Inventory of Habitat Modifications to Tidal Inlets in the U.S. Atlantic Coast Breeding Range of the Piping Plover (*Charadrius melodus*) prior to Hurricane Sandy: South Shore of Long Island to Virginia[1]

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The U.S. Fish and Wildlife Service's (USFWS's) most recent 5-Year Review for the piping plover (*Charadrius melodus*) recommends increasing "efforts to restore and maintain natural coastal formation processes in the New York-New Jersey recovery unit, where threats from development and artificial shoreline stabilization are highest, and in the Southern Recovery Unit, where the plover's habitat requirements are the most stringent …. This action is also critical to reducing adverse effects of accelerating sea level rise" for the breeding range of the federally listed (threatened) Atlantic Coast population (USFWS 2009, p. 195). There is a data need to identify habitat modifications that have altered natural coastal processes and the resulting abundance, distribution, and condition of currently existing habitat in the United States (U.S.) Atlantic coast breeding range. Two previous studies (Rice 2012a, 2012b) provided these data for the U.S. continental migration and overwintering range of the piping plover, including North Carolina where the breeding and overwintering ranges overlap. This assessment provides these data for one habitat type – namely sandy tidal inlets from Montauk Point to Virginia along the Atlantic coast of the U.S. Separate reports will assess sandy beach habitat and the northern portion of the U.S. Atlantic coast breeding range as well as the status of these two habitats immediately following and 3 years after Hurricane Sandy.

Inlets are a highly valuable habitat for piping plovers, other shorebirds, and waterbirds for foraging, loafing, and roosting (Harrington 2008, Lott et al. 2009, Maddock et al. 2009). The North Atlantic Landscape Conservation Cooperative has designated the piping plover as a representative species in all three subregions, standing as a surrogate for other species using dynamic beach systems including American oystercatchers, least terns, black skimmers, seabeach amaranth and migrating shorebirds (http://www.fws.gov/northeast/science/pdf/nalcc_terrestrial_rep_species_table.pdf). Although some information is available for the number of inlets stabilized with jetties, revetments, and other hard structures, these data have not been combined before now 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 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), the U.S. Army Corps of Engineers' Coastal Engineering Manual (USACE 2002) and in *Living by the Rules of the Sea* (Bush et al. 1996).

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METHODS

This assessment was compiled by examining many disparate sources of information regarding tidal inlets within the piping plover's U.S. Atlantic coast southern breeding 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 prior to Hurricane Sandy, 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 and their modifications within the southern portion of the breeding range of the piping plover, namely those within the states of New York (from Coney Island to Montauk), New Jersey, Delaware, Maryland and Virginia. Tidal inlets in North Carolina were assessed in Rice (2012a). Zooming in to each inlet allowed identification of existing hard structures and whether the land 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, peninsulas or adjacent headlands 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, Hayes and FitzGerald 2013; 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

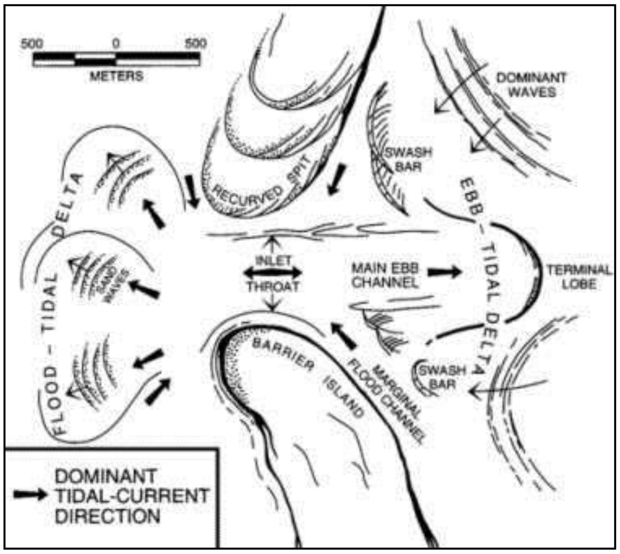

Figure 1. Schematic diagram of a typical tidal inlet with its morphological features. The ocean or Gulf is to the right in the diagram and the lagoon, bay or estuary is on the left. The net longshore sediment transport is from the top of the diagram to the bottom, the same direction as the dominant waves. 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 Hayes and FitzGerald (2013).

(Leatherman 1988, Davis and Gibeaut 1990, Bush et al. 1996, Hayes and FitzGerald 2013). These various coastal processes and variables are connected with feedback loops, producing inlet features and behavior, as well as wildlife habitat, that are in a state of dynamic equilibrium.

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 shaped by waves and longshore current. 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, Hayes and FitzGerald 2013). When an inlet closes, the relict ebb tidal shoals may weld to the new beach and the relict flood shoals may stabilize and possibly become vegetated over time. Wide, open bay or sound entrances (i.e., the entrances to Raritan Bay / Lower Bay, Delaware Bay and Chesapeake Bay) were not categorized as inlets in this assessment due to their width and the absence of active inlet shoal complexes.

