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: Maine to the North Shore of Long Island[1]

Tracy Monegan Rice
Terwilliger Consulting, Inc.
May 2015
(revised July 2016)

Recovery Task 1.2 of the U.S. Fish and Wildlife Service (USFWS) Recovery Plan for the piping plover (*Charadrius melodus*) prioritizes the maintenance of "natural coastal formation processes that perpetuate high quality breeding habitat," specifically discouraging the "construction of structures or other developments that will destroy or degrade plover habitat" (Task 1.21), and the "interference with natural processes of inlet formation, migration, and closure" (Task 1.22) (USFWS 1996, pp. 65-66). This assessment fills a data need to identify such habitat modifications that have altered natural coastal processes and the resulting abundance, distribution, and condition of currently existing habitat in the breeding range. Four previous studies provided these data for the United States (U.S.) continental migration and overwintering range of the piping plover (Rice 2012a, 2012b) and the southern portion of the U.S. Atlantic Coast breeding range (Rice 2014, 2015) and additional reports will assess the status of these two habitats in the breeding area immediately following and 3 years after Hurricane Sandy. This assessment provides these data for one habitat type – namely sandy tidal inlets within the northern portion of the breeding range along the Atlantic coast of the U.S. A separate report will provide data for sandy beach habitat in the northern portion of the U.S. Atlantic Coast breeding range.

Inlets are a highly valuable habitat for piping plovers, red knots, 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 (LCC) 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 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, including the recently listed rufa red knot (*Calidris canutus rufa*). 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.

---

[1] *Suggested citation*:
Rice, T.M. 2015. 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: Maine to the North Shore of Long Island. Report submitted to the U.S. Fish and Wildlife Service, Hadley, Massachusetts. 58 p.

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).

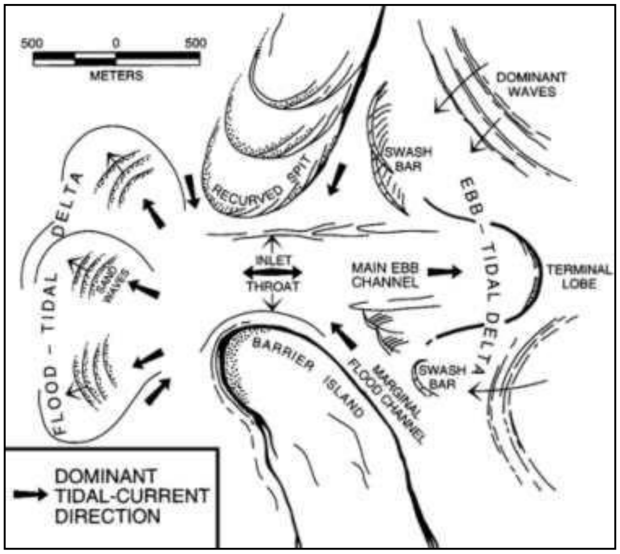
METHODS

This assessment was compiled by examining many disparate sources of information regarding tidal inlets within the piping plover's 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 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 2011 to early 2012 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 the northern portion of the U.S. Atlantic Coast breeding range of the piping plover, namely those within the states of Maine (from Georgetown south, where nearly all of the state's sandy beaches are located), New Hampshire, Massachusetts, Rhode Island, Connecticut, and New York (the Long Island Sound shoreline from Plum Point to Fishers Island and the Peconic Estuary shoreline). Tidal inlets on the South Shore of Long Island in New York to Virginia were assessed in Rice (2014) and in North Carolina in Rice (2012a). 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, 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 (Leatherman 1988, Davis and Gibeaut 1990, Bush et al. 1996, FitzGerald 1996, Hayes and FitzGerald 2013). 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 sound 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).



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, Hayes and FitzGerald 2013). 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. Wide, open bay or sound entrances (e.g., the entrance to the Connecticut River) were not categorized as inlets in this assessment due to their width and the absence of active inlet shoal complexes.

Tidal inlets are highly variable in their geomorphology, and the tidal inlets of New England and northern Long Island differ from those along the Mid-Atlantic, southeastern Atlantic and Gulf coasts. Inlets along the latter typically occur between barrier islands or along barrier spits where rock outcrops are rare. In New England and Long Island, the coast has been sculpted by glaciers and rocky shorelines and those composed of glacial materials (e.g., sand, gravel and boulders) are common. Barrier islands are limited in New England, with one stretch of barrier islands from Great Boars Head, in Hampton, New Hampshire (NH), to the Annisquam River Inlet near Cape Ann, Massachusetts (MA), and another on the outer arm of Cape Cod stretching from Coast Guard Beach just north of Nauset Inlet in Eastham south to Monomoy Island, MA (FitzGerald 1993). One barrier island historically existed in Maine at Pine Point Beach, but the island joined the Old Orchard Beach peninsula / spit after Little River Inlet closed in the 1870s and ceased to be an island (FitzGerald et al. 1989). Sandy Point that straddles the border between Rhode Island and Connecticut is the only other true barrier island in New England (since 1938 when the barrier spit was cut by a new inlet), although a number of barrier spits or baymouth bars occasionally will be breached and become sandy islands for short periods of time. Although barrier islands may be uncommon in New England, baymouth and bayhead barrier beaches and barrier spits are present along much of the coast and provide similar ecosystem functions, including piping plover habitat (Leatherman 1988, FitzGerald 1993 & 1996).

As a result of the geologic history and setting of New England, tidal inlets are slightly different from those on the rest of the Atlantic and Gulf coasts. They can be anchored or located with a headland or outcropping of rock or resistant glacial material on one side, limiting the inlet to one sandy shoreline (FitzGerald 1996). Most of New England experiences significantly higher tidal ranges than the remaining Atlantic and Gulf Coasts, which can limit flood tidal deltas or shoals and even render them nonexistent. The lagoons, ponds or bays behind these tidal inlets may be filled with wetlands and tidal creeks instead of open bodies of water. Similarly, some areas of New England such as Maine have significantly higher wave energy than other Atlantic regions, limiting ebb tidal deltas or shoals. FitzGerald (1993, 1996) describes how New England's tidal inlets may lack flood or ebb tidal shoals altogether due to higher tidal ranges and/or wave energies; others may be small or in the case of flood shoals, attached to tidal marsh landward of the inlet. Morgan et al. (2005) found no ebb shoals at Mattituck or Goldsmith Inlets along New York's Long Island Sound shoreline.

Many New England tidal inlets are located in drowned river valleys; as a result, their underlying geology controls their location and stability (FitzGerald 1996). Hampton River Inlet (NH), Merrimack River Inlet (MA), Parker River Inlet (MA), Essex River Inlet (MA) and Annisquam River Inlet (MA) are all examples of tidal inlets that are found at the mouths of drowned estuaries and naturally stabilized by the presence of rock outcrops and resistant glacial deposits

(FitzGerald 1996). These types of inlets do not migrate or have cycles of opening and closing like inlets along barrier island coastlines. The glacial history of New England also created a number of coastal ponds, many of which are located along the coastline and are separated from the ocean or sound by a narrow sandy barrier. These sandy barriers are periodically breached with inlets from the oceanside by major storms or from the pond side by seasonally high freshwater levels in the pond. Artificial inlets historically have been cut, sometimes multiple times a year, to drain high water levels or to support fisheries in the ponds (similar to the pond-letting described for southern Long Island in Rice 2014). These breachings, both artificial and natural, of coastal ponds are short-term with the inlets lasting from 2 days to a few weeks or a few months (Lee 1980, RI CRMC 1999, USFWS 2002a).

For the purposes of this assessment, therefore, tidal inlets were defined with these criteria:

1. Sandy beach habitat (either natural or artificially maintained with fill) must be present on at least one inlet shoulder, while the other shoulder may abut a bedrock headland or resistant glacial deposit (FitzGerald 1993);
2. If the inlet is stabilized with hard structures on both shoulders, at least one adjacent beach must be present to indicate that a sandy beach would be present on the inlet shoulder in absence of the stabilization structures;
3. Some body of water must be landward of the inlet for tidal exchange to be present through the inlet; i.e., a cove, bay, sound, pond, lagoon, river or tidal creek outlet. Finger canals to private development are not considered a body of water of sufficient size or shape, but small boat basins may be included if one of the first two criteria are met;
4. The inlet is not confined between two bluffs;
5. Flood or ebb tidal deltas may be absent (FitzGerald 1996); and,
6. The inlet is located on the oceanfront shoreline or the shoreline of a bay, sound or cove large enough to have significant fetch from the Atlantic Ocean, Gulf of Maine, Cape Cod Bay, Nantucket Sound, Vineyard Sound, Buzzards Bay, Block Island Sound, Long Island Sound, Gardiners Bay, Shelter Island Sound, or Great and Little Peconic Bays. [Note that upper Narragansett Bay is excluded since several large islands limit the fetch from Block Island Sound.]

Many of the tidal inlets identified in this assessment are the outlets for tidal creeks, streams or rivers. These inlets do not have an open cove, bay or pond on their landward side but typically had large wetland areas. These outlets are described as tidal inlets by FitzGerald (1993) and were considered inlets in this assessment where one of the first two criteria were met – namely that sandy beaches were present on at least one inlet shoulder or would be present in the absence of hard stabilization structures including seawalls, bulkheads, revetments, groins and jetties.

A number of inlets included in this assessment are to private boat basins, marinas or harbors, which are often entirely stabilized with jetties, bulkheads and/or seawalls. If sandy beaches are present on at least one inlet shoulder, it was assumed that the boat basin would be a small cove, pond or tidal wetland and creek area with a natural sandy inlet in the absence of the hard stabilization structures. For example, the inlet to a boat basin and the Shellfisher Preserve mariculture facility at the in Southold, NY, was included (Figure 2). It was assumed that boat basins such as these would look like Log Cabin Creek in the Mashomack Preserve on Shelter Island, NY, in the absence of human modifications (Figure 3). Notations were made where

Figure 2. An inlet to a boat basin and the Shellfisher Preserve mariculture facility in Southold, NY. Note that the inlet and the basin have been nearly entirely stabilized with hard structures including revetments, bulkheads, and box jetties. Sandy beaches are present on both inlet shoulders, although the beach on the right has narrowed due to downdrift erosion caused by stabilization structures. Image from Google Earth dated March 6, 2012.

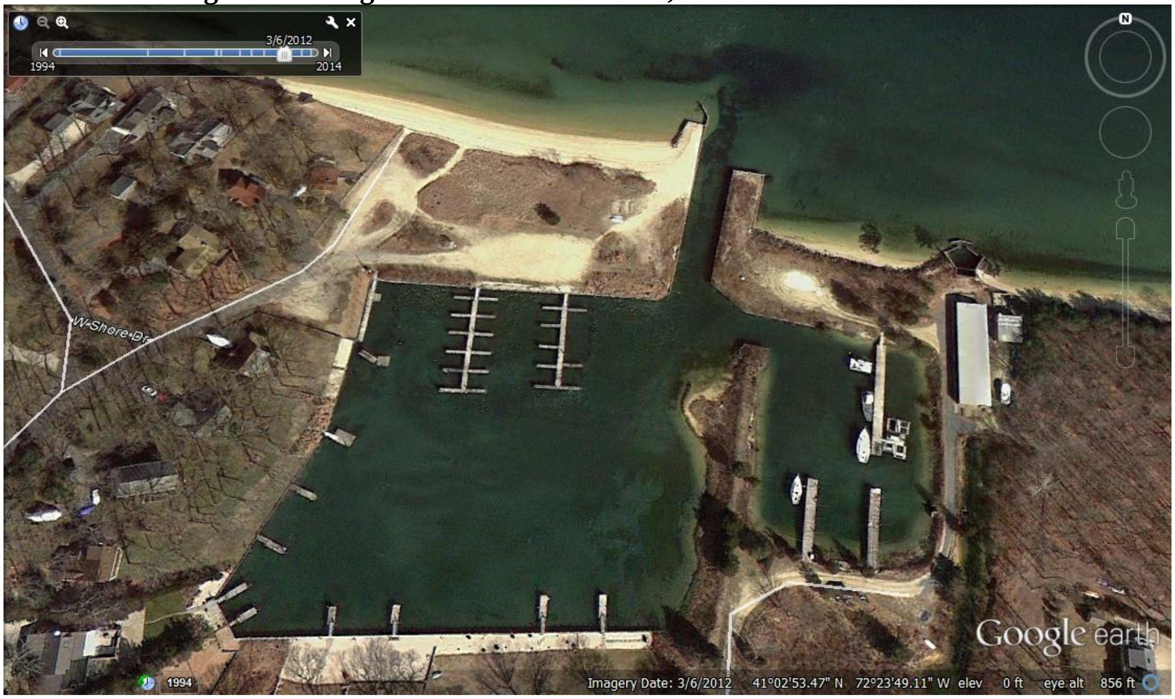


Figure 3. Miss Annie's Creek Inlet in the Mashomack Preserve on Shelter Island, NY. This inlet has not been modified and represents a natural tidal inlet and small cove or pond system. Image from Google Earth dated March 6, 2012.

available information indicated that a boat basin and its associated inlet were artificially created and thus would not exist without human modifications to the shoreline.

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 U.S. Atlantic coast prior to Hurricane Sandy in October 2012 from Georgetown, ME, to the Long Island Sound and Peconic Estuary shorelines of New York, 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 Hurricane Sandy or 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 breeding 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. This report and data will be posted on-line at the North Atlantic LCC Hurricane Sandy Science Coastal Resiliency Projects website (http://northatlanticlcc.org/projects).

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 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 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 or artificially opened or closed since the 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.

U.S. Army Corps of Engineers (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), provided details on the dates of construction of federal structures (and thus dates of habitat modification). In Massachusetts, ownership and construction date information for both public and private inlet stabilization structures were obtained from the Massachusetts Open Resource Information System (MORIS), which is maintained by the Massachusetts Office of Coastal Zone Management, Executive Office of Energy and Environmental Affairs (accessible through http://www.mass.gov/eea/agencies/czm/program-areas/mapping-and-data-management/moris/).

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 1800s. 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., The Great New England Hurricane of 1938) 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 often 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 generally 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. In Rhode Island some flood tidal shoals have been intentionally dredged for habitat restoration projects, with the dredged material beneficially placed on nearby beaches; these projects were not considered mining projects since their primary purpose is habitat restoration of shallow water habitats and not the mining of beach fill material. 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 343 tidal inlets that were open in New England and northern Long Island prior to Hurricane Sandy in October 2012, at least 29 (8%) had been artificially created (i.e., cut where there was previously no inlet or dredged open after closing naturally), 215 (63%) have been stabilized with one or more hard structures, 133 (39%) had been dredged at least once, 4 (1%) have been relocated, and at least 5 (1%) had been mined as a sediment source for beach nourishment or for commercial sale of sand and gravel. Altogether 240 (70%) of the 343 inlets have been significantly modified in one or more of these ways. Furthermore, at least 15 inlets have been closed artificially and thus are not included in the 343 total inlets that were open prior to Hurricane Sandy (Table 1).

The states with more than half of their inlets modified by any means are New Hampshire (100%), Connecticut (86%), the Long Island Sound shoreline of New York (79%), the Peconic Estuary shoreline of New York (71%), Massachusetts (66%), and Rhode Island (53%). Maine (43%) was the only state with less than half of its inlets modified. In sum, over two-thirds (70%) of all the sandy inlets within the northern portion of the U.S. Atlantic Coast breeding range of the piping plover have been modified in one way or another.

Of the 215 inlets with at least one hard structure, 96 (45%) have one or two jetties, 67 (31%) have terminal or other groin structures, 127 (59%) have revetments (sandbag or rock), seawalls and/or bulkheads, and 16 (7%) has offshore breakwaters (NOTE: the numbers total more than 215 because many inlets have more than one type of structure). Rhode Island and Maine have the lowest proportions of inlets stabilized with hard structures (35 and 38% respectively) while New Hampshire (100%) and Connecticut (84%) have the highest proportions of structural stabilization at their inlets (Table 1).

Table 1. The number of open tidal inlets, inlet modifications, and artificially closed inlets in each state, the Long Island Sound (LIS) shoreline of New York north and east of Plum Point, and the Peconic Estuary shoreline of Long Island, New York, prior to Hurricane Sandy in October 2012.

