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]

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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.

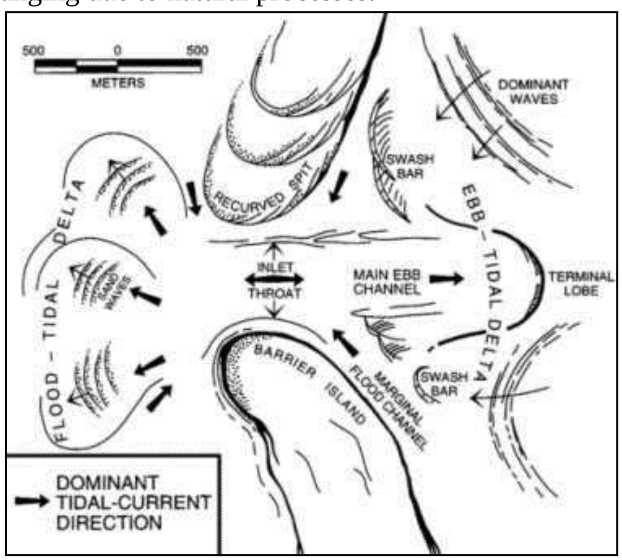

Figure 1. Schematic diagram of a typical tidal inlet with its morphological features. The ocean or Gulf is to the right in the diagram and the lagoon, bay or estuary is on the left. The net longshore sediment transport is from the top of the diagram to the bottom, the same direction as the dominant waves. 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 19^{th} 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.