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 point in time (i.e., 2011) of the inlets open along the U.S. Atlantic coast from Montauk, NY, to the Virginia-North Carolina state boundary, using the most recent imagery prior to Hurricane Sandy, publications and personal knowledge available. Inlets are very dynamic, however, and some ephemeral breaches or smaller inlets may have shifted in space or closed; those that opened after Hurricane Sandy or the publication date of this assessment will be tracked in later reports. 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 that are valuable or potentially valuable to the piping plover between Montauk, NY, and the Virginia-North Carolina boundary.

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 inlets open in 2011, 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 recent past, typically as a result of storms. History and geology books, literature and government files were referenced to identify inlets that have been relocated, artificially opened or closed, or naturally opened or closed since the late 1800s (or earlier where records are available).

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 (NWR), 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 being natural.

The primary data source for identifying 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. 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 maintenance (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 naturally or artificially opened or closed historically, including relocated inlets. Relocated inlets are those in which the inlet has been artificially moved to a new location – typically hundreds to thousands of feet away – by closing the old inlet with sediment or other materials and excavating the new inlet through land. An inlet generally is relocated as an erosion control measure to protect barrier beach 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., the Ash Wednesday Storm of 1962, nor'easters in 1992) 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. [Note that inlets that were opened by Hurricane Sandy in October 2012 will be addressed in a separate assessment.]

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 (the inlets open in 2011 and their modifications database, and the historical inlets database with natural and artificial inlet openings and closures) 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 reviewers provided comments on a draft of this assessment in order to verify and correct details, where necessary, and are listed in the Acknowledgements section.

RESULTS

Of the 36 tidal inlets that were open in December 2011 between Montauk Point, New York, and the Virginia-North Carolina line, 6 (17%) had been artificially created (i.e., cut where there was previously no inlet or dredged open after closing naturally), 1 (3%) had its channel relocated to a new position, 18 (50%) have been stabilized with one or more hard structures, 22 (61%) had been dredged at least once, and at least 13 (36%) had been mined as a sediment source for beach nourishment. Altogether 23 (64%) of the 36 inlets currently open have been significantly modified in one or more of these ways. Furthermore, at least 13 inlets have been closed artificially and thus are not included in the 36 total inlets that were open in 2011 (Table 1).

Nearly two-thirds (64%) of all the sandy inlets between Montauk Point, NY, and the Virginia-North Carolina border have been modified in one way or another, almost all of them in the New York to Maryland stretch of coast. The states with the highest proportion of inlets modified by any means are New York (100%), Delaware (100%), Maryland (100%), and New Jersey (91%). In fact only one state (Virginia) has modified few (14%) of its inlets. In the oceanfront New York-New Jersey area, 19 of 20 inlets (95%) have been modified; the only unmodified inlet in this area is adjacent to the Edwin B. Forsythe NWR in New Jersey.

Of the 18 inlets with at least one hard structure, 5 (28%) have one jetty, 9 (50%) have two jetties, 9 (50%) have terminal or other groin structures, 13 (72%) have revetments (sandbag or rock), seawalls or bulkheads, and 1 (6%) has offshore breakwaters (NOTE: the numbers total more than 18 because many inlets have more than one type of structure). The highest number of inlets without structures is found along the Virginia coast, where only 1 inlet out of 14 has hard structures (Table 1). The Eastern Shore of Virginia has the highest number of unmodified inlets, with 12 of 13 inlets not modified in any manner, serving in sharp contrast to the heavily modified inlets to the north.

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**	
NY	9	9 (100%)	6	9	0	3	4†	4
NJ	11	10 (91%)	9	9	1	8	1	5
DE	1	1 (100%)	1	1	0	1	1	0
MD	1	1 (100%)	1	1	0	1	0‡	3
VA	14	2 (14%)	1	2	0	0	0	1
TOTAL	36	23 (64%)	18 (50%)	22 (61%)	1 (3%)	13 (36%)	6 (17%)	13 (N/A)

† A fifth inlet in New York has historically been artificially opened but is no longer open.
‡ An inlet near Ocean City, MD, was artificially opened prior to World War I but closed naturally and is no longer open.

State-specific Results

New York

Nine tidal inlets currently are open in New York, of which 6 (67%) have been stabilized with hard structures along at least one shoulder (Table 2). Of the inlets with hard structures, 6 have jetties (4 with a single jetty and 2 with dual jetties), 1 has a terminal groin, 2 have groin fields on their inlet shorelines or immediately adjacent to the inlet, 1 has a dike structure, and 4 have revetments, bulkheads and/or seawalls. The single jetty at Fire Island Inlet is nearly landlocked with the accretion of Democrat Point to the west of the jetty but is included here as an existing structure that is influencing the inlet; the inlet was quickly migrating to the west at an average 200 feet per year (61 meters / year) prior to construction of the jetty (McCormick et al. 1984). The growth of Democrat Point has been considerably slower at roughly 50 feet per year (15 meters /year) since the jetty was completed in 1941. Two stabilized inlets – Shinnecock and Moriches Inlets -- have hard structures along their entire inlet shorelines, which has eliminated any sandy beach habitat along their inlet shoulders.