State	Inlets Open Prior to Hurricane Sandy in 2012							Artificially closed
	Number of Inlets	Total Number of Modified Inlets	Habitat Modification Type					
			structures[†]	dredged	relocated	mined	Artificially opened	
ME	21	9	8	6	0	1	0	0
NH	3	3	3	2	0	0	0	0
MA	122	81	75	51	2	2	14[a]	8
RI	17	9	6	8	0	0	7[b]	0[c]
CT	56	48	47	12	0	0	0	7
NY – LIS	28	22	20	8	0	2	1	0
NY - PECONIC	96	68	56	46[d]	2	0	7	0
TOTAL	343	240 (70%)	215 (63%)	133 (39%)	4 (1%)	5 (1%)	29[e] (8%)	15 (n/a)

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

a –An inlet restoration project at East Harbor (Pilgrim Lake) in Cape Cod NS near Provincetown has been proposed but is likely to include culvert alternatives rather than creation of an artificial inlet. Thirteen of the 26 inlets that have been artificially created in Massachusetts were open prior to Hurricane Sandy in October 2012.

b – Rhode Island's coastal ponds have a long history of being artificially breached stretching back to Colonial times (Lee 1980). Some ponds were and/or continue to be breached annually or multiple times annually. Records are incomplete on how many of the ponds have been artificially breached or re-opened following closure during storms, making this number a minimum number. An additional 3 inlets that are confirmed to have been opened artificially in the past were closed prior to Hurricane Sandy.

c – A number of inlets that opened during hurricanes in Rhode Island have historically been artificially closed, but precise numbers are not available.

d – An additional two inlets were proposed for dredging prior to Hurricane Sandy in October 2012.

e – The total number of inlets that have been artificially opened that were open prior to Hurricane Sandy's landfall in October 2012. At least 16 additional inlets have been artificially opened historically.

<u>State-specific Results</u>

Maine

Twenty-one (21) tidal inlets were open in Maine south of Georgetown in 2012 prior to Hurricane Sandy, of which 8 (38%) have been stabilized with hard structures along at least one shoulder (Table 2). Of the inlets with hard structures, 4 have jetties (1 with a single jetty and 3 with dual jetties) and 5 have revetments, seawalls and/or bulkheads [note that an individual inlet may have multiple types of structures; e.g., in Maine 1 inlet has both jetties and revetments]. Six (29%) 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 or artificially opened. The shoal complexes of at least 1 inlet has been mined to supply sediment for a dune / beach nourishment project at Ogunquit Beach -- Ogunquit River Inlet in 1974 (FitzGerald et al. 1989). Altogether 9 of Maine's 21 tidal inlets (43%) have been modified by humans (Table 2).

FitzGerald et al. (1989) describes 19 major inlets in Maine, 3 of which are located north of this survey area (i.e., north of Georgetown). This study confirmed the continued existence of the 16 major inlets identified by FitzGerald et al. (1989) south of Georgetown and identified 5 additional inlets, 3 of which opened since 1989 and two which are small and presumably excluded from FitzGerald et al. (1989) because of their minor size. Inlets in Maine typically are found in the southern part of the state due to the underlying geology of the coast, which does not have a steady supply of sand or low enough land topography to form sandy tidal inlets (or beaches) in the northern part of the state (FitzGerald et al. 1989).

These modifications to Maine's tidal inlets have resulted in a number of impacts. Dickson (2003, p. 3) found that "Human activity is a dominant force affecting the shoreline position and rates of shoreline change" in coastal Maine, with jetties and seawalls the primary causes. "All of the major jetties at rivers in Maine have significantly altered local sand budgets and shoreline change" (Dickson 2003, p. 4). Dickson (2003, p. 5) also found that the "cumulative amount of sediment redistribution due to dredging is as significant as or more significant than natural processes in most local sediment budgets." FitzGerald et al. (1989, p. 79) reports that there is no flood tidal delta at the Kennebunk River Inlet because of dredging and "substantial loss of intertidal area through man's encroachment." Dickson (2003, p. 6) found that the "combined influence of jetty engineering, seawalls, and dredging has accelerated shoreline change and the inland positions of floodplains in Maine in the last century." In the last 100 years, jetty stabilization, dredging and dredge disposal activities at the Saco River have increased the natural sediment transport rate (from south to north) by 300% along the Saco Bay shoreline (Dickson 2003). This increase in sediment transport has led to erosion at Camp Ellis adjacent to the northern Saco River jetty, where more than 30 homes have been lost to erosion (Slovinsky and Dickson 2003). Dredging activities at the Ogunquit, Wells, and Kennebunk Rivers has also accelerated the regional (Wells Embayment) sediment transport rate over the last 40 years (Dickson 2003).

No inlets or breaches have been closed artificially in Maine, although the natural closure of Little River Inlet was partially caused by the damming of the inlet's drainage basin with the construction of a railroad embankment in 1875 (FitzGerald et al. 1989, Kelley et al. 1989, EPA 1995). At least 5 other inlets have closed as a result of natural coastal processes. An unnamed inlet periodically separates Fox Islands from Popham Beach in Phippsburg by breaching a tombolo[2] that frequently connects the two, as it most recently formed in 2008 (Dickson 2008,

[2] A tombolo is a sandy spit that connects an island to the mainland; the island is usually composed of glacial material or is a rock outcrop that anchors the barrier spit and may provide the sediment for the spit to form. Tombolos are often found in the northeastern U.S. where offshore islands are more common (Leatherman 1988). A tombolo may also connect an offshore breakwater with the adjacent barrier island or beach.

Table 2. Open tidal inlets from north to south along the coast of Maine from Georgetown to the New Hampshire boundary prior to Hurricane Sandy in October 2012 with (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 / bulkheads	Breakwaters	Dredging	Relocation of channel or inlet	Mined for beach fill
Little River (Reid State Park)								
Kennebec River						X		
unnamed inlet between Fox Islands and Popham Beach								
Old Morse River Inlet								
Morse River Inlet								
Sprague River Inlet								
Richards Pond Inlet								
unnamed inlet at Crescent Beach State Park								
unnamed inlet in Cape Elizabeth								
Spurwink River Inlet								
Scarborough River (Pine Point) Inlet		X				X		
Goosefare Brook				X				
Saco River		D		X		X		
Biddeford Pool Inlet (Wood Island Harbor)				X				
Little River Inlet (Kennebunkport)				X				
Batson River Inlet								
Kennebunk River		D				X		
Mousam River								
Merriland / Little River (Wells)								
Wells (Webhannet River) Inlet		D				X		
Ogunquit River Inlet				X		X		X

Google Earth 2015). Morse River Inlet occasionally switches its course through a process called avulsion, when the main inlet channel shifts from a northern position next to Popham Beach State Park to a breach that periodically forms across the Seawall Beach spit to the south; a small island is present when both inlets are open until the Old Morse River Inlet closes as it did most recently in 1987. Morse River Inlet very recently switched to its southern position, in March 2010, but the Old Morse River Inlet channel was still open in 2012 prior to Hurricane Sandy (FitzGerald et al. 1989, Dickson 2011, Google Earth 2015). The only other tidal inlet in Maine known to switch locations is the Ogunquit River Inlet, which appeared on historical maps of

1760 in a location approximately 1 kilometer (km) north of its current position; an 1879 map of the same area shows the inlet had opened in its current position and the old inlet had closed (Nelson 1979, FitzGerald et al. 1989). FitzGerald et al. (1989) reports a relict inlet was identified at Seawall Beach by Nelson (1979) but precise location and dates were not provided by FitzGerald et al. (1989). Finally, the Scarborough River Inlet may have closed prior to its stabilization and dredging in the 1960s; Kelley et al. (1989) states that the inlet closed but EPA (1995) states that the inlet was filling and narrow prior to jetty construction.

"Tidal inlets in Maine have experienced relatively little historical migration and only Ogunquit River Inlet has actually changed location during the past 200 years. However, inlet processes have been and continue to be responsible for the greatest amount of shoreline change along the adjacent barriers" (FitzGerald et al. 1989, p. 94). A recent study forecasting the impacts of a 3 foot static sea level rise at and near Rachel Carson NWR identified several potential locations for breaches or new inlets – 3 on Drakes Island and 2 at Wells Beach; the study also predicts a new area of ponding near the southern jetty at Wells Inlet with both a 2 or 3 foot static rise in sea level, which could provide moist soil substrate for foraging (Slovinsky and Dickson 2006). Another recent study predicting the impacts of sea level rise in Maine found that the southern end of Pine Point would be breached (near the former Little River Inlet site) by a 1.0 meter (m) rise in sea level (EPA 1995). So although historically Maine's tidal inlets have been stable, rising sea level and climate change could open several new inlets along the state's southern coast.

New Hampshire

Three (3) tidal inlets were open in New Hampshire prior to Hurricane Sandy in October 2012, of which all 3 (100%) have been stabilized with hard structures along at least one shoulder (Table 3). Of the inlets with hard structures, 1 has dual jetties, 1 has dual breakwaters and all 3 have revetments, seawalls and/or bulkheads. [Note that the structures at Rye Harbor are considered breakwaters by the USACE, although they could also be considered jetties (USACE New England District, http://www.nae.usace.army.mil/Missions/CivilWorks/Navigation/NewHampshire/Rye.aspx).] Two inlets (67%) 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 inlets have been cut artificially in new locations. No inlets have been mined to supply sediment for beach nourishment projects. Altogether all of New Hampshire's 3 tidal inlets (100%) have been modified.

No inlets or breaches have been closed artificially, while at least 1 inlet has closed as a result of natural coastal processes – an unnamed inlet at Eel Pond in Rye Beach that closed sometime between 1894 and 1932 (University of New Hampshire Library Digital Collections 2015). Little River Inlet opened and closed naturally with large storm events but an artificial outlet was established in 1890 at the northern end of the barrier system. The culvert was replaced with increasingly larger culverts in 1929, 1948 and 2000. The 2000 Little River Salt Marsh Restoration Project replaced the old 4 ft culvert with two adjacent 6 ft by 12 ft box culverts to

Table 3. Open tidal inlets from north to south along the coast of New Hampshire prior to Hurricane Sandy in October 2012 with (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 / bulkheads	Breakwaters	Dredging	Relocation of channel or inlet	Mined for beach fill
Parsons (Stinky) Creek Inlet				X				
Rye Harbor[1]				X	X	X		
Hampton River Inlet		D		X		X		

1 – The structures on the outer entrance to Rye Harbor are considered breakwaters by the USACE but they are sometimes referred to as jetties by others.

increase tidal flow to the Little River Salt Marsh system and decrease flooding of adjacent properties (NH DES 2005, David Burdick, University of NH, pers. comm., March 22, 2015).

Massachusetts

One hundred and twenty two (122) tidal inlets were open in Massachusetts prior to Hurricane Sandy in October 2012, of which 75 (61%) have been stabilized with hard structures along at least one shoulder (Tables 4 - 9). Northern Massachusetts has 18 tidal inlets in Essex, Norfolk and the northern portion of Plymouth Counties; half of the inlets in Essex County and 90% of the inlets in Norfolk and northern Plymouth Counties have been modified (Tables 5 and 6). Barnstable County has over half (55%) of the state's inlets, 69% of which have been modified in at least one way (Table 7). Southern Massachusetts has 15 inlets in southern Plymouth County and Bristol County, with 47% of them modified (Table 8). The offshore islands in Dukes and Nantucket Counties have 21 inlets, 64% of which are modified (Table 9).

Of the 75 inlets with hard structures in Massachusetts, 42 have jetties, 26 have groins, 6 have breakwaters, and 35 have revetments, seawalls and/or bulkheads. Fifty-one (51) inlets (42%) have been or continue to be periodically dredged for navigation or erosion control purposes. Barnstable County owns and operates its own dredge, which has been used to dredge at least 19 inlets in the county. Two inlet (2%) have been artificially relocated – Chatham (Stage) Harbor Inlet in 1965 and Ellisville Harbor (Salt Pond) Inlet at Ellisville Marsh in 2003 (Howes et al. 2003, Massachusetts Executive Office of Environmental Affairs 2003).

New inlets have been cut artificially in at least 26 locations, 14 of which were open in 2012 before Hurricane Sandy: Ellisville Harbor (Salt Pond) Inlet in 2003, Cape Cod Canal between 1909 and 1914, Pamet Harbor Inlet in 1919, Chatham Harbor Inlet in 1965, East Bay Inlet (Centerville River) in the early 1900s, West Bay Inlet in 1900, Eel Pond Inlet in 1944, Bournes

Table 4. Open tidal inlets along the coasts of offshore islands in Massachusetts by county prior to Hurricane Sandy in October 2012 with total habitat modification(s) at each.

County	Existing Inlets						
	Number of Inlets	Total Number of Modified Inlets	Habitat Modification Type				
			structures	dredged	relocated	mined	Artificially opened
Essex	8	4 (50%)	4	3	0	0	0
Norfolk & north Plymouth[1]	10	9 (90%)	9	6	1	0	2
Barnstable	68	47 (69%)	45	29	1	0	9
South Plymouth[2] **& Bristol**	15	7 (47%)	6	2	0	0	1
Dukes & Nantucket	21	14 (67%)	11	11	0	2	2
TOTAL	122	81 (66%)	75 (61%)	51 (42%)	2 (2%)	2 (2%)	14 (11%)

1 – Inlets located in Plymouth County north of Cape Cod.
2 – Inlets located in Plymouth County south of Cape Cod.

Pond Inlet in the mid-1980s, Green Pond Inlet in 1951, Falmouth Inner Harbor in 1907, Allens Pond Inlet in 1985 and 1989, Oak Bluffs Harbor Inlet on Martha's Vineyard before 1858 and Katama Bay Inlet on Martha's Vineyard in 1871, 1873, 1919 and 1921 (FitzGerald 1993, 1996; Howes et al. 2003, 2005a, 2005b, 2006a, 2010, 2013a, 2013c, 2013d, 2015; Davis 2009; Massachusetts Executive Office of Environmental Affairs 2003; USACE 2013f; University of New Hampshire Library Digital Collections 2015). In addition, the stabilized and channelized inlet to Little Pond in Falmouth naturally shoaled closed 36 times between August 1988 and May 1993; the inlet was reopened with dredging repeatedly until the inlet was widened in 1995 and dredging needs decreased (Howes et al. 2006d).

Another 12 inlets have been artificially opened in the past but were not known to be open at the time of Hurricane Sandy in October 2012. Harthaven Inlet on Martha's Vineyard was opened in 1985 and 1988 (Howes et al. 2010). Westpond Inlet on Cuttyhunk Island in 2000 and 2011 (Cuttyhunk Historical Society 2014). The remaining inlets can be considered ephemeral inlets at coastal ponds that historically were or are currently breached multiple times a year (Table 10). The historical artificial opening of inlets in Massachusetts is described by Tiffney and Andrews (1990, p. 4), who state that Long Pond was connected to saltwater through nearby Hither Creek in 1665, and that:

> *From settlement to the present, it is likely that the other six major coastal ponds on Nantucket (Squam, Sesachacha, Tom Nevers, Miacomet, Hummock and Capaum) have all been opened to the sea on a more-or-less regular basis. Until 1933, pond opening was an informal process, accomplished by groups of*

Table 5. Open tidal inlets from north to south along the coast of Massachusetts in Essex County north of Boston Harbor prior to Hurricane Sandy in October 2012 with (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 / bulkheads	Breakwaters	Dredging	Relocation of channel or inlet	Mined for beach fill
Merrimack River Inlet		D		X		X		
unnamed inlet at Sandy Point Reservation								
Parker River Inlet								
Essex River Inlet								
Annisquam River Inlet				X		X		
unnamed inlet at Cape Hedge								
Little Good Harbor				X				
Saugus River				X		X		

Table 6. Open tidal inlets from north to south along the coast of Massachusetts in Norwalk and Plymouth Counties north of Cape Cod prior to Hurricane Sandy in October 2012 with (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 / bulkheads	Breakwaters	Dredging	Relocation of channel or inlet	Mined for beach fill
Cohasset Inlet				X	X	X		
Scituate Harbor		D				X		
New Inlet (North River Inlet)								
Green Harbor Inlet		D		X		X		
Plymouth Bay Inlet			X			X		
Beaver Dam Brook (Bartlett Pond)				X				
Ellisville Harbor (Salt Pond) Inlet	X		X			X	X	
Cape Cod Canal	X	D				X		
Old Sandwich Harbor		D						
Scorton Creek		D						

> *fishermen working together to dig ditches when pond levels were high enough to provide sufficient "head" for eroding substantial channels. From 1933 until 1982, the Town of Nantucket paid for heavy equipment to open ponds each year. … In 1981, pond opening ceased under provisions of the Massachusetts Wetlands Protection Act.*

Howes et al. (2013d, p. 74) describes the current process:

> *It is common practice to artificially breach closed ponds/estuaries when water levels become high, typically to prevent flooding of upland properties and to flush the systems from a build-up of contaminants adversely impacting water quality. … coastal ponds along the south coast of Martha's Vineyard, Nantucket, and the southern shoreline of Massachusetts/Rhode Island are local examples of where periodic breaching is a regular facet of pond management.*

One other inlet has been proposed to be artificially opened at East Harbor (Pilgrim Lake) at Cape Cod National Seashore in Truro to restore an inlet that was artificially closed in 1869, although the restoration is likely to utilize culverts rather than creation of a new inlet due to land ownership and highway right-of-way issues (Thelen and Thiet 2008, Watts et al. 2011, Mark Adams, NPS, pers. comm. February 27, 2015). The shoal complexes of at least 2 inlets have been mined to supply sediment for beach nourishment projects – the two inlets to Sengekontacket Pond on Martha's Vineyard (USACE 2013d, Dukes County 2015). Altogether 81 (66%) of Massachusetts' 123 tidal inlets have been modified by humans.

