserved sandy oceanfront beaches account for roughly 30% of the Louisiana coastline (Table 28). The longest is in the state-run Rockefeller Wildlife Refuge (26.5 miles).

Table 27. The approximate length of sandy oceanfront beach in each shoreline segment of Louisiana and the proportions that are developed and undeveloped (Morton et al. 2005, Morton and Peterson 2005b, Google Earth 2009 and 2010 imagery).

Shoreline Segment	Approximate shoreline length in miles	Developed shoreline miles (% of total)	Undeveloped shoreline miles (% of total)
Sabine Pass to Mermentau River Navigation Channel	51	6.9 (14%)	44.1 (86%)
Mermentau River Navigation Channel to Joseph Harbor Bayou	16.1	0	16.1 (100%)
Joseph Harbor Bayou to Flat Lake	12.1	0	12.1 (100%)
Flat Lake Entrance to Freshwater Bayou Canal	7.2	0	7.2 (100%)
Freshwater Bayou Canal to Vermilion Bay	10.1	0	10.1 (100%)

Shoreline Segment	Approximate shoreline length in miles	Developed shoreline miles (% of total)	Undeveloped shoreline miles (% of total)
Vermilion Bay to Atchafalaya Bay	2.4	0	2.4 (100%)
Atchafalaya Bay to Caillou Bay	18.6	0	18.6 (100%)
Caillou Bay to East Timbalier Island	23.7	0	23.7 (100%)
East Timbalier Island to Pass Abel	26.7	5.9 (22%)	20.8 (78%)
Pass Abel to Bay Coquette	19.5	0	19.5 (100%)
South West Pass to South Pass	14.6	0	14.6 (100%)
South Pass to Chandeleur Sound	15.6	0	15.6 (100%)
TOTAL	**217.5**	**12.8 (6%)**	**204.8 (94%)**

Approximately 15.9 miles (7%) of sandy oceanfront beach has been armored with hard structures (Morton et al. 2005, Morton and Peterson 2005b, Google Earth). Beach restoration projects are much more extensive than shoreline armoring, with at least 60.4 miles of sandy oceanfront beach receiving beach fill or dredge spoil (Table 29). Coastal Wetlands Planning, Protection and Restoration Act (CWPPRA) projects have restored sandy beaches that have eroded or been lost due to sediment starvation, local subsidence and sea level rise (see http://lacoast.gov/new/Projects/List.aspx for a list of projects and their details). Numerous other beach restoration (nourishment) projects are planned as part of the Louisiana Coast 2050 effort (see http://www.coast2050.gov/ for more information).

Table 28. Preserved sandy oceanfront beaches in Louisiana, the parish in which each is located, and approximate shoreline length of each.

Preserved Land	Parish Location	Approximate Length in Miles
Rockefeller Wildlife Refuge	Vermilion	26.5
Paul J. Rainey Wildlife Sanctuary	Vermilion	0 (no sand)
Marsh Island Refuge	St. Mary and Iberia	0 (no sand)
Terrebonne Barrier Islands Refuge	Terrebonne	13.9
Elmer's Island Wildlife Refuge	Jefferson	2.3
Grand Isle State Park	Jefferson	0.9
Pass A Loutre WMA	Plaquemines	7.1
Breton NWR	St. Bernard & Plaquemines	15.6
	TOTAL MILES	**66.3 (30% of state shoreline)**

Table 29. The approximate lengths of authorized constructed beach nourishment (restoration) and dredge disposal placement projects on Louisiana's sandy oceanfront beaches (from PSDS 2012, Google Earth imagery, CWPPRA project data, and USFWS files). Note that the Chandeleur Island Chain, Pelican Island, Scofield and Shell Island all received fill material during the Deepwater Horizon oil spill response efforts.