All 9 (100%) of New York's oceanfront inlets have been or continue to be periodically dredged for navigation or erosion control purposes to redirect channels away from buildings or infrastructure. No inlets have been relocated. New inlets have been cut artificially in 5 locations (most noticeably the "pond letting" that frequently has occurred at Hook, Georgica, Sagaponack and Mecox Ponds), but only one (Moriches Inlet) has been hardened with structures (Bokuniewicz et al. 2011, Rosati et al. 1999, Schmeltz et al. 1982, Smith and Zarillo 1988). The shoal complexes of at least 3 inlets have been mined to supply sediment for beach nourishment projects: Shinnecock Inlet in 1990 and 1993, Fire Island Inlet in 1977, and Rockaway Inlet in 1929 to provide fill to expand Floyd Bennett Field and in 1936 to use as beach fill at Jacob Riis Park (Buonaiuto et al. 2008, Cialone and Stauble 1998, Dallas et al. 2013, McCormick et al. 1984).

Table 2. Open tidal inlets from east to west along the New York 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
Georgica Inlet, NY	**X**					**X**		
Sagaponack Inlet, NY	**X**					**X**		
Mecox Inlet, NY	**X**					**X**		
Shinnecock Inlet, NY		**D**		**X**		**X**		**X**
Moriches Inlet, NY	**X**	**D**		**X**		**X**		
Fire Island Inlet, NY†		**X**				**X**		**X**
Jones Inlet, NY		**X**	**X**	**X**		**X**		
East Rockaway Inlet, NY		**X**	**X**			**X**		
Rockaway Inlet (Jamaica Bay Inlet), NY		**X**	**X**	**X**		**X**		**X**

† Fire Island Inlet has an earthen and riprap dike on its northern/western shoreline extending perpendicular to the shoreline into the inlet.

The oceanfront coastline of New York has a long history of inlets opening and closing, both naturally and artificially. According to Bokuniewicz et al. (2011, p. 112),

> *Since pre-colonial times, some coastal ponds on Long Island's ocean shoreline (New York) have been opened to the Atlantic Ocean manually (referred to as "pond letting" locally), temporarily creating an artificial inlet across the barrier beach. The operation is intended to reduce the water level in the pond and flooding of adjacent property, and allows the temporary incursion of salt water. ... Residents have apparently been opening [ponds] for hundreds of years ... This is done to manage local fisheries by digging a trench near sea level across the beach and dune leaving a sand plug, then removing the plug at low tide (Wamsley and Kraus, 2005). The letting allows diadromous fish ... into and out of the pond.*

Some of these temporary inlets occur naturally approximately once a year (e.g., Georgica Inlet was opened by Hurricane Bill in 2009) and artificially on average 7 times a year. The inlets tend to close quickly by natural processes, as Mecox Inlet did within 8 days after artificial opening in 1985 and Georgica Inlet within 5 days of an artificial opening in 2008. Hook Pond has a buried, permanent pipeline outlet to the Atlantic Ocean to control water levels instead of pond letting as was historically done (Bokuniewicz et al. 2011, Smith and Zarillo 1988).

Moriches Inlet was opened by a storm in 1931 approximately 3,500 feet (1067 meters) east of its current location. The inlet migrated west to near its current location and then closed in 1951; a dual jetty system was built on dry land in 1952-53 and the artificial opening of a new inlet within the jetties had been initiated in 1953 when a September storm opened the inlet the rest of the way (Connell and Zarillo 2011, Rosati et al. 1999, USACE 2014b).

At least 4 inlets or breaches have been closed artificially after having been opened by storm events – one near Moriches Inlet and three in Westhampton. An unnamed breach opened next to Moriches Inlet in a 1980 nor'easter and was artificially closed the following year (Connell and Zarillo 2011, Rosati et al. 1999, Schmeltz et al. 1982). An extratropical storm cut a small new inlet in Westhampton in late 1950 which "was easily closed" (Leatherman 1989, p. 111). A nor'easter in 1992 opened Pikes Inlet and Little Pikes Inlet in Westhampton, both of which were closed artificially the following year (Connell and Zarillo 2011, Rosati et al. 1999, Terchunian and Merkert 1995).

Historically at least 51 inlets have opened naturally along Long Island's south shore, of which 38 closed naturally, 4 were closed artificially as described above, and 9 remain open. Over half of these inlets (27) were located between (and including) Shinnecock and Fire Island Inlets and 12 on or adjacent to Fire Island. Leatherman (1989) states that Fire Island Inlet was open on historical maps drafted since 1620. In the late 1700s to mid-1800s, 6 named inlets were open between western Fire Island and present-day Shinnecock Inlet; these inlets were all open at the same time and for approximately 50 years each. All of these inlets closed naturally by the mid-1800s. One of these inlets (Quogue Inlet) re-opened a short time later, soon after Lanes Inlet opened just east of the position of the current Shinnecock Inlet. Quogue and Lanes Inlets remained open until the late 1800s, when they naturally closed. The period between the late 1800s and the 1938 hurricane was a period of few inlets, with only Fire Island Inlet open along the coast between Fire Island and Southampton (Leatherman 1989). Leatherman (1989) found that the long-term sustainability of Fire Island and surrounding areas was dependent on the migration of inlets that provide flood shoal deposit platforms on the bayside of the island(s) onto which the island(s) can migrate.