At least 7 inlets have been closed artificially and available information indicates that one other inlet has been closed artificially in Massachusetts. An inlet at Eel Pond in Falmouth that had opened in the Great Hurricane of 1938 was closed by the USACE in 1941 only to be artificially reopened again in 1944 (Howes et al. 2005b). The Cape Cod Canal channel historically was east of Hog and Mashnee Islands in Falmouth, with the two islands separated from each other and the mainland by two inlets; improvements to the Cape Cod Canal in the mid-1930s created the Mashnee Island causeway with dredge spoil, closing the two inlets and rerouting the navigation channel west of the islands (Howes et al. 2006f). An inlet at East Harbor in Truro was artificially closed in 1869 with construction of a timber-stone dike and more than 100 buried groins across the inlet at the north end, forming Pilgrim Lake (FitzGerald 1993, Thelen and Thiet 2008, Watts et al. 2011). A restoration project has been proposed to artificially cut a new inlet at the southern end of the lake (through Moon Pond) to restore tidal flushing, water quality and marsh habitat; current private land ownership, development and infrastructure limit the location and size of the proposed inlet and prevent the complete restoration of the original inlet (Watts et al. 2011). Tidal exchange is currently through a 6-foot culvert at the southern end of the lake through Moon Pond (Mark Adams, NPS, pers. comm., February 27, 2015).

Table 7. Open tidal inlets along the coast of Massachusetts in Barnstable County clockwise from Cape Cod Bay around the Cape to Buzzards Bay prior to Hurricane Sandy in October 2012 with (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 / bulkheads	Breakwaters	Dredging	Relocation of channel or inlet	Mined for beach fill
Barnstable Harbor						X		
Bass Hole Inlet								
Sesuit Harbor Inlet		D				X		
Quivett Creek								
Paine's Creek Inlet			X					
unnamed small inlet at Ocean Edge Resort in Brewster			X	X				
Namskaket Creek Inlet complex								
Little Namskaket Creek Inlet complex								
Rock Harbor Inlet		X	X			X		
Boat Meadow River Inlet								
Herring River Inlet complex (Eastham)								
Herring Brook Inlet								
Hatches Creek Inlet								
unnamed inlet 1 at Lieutenant Island								
unnamed inlet 2 at Lieutenant Island								
unnamed inlet 3 at Lieutenant Island								
Blackfish Creek Inlet complex				X				
unnamed inlet near Omaha Road in South Wellfleet				X				
Wellfleet Harbor (Duck Creek) Inlet		X			X	X		
Herring River Inlet (Wellfleet)				X				
unnamed inlet 1 at Great Island								
unnamed inlet 2 at Great Island								
Pamet Harbor Inlet	X	D				X		
Hatches Harbor Inlet[1]								
Nauset Inlet								
North Inlet[2]								
New (South) Inlet								
Hospital Pond Inlet								
unnamed inlet between North and South Monomoy Islands								

Inlet	Type of Habitat Modification							
	Artificially created	Jetties	Terminal groins / groin field	Seawalls / revetments / bulkheads	Breakwaters	Dredging	Relocation of channel or inlet	Mined for beach fill
Chatham (Stage) Harbor Inlet	X	X		X		X	X	
Bucks Creek Inlet			X	X				
Mill Creek Inlet		X	X			X		
Red River			X					
Saquatucket Harbor (Andrews River)		D		X		X		
Wychmere Harbor			X	X	X	X		
Doanes Creek (Allen Harbor)			X	X		X		
Herring River (Harwich / Dennis)		D		X		X		
Swan Pond River		X				X		
Bass River Inlet		D		X		X		
Parker's River (Yarmouth)		X	X	X		X		
Lewis Bay / Hyannis Harbor		X	X			X		
Halls Creek			X					
East Bay (Centerville River)	X	X	X	X		X		
West Bay	X	D				X		
Cotuit Bay Inlet			X	X		X		
Popponesset Bay Inlet						X		
Waquoit Bay Inlet		D						
Eel Pond (Childs River) Inlet	X		X	X		X		
Bournes Pond Inlet	X	D				X		
Green Pond Inlet	X	D				X		
Great Pond Inlet		D		X		X		
Little Pond Inlet	X	D				X		
Falmouth Inner Harbor Inlet	X	D		X		X		
Siders Pond Outlet		D						
Salt Pond Outlet		D						
Trunk River (Oyster Pond)		D				X		
Wood Neck Inlet				X				
Great Sippewisset Creek								
West Falmouth Harbor		X			X			
Herring Brook (Old Silver Beach)		D			X			
Wild Harbor River Inlet			X					
Wild Harbor Boat Basin		X	X	X		X		
Fiddlers Cove				X		X		
Rands Harbor			X	X		X		
Megansett Harbor			X	X	X			
Pocasset River			X					

Inlet	Type of Habitat Modification							
	Artificially created	Jetties	Terminal groins / groin field	Seawalls / revetments / bulkheads	Breakwaters	Dredging	Relocation of channel or inlet	Mined for beach fill
Ox Pond								
Back River			X					

1 – Hatches Harbor Inlet, near the Race Point Lighthouse at the north end of Cape Cod NS, has an armored earth fill dike approximately 500 meters inland that constricts the inlet's main tidal creek with a bridge and culvert.
2 – North Inlet opened in 2007 and is north of North Chatham (Giese et al. 2009).
3 – New Inlet is also referred to as South Inlet; the inlet opened in 1987 (FitzGerald 1993, 1996; Buynevich and Donnelly 2006, Giese et al. 2009).

Wood End Cut or Inlet on Long Point near Provincetown was closed artificially in both 1885 and 1940 with timber brush bulkheads. In 1914 the USACE constructed a permeable stone dike to connect the Wood End barrier island to Provincetown to protect the adjacent harbor from future breaches (Ashley 1987). An inlet to Edgartown Great Pond on Martha's Vineyard was in the process of being closed artificially in Google Earth imagery from March 2012 (Google Earth 2015).

Long Island in Fairhaven historically was separated from Sconicut Neck by an inlet which appears to have been closed with a road causeway sometime after 1940 (University of New Hampshire Library Digital Collections, Google Earth 2015). Most recently, Ellisville Harbor (Salt Pond) Inlet was closed as part of an inlet relocation project in 2003 (Massachusetts Executive Office of Environmental Affairs 2003).

Available records document that at least 72 inlets have opened naturally on the Massachusetts coast, 55 of which had closed prior to Hurricane Sandy in October 2012. New Inlet was opened by the Portland Gale of 1898 and became the new outlet for the North River in Marshfield, leading the natural closure of South Inlet to the south, which was the old North River Inlet until then (FitzGerald 1993, Buynevich and Donnelly 2006). Shirley Gut historically separated Deer Island from Point Shirley in Boston Harbor; it was open on a 1739 map and closed between 1934 and 1936 (FitzGerald 1993, University of New Hampshire Library Digital Collections). FitzGerald et al. (2001) found evidence of 18 inlets at Duxbury Beach that have historically breached the spit, including a breach that opened following the Halloween Eve storm of 1991. Beaver Dam Brook to Bartlett Pond on White Horse Beach opened sometime after 1889 but it is unknown whether it opened naturally or artificially (University of New Hampshire Library Digital Collections).

Table 8. Open tidal inlets from east to west along the coast of Massachusetts in Plymouth (south of the Cape) and Bristol Counties prior to Hurricane Sandy in October 2012 with (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 / bulkheads	Breakwaters	Dredging	Relocation of channel or inlet	Mined for beach fill
Little Harbor								
Bourne Cove				X				
unnamed inlet in Mattapoisett (culvert to Eel Pond)			X					
Eel Pond (Mattapoisett)								
Mattapoisett River								
unnamed inlet west of Brandt Island Road in Mattapoisett			X					
unnamed inlet in Shaws Cove in Fairhaven			X					
unnamed inlet on West Island								
unnamed inlet at Winseganett Marsh, Fairhaven								
Winseganett Pond								
Little River (Dartmouth)				X				
Slocum River Inlet								
Allens Pond Inlet	X					X		
Westport River Inlet			X			X		
Richmond Pond								

Herring Brook Inlet in Eastham opened sometime between 1893 and 1944, three unnamed inlets on the south side of Lieutenant Island in South Wellfleet have opened within the last century, and a second inlet to the cove between Great Island and Great Beach Hill Island opened sometime after 1944 (University of New Hampshire Library Digital Collections). An inlet south of Jeremy Point historically separated the Point from Billingsgate Island before the island eroded away around 1942; an inlet may be reappearing sincea low tide shoal re-emerged in 2010 (Finch 1993, University of New Hampshire Library Digital Collections, Mark Adams, NPS, pers. comm., February 27, 2015, Google Earth 2015). Duck Harbor on the north side of Griffin Island in Wellfleet historically had an inlet which closed sometime after 1893 (University of New Hampshire Library Digital Collections). Prior to its stabilization with jetties, the Pamet River Inlet in Truro would migrate north, a new inlet would breach the spit to the south, the old inlet would close and the cycle would repeat (FitzGerald 1993).

Table 9. Open tidal inlets along the coasts of offshore islands in Massachusetts in Dukes and Nantucket Counties prior to Hurricane Sandy in October 2012 with (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 / bulkheads	Breakwaters	Dredging	Relocation of channel or inlet	Mined for beach fill
unnamed inlet on Pasque Island in Gosnold (Pasque Island)				X				
Cuttyhunk Harbor (Cuttyhunk Island)		D		X		X		
Katama Bay (Martha's Vineyard / Chappaquiddick)	X†					X		
Menemsha Creek (Martha's Vineyard)		D				X		
Paint Mill Brook (Martha's Vineyard)								
James Pond (Martha's Vineyard)								
Lake Tashmoo Inlet (Martha's Vineyard)		D				X		
unnamed inlet at Mink Meadows east of Lake Tashmoo (Martha's Vineyard)		D						
Lagoon Pond (Martha's Vineyard)		X		X		X		
Oak Bluffs Harbor Inlet (Martha's Vineyard)	X	D		X		X		
Harthaven Harbor Inlet (Martha's Vineyard)		D						
North Inlet (Sengekontacket Pond - Martha's Vineyard)		D				X		X
South Inlet (Sengekontacket Pond - Martha's Vineyard)		D				X		X
Edgartown Harbor (Martha's Vineyard)						X		
Cape Poge Gut (Martha's Vineyard / Chappaquiddick)						X		
unnamed inlet between Tuckernuck and Esther Islands (Nantucket)								
unnamed inlet between Muskeget and Tuckernuck Islands (Nantucket)								
North Pond (Tuckernuck Island)								
East Pond (Tuckernuck Island)								

Inlet	Type of Habitat Modification							
	Artificially created	Jetties	Terminal groins / groin field	Seawalls / revetments / bulkheads	Breakwaters	Dredging	Relocation of channel or inlet	Mined for beach fill
unnamed inlet at Eel Point on Nantucket (Nantucket)								
Nantucket Harbor (Nantucket Island)		**D**				**X**		

† An inlet to Katama Bay periodically opens and closes naturally, most recently opening naturally in 2007. Historically an artificial inlet was created in 1871, 1873, 1919 and 1921 (FitzGerald 1993).

Wood End Cut or Inlet would periodically open on Long Point near Provincetown, most recently in the blizzard of 1978. Its openings in 1885 and 1940 were closed artificially but its 1978 opening closed naturally sometime between 1985 and 1995 (Ashley 1987, Google Earth 2015).

Historically the Herring Cove area had a barrier beach that separated a back-barrier lagoon (Lancy's Harbor) from the cove between 1830 and 1920, with at least one inlet in the present day Herring Cove Beach area (NOAA 2015, University of New Hampshire Library Digital Collections, Mark Adams, NPS, pers. comm., February 27, 2015).

On the outer arm of Cape Cod, Nauset Inlet periodically breaches its adjacent spits as it slowly migrates north; the breaches eventually merge with the main inlet (Speer et al. 1982, Giese et al. 2010). North Inlet between North Beach and North Beach Island on Cape Cod NS most recently opened in 2007 (Giese et al. 2009), New (South) Inlet between North Beach Island and South Beach in 1987 (FitzGerald 1993 and 1996, Buynevich and Donnelly 2006, Giese et al. 2009), Chatham Inlet between the Nauset spit and South Beach / South Monomoy Island most recently (prior to Hurricane Sandy) in 1950 (FitzGerald 1996), the inlet separating North and South Monomoy Islands in 1978 (USFWS 2014), and the Monomoy Breach between South Beach and South Monomoy Island most recently in 1978 (FitzGerald 1993, USFWS 2014). North Inlet and New (South) Inlet remain open, but Chatham Inlet and Monomoy Breach had closed prior to Hurricane Sandy, closing sometime between 1985 and 1995 and in 2006 respectively (FitzGerald 1993, 1996, USFWS 2014, Google Earth 2015). Powder Hole on South Monomoy Island was historically a harbor of refuge in the 19th century but has now been nearly enclosed, with an inlet that periodically opens and closes on average every 1.5 years (Giese et al. 2010, USFWS 2014, University of New Hampshire Library Digital Collections). [Note that inlet openings and closings occurring after Hurricane Sandy will be addressed in a separate report.]

Table 10. Several coastal ponds in Massachusetts have historically been artificially breached on a regular basis, many since Colonial or Native American times. Six ponds on Martha's Vineyard and Nantucket continue to be artificially breached several times a year. The inlets remain open for a few days to a few months on average. Sources: Tiffney and Andrews (1990), Davis (2009), Great Pond Foundation (2010, 2011, 2012, 2013), Howes et al. (2006c, 2006d, 2008, 2013d, 2014, 2015).

Location	Coastal Pond	Historical breaching	Current breaching schedule
Martha's Vineyard	Edgartown Great Pond	unrecorded	Up to 4 times annually
Martha's Vineyard	Oyster Pond	Recorded since 1909	4-5 times annually
Martha's Vineyard	Tisbury Great Pond	unrecorded	3 times annually
Martha's Vineyard	Chilmark Pond	Recorded since 1904	Up to 3 times annually
Nantucket	Squam Pond	Colonial times to 1981	
Nantucket	Sesachacha Pond	Colonial times to 1981	2-3 times annually since 1991
Nantucket	Tom Nevers Pond	Colonial times to 1981	
Nantucket	Miacomet Pond	Colonial times to 1981	
Nantucket	Hummock Pond	Colonial times to 1981	Biannually since 1995
Nantucket	Capaum Pond	Colonial times to 1981	

In southern Massachusetts, inlets have historically occurred at several ponds and former islands in Barnstable, Fairhaven, Dartmouth, and Falmouth. Bournes Pond at Menauhant Beach in Falmouth Harbor has had inlets located both east and west of the current inlet (Buynevich and Donnelly 2006). On Martha's Vineyard, inlets periodically open and close at a number of locations, including Katama Bay, Edgartown Great Pond, Ripley Cove, and Chilmark Pond. On Nantucket inlets open and close occasionally on Sesachacha, Hummock and Narrow Creek Ponds. Tuckernuck Island to the west of Nantucket historically was located behind a barrier spit extending northwest from Esther Island / Nantucket, with a small inlet dividing the tip of the spit; the spit no longer exists and most likely welded onto Tuckernuck Island (University of New Hampshire Library Digital Collections, Google Earth 2015).