Location	Project Length (miles)
Bay Joe Wise (Pass Chaland to Grand Bayou Pass)	2.25
Chandeleur Island Chain	7.0
East Grand Terre Island	2.8
East Timbalier Island	2.5
Grand Isle	7.4
Grand Terre Island	4.5
Holly Beach	9.5
Pelican Island	2.4
Raccoon Island (Isles Dernieres)	1.0
Scofield	2.9
Shell Island	1.6
Timbalier Island	2.2
Trinity and East Islands (Isles Dernieres)	7.5
West Belle Pass Headland	3.1
Whiskey Island (Isles Dernieres)	3.8
TOTAL MILES	**60.4 (28% of state shoreline)**

Texas

Virtually the entire coast, except the inlets, comprises the approximately 370 miles of sandy oceanfront beach in Texas (Table 30). Roughly 14% of these beaches are developed and 86% are undeveloped. Although many long segments of barrier islands and peninsulas are preserved (Table 31), some long undeveloped beaches, such as those on San Jose Island and the west Matagorda peninsula, are privately owned with no public access, minimal structures, and private airstrips (Morton et al. 1983, Google Earth 2011 imagery). Padre Island National Seashore is reportedly the longest undeveloped barrier island in the world, with nearly 66 miles of preserved sandy oceanfront beach (NPS 2011). Altogether, preserved sandy oceanfront beaches account for approximately 152.7 miles (41%) of the Texas coastline (Table 31). Besides Padre Island National Seashore, the Matagorda Island NWR and State Natural Area also protect a substantial proportion of the coast (38 miles).

Table 30. The approximate lengths of sandy oceanfront beach in each shoreline segment of Texas and the proportions that are developed and undeveloped (Morton and Peterson 2005c, 2006a, and 2006b, Google Earth 2011 imagery).

Shoreline Segment	Approximate shoreline length in miles	Developed shoreline miles (% of total)	Undeveloped shoreline miles (% of total)
Sabine Pass to Colorado River	150.7	39.1 (26%)	111.6 (74%)
Colorado River Mouth to	23.7	0	23.7

Shoreline Segment	Approximate shoreline length in miles	Developed shoreline miles (% of total)	Undeveloped shoreline miles (% of total)
Matagorda Ship Channel			(100%)
Matagorda Ship Channel to Pass Cavallo	4.1	0	4.1 (100%)
Pass Cavallo to Aransas Pass	56	0	56.0 (100%)
Aransas Pass to Mansfield Channel	93	6.9 (7%)	86.1 (93%)
Mansfield Channel to Rio Grande River	42.4	4.7 (11%)	37.7 (89%)
TOTAL	**369.9**	**50.7 (14%)**	**319.2 (86%)**

Approximately 36.6 miles (10%) of Texas's sandy oceanfront beach has been armored (Morton and Peterson 2005c, 2006a, 2006b, Google Earth). At least 28 miles (8%) of sandy oceanfront beach has received beach nourishment or dredge disposal, some areas multiple times (Table 32). Galveston Island has the longest reaches of nourished beach, and the town of South Padre Island – Isla Blanca Park area has 30,000 feet of oceanfront beach that periodically receives dredged materials.

Table 31. Preserved sandy oceanfront beaches in Texas, the county in which each is located, and approximate shoreline length of each.

Preserved Land	County Location	Approximate Length in Miles
Sea Rim State Park	Jefferson	5.2
Bolivar Flats Shorebird Sanctuary	Galveston	2.3
East End Lagoon Park and Nature Preserve	Galveston	2.8
Galveston Island State Park	Galveston	1.5
Justin Hurst WMA	Brazoria	1.3
San Bernard NWR	Brazoria	5.8
Matagorda Bay Nature Park	Matagorda	2.0
Matagorda Island NWR and State Natural Area	Matagorda	38.0
I.B. Magee Beach Park	Nueces	0.7
Mustang Island State Park	Nueces	5.0
Padre Island NS, North Padre Island	Kleberg, Kenedy, & Willacy	65.5
Laguna Atascosa NWR, South Padre Island Unit	Willacy & Cameron	9.6
Andie Bowie County Park	Cameron	0.5
Isla Blanca Park	Cameron	1.0
Boca Chica Tract, Lower Rio Grande River NWR	Cameron	5.5
	TOTAL MILES	**152.7 (41% of state shoreline)**

Table 32. The approximate lengths of authorized constructed beach nourishment and dredge disposal placement projects on Texas's sandy oceanfront beaches (from PSDS 2012, Google Earth imagery, and Morton and Miller 2004).