The Great New England Hurricane of 1938 opened 11 new inlets or breaches on Long Island between Fire Island Inlet and Montauk Point, including Shinnecock Inlet (Buonaiuto and Bokuniewicz 2008, Leatherman 1989, McCormick et al. 1984, USACE 2014b). A natural inlet was opened on Westhampton Beach in 1954, and the Ash Wednesday Storm of 1962 opened several breaches in Westhampton (Connell and Zarillo 2011, Leatherman 1989, McCormick et al. 1984). Numerous other inlets have opened naturally along the oceanfront coastline of New York and have closed naturally, including Quantuck Inlet between Hampton and Westhampton Beaches and inlets at Tiana Beach, Great South Beach, Davis Park, Oak Beach and Jones Island. Inlets historically separated Captree Island and Oak Island, Gilgo and Tobay Beaches, and Tobay and Jones Beaches; the last of these was closed by 1930 but it is unknown if their closures were natural or artificial (Kraus et al. 2003, McCormick et al. 1984). Zach's Inlet once connected Zach's Bay with the Atlantic Ocean near the East Bathhouse at Jones Island State Park, but closed naturally in the mid-1920s just prior to development of the park (Hanc 2007). New Inlet was open in 1907 at the western end of Jones Island a reported 2 miles east of Point Lookout, but it is unknown how long the inlet was open and when it closed (US Life-Saving Service 1908).

New Jersey

Eleven tidal inlets currently are open in New Jersey, of which 9 (82%) have been stabilized with hard structures along at least one shoulder (Table 3). Of the inlets with hard structures, 5 have jetties (1 with a single jetty and 4 with dual jetties), 2 have terminal groins, 5 have groins, and 7 have revetments, bulkheads and/or seawalls. Manasquan Inlet was first stabilized with jetties in 1882, then Cape May Inlet (also known as Cold Springs Inlet) in 1911, making them two of the oldest jetty systems on the East Coast. Three stabilized inlets – Shark River, Manasquan, and Barnegat Inlets -- have hard structures along their entire inlet shorelines, which has eliminated any sandy beach habitat along their inlet shoulders.

Ten (91%) inlets have been or continue to be periodically dredged for navigation or erosion control purposes to redirect channels away from buildings or infrastructure. Only one inlet (Townsends Inlet) has had its main channel relocated, in 1978 (Farrell et al. 1989, Nordstrom 1988, Nordstrom et al. 1986, USFWS 2005). Manasquan Inlet is the only inlet that has been cut artificially in New Jersey (in 1931 after it closed naturally in 1926), after which new rock jetties were built to stabilize the inlet (Farrell et al. 1989). The shoal complexes of at least 7 inlets have been mined to supply sediment for beach nourishment projects (Barnegat Inlet in 1979; Absecon Inlet four times between the 1970s and 2011; Great Egg Harbor Inlet nine times between 1989 and 2011; Corson's Inlet in 1984 and 2009; Townsends Inlet in 1978, 2003 and 2011; Hereford Inlet in 2003, 2009 and 2011; and Brigantine Inlet in 2006) (Cialone and Stauble 1998, Farrell et al. 1989, NJDEP Bureau of Coastal Engineering 2009a, 2009b, NJGWS 2012, NMFS 2014, Nordstrom 1988). Little Egg Inlet is the only unmodified inlet in New Jersey (Table 3) and is also the only unmodified inlet between Montauk, NY, and Gargathy Inlet at the south end of Assawoman Island, VA.

Table 3. Open tidal inlets from north to south along the New Jersey 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**
Shark River Inlet, NJ		**D**				**X**		
Manasquan Inlet, NJ	**X**	**D**		**X**		**X**		
Barnegat Inlet, NJ		**D**		**X**		**X**		**X**
Little Egg Inlet, NJ								
Brigantine Inlet, NJ						**X**		**X**
Absecon Inlet, NJ		**X**	**X**	**X**		**X**		**X**
Great Egg Harbor Inlet, NJ			**X**	**X**		**X**		**X**
Corson's Inlet, NJ			**X**	**X**		**X**		**X**
Townsends Inlet, NJ			**X**	**X**		**X**	**X**	**X**
Hereford Inlet, NJ			**X**	**X**		**X**		**X**
Cape May Inlet (Cold Spring Inlet), NJ		**D**				**X**		

Historically, at least 28 other inlets have been open along the New Jersey coast. Breaches would periodically open along the northern New Jersey coast at Takanassee Lake, Deal Lake, Sunset Pond, Wesley Lake, Fletcher Lake, Sylvan Lake, Silver Lake, Lake Como, Spring Lake and Wreck Pond until Ocean Avenue and other structures prevented storm breaching of the ponds/lakes (Farrell et al. 1989, NJDEP 1981). Five rivers historically drained directly into the Atlantic Ocean through inlets at the Navesink, Shrewsbury, the old mouth of the Manasquan, Metedoconk and Toms Rivers (Dallas et al. 2013, NJDEP 1981). At least 13 other inlets have opened naturally since the 1700s and before Hurricane Sandy, but only 6 of them were in the 20th century: an unnamed breach at Harvey Cedars (1962 Ash Wednesday Storm), Beach Haven Inlet (periodically from 1687-1920), Wreck Inlet on Little Beach Island (in 1905), Brigantine Island Breach 1.5 miles (2.4 kilometers (km)) north of Absecon Inlet (prior to 1904), an unnamed breach at the north end of Ludlum Island (1962 Ash Wednesday Storm), and Turtle

Gut Inlet in Wildwood Crest (sometime between 1909 and 1917) (Farrell et al. 1989, NJDEP 1981, Nordstrom et al. 1986). None of these inlets or breaches are currently open.