In the future, FitzGerald et al. (2001, p. 447) states that Duxbury Beach "is highly susceptible to future storm breaching. Furthermore, the concentration of former inlets along the central portion of Duxbury Beach and the lack of paleo-inlets to the north and south suggest that portions of the barrier which abut high marsh are less vulnerable to breaching and inlet formation." High marshes make barrier islands wider and retard the formation of overwash channels that can lead to the opening of new inlets during storms (FitzGerald et al. 2001). As a result, beaches and barrier spits that are narrow and lack high marshes on their landward shorelines may be the most vulnerable to new inlet formation in Massachusetts as sea level continues to rise.

New inlets are likely to open and close at many of southern Massachusetts' coastal ponds just as they have historically. As sea level rises and climate changes, these inlets may remain open for longer periods of time or permanently, in the absence of human modifications, as the rising sea allows the tides to more efficiently perpetuate the inlets.

Rhode Island

Seventeen (17) tidal inlets were open in Rhode Island in 2012 before Hurricane Sandy, of which 6 (35%) have been stabilized with hard structures along at least one shoulder (Table 11). Of the inlets with hard structures, 5 have dual jetties, 1 has a breakwater, and 4 have revetments, seawalls and/or bulkheads; 5 of the 6 inlets with hard stabilization structures are located west of Narragansett Bay. Eight (8) inlets (47%) have been or continue to be periodically dredged for navigation or habitat restoration projects. No inlets have been relocated, with artificial closures of existing inlets and openings of new inlets nearby. No inlets have been mined to supply sediment for beach nourishment projects, although dredge spoil is placed on nearby beaches at some inlets. Altogether 9 of the 17 inlets (53%) have been modified in at least one way (Tables 1 and 11).

Rhode Island's southern coast has 25 coastal ponds that are separated from Block Island Sound by barrier spits that have formed between adjacent headlands. These spits are periodically overwashed or breached during storms. Rhode Island's coastal ponds have a long history of being artificially breached stretching back nearly 400 years (Lee 1980). Records are incomplete on how many of the ponds have been artificially breached, with at least 10 artificial inlets known to have been cut: Quicksand Pond Inlet, Wesquage Pond Inlet, two locations at Point Judith Pond, and one at Potters Pond, Cards Pond, Trustom Pond, the Charlestown Breachway, the Quonochontaug Breachway and the Weekapaug Breachway (Lee 1980, Goldin and Regosin 1998, RI CRMC 1999, USFWS 2002a, Stolt et al. 2011, Bonnet Shores Land Trust 2015). Seven (7) of the 10 inlets that are confirmed to have been opened artificially were open prior to Hurricane Sandy, with the western Point Judith Pond, Potters Pond and Trustom Pond openings closed before the storm. Most of the artificial breachways were stabilized and made permanent in the 1950s and 1960s (Lee 1908, RI CRMC 1999, Stolt et al. 2011).

Artificial breachways were dug every spring and fall by local residents during the Colonial period at many salt ponds, either to release high seasonal freshwater levels or to enhance fisheries in the ponds, a practice that continues today at Quicksand, Wesquage, Trustom and Cards Ponds (Lee 1980, Erkan 2002). The USFWS mechanically has breached Trustom Pond at least once annually to enhance bird habitat in the spring and Cards Pond 4 to 6 times annually (in addition to multiple annual natural breaches), typically in response to adjacent landowner concerns about high pond water levels (USFWS 2002a; Ryan Kleinert, USFWS, pers. communication, March 26, 2015). The artificial breaches are temporary, lasting anywhere from 2 days to a few months (Lee 1980, RI CRMC 1999, USFWS 2002a). Quicksand and Wesquage Ponds are mechanically breached at least twice annually if the inlet is not naturally breached or open in spring and fall for fisheries migration (Goldin and Regosin 1998, Erkan 2002).

Table 11. Open tidal inlets from east to west along the coast of Rhode Island prior to Hurricane Sandy in October 2012 with (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 / bulkheads	Breakwaters	Dredging	Relocation of channel or inlet	Mined for beach fill
Quicksand Pond Inlet	X					X		
Tunipus Pond Inlet								
Little Pond Inlet								
Briggs Marsh Inlet								
Long Pond Inlet								
Gardiner Pond Inlet								
Easton Pond Inlet				X				
Almy Pond Inlet								
Wesquage Pond Inlet	X					X		
The Narrows Inlet								
Point Judith Harbor	X	D			X	X		
Cards Pond Breachway	X					X		
Charlestown Breachway	X	D				X		
Quonochontaug Breachway	X	D		X		X		
Weekapaug Breachway	X	D		X		X		
Little Narragansett Bay (at Napatree Point)								
Great Salt Pond (Block Island)		D		X		X		

Ponds are also breached naturally, either from the sound side by storms or from the pond side by high freshwater pond levels. The Great September Gale of 1815 opened an inlet to Point Judith Pond at the Narragansett-South Kingstown boundary (the boundary was later drawn through the inlet) and closed the existing inlet into Point Judith Pond that was located to the east at Sand Hill Cove (Lee 1980). The Great Hurricane of 1938 opened inlets at Quicksand Pond and Briggs Marsh; the storm also cut 7 overwash channels through East Beach at Charlestown – Green Hill Ponds and severed Sandy Point from Napatree Point on Little Narragansett Bay (Lee 1980, Patton and Kent 1992, FitzGerald 1993). Inlets were again opened to Quicksand Pond and Briggs Marsh in a blizzard in 1978 (FitzGerald 1993). The natural breaches to ponds are ephemeral and close within months (FitzGerald 1993), although geological surveys indicate that many ponds, especially the larger ones, historically have had semi-permanent inlets (Janet Freedman, RI CRMC, pers. comm. February 23, 2015).

New inlets are likely to open and close at many of Rhode Island's coastal ponds just as they have historically. As sea level rises and climate changes, these inlets may remain open for longer periods of time or permanently, in the absence of human modifications, as the rising sea allows the tides to more efficiently perpetuate the inlets.

Connecticut

Fifty-six (56) tidal inlets were open in Connecticut prior to Hurricane Sandy in 2012, of which 47 (84%) have been stabilized with hard structures along at least one shoulder (Table 12). Of the inlets with hard structures, 15 have jetties (9 with a single jetty and 6 with dual jetties), 18 have groins, 8 have breakwaters, and 30 have revetments, seawalls and/or bulkheads. Eleven (11) inlets (20%) have been or continue to be periodically dredged for navigation or erosion control purposes. No inlets have been relocated in Connecticut. No new inlets have been confirmed to have been cut artificially, but some small boat basins with inlets could be artificial. The shoal complexes of no inlets have been mined to supply sediment for beach nourishment projects, although dredge spoil is placed on nearby beaches at some inlets. Altogether 48 of the 56 inlets (86%) have been modified in at least one way (Tables 1 and 12).

At least 7 inlets or breaches have been closed artificially. Bride Lake Brook appears as a natural inlet on 1893 and 1938 maps but the tidal creek and wetlands now drain through what appears to be an armored culvert and can no longer be considered an inlet (MyTopo Online Historical Maps Collection, Google Earth 2015). Cedar Island in Clinton was separated from the mainland by a storm in 1840 and the resulting inlet was locally referred to as The Straits of Dardanelles; the inlet was artificially closed in 1883 by a dike (Patton and Kent 1992, Visel 2009). Dowd's Inlet would periodically open and close to a salt pond at Hammonasset Beach State Park during the late 1800s and early 1900s, but the inlet and salt pond were both filled with material during construction of the Grand Pavilion around 1964; the inlet site was later covered by a parking lot (Visel 2009). In the early 1970s a breach opened during a storm between the former Dowd's Inlet site and Tom's Creek at the western end of Hammonasset Beach but was soon closed by park staff (Visel 2009).

An inlet historically separated Fayerweather Island from the mainland in Bridgeport; the inlet was closed with a dike in 1869 and the land was drained, diked, filled, and stabilized with a seawall to develop Seaside Park (MyTopo Online Historical Maps Collection, City of Bridgeport 2015). The Great Hurricane of 1938 opened an inlet at the east end of Long Beach in Stratford, connecting Lewis Gut to Long Island Sound; the inlet was artificially closed in 1961, then five groins were built in front of the inlet in 1965-66 and 600,000 cubic yards of fill were placed on the beach to further stabilize the former inlet site (Patton and Kent 1992). In Greenwich, Tod's Point, or Greenwich Point Park, historically was an island separated from the mainland by an inlet. Around 1892 the inlet was closed with fill and a road by J. Kennedy Tod when he developed the island property (MyTopo Online Historical Maps Collection, Friends of Greenwich Point 2015).

A number of other inlets have opened and closed naturally in Connecticut. Bushy Point Inlet in Groton was opened in the Great Hurricane of 1938 and periodically opens and closes when a tombolo connects Bushy Point with the mainland (Patton and Kent 1992, Google Earth 2015). Two unnamed inlets on a sandy spit in Jordan Cove in Waterford open and close periodically,

Table 12. Open tidal inlets from east to west along the coast of Connecticut prior to Hurricane Sandy in October 2012 with (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 / bulkheads	Breakwaters	Dredging	Relocation of channel or inlet	Mined for beach fill
Wequetequock Cove / Anguilla Brook (Little Narragansett Bay at Sandy Point)		X				X		
Quiambog Cove				X				
Wilcox Cove								
Palmer Cove				X				
Venetian Harbor		D						
Mumford Cove								
Bushy Point Inlet								
Alewife Cove		D						
Goshen Cove								
Jordan Cove								
Niantic River				X		X		
Three Mile River				X				
Armstrong Brook								
Mile Creek				X		X		
Plum Bank Creek			X	X				
Oyster River Inlet			X	X				
Mud Creek		D						
Cold Spring Brook			X	X				
Money Point Inlet			X	X				
Menunketesuck / Patchogue Rivers		X	X	X		X		
Clinton Harbor			X			X		
Toms Creek		X	X					
Fence Creek				X				
East River (Guilford Harbor)						X		
Great Harbor Marsh inlet (in Joshua Cove)				X				
Mansfield Point Inlet				X				
Caroline Creek				X				
Morris Creek			X	X				
Sandy Point Inlet					X			
Old Field Creek Outlet 1					X			
Old Field Creek Outlet 2					X			
Cove River			X	X				

Inlet	Type of Habitat Modification							
	Artificially created	Jetties	Terminal groins / groin field	Seawalls / revetments / bulkheads	Breakwaters	Dredging	Relocation of channel or inlet	Mined for beach fill
Oyster River				X				
Bayview Beach Inlet			X	X				
Milford Harbor / Indian River		D	X			X		
Fletcher's Creek								
Nettleson Creek			X					
Housatonic River					X	X		
Bridgeport Harbor					X	X		
Ash Creek		X						
Pine Creek		X		X				
Southport Harbor				X	X	X		
Sasco Creek			X	X				
Green Farms Brook		D						
Sherwood Millpond		X		X				
Grays Creek				X				
Saugatuck Harbor			X	X				
Cedar Point Harbor			X					
Canfield Inlet		D						
Shorehaven Inlet				X				
Charles Creek			X	X	X			
Goodwives River			X	X				
Holly Pond (Cove Harbor)		X		X	X			
Cove River (west of Cove Island)								
Halloween Basin		X	X	X		X		
Dolphin Cove		X		X				

with the most recent cycle breaching the spit around 1991 and closing or merging with the cove as the spit erodes between 2002 and 2005 (Patton and Kent 1992, Google Earth 2015). The Griswold Point bar in Old Lyme was breached by an inlet in September 2004 imagery, but the inlet closed between 2008 and 2010 (Google Earth 2015). Menunketesuck Island historically was connected to the mainland in Westbrook Center, but two unnamed breaches opened and separated the island from Grove Beach sometime between 1838 and 1877, creating an unnamed sand shoal and Menunketesuck Island (Patton and Kent 1992). The historical inlet breach has widened sufficiently enough that it can no longer be considered a tidal inlet (Google Earth 2015). Old Field Creek in New Haven currently has two outlets to New Haven Harbor behind Sandy Point, but 1892 and 1914 maps show the creek as having an inlet directly to Long Island Sound west of the Sandy Point spit; it is unknown when or how the old inlet closed. Finally, an 1893 map for Bridgeport shows an unnamed inlet draining the tidal wetlands and creeks north of

Charles Island and east of Silver Sands State Park; the tidal creek is now directed through a culvert to the south and can no longer be considered an inlet (MyTopo Online Historical Maps Collection, Google Earth 2015).

A number of tidal inlets in Connecticut have been restricted and confined by tide gates. Because of the high tidal range in western Connecticut (exceeding 7 feet), many inlets were dammed with tide gates. Coastal ponds would fill at high tide, the tide gate would be closed, a pond would be created, then the ebb flow would be diverted through a mill race to generate water power before the gates were re-opened at low tide to refill the basin again (Patton and Kent 1992). The mills are no longer present or used, but the gates often remain closed to retain the ponds, which has eliminated tidal flushing and resulted in declining water quality (Patton and Kent 1992). Holly Pond at the mouth of the Noroton River in Stamford and the nearby Gorshams Pond at the mouth of the Goodwives River are two examples of Connecticut inlets that are restricted by tide gates in this manner (Patton and Kent 1992).

In addition to the impacts to tidal inlets from tide gates, dredging has generated impacts to some of the state's inlets. Dredging typically results in impacts to the inlet's dynamic equilibrium, the local and possibly regional sediment transport system, and removal of shoals. In Connecticut, dredging has also removed backbarrier wetland habitat and converted it to deepwater basins for boats. For example, Halloween Basin, or the Cummings Park boat basin, in Stamford was formerly a salt marsh before it was dredged to create the boat basin (Patton and Kent 1992).

New York – Long Island Sound Shoreline

Tidal inlets along the North Shore (Long Island Sound) of Long Island have been less studied and tend to be smaller than tidal inlets along the South Shore (Atlantic Ocean) of Long Island (Morgan et al. 2005). "It appears that most inlets on the north shore have been more stable [in location] and in existence longer than the inlets on the south shore" (Morgan et al. 2005, p. ii). "The stability of inlets on the north shore derives in part from a relatively steep inner shore face, presence of geologic controls such as glacial erratics or hard points on shore, origins of ponds as low-lying areas created after glaciation, and relatively weak longshore sediment transport that is about an order of magnitude less than that on the south shore of Long Island" (Morgan et al. 2005, p. ii). The tidal range on the North Shore is approximately twice that on the South Shore, waves are steeper on the North Shore than the South Shore, beaches of the North Shore tend to be backed with high bluffs rather than dunes as on the South Shore, and sediment on the North Shore has a wider range of grain size that includes gravel and cobbles that are absent on the South Shore (Morgan et al. 2005).