Location	Project Length (miles)
Caplen Shores area west of Rollover Pass	1.1
Corpus Christi	1.4
Galveston Island	6.8
Galveston Island State Park	Unknown
Galveston Island west end subdivisions	6.3
Gilchrest Subdivision east of Rollover Pass	1.0
McFaddin NWR	1.0
North Padre Island	1.0
Quintana	1.0
Rollover Pass area shorelines	2.0
South Padre Island and Isla Blanca Park	5.7
Surfside Beach	1.0
Texas Point NWR	Unknown
TOTAL MILES	**28.3 (8% of state shoreline)**

DISCUSSION

A substantial proportion of the sandy oceanfront beaches within the U.S. continental wintering and migration range of the piping plover have been developed (40%), filled with sediment (at least 32%) and armored (at least 11%). These habitat modifications tend to occur in the same locations as each other, resulting in localized adverse cumulative effects. When combined with the habitat modifications to the tidal inlets within the continental wintering range (results of Rice 2012), significant cumulative loss and degradation of piping plover habitat has resulted, for example on areas such as the east coast of Florida where 90% of the inlets have been armored and/or dredged, 63% of the oceanfront beach has been developed, 51% has received sand placement, and at least 16% of the beach has been armored. The number of beach nourishment projects is increasing in virtually every state (Trembanis et al. 1998, Bush et al. 2004, USFWS 2009), resulting in an increasing magnitude of habitat modification. This assessment did not include other forms of habitat modification, such as dune building and maintenance, vegetation plantings, beach scraping (using bulldozers to push up artificial levees or "dunes" with sediment from the beach), the maintenance and protection of coastal roads, and the alterations caused by driving ORVs on beaches and dunes. However, all of these activities occur throughout the range and cumulatively they increase the adverse effects on habitats used by piping plovers and other wildlife that use beaches.

Over 811 miles of sandy oceanfront beaches in the continental migration and wintering range of the piping plover has been conserved and protected through preservation and easements. These preserved lands are not uniformly distributed throughout the range however. Federal lands have been especially important as preserved sandy oceanfront beach habitat. For example, the National Seashores – Cape Hatteras, Cape Lookout, Cumberland, Cape Canaveral, Gulf Islands, and Padre Island – contribute over 280 miles of protected sandy beaches. This protection does not equate to pristine, undisturbed, and unmodified habitat, however, because the seashores have been and continue to be modified by beach nourishment and placement of dredge disposal (Gulf Islands, Cape Hatteras), permitted ORV use (Cape Hatteras, Cape Lookout, Padre Island), protection and maintenance of coastal highways (Cape Hatteras, Gulf Islands), the potential for incompatible activities on private inholdings (Cape Hatteras, Cumberland), creation and maintenance of artificial dune ridges (Cape Hatteras, Gulf Islands), and closure of new inlets (Cape Hatteras). National Wildlife Refuges have also preserved sandy oceanfront beaches throughout the range, most notably on Pea Island (NC), Cape Romain (SC), Archie Carr (FL), Breton (LA), and Matagorda Island (TX). Other significant federal lands as important habitat for piping plovers include those of military bases (Camp Lejeune in NC, Eglin and Tyndall AFBs in FL) and the NERR system (Masonboro in NC, Apalachicola, Guana Tolomato Matanzas and Rookery Bay in FL). Although they are generally shorter in length than the federal lands, lands owned by state, county, local, and conservation organizations collectively make an important contribution to the total inventory of preserved lands.

This inventory of preserved lands can be used to identify geographic gaps where conservation efforts may be prioritized to maintain and increase habitat availability and quality as sea level rises and climate changes. The area with the least modified habitat, i.e., retaining the most constituent elements of the wintering critical habitat designation, appears to be in Texas. Long stretches of undeveloped barrier islands and peninsulas, with overwash passes and flats, discontinuous dunes, and sparse vegetation are common on the Texas coastline. The islands of the Gulf Islands National Seashore in Mississippi and the area of the Florida panhandle protected by the Gulf Islands National Seashore, Eglin AFB and Tyndall AFB provide similar habitat and opportunities for better conservation efforts to avoid higher levels of modification and disturbance as sea level rises. The beaches and islands of Cape Lookout NS and Cape Romain NWR constitute the only comparably analogous lands on the Atlantic Coast in terms of habitat features or elements. The undeveloped and preserved islands of Georgia provide a uniquely contiguous suite of inlets and sandy beach habitats. All of these areas are well-suited to allow habitat migration with rising sea level. Indeed, some are already showing signs of doing so.