Historically the New Jersey coast has two dual inlet systems (Farrell et al. 1989). The two inlets in a dual inlet system periodically merge as an inlet breaches a barrier island spit and proceeds to migrate downdrift towards another inlet. The updrift inlet migrates downdrift until it merges with the comparably more stable second inlet. In terms of inlet-associated habitats, a dual inlet system creates a dynamic cycle where bare or sparsely vegetated substrate lacking high, vegetated dunes is continuously formed and reformed as the updrift inlet migrates down the spit or barrier island. The newly formed island between the two inlets would have been disconnected from adjacent development and associated disturbance. As the island between the inlets erodes, it eventually becomes emergent shoal(s) within the merged inlet complex. The updrift barrier spit grows as the intermediate island erodes, most likely with increased bayside shoals or shallower bayside platforms that facilitate landward island migration as the migrating inlet leaves behind flood shoal deposits (a process described as vital in the long-term sustainability of Fire Island and surrounding areas by Leatherman 1989).

The first dual inlet system in New Jersey is Beach Haven and Little Egg Inlets. Beach Haven Inlet would breach the southern end of Long Beach Island, migrate south over 3.16 miles (5.1 km), then merge with Little Egg Inlet. The dual inlet system was the largest inlet complex in New Jersey and was capable of scouring 60 foot deep channels. The short-lived island in between the two inlets was locally known as Tucker’s Island, which eroded as Beach Haven Inlet migrated south and the island turned into emergent shoals and/or bars. This area is now the Holgate Unit of the Edwin B. Forsythe National Wildlife Refuge. The inlet formation, migration and merging cycle historically occurred every 60 to 80 years (Farrell et al. 1989). Beach Haven Inlet last opened in 1920 and Tucker’s Island was eroded into a shoal by 1953 (NJDEP 1981).

This area breached during the Ash Wednesday Storm of 1962 but the new Beach Haven Inlet was artificially closed (NJDEP 1981), preventing the natural cycle from proceeding. The cycle is currently due to repeat based on historical patterns. A groin field that armors the beach immediately north of the historic Beach Haven Inlet area should increase downdrift erosion, and the shoreline is indeed offset south of the groin field. Google Earth imagery from 1995 to 2010 indicates that the Holgate spit is narrowing at its northern end and could be vulnerable to breaching. [NOTE that changes to the landscape caused by Hurricane Sandy will be addressed in a later report.] Large-scale beach nourishment projects on Long Beach Island updrift of the Holgate spit, however, could delay or prevent the dual inlet cycle, due to the large pulses of new sediment added to the overall island system that counterbalance the downdrift erosion and breach vulnerability caused by the groin field.

Great Egg Harbor Inlet historically was also a dual inlet with “New Inlet” that breached the Longport spit every 15 years or so; the last cycle ended in 1891 when protection efforts for the railroad line on the Longport spit prevented another breach. Prior to stabilization, material was naturally bypassed from the north to the south across the inlet via the largest ebb-tidal delta in the state (Farrell et al. 1989).

At least 5 inlets in New Jersey have been closed artificially. The Navesink and Shrewsbury Rivers near Sea Bright and Sandy Hook historically entered directly into the ocean through inlets. The Navesink River Inlet was open prior to 1835 and Sandy Hook was connected to the Highlands instead of to Sea Bright. The railroad closed the inlet artificially in 1856 but the inlet reopened naturally in 1896-97. The inlet was closed artificially a second time in 1900-01. The Shrewsbury River Inlet was also closed artificially by the railroad in 1856 (NJDEP 1981). Turtle Gut Inlet at the north end of Two Mile Beach (Wildwood Crest) was closed in 1917 or 1922 (Dorwart 2002, Farrell et al. 1989, NJDEP 1981). Storm breaches at Harvey Cedars and Holgate from the Ash Wednesday Storm of 1962 were also closed artificially (NJDEP 1981, Nordstrom et al. 1986).

The remaining historic inlets along the New Jersey coast closed naturally. In addition, Manasquan Inlet closed naturally in 1926 but was artificially reopened in 1931 and remains open and stabilized with dual jetties (Dorwart 2002, Farrell et al. 1989).

Delaware

One tidal inlet currently is open in Delaware, Indian River Inlet, and it has been stabilized with hard structures along both shoulders (Table 4). Indian River Inlet has dual jetties and bulkheads, which has eliminated any sandy beach habitat along the inlet shoulders. The inlet has been dredged periodically since 1876 although the jetties were not constructed until 1939 and the bulkheads in 1941. There is a sand bypassing plant at the inlet which bypasses sediment annually to beaches to the north. The flood shoal of the inlet was mined in 1990 and 1992 to nourish the beach to the north of the inlet (NMFS 2014). No inlets in Delaware have been relocated. Historically Indian River Inlet naturally opened and closed several times, most recently between 1911 and 1933, with periodic efforts to artificially re-open the inlet having various levels of success. The inlet has remained open since it was stabilized with the aforementioned hard structures (Delaware Inland Bays Estuary Program 1993, Smith 1988).

Table 4. Open tidal inlets from north to south along the Delaware 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.