Twenty-eight (28) tidal inlets were open along the Long Island Sound shoreline of New York west of Plum Point prior to Hurricane Sandy in 2012, of which 20 (71%) have been stabilized with hard structures along at least one shoulder (Table 13). Of the inlets with hard structures, 9 have jetties (5 with a single jetty and 4 with dual jetties), 5 have groins, and 9 have revetments, seawalls and/or bulkheads. Eight (8) inlets (29%) have been or continue to be periodically dredged for navigation or erosion control purposes, most of them by Suffolk County which has

Table 13. Open tidal inlets along the Long Island Sound shoreline of New York from east to west (Fishers Island to Plum Point) prior to Hurricane Sandy in October 2012 with (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 / bulkheads	Breakwaters	Dredging	Relocation of channel or inlet	Mined for beach fill
Silver Eel Pond (Fishers Island)		X				X		
Hay Harbor (Fishers Island)								
unnamed inlet into pond near North Hill (Fishers Island)								
unnamed inlet in East Harbor into pond on Fishers Island Golf Course (Fishers Island)				X				
Goldsmith Inlet		X				X		
Mattituck Inlet		D				X		X[1]
Baiting Hollow Inlet								
Wading River Creek[2]			X					
Mt. Sinai Harbor		D						
Port Jefferson Harbor		D						
Flax Pond Inlet	X	D				X		X[3]
Stony Brook Harbor			X			X		
Nissequogue River						X		
Crab Meadow Inlet[4]			X					
Eatons Neck Harbor						X		
Sand Hole Inlet		X						
Lloyd Harbor				X				
unnamed inlet into a lagoon near Cold Spring Harbor				X				
Cold Spring Harbor								
Eel Creek								
unnamed inlet on Center Island near Mountain Avenue				X				
Frost Creek		X		X				
Dosoris Pond			X	X				
West Pond		X	X					
Glen Cove Creek				X		X		
Hempstead Harbor				X				
East Creek				X				
unnamed inlet at West Creek Farms Road in Sands Point								

1 – Mattituck Inlet was mined occasionally for commercial purposes from about 1920 to 1970, with Morgan et al. (2005) estimating that from 250,000 to 500,000 cy of material was mined in addition to the dredging of the federal navigation channel since 1907. Sediment impounded by the west jetty at Breakwater Beach was also commercially mined from at least 1960 to 1977, with an estimated 260,000 to 380,000 cy of sediment removed from the system (Morgan et al. 2005).

2 – The lagoon to the Shoreham Power Plant immediately west of Wading River Creek inlet was not counted as an inlet for the purposes of this assessment. No tidal creek or lagoon is shown on a 1914 map of Long Island (Fuller 1914), indicating the lagoon outlet is not a natural inlet but more likely a cooling pond or water intake. The lagoon outlet has dual jetties which will be included in the sandy beaches inventory for this area.

3 – Flax Pond Inlet was mined for commercial sale of sand and gravel in the 1940s, and its adjacent beaches were mined since at least 1874 for sale to New York City industries (Abrams et al. 2008).

4 – The two lagoons at the Northport Power Station in Fort Salonga west of Crab Meadow Inlet were not counted as inlets for the purposes of this assessment. Neither lagoon is shown on a 1914 map of Long Island (Fuller 1914), indicating the lagoon outlets are not natural inlets but more likely a cooling pond and/or water intake. The eastern lagoon outlet has bulkheads perpendicular to the beach and the western lagoon (Northport Basin) has dual jetties. All of these structures will be included in the sandy beaches inventory for this area.

owned and operated its own dredge since 1949 (Town of East Hampton 1999). No inlets have been relocated. At least one inlet was cut artificially – Flax Pond Inlet in 1803 in Brookhaven; the inlet was dredged periodically from then to at least 1947 when dual jetties were built to stabilize the inlet (Abrams et al. 2008). Two inlets have been mined to supply sediment for commercial purposes – Mattituck Inlet and Flax Pond Inlet. Mattituck Inlet and the beach directly to the west of the inlet were mined occasionally for commercial sand and gravel purposes from 1925 to at least 1948 in the inlet and from before 1960 (probably between 1947 and 1955) to 1977 at the adjacent Breakwater Beach to the west (Morgan et al. 2005, Batten and Kraus 2006). Flax Pond Inlet was mined by the McCormack Sand and Gravel Company in the 1940s for commercial sale. The beaches adjacent to Flax Pond Inlet had been mined every summer since at least 1874 for use in New York City industries; it is unknown how long the mining took place, but no mining has occurred since the state purchased the Flax Pond and surrounding property in 1966 (Abrams et al. 2008). Altogether 22 of the 28 inlets (79%) have been modified in at least one way (Tables 1 and 13).

No known inlets or breaches have been closed artificially along the Long Island Sound shoreline of New York. A number of inlets have opened and closed naturally, however. Three small inlets have opened on Fishers Island in recent years. A small inlet to Beach Pond appears on 1991 imagery and is larger in 1994 imagery. The inlet is closed in 2001 imagery before opening again for a few months in late 2011 imagery. The Hay Harbor spit was breached by a small inlet sometime between 1991 and 1994 imagery but was closed by 2001. The third Fishers Island inlet is an unnamed inlet into a pond near North Hill, which opened sometime between 1991 and 1994 and was still open in 2012 prior to Hurricane Sandy (Google Earth 2015). On the North Shore, a breach opened east of the Mattituck Inlet east jetty around 1935 (Batten and Kraus 2006).

New York – Peconic Estuary Shoreline

Ninety-six (96) tidal inlets were open in 2012 prior to Hurricane Sandy along the Peconic Estuary shoreline of New York, of which 56 (58%) have been stabilized with hard structures along at least one shoulder (Table 14). Of the inlets with hard structures, 21 have dual jetties, 2 have single box jetties, 16 have groins, 42 have revetments, seawalls and/or bulkheads, and 1 has a breakwater. Forty-six (46) inlets (48%) have been or continue to be periodically dredged for navigation or erosion control purposes and another three were proposed for dredging; another 2 inlets were proposed for dredging prior to Hurricane Sandy in October 2012. Suffolk County owns its own dredge (Peconic Estuary Program 2004; USACE 2012c, 2012e, 2015) and maintains at least 41 inlets in the Peconic Estuary and along the Long Island Sound shoreline within the county.

Two inlets have been relocated in the Peconic Estuary – Accabonac Harbor in 1959 and Northwest Creek in 1961, both in the Town of East Hampton (Town of East Hampton 1999). Five other new inlets have been confirmed to have been cut artificially. Lake Montauk Inlet was cut open in 1879 and 1926 and Hog Creek Inlet in the 1950s, both in the Town of East Hampton (Town of East Hampton 1999). Fresh Pond in Amagansett has occasionally been breached by the Town of East Hampton for water quality purposes, and dredging the inlet and shortening its groins has been proposed (Town of East Hampton 1999). Brick (Sage) Cove in Southold was artificially created from a clay pit that historically supplied a nearby brick plant (Town of Southold 2011). Schoolhouse Creek in Southold was also artificially created (Town of Southold 2011). Some small boat basins with inlets could be artificial as well (e.g., the unnamed inlet to a boat basin immediately adjacent to Northwest Creek Inlet in Northwest Harbor) but are unconfirmed. The shoal complexes of no inlets have been mined to supply sediment for beach nourishment projects, although dredge spoil is placed on nearby beaches at some inlets. Altogether 68 of the 96 inlets (71%) have been modified in at least one manner (Tables 1 and 14).

No inlets or breaches have been closed artificially, but at least 11 inlets have opened and closed naturally along the Peconic Estuary shoreline (Google Earth 2015). An inlet periodically opens and closes into Oyster Pond in Montauk, most recently open for short periods in 2009, 2011 and 2012. Hurricane Bob in 1991 breached the Goff Point spit at the north end of Napeague Harbor; it closed naturally in 6 months (Town of East Hampton 1999). An inlet also periodically opens and closes to separate the Hicks Island spit at Napeague Harbor, most recently open from 2007 to early 2012. The spit or peninsula north of Accabonac Harbor was breached by a small inlet in 2006 imagery but closed by late 2011 imagery; a bridge and armored abutments appear to stabilize the site (Google Earth 2015). Historically Cedar Island with its lighthouse in Northwest Harbor was separated from the mainland of Long Island by an inlet, but the Great Hurricane of 1938 closed the inlet (Suffolk County 2015). Goose Creek in Flanders has recently had two inlet openings to the bay, with the second opening near the end of Fantasy Drive open in 1994 to 2004 imagery but had closed by October 2006.

A 1914 map of Long Island shows an inlet connected to Husing Pond by Horton Creek in Laurel where a baseball field exists today; it is unknown whether the inlet closed naturally or was artificially closed and when (Fuller 1914). Two small inlets have breached a pond on the northeastern side of Robins Island, the northern one opening sometime between 1994 and 2001, closing between 2004 and 2006. The southern inlet opened sometime between 2004 and 2006 and closed between September 2010 and November 2011. An inlet to an unnamed pond at Mashomack Preserve on Shelter Island opened between November 2011 and March 2012.

Table 14. Open tidal inlets along the Peconic Estuary shoreline of Long Island, New York, clockwise from Montauk to Orient Point prior to Hurricane Sandy in October 2012 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 / bulkheads	Breakwaters	Dredging	Relocation of channel or inlet	Mined for beach fill
Oyster Pond Inlet								
Lake Montauk	X	D				X		
Napeague Harbor						X		
unnamed inlet to the Devon Yacht Club marina		D				X		
Fresh Pond	X		X			P		
Accabonac Harbor						X		
Hog Creek	X	X	X	X		X		
Three Mile Harbor Inlet		D				X		
Alewife Brook								
unnamed inlet immediately north of unnamed inlet east of Northwest Creek		D						
unnamed inlet east of Northwest Creek								
Northwest Creek	X					X	X	
Little Northwest Creek								
Sag Harbor Inlet				X				
Great Pond Creek				X				
Fresh Pond (North Haven)								
unnamed inlet north of Goodwood Road in North Haven								
unnamed inlet in North Haven near Tyndal Point		D						
Ganet Creek		D				P		
Mill Creek						X		
Noyack Creek						X		
unnamed inlet on Jessup's Neck								
Fresh Pond (Noyack)				X		X		
Wooley Pond				X		X		
Davis Creek / North Sea Harbor						X		
Little Sebonac Creek								
Sebonac (Creek) Inlet				X		X		
Cold Spring Pond				X		X		
Shinnecock Canal / Huntington		D		X		X		

Inlet	Type of Habitat Modification							
	Artificially created	Jetties	Terminal groins / groin field	Seawalls / revetments / bulkheads	Breakwaters	Dredging	Relocation of channel or inlet	Mined for beach fill
Harbor								
Squire Pond								
Red Creek Pond				X		X		
Hubbard Creek								
Goose Creek								
Meetinghouse Creek			X	X		X		
Reeves Creek				X		X		
Dreamers Cove		D		X				
Miamogue Lagoon		D		X		X		
Hawks Creek		D		X		X		
East Creek (South Jamesport/Riverhead)						X		
unnamed creek southwest of Beach Road in Jamesport								
Brushs Creek			X	X		X		
James Creek			X	X		X		
Deep Hole Creek			X	X		X		
Halls Creek			X	X		X		
Downs Creek				X				
West Creek			X	X		X		
unnamed breach to lagoon on northwest end of Robins Island (Robins Island)								
Schoolhouse Creek	X		X	X		X		
Wickham Creek			X	X		X		
Mud Creek						X		
Wunneweta Pond		D				X		
The Lagoon at Nassau Point		D						
Little Creek						X		
Richmond Creek				X		X		
Corey Creek						X		
West Lake (Southold)			X	X				
Cedar Beach Creek			X	X		X		
unnamed inlet near Paradise Point in Southold		D		X				
Reydon Shores Inlet		D		X				
unnamed inlet at Harbor Lights in Southold		D						
Goose Creek				X		X		

Inlet	Type of Habitat Modification							
	Artificially created	Jetties	Terminal groins / groin field	Seawalls / revetments / bulkheads	Breakwaters	Dredging	Relocation of channel or inlet	Mined for beach fill
Town Creek			X	X		X		
unnamed inlet southwest of Rogers Road in Southold				X				
Pettys Pond / Beixedon Creek		D		X				
Budds Pond								
Brick (Sage) Cove	X	X		X		X		
unnamed inlet near Conkling Point								
Moores Drain								
unnamed inlet northwest of Fanning Point in Greenport		D		X				
unnamed inlet northeast of Fanning Point in Greenport					X			
Stirling Basin (Greenport Harbor)				X		X		
Gull Pond		D		X		X		
Spring Pond		D	X	X		X		
Dam Pond				X				
Oysterponds Creek				X				
Long Beach Bay			X					
Coecles Harbor (Shelter Island)						X		
unnamed inlet 1 on Shelter Island near Mashomack Point								
unnamed inlet 2 on Shelter Island near Mashomack Point								
unnamed inlet 3 in Majors Harbor on Shelter Island								
unnamed inlet 4 in Majors Harbor on Shelter Island								
unnamed inlet 5 on Shelter Island near Majors Point								
Bass Creek (Shelter Island)								
Log Cabin Creek (Shelter Island)								
Miss Annie's Creek (Shelter Island)								
Smith Cove				X		X		
unnamed inlet on Shelter Island near South Ferry landing			X	X				
Dickerson Creek (Shelter Island)				X		X		
unnamed inlet to small marina southeast of Crab Creek on Shelter Island		D						

Inlet	Type of Habitat Modification							
	Artificially created	Jetties	Terminal groins / groin field	Seawalls / revetments / bulkheads	Breakwaters	Dredging	Relocation of channel or inlet	Mined for beach fill
Crab Creek (Shelter Island)						**X**		
Gardiners Creek (Shelter Island)				**X**		**X**		
unnamed inlet on Shelter Island near Hay Beach Point								
Great Pond (Gardiners Island)								
Gaylor Hole (Gardiners Island)		**D**				**X**		
Home Pond (Gardiners Island)								
unnamed inlet on Gardiners Island spit								

Finally, an inlet to Little Pond on Gardiner's Island was open prior to 1994 and closed between March 2007 and October 2008 (Google Earth 2015).

DISCUSSION

Over two-thirds (70%) of the 343 sandy tidal inlet habitats from Georgetown, Maine, to the Long Island Sound and Peconic Estuary shorelines of New York that were open prior to Hurricane Sandy in 2012 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 opening and closing of inlets (Table 1). The southern Massachusetts coast is the most continguously modified, with all 23 inlets from Chatham (Stage) Harbor to the Trunk River modified by hard structures and/or dredging (Table 7). In Buzzards Bay, Massachusetts, 14 of 25 inlets are modified (Tables 7 and 8). Only 3 of Martha's Vineyard's 14 inlets are not modified (Table 9). Connecticut also has a section of coast with numerous contiguous inlets modified, with 22 modified inlets from Mile Creek in New London to Milford Harbor at the Indian River (Table 12).

In contrast, the highest number of contiguous inlets that are **not** modified is 8, all on Shelter Island in the Peconic Estuary of New York (Table 14). There are 7 contiguous inlets in Maine that are not modified, along with 7 on the Cape Cod Bay shoreline of Cape Cod National Seashore in Massachusetts (Tables 2 and 7 respectively). The only other significant section of shoreline with no modified inlets is the 5 inlets east of Narragansett Bay from Tunipus Pond Inlet, to Gardiner Pond Inlet, RI (Tables 8 and 11). Throughout the rest of the survey area 2 to 3 contiguous inlets that are not modified is more typical.

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), Kraus (2006), 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), Kraus (2006), Otvos (2006), Morton (2008), Otvos and Carter (2008), Beck and Wang (2009), and Stockdon et al. (2010).

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), Kraus (2006), Wamsley and Kraus (2005) and Kraus (2007). In the northeastern U.S., the majority of artificially created inlets are the result of mechanical breaching of coastal ponds. At least 11 coastal ponds in MA and at least 9 in RI have been or continue to be artificially breached by mechanical means. Most of these ponds are breached several times a year, depending on whether they have been naturally breached (see Table 10, for example). The primary purposes of these projects generally are to reduce high water levels in the ponds, improve water quality, or to allow passage of fisheries resources into and out of the ponds. These artificial breaches tend to be temporary, remaining open for days to weeks and occasionally months at a time. Dredging is rarely involved. Most, if not all, of these coastal ponds also are naturally breached periodically. The exposure of coastal pond mudflats (after breaching) to piping plovers and chicks can provide access to additional foraging habitat that increases the chick survivorship and fledging success of piping plover broods when compared to those limited to oceanfront beach habitat (Goldin and Regosin 1998). Therefore the environmental impacts of these mechanical breaches are likely to be significantly less than those of large-scale artificial inlet creation projects (e.g., Charlestown, Quonochontaug and Weekapaug Breachways in RI) where dredging is involved and the new inlets are intended to remain open permanently, with inlet stabilization and/or maintenance dredging implemented as necessary to do so.