REFERENCES

Bush, D. M., O. H. Pilkey, Jr., and W. J. Neal. 1996. Living by the rules of the sea. Duke University Press, Durham, North Carolina. 179 pp.

Bush, D. M., N. L. Longo, W. J. Neal, L. S. Esteves, O. H. Pilkey, D. F. Pilkey, and C. A. Webb. 2001. Living on the edge of the Gulf: The west Florida and Alabama coast. Duke University Press, Durham, North Carolina. 340 pp.

Bush, D. M., W. J. Neal, N. J. Longo, K. C. Lindeman, D. F. Pilkey, L. Slomp Esteves, J. D. Congleton, and O. H. Pilkey. 2004. Living with Florida's Atlantic beaches: Coastal hazards from Amelia Island to Key West. Duke University Press, Durham, North Carolina. 338 pp.

Cathcart, T., and P. Melby. 2009. Landscape management and native plantings to preserve the beach between Biloxi and Pass Christian, Mississippi. Mississippi-Alabama Sea Grant Consortium Publication MASGP-08-024. 32 pp. Available at http://www.masgc.org/pdf/masgp/08-024.pdf.

Clayton, T. D., L. A. Taylor, Jr., W. J. Cleary, P. E. Hosier, P. H. F. Graber, W. J. Neal, and O. H. Pilkey, Sr. 1992. Living with the Georgia shore. Duke University Press, Durham, North Carolina. 188 pp.

Defeo, O., A. McLachlan, D. S. Schoeman, T. A. Schlacher, J. Dugan, A. Jones, M. Lastra, and F. Scapini. 2009. Threats to sandy beach ecosystems: A review. Estuarine, Coastal and Shelf Science 81:1-12.

Douglass, S. 2002. Saving America's beaches: The causes of and solutions to beach erosion. Advanced Series on Ocean Engineering, Volume 19. World Scientific, River Edge, NJ. 91 pp.

Ecological Associates, Inc. 2005. Habitat conservation plan – A plan for the protection of sea turtles on the beaches of Volusia County, Florida. Prepared for the U.S. Fish and Wildlife Service, Atlanta, Georgia. Latest revision February 2005. 322 pp.

Florida Department of Environmental Protection (FL DEP). 2011. Beach Management Funding Assistance Program, FY 2011/2012 Local Government Funding Requests. Division of Water Resource Management, Bureau of Beaches and Coastal Systems. 76 pp. Available at http://www.dep.state.fl.us/beaches/programs/pdf/fco11-12.pdf.

Froede, C. R., Jr. 2007. Elevated waves erode the western end of the recently completed sand berm on Dauphin Island, Alabama (U.S.A.). Journal of Coastal Research 23(6):1602-1604.

Google, Inc. 2012. Google Earth (Version 6.2) [Software]. Available from http://www.google.com/earth/index.html.

Herrington, T. O. 2003. Manual for coastal hazard mitigation. New Jersey Sea Grant College Program, Publication NJSG-03-0511. 108 pp. Available at http://www.state.nj.us/dep/cmp/coastal_hazard_manual.pdf.

Kraus, N. C. 2007. Coastal inlets of Texas, USA. Proceedings Coastal Sediments '07. ASCE Press, Reston, Virginia. Pp. 1475-1488. Available at http://www.dtic.mil/cgi-bin/GetTRDoc?Location=U2&doc=GetTRDoc.pdf&AD=ADA481728.

Lennon, G., W. J. Neal, D. M. Bush, O. H. Pilkey, M. Stutz, and J. Bullock. 1996. Living with the South Carolina coast. Duke University Press, Durham, North Carolina. 241 pp.

Lott, C. A., P. A. Durkee, W. A. Gierhart, and P. P. Kelly. 2009. Florida coastal engineering and bird conservation geographic information system (GIS) manual. Dredging Operations and Environmental Research Program Publication ERDC/EL TR-09-15. Engineer Research and Development Center, U.S. Army Corps of Engineers, Washington, D.C. 42 pp.

Morton, R. A. 2008. Historical changes in the Mississippi-Alabama barrier-island chain and the roles of extreme storms, sea level, and human activities. Journal of Coastal Research 24(6):1587-1600.