	Type of Habitat Modification							
Inlet	**Artificially created**	**Jetties**	**Terminal groins / groin field**	**Seawalls / revetments**	**Breakwaters**	**Dredging**	**Relocation of channel or inlet**	**Mined for beach fill**
Indian River Inlet, DE	**X**	**D**		**X**		**X**		**X**

Historically, an inlet named Assawoman Inlet was open in 1690 but closed sometime before 1880 just north of the Maryland border on Fenwick Island (Krantz et al. 2009). Although no new inlets have been cut along the Delaware coast in more than a century, one artificial cut was temporarily made to drain a storm-flooded Silver Lake in Rehoboth Beach to the ocean following a hurricane in 1933 (Morgan 2009).

Maryland

One tidal inlet currently is open in Maryland, Ocean City Inlet, and it has been stabilized with hard structures along both shoulders (Table 5). Ocean City Inlet has dual jetties, a seawall, and three breakwaters on its southern shoreline. This inlet has been dredged since 1933 and is well known for its downdrift erosion impacts on Assateague Island National Seashore and State Park (Brock et al. 2004, Dean 1993, Hemsley 1990, Rosati 2005, Schupp et al. 2014, Smith 1988). No inlets have been relocated but one was cut artificially shortly before World War I near Ocean City, although it did not remain open long (Morgan 2011). A larger effort to cut a new inlet approximately 5 miles south of the present-day

Ocean City Inlet had state funding in 1933 but was awaiting federal funding when the hurricane of 1933 created Ocean City Inlet (Morgan 2011, Schupp et al. 2014). The shoal complex of Ocean City Inlet has been mined twice annually since 2004 to supply sediment for a mechanical sand bypassing project on Assateague Island to compensate for long-term erosional losses from the jetties and dredging at the inlet; this 25-year project is scheduled to mine sediment from the inlet and its shoals twice annually to mechanically bypass sediment to the nearshore and surf zone area along northern Assateague Island (Schupp et al. 2013, 2014).

Table 5. Open tidal inlets from north to south along the Maryland 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
Ocean City Inlet, MD		D		X	X	X		X

Historically at least 16 inlets have been open on the Maryland portions of Assateague and Fenwick Islands. Thirteen of these historic inlets closed naturally and the other 3 were closed artificially. Sinepuxent Inlet was mapped in 1524 south of present-day Ocean City near Tingles Island when French explorers first visited the area; that inlet remained open until around 1830 (Krantz et al. 2009, Morgan 2011). Other historic inlet sites on Assateague Island include areas near Sandy Point Island, the Bayside Campground and Ferry Landing, Fox Hill, the Assateague Island Lighthouse, Green Run Bay, and just north of the Virginia state line; historic maps show these inlets open for varying lengths of time from 1649 through 1929. Two inlets (Mattapany and Beach Inlets) were historically open on northern Fenwick Island from the late 17th century to the late 19th century (Krantz et al. 2009, Morgan 2011).

Dune construction and beach fill projects since 1950 have prevented new breaches on the Maryland portion of Assateague Island with the exception of the Ash Wednesday Storm of 1962 (Schupp et al. 2013, 2014). A storm breach was cut immediately south of the southern jetty at Ocean City Inlet in 1961. The Ash Wednesday Storm of March 1962 widened this breach and opened two other breaches - one approximately 1.2 miles (2 kilometers (km)) south of Ocean City Inlet and the other 4.2 miles (6.7 km) north on Fenwick Island. The jetty area breach and the Fenwick Island breach were closed artificially in less than a year. Initial attempts to close the southern breach in the spring of 1962 failed and the breach finally closed in early 1965 (Rosati 2005).

Virginia

Fourteen tidal inlets currently are open in Virginia, of which 1 (7%) has been stabilized with hard structures (Table 6). Rudee Inlet, the inlet with hard structures, has dual jetties. Two (14%) inlets have been or continue to be periodically dredged for navigation or erosion control purposes to redirect channels away from buildings or infrastructure. No inlets have been relocated, with artificial closures of existing inlets and openings of new inlets nearby. No new inlets have been cut artificially in Virginia. One inlet opened by the Ash Wednesday Storm of 1962 on southern Wallops Island was artificially closed shortly thereafter (King et al. 2010). Although no inlet shoal complexes have been mined to supply sediment for beach nourishment projects, sediment dredged from Rudee Inlet is frequently deposited on the beaches of Virginia Beach.

Table 6. Open tidal inlets from north to south along the Virginia 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**
Chincoteague Inlet, VA						**X**		
Gargathy Inlet, VA								
Metompkin Inlet, VA								
Wachapreague Inlet, VA								
Quinby Inlet, VA								
Great Machipongo Inlet, VA								
Sand Shoal Inlet, VA								
New Inlet, VA								
Ship Shoal Inlet, VA								
Unnamed inlet between Myrtle and Mink Islands, VA								
Unnamed breach in Myrtle Island, VA								
Little Inlet, VA								
Fishermans Inlet, VA								
Rudee Inlet, VA		**D**				**X**		

In addition to the 14 inlets currently open in Virginia, at least 12 more have been open historically. The Virginia portion of Assateague Island has had four inlets open long enough to be mapped, although only one had a name (Assateague Inlet) (Krantz et al. 2008). Assawoman Inlet separated Wallops and Assawoman Islands for well over a century before it closed naturally sometime between 1988 and 1994 (King et al. 2010). Cobb Island was separated from another island to its north by a dual inlet system on survey maps from 1852, and Wreck Inlet historically separated Bone and Wreck Islands (Barnes et al. 2008).