Cialone and Stauble (1998) describe the impacts of mining ebb shoals within inlets as a source of beach fill material 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, Kraus 2006, Dabees and Kraus 2008). In the northeastern U.S., however, some inlets lack ebb shoals and flood shoals are the more likely source of mined material. The majority of the inlets that are dredged place the dredged material on nearby beaches, but not as a part of a large-scale, designed beach nourishment or storm damage reduction project. Only 5 inlets (of 343) are known to have been mined for any purpose – 3 for beach fill and 2 for commercial sale of sand and gravel. Morgan et al. (2005) found no ebb shoals at Mattituck Inlet along the North Shore of Long Island, but commercial mining of the inlet and its flood shoals permanently removed an estimated 250,000 to 500,000 cy of material from the system over approximately 50 years. The commercial mining of sand and gravel from tidal inlet (and adjacent beach) systems such as Mattituck and Flax Pond Inlets in NY, although historical in nature, created a permanent loss of large volumes of sediment to the local and perhaps regional coastal system. Morgan et al. (2005) did find that the mining of Mattituck Inlet sediment helped to maintain the hydraulic efficiency of the inlet, and mining of the adjacent beach to the west kept the updrift western jetty from becoming fully impounded, extending the jetty's life and easing shoaling in the inlet that would have increased dredging needs. Downdrift beaches have increased erosion rates due to the jetties, mining and dredging of the inlet, however.

The cumulative effects of the habitat modifications to sandy tidal inlets within the northern U.S. Atlantic Coast breeding range of the piping plover are significant. The cumulative effects catalogued herein are regional, covering all six states in this range. Between Georgetown, ME, and the Long Island Sound and Peconic Estuary shorelines of New York, 70% 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 for up to 3.7 – 8.1 miles (6 – 13 km). Kraus (2006) states that the impacts of jetties on adjacent shorelines may extend for several kilometers. Batten and Kraus (2006) identified the downdrift impacts of the dual jetty system and dredging of the Federal navigation channel at Mattituck Inlet on the North Shore of Long Island extends for 1.81 miles (2.91 km) east of the inlet, with higher rates of erosion closer to the inlet. The environmental consequences from human modifications of inlets therefore can extend on the order of several miles (or kilometers) from each inlet depending on the size of the inlet and its adjacent geologic setting (i.e., barrier island or lengthy spit versus nearby rocky headlands or bluffs).

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 (43, 29 of which were currently open at the time of Hurricane Sandy) have been artificially created between Georgetown, ME, and the Long Island Sound and Peconic Estuary shorelines of New York (Table 1). These artificially created inlets tend to need hard structures to remain open or stable, with 22 of the 29 (76%) of them having hard structures prior to Hurricane Sandy. At least 15 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. At Mattituck Inlet on Long Island's North Shore, Batten and Kraus (2006, p. xiii) found that "the Federal navigation project at Mattituck Inlet caused a 94 percent reduction in average annual longshore sediment transport between 1906 and 1950, and a 58 percent reduction between 1950 and 2004. Total volume loss attributable to the Federal navigation project was estimated at 1,063,000 cu yd [cubic yards] (± 238,000 cu yd)." The net loss of sediment to downdrift beaches after volumes removed by commercial mining of the updrift jetty fillet, loss to offshore via natural processes, and placement of dredged material on adjacent beaches are accounted for was estimated to be 493,000 cy (± 216,000 cy; Batten and Kraus 2006). Batten and Kraus (2006) recommend these downdrift impacts could be mitigated by continuing the current practice of bypassing dredged material to downdrift beaches with additional bypassing of material from the updrift jetty fillet annually or once every 8 to 10 years in conjunction with supplemental dredging of the flood tidal shoals at the inlet.

Kraus (2006) describes how inlet equilibrium can be so unbalanced due to the construction of jetties or inlet relocation that the ebb shoal can collapse. "Maintenance of coastal inlet navigation channels and the adjacent beaches brings conflicting requirements. For example, jetties are built in part to confine and strengthen the current, but the resultant seaward translation of the ebb shoal interrupts natural sediment bypassing. In turn, interruption of the natural bypassing rates and pathways compromise the integrity of the adjacent beaches, with potential feedback to destabilize the jetties and inlet navigation channel" (Kraus 2006, p. 10).

Of the dredged inlets included in this analysis, dredging efforts began as early as 1803 and continue to the present, generating long-term and even permanent effects on inlet habitat; at least 6 inlets have been dredged since the 1800s and mechanical pond breaching of numerous inlets in Rhode Island and Massachusetts has occurred since the early 1600s (Lee 1980). Dredging is typically conducted annually or every 2 to 5 years, which results in continual perturbations and modifications to inlet and adjacent shoreline habitat. The volumes of sediment dredged and removed from inlets in the northeast tend to be on the order of thousands or tens of thousands of cubic yards, which is less than the volumes typically dredged from oceanfront inlets in the Mid-Atlantic, southeastern Atlantic and Gulf coast regions (Rice 2012a, 2014). Kraus (2006, p. 11) notes that "inlet morphology evolves over decades to centuries, and shoal development and change can be complex. Thus, the consequences of modifications to an existing inlet may not be noted for many years."

The mining of inlet shoals in this survey area is currently much less common than along other regions (Rice 2012a, 2014), where mining can remove massive amounts of sediment for beach fill. The two exceptions are at Mattituck and Flax Pond Inlets on the North Shore of Long Island, which were commercially mined for sand and gravel for several decades (Morgan et al. 2005, Batten and Kraus 2006, Abrams et al. 2008). Mining of inlets for commercial sale results in an instantaneous and permanent sediment loss to the system. Batten and Kraus (2006, p. 91) found that the mining of the Mattituck Inlet channel and impoundment fillet at the west jetty removed between 443,000 and 903,000 cy of sediment from the system, a volume loss "equal to, and potentially greater than, the volume of material eroded from the downdrift beach" due to the dual jetty system and dredging of the Federal navigation channel at the inlet. As sea level continues to rise and climate changes, more inlets in this survey area may be proposed for mining for beach fill to protect development and infrastructure.

The hard stabilization of inlets is another contributor to the appreciable cumulative adverse effects to inlet habitat along the coast from Georgetown, ME, to the Long Island Sound and Peconic Estuary shorelines of New York. The construction of jetties, groins, seawalls and revetments leads to habitat loss and both direct and indirect impacts to adjacent shorelines. Several 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 21 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.

In this survey area, the construction and development of the Cape Cod Canal led to the closure of the nearby Scusset Mill Creek Inlet in Sagamore in the early 1900s (FitzGerald 1993). Dredging of the Saco River in Maine with dredge spoil placement on the shoreline to the north increased the sediment supply to the adjacent beaches and was partially responsible for the closure of Little River Inlet, accretion and subsequent development of Pine Point, the filling and narrowing of the Scarborough River Inlet, and the subsequent need to stabilize the Scarborough River Inlet with a jetty and dredging (FitzGerald et al. 1989, Kelley et al. 1989, EPA 1995).

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 breakwaters 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). Buonaiuto et al. (2008) found that the direct impacts of stabilization and dredging of Shinnecock Inlet on Long Island’s South Shore in New York 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 were proposed to be rebuilt or repaired as recently as 2012 just prior to Hurricane Sandy, although the construction of new tidal inlets with jetties is rare (Kraus 2006, Watts et al. 2011). Kraus (2006, p. 1) notes that the jetties built at many of the larger inlets in the U.S. were built around the turn of the 20th century when the coast “far from infrastructure and development … so consideration of the beaches adjacent to the inlets was minimal.” “As coastlines have become more developed, … environmental and engineering consequences for new or modified inlets have never been greater” (Kraus 2006, p. 1). With sea level rising and global climate change altering storm dynamics, the pressure to further modify the 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 240 of the 343 inlets, as described in this assessment, should be addressed in current and future proposals that would affect sandy tidal inlets within the northern U.S. Atlantic Coast breeding range of the piping plover between Georgetown, ME, and the Long Island Sound and Peconic Estuary shorelines of New York. 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, the beneficial use of dredged material and the restoration of artificially closed inlets.

ACKNOWLEDGEMENTS

Thank you to the following individuals who reviewed this paper and provided helpful comments: Anne Hecht, Megan Tyrrell, Kate Iaquinto, Ryan Kleinert, Kate O'Brien, and Wendy Walsh of the USFWS; Amanda Babson, Mary Foley (emeritus) and Mark Adams of the NPS; Laura Zitske of Maine Audubon; David Burdick of the University of New Hampshire; Dan Sampson and Rebecca Haney of the Massachusetts Office of Coastal Zone Management; Janet Freedman of the Rhode Island Coastal Resources Management Council; Laura Saucier and Harry Yamalis of the Connecticut Department of Energy and Environmental Protection; and Jay Tanski of NY Sea Grant Program and Stony Brook University.

REFERENCES

Abrams, S., K. Chytalo, C. Hamilton, F. Mushacke, G. Richards, H. Young, and W. Wise. 2008. Flax Pond Unit Management Plan, Public Review Draft. New York State Department of Environmental Conservation / Stony Brook University. Stony Brook, NY. 48 p.

Ashley, G.M. 1987. Assessment of the hydraulics and longevity of Wood End Cut (Inlet), Cape Cod, Massachusetts, USA. *Journal of Coastal Research* 3(3):281-295.

Barnstable County. 2009. Report from the Barnstable County Dredge. Pp. 186-188 *in* Barnstable County Annual Report – FY 2009. Barnstable, MA. Available at http://www.barnstablecounty.org/dredge/. Accessed January 13, 2015.

Barnstable County. 2010. Report from the Barnstable County Dredge. Pp. 183-185 *in* Barnstable County Annual Report – FY 2010. Barnstable, MA. Available at www.barnstable**county**.org/2011/09/16/fy**2010-annual-report**/. Accessed January 13, 2015.

Barnstable County. 2011. Report from the Barnstable County Dredge. Pp. 167-169 *in* Barnstable County Annual Report – FY 2011. Barnstable, MA. 170 p. Available at www.barnstable**county**.org/wp-content/uploads/2012/04/AR_FY11.pdf. Accessed January 13, 2015.

Barnstable County. 2012. Report from the Barnstable County Dredge. Pp. 193-196 *in* Barnstable County Annual Report – FY 2012. Barnstable, MA. 196 p. Available at www.barnstable**county**.org/wp-content/.../BC-**Annual-Report**-FY2012.pdf. Accessed January 13, 2015.

Batten, B. K., and N. C. Kraus. 2006. Evaluation of downdrift shore erosion of Mattituck Inlet, New York: Section 111 study. Technical Report ERDC/CHL TR-06-1, U.S. Army Corps of Engineers, Engineer Research and Development Center, Vicksburg, MS. 125 p.

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 p.

Buonaiuto, F.S., Jr., H.J. Bokuniewicz, and D.M. FitzGerald. 2008. Principal component analysis of morphology change at a tidal inlet: Shinnecock Inlet, New York. *Journal of Coastal Research* 24(4):867-875.

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*. Durham, NC: Duke University Press. 340 p.

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*. Durham, NC: Duke University Press. 338 p.

Buynevich, I.V., and J.P. Donnelly. 2006. Geological signatures of barrier breaching and overwash, southern Massachusetts, USA. *Journal of Coastal Research*, Special Issue No. 39, Proceedings of the 8th International Coastal Symposium (ICS 2004), Vol. 1 (Winter 2006), pp.112-116.

Cialone, M.A., and D.K. Stauble. 1998. Historical Findings on Ebb Shoal Mining. *Journal of Coastal Research* 14(2):537-563.

City of Bridgeport. 2015. Seaside Park History. Bridgeport, CT. Available at http://www.bridgeportct.gov/content/89019/95776/95824.aspx. Accessed January 15, 2015.

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.

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

Cuttyhunk Historical Society. 2014. Cuttyhunk Island and the Elizabeth Islands Time Line. Gosnold, MA. 23 p. Available at http://www.cuttyhunkhistoricalsociety.org/timeline/. Accessed January 7, 2015.

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, S.C. 2009. Request for Advisory Opinion – Routine Maintenance, Periodic Opening of Oyster Pond – Edgartown, Massachusetts. Letter dated July 13, 2009, to the Honorable Ian A. Bowles, Secretary, Executive Office of Energy and Environmental Affairs. Boston, MA. 36 p. with attachments.

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.

Dean, R.G. 1993. Terminal Structures at Ends of Littoral Systems. *Journal of Coastal Research* Special Issue 18, pp. 195-210.

Dickson, S.M. 2001. Laudholm and Drakes Island Beaches: Before and After Beach Nourishment. Geologic Site of the Month, October 2001. Maine Geological Survey. Augusta, ME. 16 p. Available at www.**maine**.gov/dacf/mgs/explore/marine/sites/oct01.pdf.

Dickson, S.M. 2003. Coastal Erosion Assessment for Maine FIRMs and Map Modernization Plan. Maine Geological Survey. Augusta, ME. 39 p.

Dickson, S.M. 2008. Tombolo Breach at Popham Beach State Park, Phippsburg, Maine. Geologic Site of the Month, March 2008. Maine Geological Survey. Augusta, ME. 24 p. Available at www.maine.gov/dacf/mgs/explore/marine/sites/mar08.pdf.

Dickson, S.M. 2009. Coastal Erosion at Crescent Beach State Park, Cape Elizabeth, Maine. Geologic Site of the Month, March 2009. Maine Geological Survey. Augusta, ME. 15 p. Available at www.maine.gov/dacf/mgs/explore/marine/sites/mar09.pdf.

Dickson, S.M. 2011. Setting the Stage for a Course Change at Popham Beach, Phippsburg. Geologic Site of the Month, February 2011. Maine Geological Survey. Augusta, ME. 33 p. Available at www.maine.gov/dacf/mgs/explore/marine/sites/feb11.pdf.

Dickson, S.M. 2012. Beach Scraping at Popham Beach State Park, Phippsburg, Maine. Geologic Site of the Month, February 2012. Maine Geological Survey. Augusta, ME. 19 p. Available at www.maine.gov/dacf/mgs/explore/marine/sites/feb12.pdf.

Dunlop, T. 2004. Saving Farm Pond. *Martha's Vineyard Magazine*. September/October 2004. Pp. 30-37.

Dukes County. 2015. County of Dukes County Dredging. Edgartown, MA. Available at http://www.dukescounty.org/pages/dukescountyma_naturalresources/Dredging. Accessed January 7, 2015.

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 p.

Erkan, D.E. 2002. Strategic Plan for the Restoration of Anadromous Fishes to Rhode Island Coastal Streams. Rhode Island Department of Environmental Management, Division of Fish and Wildlife. Providence, RI. 81 p. Available at http://www.bonnetshoreslandtrust.org/?page_id=407.

Federal Inlet Aerial Photo Database. 2015. Available at http://www.oceanscience.net/inletsonline/map/map.html.

Fenster, M., and R. Dolan. 1996. Assessing the Impact of Tidal Inlets on Adjacent Barrier Island Shorelines. *Journal of Coastal Research* 12(1):392-310.

Finch, R. 1993. *Cape Cod: Its Natural and Cultural History – A Guide to Cape Cod National Seashore, Massachusetts*. National Park Service Handbook 148. Washington, D.C. 112 p.

FitzGerald, D.M. 1993. Origin and stability of tidal inlets in Massachusetts. *Coastal and Estuarine Studies* 44:1-61.

FitzGerald, D.M. 1996. Geomorphic variability and morphologic and sedimentologic controls at tidal inlets. *Journal of Coastal Research*, Special Issue No. 23, pp. 47-71.

FitzGerald, D.M., J.M. Lincoln, L.K. Fink, Jr., and D.W. Caldwell. 1989. Morphodynamics of tidal inlet systems in Maine. *Studies in Maine Geology* 5(1989):67-96.

FitzGerald, D.M., I.V. Buynevich, and P.S. Rosen. 2001. Geologic evidence of former tidal inlets along a retrograding barrier: Duxbury Beach, Massachusetts, USA. *Journal of Coastal Research*, Special Issue No. 34, pp. 437-448.

Friends of Greenwich Point. 2015. History of Greenwich Point. Old Greenwich, CT. Available at http://www.friendsofgreenwichpoint.org/#!history-timeline/cvh3. Accessed January 15, 2015.

Fuller, M.L. 1914. The geology of Long Island, New York. U.S. Geological Survey Professional Paper 82. Available at http://pubs.er.usgs.gov/publication/pp82.