Morton, R. A., and T. A. Miller. 2004. Spatial extents of beach nourishment along the Texas Coast. U.S. Geological Survey Open-File Report 2004-1089. Coastal and Marine Geology Program, U.S. Geological Survey, Center for Coastal and Watershed Studies, St. Petersburg, FL. Available at http://pubs.usgs.gov/of/2004/1089/index.html.

Morton, R. A., and R. L. Peterson. 2003a. Coastal classification atlas: West-central Florida coastal classification maps - Anclote Key to Venice Inlet. Version 1.1. USGS Open File Report 03-227. Available online with maps at http://pubs.usgs.gov/of/2003/of03-227/.

Morton, R. A., and R. L. Peterson. 2003b. Coastal classification atlas: Southwestern Florida coastal classification maps - Venice Inlet to Cape Romano. Version 1.2. USGS Open File Report 03-322. Available online with maps at http://pubs.usgs.gov/of/2003/of03-322/.

Morton, R. A., and R. L. Peterson. 2004. Coastal classification atlas: Eastern Panhandle of Florida coastal classification maps - Lighthouse Point to St. Andrew Bay Entrance Channel. USGS Open File Report 2004-1044. Available online with maps at http://pubs.usgs.gov/of/2004/1044/.

Morton, R. A., and R. L. Peterson. 2005a. Coastal classification atlas: Alabama-Mississippi coastal classification maps - Perdido Pass to Cat Island. USGS Open File Report 2005-1151. Available with maps at http://pubs.usgs.gov/of/2005/1151/index.html.

Morton, R. A., and R. L. Peterson. 2005b. Coastal classification atlas: Southeastern Louisiana coastal classification maps - Pass Abel to East Timbalier Island. USGS Open File Report 2005-1003. Available online with maps at http://pubs.usgs.gov/of/2005/1003/index.html.

Morton, R. A., and R. L. Peterson. 2005c. Coastal classification atlas: Southeast Texas coastal classification maps - Sabine Pass to the Colorado River. USGS Open File Report 2005-1370. Available online with maps at http://pubs.usgs.gov/of/2005/1370/index.html.

Morton, R. A., and R. L. Peterson. 2006a. Coastal classification atlas: Central Texas coastal classification maps - Aransas Pass to Mansfield Channel. USGS Open File Report 2006-1096. Available online with maps at http://pubs.usgs.gov/of/2006/1096/.

Morton, R. A., and R. L. Peterson. 2006b. Coastal classification atlas: South Texas coastal classification maps - Mansfield Channel to the Rio Grande. USGS Open File Report 2006-1133. Available online with maps at http://pubs.usgs.gov/of/2006/1133/.

Morton, R. A., R. L. Peterson, and T. L. Miller. 2004. Coastal classification atlas: Northwestern Panhandle of Florida coastal classification maps - St. Andrew Bay Entrance Channel to Perdido Pass. USGS Open File Report 2004-1217. Available online with maps at http://pubs.usgs.gov/of/2004/1217/index.html.

Morton, R. A., R. L. Peterson, and T. L. Miller. 2005. Coastal classification atlas: Western Louisiana coastal classification maps - Lower Mud Lake Entrance Channel to Sabine Pass. USGS Open File Report 2005-1261. Available online with maps at http://pubs.usgs.gov/of/2005/1261/index.html.

Morton, R. A., O. H. Pilkey, Jr., O. H. Pilkey, Sr., and W. J. Neal. 1983. Living with the Texas shore. Duke University Press, Durham, NC. 190 pp.

NMFS (National Marine Fisheries Service) and USFWS (U.S. Fish and Wildlife Service). 1991a. Recovery plan for U.S. population of loggerhead turtle. National Marine Fisheries Service. Washington, D.C. 64 pp.

NMFS and USFWS. 1991b. Recovery plan for U.S. population of Atlantic green turtle. National Marine Fisheries Service. Washington, D.C. 52 pp.

National Park Service (NPS). 2010. Cape Hatteras National Seashore draft off-road vehicle management plan and environmental impact statement. Manteo, NC. 810 pp.

NPS. 2011. Beach vehicle environmental assessment, Padre Island National Seashore, Texas. Corpus Christi, TX. 155 pp.