More recently, Finkelstein (1988) states that both Metompkin and Smith Islands experienced numerous major breaches in the 20th century and that Cedar and Myrtle Islands have also been breached. Metompkin Inlet has periodically opened and closed in different locations along Metompkin Island numerous times in the last century (Fenster and Dolan 1996). Cedar Island is periodically breached by an ephemeral inlet that opens and closes periodically approximately 1.5 miles (2.4 km) north of Wachapreague Inlet; it most recently closed in 2007 (Nebel et al. 2012). Bungalow Inlet historically divided Smith Island and was open from 1929 to about 1969 (Finkelstein 1988). All the inlets currently open in Virginia with the addition of Assawoman have been open since at least 1852 and appear on historic survey maps from then to now, although a few were originally known by other names (Barnes et al. 2008). The inlets have not migrated significantly in the last century and a half, although a few of the islands are migrating relatively quickly and are frequently breached by overwash and ephemeral channels. In general the existing inlets are relatively stable since they overlie paleochannels (Nebel et al. 2012).

DISCUSSION

The majority (64%) of the sandy tidal inlet habitats from Montauk Point, NY, to the Virginia-North Carolina line that existed in 2010-2011 have 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 oceanfront Atlantic coast of New York and northern New Jersey has the most contiguously modified habitat; by contrast, nearly the entire Eastern Shore of Virginia has remained unmodified. Only one inlet between Montauk, NY, and Assawoman Island, VA, is unmodified – Little Egg Inlet, NJ, which is adjacent to the Edwin B. Forsythe NWR (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 Leatherman (1989), Dean (1993), Bush et al. (1996, 2001, 2004), Cleary and Marden (1999), Seabergh et al. (2003), Wamsley and Kraus (2005), Thomas et al. (2011) and many others. The maintenance of navigation channels by dredging can significantly alter the natural coastal processes on adjacent inlet shorelines, as described by Leatherman (1989), Dean (1993), Otvos (2006), Morton (2008), Otvos and Carter (2008), Beck and Wang (2009), and Stockdon et al. (2010).

In the area covered by this assessment, Leatherman (1989) describes the impacts of hard stabilization and dredging of inlets along the south shore of Long Island. "Jettied inlets may interfere with the long-term sedimentary dynamics of a landward-migrating barrier island. Stabilization and maintenance dredging of [Fire Island, Moriches and Shinnecock Inlets] have already had a direct effect by precluding full development of flood tidal shoals and preventing closure of Moriches and Shinnecock Inlets. The indirect, longer-term effects are insidious and more difficult to quantify, due to artificial inlet control interfering with the most important process promoting landward barrier migration" (Leatherman 1989, p. 115).

Leatherman (1989) argues that Moriches and Shinnecock Inlets would have closed naturally long ago if they had not been stabilized with jetties and dredged. "The existence of these stabilized inlets is interfering at least indirectly, if not directly, with barrier-island dynamics, but it is difficult to quantify the impacts over the short term" (Leatherman 1989, p. 114). The stabilized Fire Island, Moriches and Shinnecock Inlets "are probably beginning to interfere with long-term dynamics of the south shore barriers by retarding the present [barrier island] migrational process and largely precluding new salt marsh formation both indirectly and directly (by dredging of the flood shoals)" (Leatherman 1989, p. 115). Moreover, Leatherman (1989) states that by artificially maintaining the presence of existing inlets the potential of new inlets breaching during storms is minimized since the existing inlets serve as an outlet for storm surge, which would otherwise breach barrier islands where they are low and narrow.

The relocation of inlets or the artificial 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 southern oceanfront U.S. breeding range of the piping plover are significant. The cumulative effects catalogued herein are regional, covering all five states in this range. Between Montauk, NY, and the Virginia-North Carolina boundary, nearly two-thirds (64%) of the inlets and their associated habitats have been modified. The cumulative environmental consequences are adverse, major and long-term. Fenster and Dolan (1996) found that the barrier island inlets of Virginia and northern North Carolina dominate coastal processes and adjacent island shorelines up to 2.5 – 3.1 miles (4 – 5 km) and influence adjacent shorelines up to 3.7 – 8.1 miles (6 – 13 km). Although this range of dominance and influence is variable for each (unmodified) inlet, it indicates that the environmental consequences from human modifications of inlets extend on the order of several miles (or kilometers) from each inlet.

The artificial opening and closing of inlets modifies inlet habitat in the most extreme manner, resulting in the artificial conversion of habitat types and alteration of their abundance and distribution. A number of inlets (8, 6 of which are currently open) have been artificially created between Montauk, NY, and the Virginia-North Carolina line (Table 1). These artificially created inlets tend to need hard structures to remain open or stable, with 3 of the 8 (38%) of them having hard structures at present and 3 more often closing within days of their artificial openings. At least 13 inlets have been artificially closed; artificial closure of inlets results in complete loss of inlet habitat.