Giese, G.S., S.T. Mague, and S.S. Rogers. 2009. A geomorphological analysis of Nauset Beach / Pleasant Bay / Chatham Harbor for the purpose of estimating future configurations and conditions. Report prepared for The Pleasant Bay Resource Management Alliance. Provincetown Center for Coastal Studies, Provincetown, MA. 32 p.

Giese, G.S., S.T. Mague, S.S. Rogers and M. Borrelli. 2010. A geomorphological analysis of the Monomoy Barrier System. Provincetown Center for Coastal Studies, Provincetown, MA. Appendix I *in* U.S. Fish and Wildlife Service (2014), Monomoy National Wildlife Refuge Draft Comprehensive Conservation Plan and Environmental Impact Statement, Chatham, MA. 40 p.

Goldin, M.R., and J.V. Regosin. 1998. Chick behavior, habitat use, and reproductive success of piping plovers at Goosewing Beach, Rhode Island. *Journal of Field Ornithology* 69(2):228-234.

Great Pond Foundation. 2010. Annual Report 2010. Edgartown, MA. 15 p. Available at http://www.greatpondfoundation.org/publications.cfm.

Great Pond Foundation. 2011. Annual Report, July 1, 2010, to June 30, 2011. Edgartown, MA. 16 p. Available at http://www.greatpondfoundation.org/publications.cfm.

Great Pond Foundation. 2012. Annual Report, July 1, 2011, to June 30, 2012. Edgartown, MA. 9 p. Available at http://www.greatpondfoundation.org/publications.cfm.

Great Pond Foundation. 2013. Annual Report, July 1, 2012, to June 30, 2013. Edgartown, MA. 16 p. Available at http://www.greatpondfoundation.org/publications.cfm.

Google, Inc. 2015. Google Earth (Version 7.1.2.2041) [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.

Hayes, M.O., and D.M. FitzGerald. 2013. Origin, Evolution, and Classification of Tidal Inlets. *Journal of Coastal Research* Special Issue 69, pp. 14-33.

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.

Howes, B., R. Samimy, D. Schlezinger, S. Kelley, J. Ramsey, and E. Eichner. 2003. Linked Watershed-Embayment Model to Determine Critical Nitrogen Loading Thresholds for Stage Harbor, Sulphur Springs, Taylors Pond, Bassing Harbor, and Muddy Creek, Chatham, Massachusetts. Massachusetts Estuaries Project, Massachusetts Department of Environmental Protection. Boston, MA. 272 p.

Howes, B., S. Kelley, J. Ramsey, R. Samimy, E. Eichner, D. Schlezinger, and J. Wood. 2004. Linked Watershed-Embayment Model to Determine Critical Nitrogen Loading Thresholds for Popponesset Bay, Mashpee and Barnstable, Massachusetts. Massachusetts Estuaries Project, Massachusetts Department of Environmental Protection. Boston, MA. 150 p.

Howes, B., R. Samimy, D. Schlezinger, J. Ramsey, S. Kelley, and E. Eichner. 2005a. Linked Watershed-Embayment Model to Determine Critical Nitrogen Loading Thresholds for Great/Perch Pond, Green Pond and Bournes Pond, Falmouth, Massachusetts. Massachusetts Estuaries Project, Massachusetts Department of Environmental Protection. Boston, MA. 221 p.

Howes, B., R. Samimy, D. Schlezinger, S. Kelley, J. Ramsey, T. Ruthven, and E. Eichner. 2005b. Linked Watershed-Embayment Model to Determine Critical Nitrogen Loading Thresholds for the Quashnet River, Hamblin Pond, and Jehu Pond, in the Waquoit Bay System of the Towns of Mashpee and Falmouth, Massachusetts. Massachusetts Estuaries Project, Massachusetts Department of Environmental Protection. Boston, MA. 164 p.

Howes, B., R. Samimy, D. Schlezinger, T. Ruthven, J. Ramsey, and E. Eichner. 2006a. Linked Watershed-Embayment Model to Determine Critical Nitrogen Loading Thresholds for Centerville River System, Barnstable, Massachusetts. Massachusetts Estuaries Project, Massachusetts Department of Environmental Protection. Boston, MA. 172 p.

Howes B., S. W. Kelley, J. S. Ramsey, R. Samimy, D. Schlezinger, and E. Eichner. 2006b. Linked Watershed-Embayment Model to Determine Critical Nitrogen Loading Thresholds for Three Bays, Barnstable, Massachusetts. Massachusetts Estuaries Project, Massachusetts Department of Environmental Protection. Boston, MA. 183 p.

Howes, B., R. Samimy, D. Schlezinger, T. Ruthven, J. Ramsey, and E. Eichner. 2006c. Linked Watershed-Embayment Model to Determine Critical Nitrogen Loading Thresholds for Rushy Marsh Pond in the Town of Barnstable, Massachusetts. Massachusetts Estuaries Project, Massachusetts Department of Environmental Protection. Boston, MA. 118 p.

Howes, B., R. Samimy, D. Schlezinger, S. Kelley, J. Ramsey, M. Osler and E. Eichner. 2006d. Linked Watershed-Embayment Model to Determine Critical Nitrogen Loading Thresholds for Sesachacha Pond, Town of Nantucket, Nantucket Island, Massachusetts. Massachusetts Estuaries Project, Massachusetts Department of Environmental Protection. Boston, MA. 107 p.

Howes B., R. Samimy, D. Schlezinger, J. Ramsey, S. Kelley, and E. Eichner. 2006e. Linked Watershed-Embayment Model to Determine Critical Nitrogen Loading Thresholds for Little Pond System, Falmouth, Massachusetts. SMAST/DEP Massachusetts Estuaries Project, Massachusetts Department of Environmental Protection. Boston, MA. 142 p.

Howes, B.L., S. W. Kelley, J.S. Ramsey, E.M. Eichner, R.I. Samimy, and D.R. Schlezinger. 2006f. Linked Watershed-Embayment Model to Determine Critical Nitrogen Loading Thresholds for the Oyster Pond System, Falmouth, MA. SMAST/DEP Massachusetts Estuaries Project, Massachusetts Department of Environmental Protection. Boston, MA. 127 p.

Howes, B., S. W. Kelley, J. S. Ramsey, R. Samimy, D. Schlezinger, E. Eichner. 2006g. Linked Watershed-Embayment Model to Determine Critical Nitrogen Loading Thresholds for the Phinneys Harbor – Eel Pond – Back River System, Bourne, Massachusetts. Massachusetts Estuaries Project, Massachusetts Department of Environmental Protection. Boston, MA. 142 p.

Howes, B., R. Samimy, D. Schlezinger, S.W. Kelley, J.S. Ramsey, E. Eichner. 2006h. Linked Watershed-Embayment Model to Determine Critical Nitrogen Loading Thresholds for West Falmouth, Falmouth, Massachusetts. Massachusetts Estuaries Project, Massachusetts Department of Environmental Protection. Boston, MA. 161 p.

Howes, B.L., S.W. Kelley, J. S. Ramsey, R.I. Samimy, D.R. Schlezinger, E.M. Eichner. 2007. Linked Watershed-Embayment Model to Determine Critical Nitrogen Loading Thresholds for the Rock Harbor Embayment System, Orleans, MA. SMAST/DEP Massachusetts Estuaries Project, Massachusetts Department of Environmental Protection. Boston, MA. 123 p.

Howes, B., R. Samimy, D. Schlezinger, J. Ramsey, and E. Eichner. 2008. Linked Watershed-Embayment Model to Determine Critical Nitrogen Loading Threshold for Edgartown Great Pond System, Edgartown, Massachusetts. Massachusetts Estuaries Project, Massachusetts Department of Environmental Protection. Boston, MA. 120 p.

Howes, B., R. Samimy, D. Schlezinger, E. Eichner, S. Kelley, J. Ramsey, and W. Wilcox. 2010. Linked Watershed-Embayment Model to Determine the Critical Nitrogen Loading Threshold for the Farm Pond System, Oak Bluffs, Massachusetts. SMAST/DEP Massachusetts Estuaries Project, Massachusetts Department of Environmental Protection. Boston, MA. 133 p.

Howes, B., R. Samimy, D. Schlezinger, E. Eichner, S. Kelley, J. Ramsey, and P.J. Detjens. 2011. Linked Watershed-Embayment Model to Determine Critical Nitrogen Loading Thresholds for the Bass River Embayment System, Towns of Yarmouth and Dennis, Massachusetts. SMAST/DEP Massacusetts Estuaries Project, Massachusetts Department of Environmental Protection. Boston, MA. 222 p.

Howes, B., E. Eichner, R. Samimy, D. Schlezinger, T. Ruthven, J. Ramsey, and P.J. Detjens. 2012. Linked Watershed-Embayment Model to Determine Critical Nitrogen Loading Thresholds for the Swan Pond River Embayment System, Town of Dennis, Massachusetts. SMAST/DEP Massachusetts Estuaries Project, Massachusetts Department of Environmental Protection. Boston, MA. 166 p.

Howes, B., R. Samimy, D. Schlezinger, E. Eichner, R. Acker, J. Ramsey, and P.J. Detjens. 2013a. Linked Watershed-Embayment Model to Determine Critical Nitrogen Loading Thresholds for the Falmouth Inner Harbor Embayment System, Town of Falmouth, Massachusetts. SMAST/DEP Massachusetts Estuaries Project, Massachusetts Department of Environmental Protection. Boston, MA. 148 p.

Howes, B., R. Samimy, E. Eichner, D. Schlezinger, S. Kelley, J. Ramsey, and P.J. Detjens. 2013b. Linked Watershed-Embayment Model to Determine Critical Nitrogen Loading Thresholds for the Fiddlers Cove and Rands Harbor Embayment Systems, Town of Falmouth, Massachusetts. SMAST/DEP Massachusetts Estuaries Project, Massachusetts Department of Environmental Protection. Boston, MA. 174 p.

Howes, B., R. Samimy, D. Schlezinger, E. Eichner, S. Kelley, J. Ruthven, J. Ramsey, and P.J. Detjens. 2013c. Linked Watershed-Embayment Model to Determine Critical Nitrogen Loading Threshold for the Oak Bluffs Harbor System, Town of Oak Bluffs, Massachusetts. SMAST/DEP Massachusetts Estuaries Project, Massachusetts Department of Environmental Protection. Boston, MA. 141 p.

Howes, B., E. Eichner, R. Samimy, D. Schlezinger, S. Kelley, J. Ramsey, and P.J. Detjens. 2013d. Linked Watershed-Embayment Model to Determine Critical Nitrogen Loading Threshold for the Tisbury Great Pond / Black Point Pond System, Towns of Chilmark and West Tisbury, Massachusetts. SMAST/DEP Massachusetts Estuaries Project, Massachusetts Department of Environmental Protection. Boston, MA. 180 p.

Howes, B., E. Eichner, R. Samimy, D. Schlezinger, S. Kelley, J. Ramsey, and P.J. Detjens. 2013e. Linked Watershed-Embayment Model to Determine Critical Nitrogen Loading Thresholds for Wild Harbor Embayment System, Town of Falmouth, Massachusetts.

SMAST/DEP Massachusetts Estuaries Project, Massachusetts Department of Environmental Protection. Boston, MA. 163 p.

Howes, B., R. Samimy, D. Schlezinger, E. Eichner, J. Ramsey, and S. Kelley. 2014. Linked Watershed-Embayment Model to Determine Critical Nitrogen Loading Threshold for the Hummock Pond System, Towns of Nantucket, MA. SMAST/DEP Massachusetts Estuaries Project, Massachusetts Department of Environmental Protection, Boston, MA. 151 p.

Howes, B., R. Samimy, D. Schlezinger, E. Eichner, S. Kelley, J. Ramsey, and G. Simmons. 2015. Linked Watershed-Embayment Model to Determine Critical Nitrogen Loading Threshold for the Chilmark Pond System, Town of Chilmark, MA. SMAST/DEP Massachusetts Estuaries Project, Massachusetts Department of Environmental Protection, Boston, MA. 151 p.

Kelley, J.T., A.R. Kelley, and O.H. Pilkey, Sr. 1989. *Living with the Coast of Maine*. Durham, NC: Duke University Press. 174 p.

Kraus, N.C. 2006. Coastal inlet functional design: anticipating morphologic response. *Proceedings Coastal Dynamics '05*, ASCE Press. 13 p. Available at http://cirp.wes.army.mil/Downloads/PDF/CD05InletFunctDesign.pdf. Accessed January 15, 2015.

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*. Corpus Christi, TX: World Scientific Publishing Corp. and East Meets West Productions. 15 p. Available at http://www.google.com/url?sa=t&rct=j&q=&esrc=s&source=web&cd=4&ved=0CDUQFjAD&url=http%3A%2F%2Fwww.dtic.mil%2Fget-tr-doc%2Fpdf%3FAD%3DADA482234&ei=So7FU-XcJ5avyASgvYLAAw&usg=AFQjCNGAuAEoKgM4nY2ebxSYey9VW7ATbg&bvm=bv.70810081,d.aWw accessed July 15, 2014.

Leatherman, S.P. 1988. *Barrier Island Handbook*. College Park, Maryland: Coastal Publication Series, Laboratory for Coastal Research, The University of Maryland. 92 p.

Leatherman, S.P. 1989. Role of inlets in geomorphic evolution of the south shore barriers of Long Island, New York, USA. *Environmental Management* 13(1):109-115.

Lee, V. 1980. An Elusive Compromise: Rhode Island Coastal Ponds and Their People. Coastal Resources Center, University of Rhode Island Marine Technical Report 73. Narragansett, RI. 91 p. Available at http://www.nsgl.gso.uri.edu/riu/riut80009.pdf.

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.

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.

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 p. Available at http://nsgl.gso.uri.edu/tamu/tamut71009.pdf.

Massachusetts Department of Environmental Protection (MA DEP). 2008. 401 Water Quality Certification Application for BRP WW07, Major Project Dredging at the Channel of Herring River, Allen Harbor, Wychmere Harbor, Saquatucket Harbor in Harwich / Nantucket Sound. 401 WQC Transmittal No: W001321 Letter dated August 18, 2008, to the Harbor Master, Town of Harwich, MA. Available at http://threeharbors.com/Harwich%20DEP%20Dredging%20Permits.htm. Accessed January 13, 2015.

Massachusetts Executive Office of Environmental Affairs. 2013. Environmental Notification Form: Ellisville Inlet Relocation. Massachusetts Environmental Policy Act (MEPA) Office, Boston, MA. 4 p.

Massachusetts Office of Coastal Zone Management (CZM), Executive Office of Energy and Environmental Affairs. 2015. Massachusetts Open Resource Information System (MORIS). Available at http://www.mass.gov/eea/agencies/czm/program-areas/mapping-and-data-management/moris/.

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 p. Available at http://nsgl.gso.uri.edu/ncu/ncut73013.pdf.

Morgan, M. J., N.C. Kraus, and J.M. McDonald. 2005. Geomorphic analysis of Mattituck Inlet and Goldsmith Inlet, Long Island, New York. ERDC/CHL TR-05-2. U.S. Army Corps of Engineers, Engineer Research and Development Center, Vicksburg, MS. 330 p.

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.

MyTopo Online Historical Maps Collection. 2015. Historical Maps. Available at http://historical.mytopo.com/index.cfm?CFID=935450&CFTOKEN=88685760. Last accessed January 16, 2015.

National Oceanic and Atmospheric Administration (NOAA). 2015. NOAA's Historical Map & Chart Collection. Available at http://historicalcharts.noaa.gov/.

Nelson, B.W. 1979. Shoreline Changes and Physiography of Maine's Sandy Coastal Beaches. M.S. Thesis, Department of Oceanography, University of Maine, Orono. ME. 302 p.

New Hampshire Department of Environmental Services (NH DES). 2005. NH Salt Marsh Restoration: Little River Salt Marsh, North Hampton. Fact Sheet WMB-CP-14. 3 p. Available at http://des.nh.gov/organization/commissioner/pip/factsheets/cp/documents/cp-14.pdf.

Nordstrom, K.F. 1988. Effects of shore protection and dredging projects on beach configuration unjettied near tidal inlets in New Jersey. *In* D.G. Aubrey and L. Weisher (eds), Hydrodynamics and Sediment Dynamics of Tidal Inlets. *Lecture Notes on Coastal and Estuarine Studies* 29:440-454. Available at http://www.agu.org/books/ln/v029/LN029p0440/LN029p0440.pdf. Accessed June 26, 2014.