North Carolina Department of Environment and Natural Resources (NC DENR). 2011. North Carolina beach & inlet management plan. Final report. Raleigh, North Carolina. Various paginations + appendices. Available at http://dcm2.enr.state.nc.us/BIMP/BIMP%20Final%20Report.html.

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

Peterson, C. H., D. H. M. Hickerson, and G. G. Johnson. 2000. Short-term consequences of nourishment and bulldozing on the dominant large invertebrates of the sandy beach. Journal of Coastal Research 16(2):368-378.

Program for the Study of Developed Shorelines (PSDS). 2012. Beach nourishment: The U.S. beach nourishment experience including New England, East Coast barrier islands, Pacific Coast, and Gulf of Mexico shorelines. Online database at http://www.wcu.edu/1038.asp.

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. Terwilliger Consulting, Inc., Locustville, Virginia. 21 pp.

Rice, T. M. 2012. Inventory of habitat modifications to tidal inlets in the continental U.S. coastal migration and wintering range of the piping plover (*Charadrius melodus*). Appendix 1B *in* Comprehensive Conservation Strategy for the piping plover (*Charadrius melodus*) in its coastal migration and wintering range. U.S. Fish and Wildlife Service. 37 pp.

Smith, C. G., S. J. Culver, S. R. Riggs, D. Ames, D. R. Corbett, and D. Mallinson. 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.

South Carolina Coastal Council (SCCC). 1992. South Carolina's beachfront management plan. Charleston, SC. 142 pp.

South Carolina Department of Health and Environmental Control (SC DHEC). 2010. Adapting to shoreline change: A foundation for improved management and planning in South Carolina. Final report of the Shoreline Change Advisory Committee. 192 pp.

Trembanis, A. C., H. R. Valverde, and O. H. Pilkey. 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). 2009. Comprehensive plan and integrated programmatic environmental impact statement, Mississippi Coastal Improvements Program (MsCIP) Hancock, Harrison, and Jackson Counties, Mississippi. Mobile, Alabama. 417 pp. Available at http://www.mscip.usace.army.mil/.

USACE. 2010a. Record of decision, Mississippi Coastal Improvements Program (MsCIP) Hancock, Harrison, and Jackson Counties, Mississippi. Mobile, Alabama. 5 pp. Available at http://www.sam.usace.army.mil/mscip/docs/MSCIP%20final%20signed%20ROD%20Jan%2010.pdf.

USACE. 2010b. Supplemental environmental assessment – Pascagoula Beach Boulevard Restoration Project. Mississippi Coastal Improvements Program (MsCIP) Hancock, Harrison, and Jackson

Counties, Mississippi. Mobile, Alabama. 17 pp. Available at http://www.sam.usace.army.mil/pd/Document/PascagBeachS_EA.pdf.

U.S. Fish and Wildlife Service (USFWS). 2005. Bon Secour National Wildlife Refuge comprehensive conservation plan. Atlanta, GA. 178 pp.

USFWS. 2006a. Pea Island National Wildlife Refuge comprehensive conservation plan. Atlanta, GA. 202 pp.

USFWS. 2006b. Hobe Sound National Wildlife Refuge comprehensive conservation plan. Atlanta, GA. 71 pp.

USFWS. 2006c. Biological opinion for the Kiawah Island Beach Nourishment Project, Charleston County, South Carolina. Charleston Ecological Services Field Office, Charleston, South Carolina. 59 pp.

USFWS. 2008a. Currituck National Wildlife Refuge comprehensive conservation plan. Atlanta, GA. 222 pp.

USFWS. 2008b. Delta and Breton National Wildlife Refuges comprehensive conservation plan. Atlanta, GA. 148 pp.

USFWS. 2009. Piping plover (*Charadrius melodus*) 5-year review: summary and evaluation. Northeast Region, Hadley, Massachusetts. 206 pp.

USFWS. 2010a. Cape Romain National Wildlife Refuge comprehensive conservation plan. Atlanta, GA. 202 pp.

USFWS. 2010b. Tampa Bay Refuges: Egmont Key, Pinellas, and Passage Key National Wildlife Refuges comprehensive conservation plan. Atlanta, GA. 120 pp.

USFWS. 2010c. J. N. “Ding” Darling National Wildlife Refuge comprehensive conservation plan. Atlanta, GA. 391 pp.