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. Cialone and Stauble (1998, p. 539) state that “Any removal of sand from an inlet system lowers the elevation of that portion of the system, resulting in a flow of sand to restore local equilibrium.” Dean (1993) also found that the dredging of deepened navigational channels causes erosion on adjacent shorelines and faster deposition within the dredged channel; the alteration of one element that contributes to an inlet’s equilibrium will affect all the other elements and disrupt the dynamic equilibrium.

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; Indian River Inlet (DE) has been dredged since 1876 and pond letting of 3 or 4 inlets on Long Island has occurred since pre-Colonial times (Delaware Inland Bays Estuary Program 1993, Bokuniewicz et al. 2011). Dredging is conducted multiple times a year at several inlets: Shark River Inlet (NJ), Barnegat Inlet (NJ), Ocean City (MD), and Rudee Inlet (VA). Dredging is typically conducted annually or every 2 to 3 years, which results in continual perturbations and modifications to inlet and adjacent shoreline habitat that are magnified by dredging multiple times a year. The volumes of sediment removed can be major, with an average of 300,000 cubic yards being removed annually from Barnegat Inlet (NJ) and 100,000 cubic yards bypassed annually at Indian River Inlet (DE) (Delaware Inland Bays Estuary Program 1993, USACE 2013).

The mining of inlet shoals also removes massive amounts of sediment, with 1.6 million cubic yards (mcy) mined for beach fill from Corson’s Inlet (NJ) in 1984, 2.6 mcy mined from Great Egg Harbor Inlet (NJ) in 1992 and another 3.5 mcy mined in two episodes 1993 (Cialone and Stauble 1998, Farrell et al. 1989).

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, although the impacts are concentrated in NY, NJ, DE and MD.

The hard stabilization of inlets is another contributor to the appreciable cumulative adverse effects to inlet habitat along the oceanfront coast from New York to Virginia. The construction of jetties, groins, seawalls and revetments leads to habitat loss and both direct and indirect impacts to adjacent shorelines. Four inlets in this assessment region have hard stabilization structures along their entire inlet shorelines, eliminating all sandy beach habitat from their inlet shoulders. Habitat modifications resulting from the construction of hard structures are long-term and essentially permanent where the structures are maintained in perpetuity; at least 3 inlets have hard structures that are a century old or more.

Even without jetties at an inlet, adjacent development may affect inlets. Nordstrom (1988) found that inlets were less mobile when the adjacent shorelines are developed than those that were undeveloped. At the four unjettied inlets Nordstrom (1988) analyzed in New Jersey, he found that the inlets are naturally cyclical in their erosion and accretion patterns. Maintenance dredging can stabilize the channel position and suppress the natural inlet cycle where the ebb channel is allowed to fluctuate widely. Bulkheads, groins (including terminal groins) and beach fill projects on adjacent developed areas can prevent breaches updrift of the inlets, alter erosion and accretion patterns and diminish the magnitude of the inlet cycle as well.

Most inlets that have been modified are modified in multiple ways. Dean (1993) noted that the erosional losses and channel shoaling issues resulting from dredged channels can be ameliorated by terminal structures on the inlet shorelines such as the breakwaters installed on the Assateague Island shoreline at Ocean City Inlet (MD) or by terminal groins and jetty modifications. "The installation of a terminal structure on the updrift side of the entrance is always beneficial to dredging interests and the stability of the updrift shorelines, but is always detrimental to the stability of the downdrift shorelines" (Dean 1993, pp. 208-9). One inlet modification (dredging) thus can lead to additional modifications (hard stabilization). Shinnecock Inlet (NY) is another example of an inlet modified in multiple ways, where the inlet has been stabilized with dual jetties plus a revetment, the inlet is dredged, and its ebb shoals have been mined for beach fill. Buonaiuto et al. (2008, p. 873) found that "The configuration of Shinnecock Inlet and its associated ebb shoal has been influenced by storm events, dredging operations, and nourishment projects, which have altered the morphology over the past 68 years." They found that from the time that the inlet was opened and its jetties were constructed, the ebb shoal had reached roughly 60% of its equilibrium volume of sediment by 1998; at the rate of growth measured under these modified conditions, it would take an additional 75 years or so to for the inlet shoals to reach full equilibrium and more effectively bypass sediment to adjacent beaches. "However, dredging of the ebb shoal will periodically set back the evolution of the inlet" (Buonaiuto et al. 2008, p. 869). Therefore the direct impacts of the inlet's stabilization and dredging will persist for nearly 150 years and possibly longer.

The effects of inlet modifications are on-going, cumulative, and increasing in intensity, as hard structures continue to be built or rebuilt as recently as 1991. With sea level rising and global climate change altering storm dynamics, the pressure to further modify these sandy tidal inlets in this area 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.

The cumulative effects of the existing habitat modifications to 23 of the 36 inlets, as described in this assessment, should be addressed in current and future proposals that would affect sandy tidal inlets within the southern oceanfront U.S. breeding range of the piping plover between Montauk, NY, and the Virginia-North Carolina boundary. Fenster et al. (2011) theorize that tidal inlets may widen, more sand may be sequestered in ebb shoals, and the Virginia barrier islands in particular may fragment as new inlets open and the islands rapidly retreat as sea level rise continues to accelerate. Rising sea level and climate change are likely to continue to increase the number of inlets in the near future. Whether 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. 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.

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