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.

Patton, P.C., and J.M. Kent. 1992. *A Moveable Shore: The Fate of the Connecticut Coast*. Durham, NC: Duke University Press. 143 p.

Peconic Estuary Program. 2004. Peconic Estuary Program Critical Lands Protection Plan. Yaphank, NY. 61 p. Available at http://www.peconicestuary.org/reports.php. Accessed January 8, 2015.

Pilkey, O. H., and R. Young. 2009. *The Rising Sea*. Washington, D.C.: Island Press. 203 p.

Rhode Island Coastal Resources Management Council (RI CRMC). 1999. Rhode Island's Salt Pond Region: A Special Area Management Plan (Maschaug to Point Judith Ponds). Providence, RI. 238 p. Available at http://www.crmc.ri.gov/samp_sp.html.

Rice, T. M. 2009. Best management practices for shoreline stabilization to avoid and minimize adverse environmental impacts. Prepared for the USFWS, Panama City Ecological Services Field Office. Terwilliger Consulting, Inc., Locustville, Virginia. 21 pp.

Rice, T. M. 2012a. 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. 30 p.

Rice, T. M. 2012b. The Status of Sandy, Oceanfront Beach Habitat in the Continental U.S. Coastal Migration and Wintering Range of the Piping Plover (*Charadrius melodus*). Appendix 1c *in* Comprehensive Conservation Strategy for the Piping Plover (*Charadrius melodus*) in its Coastal Migration and Wintering Range in the Continental United States, U.S. Fish and Wildlife Service, East Lansing, Michigan. 36 p.

Rice, T.M. 2014. 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. Report submitted to the U.S. Fish and Wildlife Service, Hadley, Massachusetts. 25 p.

Rice, T.M. 2015. Inventory of Habitat Modifications to Sandy Oceanfront Beaches 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. Report submitted to the U.S. Fish and Wildlife Service, Hadley, Massachusetts. 47 p.

Sargent, F.E., and R.R. Bottin, Jr. 1989. Case Histories of Corps Breakwater and Jetty Structures. Report 7: New England Division. U.S. Army Corps of Engineers, Coastal Engineering Research Center Technical Report REMR-CO-3. Vicksburg, MS. 110 p. Available at http://chl.erdc.usace.army.mil/%5CMedia%5C4%5C4%5C6%5CTechReport7.pdf. Accessed June 3, 2014.

Seabergh, W.C., and L.J. Thomas. 2002. Weir Jetties at Coastal Inlets: Part 2, Case Studies. U.S. Army Corps of Engineers Coastal and Hydraulics Engineering Technical Note ERDC/CHL CHETN-IV-54. Vicksburg, MS. 21 p. Available at http://chl.erdc.usace.army.mil/library/publications/chetn/pdf/chetn-iv-54a.pdf. Accessed June 3, 2014.

Slovinsky, P.A., and S.M. Dickson. 2003. Variation of beach morphology along the Saco Bay littoral cell: An analysis of recent trends and management alternatives. Maine Geological Survey Open-File Report 03-78. Augusta, ME. 64 p.

Slovinsky, P.A., and S.M. Dickson. 2003. Impacts of future sea level rise on the coastal floodplain. Maine Geological Survey Open-File Report 06-14. Augusta, ME. 27 p.

Smith, E.R. 1988. Case Histories of Corps Breakwater and Jetty Structures. Report 5: North Atlantic Division. U.S. Army Corps of Engineers, Coastal Engineering Research Center Technical Report REMR-CO-3. Vicksburg, MS. 117 p. Available at http://chl.erdc.usace.army.mil/%5CMedia%5C4%5C4%5C4%5CTechReport5.pdf. Accessed June 3, 2014.

Smith, J.B., and D.M. FitzGerald. 1994. Sediment transport patterns at the Essex River Inlet ebb-tidal delta, Massachusetts, USA. *Journal of Coastal Research* 10(3):752-774.

Speer, P.E., D.G. Aubrey, and E. Ruder. 1982. Beach changes at Nauset Inlet, Cape Cod, Massachusetts, 1670-1981. Woods Hole Oceanographic Institution Technical Report WHOI-82-40. Woods Hole, MA. 100 p.

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.

Stolt, M., M. Bradley, J. Turenne, M. Payne, E. Scherer, G. Cicchetti, E. Shumchenia, M. Guarinello, J. King, J. Boothroyd, B. Oakley, C. Thornber, and P. August. 2011. Mapping shallow coastal ecosystems: A case study of a Rhode Island lagoon. *Journal of Coastal Research* 27(6A):1-15.

Suffolk County Planning Department. 1985. Analysis of dredging and spoil disposal activity by Suffolk County, County of Suffolk, New York: Historical perspective and a look to the future. Suffolk County Planning Department, Hauppauge, NY. 85 p.

Suffolk County. 2015. Cedar Point County Park. Hauppauge, NY. Available at http://www.suffolkcountyny.gov/Departments/Parks/Parks/CedarPointCountyPark.aspx. Accessed January 5, 2015.

Thelen, B.A., and R.K. Thiet. 2008. Molluscan community recovery following partial tidal restoration of a New England estuary, U.S.A. *Restoration Ecology* 17(5):695-703.

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.

Tiffney, W.N., and C. Andrews. 1990. Sesachacha & Sankaty: Pond Opening and Erosion on Nantucket's Eastern Shore. *Historic Nantucket* 38(1):4-6. Available at http://www.nha.org/history/hn/HN-tiffney-sechacha.htm.

Town of East Hampton. 1999. Town of East Hampton Local Waterfront Revitalization Program. As adopted December 3, 1999, by the Town of East Hampton, approved by New York State Secretary of State December 20, 2007, and concurred by US Office of Ocean and Coastal Resources Management August 26, 2008. East Hampton, NY. 879 p. Available at http://docs.dos.ny.gov/communitieswaterfronts/LWRP/East%20Hampton_T/Index.html.

Town of East Hampton. 2013. Piping Plover and Least Tern Breeding Bird Management Program End of Season Report. September 2013. Town of East Hampton, New York. 31 p.

Town of Nantucket. 2015. Pond Openings. Available at http://www.nantucket-ma.gov/556/Pond-Openings. Accessed March 17, 2015.

Town of Southold. 2009. Short-Term Work Plan to Assess, Mitigate and Restore the Ecological Function and Values of Goldsmith Inlet - Goldsmith Inlet Management Plan. Town of Southold, New York. 16 p.

Town of Southold. 2011. Town of Southold Local Waterfront Revitalization Program, as amended. Southold, NY. 1,017 p. Available at http://docs.dos.ny.gov/communitieswaterfronts/LWRP/Southold_T/Index.html.

Trustees of Reservations. 2015. About Wasque. Available at http://www.thetrustees.org/places-to-visit/cape-cod-islands/wasque-reservation.html.

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. 1996. Department of the Army Permit No. 199600817 to the Massachusetts Highway Department, Interim Shore Protection Project, Oak Bluffs / Edgartown. New England District, U.S. Army Corps of Engineers, Concord, MA. 6 p.

USACE. 2002. Coastal Engineering Manual. Manual No. EM 1110-2-1100. U.S. Army Corps of Engineers, Washington D.C. Various paginations in 6 volumes. Available at http://www.publications.usace.army.mil/USACEPublications/EngineerManuals/tabid/16439/u43544q/436F617374616C20456E67696E656572696E67204D616E75616C/Default.aspx.

USACE. 2006. Maintenance Dredging of the Harbor of Refuge Federal Navigation Project, Point Judith, Rhode Island. Fact Sheet. November 2006. New England District, U.S. Army Corps of Engineers, Concord, MA. 2 p.

USACE. 2008. Ninigret and Cross Mills Ponds Habitat Restoration Project, Charlestown, Rhode Island. Operations and Maintenance Manual. New England District, U.S. Army Corps of Engineers, Concord, MA. 32 p.

USACE. 2011a. Maintenance and Advance Maintenance Dredging of the Federal Navigation Project in the Kennebec River, Maine. 30 Day Public Notice, March 1, 2011. New England District, U.S. Army Corps of Engineers, Concord, MA. 8 p.

USACE. 2011b. Maintenance of Portions of the 8-foot Federal Navigation Channels in the Patchogue River, Westbook, and Clinton Harbor, Connecticut. 30 Day Public Notice, May 8, 2011. New England District, U.S. Army Corps of Engineers, Concord, MA. 10 p.

USACE. 2012a. Maintenance Dredging of the Federal Navigation Project in Cuttyhunk Harbor, Gosnold, Massachusetts. 30 Day Public Notice, April 19, 2012. New England District, U.S. Army Corps of Engineers, Concord, MA. 7 p.

USACE. 2012b. Maintenance Dredging of the Federal Navigation Project in the Housatonic River, Stratford and Milford, Connecticut. 30 Day Public Notice, August 15, 2012. New England District, U.S. Army Corps of Engineers, Concord, MA. 6 p.

USACE. 2012c. Application for dredging with ten years maintenance with beach nourishment. Accabonac harbor, Gardiner's Bay, Suffolk County, New York. Public Notice No. NAN-2012-00042-ESP. June 7, 2012. New York District, U.S. Army Corps of Engineers, New York, NY. 11 p.

USACE. 2012d. Application for maintenance dredging of Spring Pond Channel. Town of Southold, Suffolk County, New York. Public Notice No. NAN-2011-00745-EST. February 6, 2012. New York District, U.S. Army Corps of Engineers, New York, NY. 12 p.

USACE. 2012e. Application for dredging with ten years maintenance with beach nourishment. Dickerson Creek, Shelter Island, Suffolk County, New York. Public Notice No. NAN-2011-01446-EST. February 29, 2012. New York District, U.S. Army Corps of Engineers. 11 p.

USACE. 2013a. Maintenance Dredging of the Federal Navigation Project in the Scaborough River, Scarborough, Maine. 30 Day Public Notice, May 20, 2013. New England District, U.S. Army Corps of Engineers, Concord, MA. 6 p.

USACE. 2013b. Maintenance Dredging of the 8-foot Channel of the Federal Navigation Project in the Kennebunk River, Kennebunk & Kennebunkport, Maine. 30 Day Public Notice, September 30, 2013. New England District, U.S. Army Corps of Engineers, Concord, MA. 7 p.

USACE. 2013c. Maintenance Dredging of the Federal Navigation Project in Hyannis Harbor, Hyannis, Massachusetts. 30 Day Public Notice, April 2, 2013. New England District, U.S. Army Corps of Engineers, Concord, MA. 7 p.

USACE. 2013d. Application by the Town of Oak Bluffs, Massachusetts, to Modify Permit NAE-2009-01128 to Dredge Sengekontacket Pond at Little Bridge. 15 Day Public Notice NAE-2009-01128, December 17, 2013. New England District, U.S. Army Corps of Engineers, Concord, MA. 11 p.

USACE. 2013e. Breakwater Rehabilitation, Sag Harbor, New York, Federal Navigation Project. Public Notice No. SAG HARBOR, May 8, 2013. New York District, U.S. Army Corps of Engineers, New York, NY. 5 p.

USACE. 2013f. Application by the Town of Gosnold, Cuttyhunk Island, Massachusetts, to Excavate an Opening between Westend Pond and Buzzards Bay. Public Notice NAE-2010-938, December 10, 2013. New England District, U.S. Army Corps of Engineers, Concord, MA. 9 p.

USACE. 2014a. Maintenance Dredging of the Federal Navigation Project in Cohasset Harbor, Cohasset and Scituate, Massachusettts. 30 Day Public Notice, March 5, 2014. New England District, U.S. Army Corps of Engineers, Concord, MA. 7 p.

USACE. 2014b. Maintenance Dredging of the Federal Navigation Project in Menemsha Creek, Chilmark & Aquinnah, Massachusetts. 30 Day Public Notice, June 6, 2014. New England District, U.S. Army Corps of Engineers, Concord, MA. 6 p.

USACE. 2014c. Application for Maintenance Dredging and Beach Nourishment of Several Sites in the Town of Edgartown, Massachusetts. Revised Public Notice NAE-2011-1511, May 27, 2014. New England District, U.S. Army Corps of Engineers, Concord, MA. 11 p.

USACE. 2014d. Federal Maintenance of East and West Jetty, Nantucket Harbor, Nantucket, Massachusetts. 30 Day Public Notice, November 17, 2014. New England District, U.S. Army Corps of Engineers, Concord, MA. 6 p.

USACE. 2014e. Camp Cronin Revetment, Point Judith Harbor of Refuge, Narragansett, Rhode Island. 30 Day Public Notice, February 21, 2014. New England District, U.S. Army Corps of Engineers, Concord, MA. 6 p.

USACE. 2014f. Amendment – Maintenance Dredging of the Guilford Harbor Federal Navigation Project, Guilford, Rhode Island. 15 Day Public Notice, July 1, 2014. New England District, U.S. Army Corps of Engineers, Concord, MA. 8 p.

USACE. 2014g. Lake Montauk Harbor, New York, Federal Navigation Project Maintenance Dredging. 30 Day Public Notice, March 12, 2014. New York District, U.S. Army Corps of Engineers, New York, NY. 5 p.

USACE. 2014h. Application for maintenance dredging of Wading River Creek with beach placement. Wading River Creek, Town of Riverhead, Suffolk County, New York. Public Notice No. NAN-2014-00259-EBO. June 23, 2014. New York District, U.S. Army Corps of Engineers. 8 p.

USACE. 2015. ORM Permit Decisions (Version 1.0). U.S. Army Corps of Engineers, Regulatory Division. Available at http://geo.usace.army.mil/egis/f?p=340:1:0:::::. Last accessed January 9, 2015.

U.S. Environmental Protection Agency (EPA). 1995. Vulnerability of Maine Sites to Accelerated Sea-Level Rise. Chapter 2 *in* Anticipatory Planning for Sea-Level Rise Along the Coast of Maine. EPA-230-R-95-900. U.S. Environmental Protection Agency

Office of Policy, Planning, and Evaluation, Washington, D.C. 48 p. Available at http://papers.risingsea.net/federal_reports/maine_2.pdf.

U.S. Fish and Wildlife Service (USFWS). 1996. Piping Plover (Charadrius melodus) Atlantic Coast Population Revised Recovery Plan. Hadley, MA. 236 p.

USFWS. 2002a. Trustom Pond National Wildlife Refuge Comprehensive Conservation Plan. Hadley, MA. 85 p. + appendices.

USFWS. 2002b. Ninigret Pond National Wildlife Refuge Comprehensive Conservation Plan. Hadley, MA. 81 p. + appendices.

USFWS. 2007. Rachel Carson National Wildlife Refuge Comprehensive Conservation Plan and Environmental Assessment. Hadley, MA. 134 p. + appendices.

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

USFWS. 2014. Monomoy National Wildlife Refuge Draft Comprehensive Conservation Plan and Environmental Impact Statement,. Chatham, MA. 556 p. + appendices. Available at http://www.fws.gov/refuge/Monomoy/what_we_do/draftccp.html.

University of New Hampshire Library Digital Collections. 2015. Historic USGS Maps of New England and New York. Available at http://docs.unh.edu/nhtopos/nhtopos.htm. Last accessed January 12, 2015.

Visel, T. 2009. The Hammonasset Beach Erosion Problem: A Case History of Habitat Transitions for Creation, Enhancement and Mitigation. Written comments provided to The Long Island Sound EPA Habitat Restoration Initiative. 27 p. Available at http://www.google.com/url?sa=t&rct=j&q=&esrc=s&source=web&cd=2&ved=0CCQQFjAB&url=http%3A%2F%2Fwww.soundschool.com%2FThe%2520Long%2520Island%2520Sound%2520EPA.pdf&ei=-WC9VKSGLoSgNsHXgIAD&usg=AFQjCNEMDtsqhpsniYIv0mIHEEXHO6ksBA&bvm=bv.83829542,d.eXY&cad=rja. Accessed January 16, 2015.

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 p.

Watts, I.M, J.D. Rosati, and M. Borrelli. 2011. Re-establishing a historical inlet at East Harbor, Cape Cod, Massachusetts. *Proceedings of the Coastal Sediments '11 Specialty Conference*, May 2-6, 2011, Miami, FL. Pp. 419-429.

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.