Habitat Modifications in the U.S. Atlantic Coast Breeding Range of the Piping Plover (*Charadrius melodus*) prior to Hurricane Sandy: A Synthesis of Tidal Inlet and Sandy Beach Habitat Inventories[1]

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Tidal inlet and sandy beach habitat have been modified throughout the entire U.S. Atlantic Coast breeding range of the piping plover (*Charadrius melodus*), from Maine to North Carolina. This summary report synthesizes the results of six recent detailed inventories of these two habitat types for the northern and southern portions of the U.S. Atlantic Coast breeding range of the piping plover. The results of the habitat inventories for the northern portion of the breeding range include data on the tidal inlet (Rice 2015a) and sandy beach habitats (Rice 2015b) of the exposed shorelines of Maine (ME), New Hampshire (NH), Massachusetts (MA), Rhode Island (RI), Connecticut (CT), and the Long Island Sound and Peconic Estuary shorelines of New York (NY). The results of the habitat inventories for the southern portion of the breeding range include data on the tidal inlet (Rice 2014) and sandy beach habitats (Rice 2015c) of the Atlantic Ocean shoreline of NY, New Jersey (NJ), Delaware (DE), Maryland (MD), and Virginia (VA). Data on the sandy beaches of North Carolina (NC) were included in the inventories for tidal inlet (Rice 2012a) and sandy beach habitat (Rice 2012b) in the migratory and overwintering range of the piping plover, since habitats in that state support all phases of the species' annual cycle. Combining the data from these six reports, the status of tidal inlet and sandy beach habitat prior to Hurricane Sandy within each recovery unit of the piping plover can be evaluated. Additional future reports will assess the status of these two habitats in the breeding range immediately following and 3 years after Hurricane Sandy.

INTRODUCTION

Recovery Task 1.2 of the U.S. Fish and Wildlife Service (USFWS) Recovery Plan for the piping plover 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). The USFWS's most recent 5-Year Review for the piping plover recommends increasing "efforts to restore and maintain natural coastal formation processes in the New York-New Jersey recovery unit, where threats from development and artificial shoreline stabilization are highest, and in the Southern Recovery Unit, where the plover's habitat requirements are the most stringent …. This action is also critical to reducing adverse effects of accelerating sea level rise"

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for the breeding range of the federally listed (threatened) Atlantic Coast population (USFWS 2009, p. 195).

Data are needed to identify habitat modifications that have altered natural coastal processes and the resulting abundance, distribution, and condition of currently existing habitat in the United States (U.S.) Atlantic coast breeding range. This report summarizes these data for tidal inlet and sandy beach habitats for the entire U.S. Atlantic Coast breeding range, synthesizing the results of six recent inventories of these habitats for the northern and southern portions of the breeding range.

The U.S. Atlantic Coast breeding range of the piping plover stretches from Maine to North Carolina. The U.S. Atlantic Coast breeding range has been divided into three recovery units – New England, New York-New Jersey, and Southern (USFWS 1996). The New England recovery unit includes Maine, New Hampshire, Massachusetts, Rhode Island and Connecticut. The New York – New Jersey recovery unit includes the Long Island Sound, Peconic Estuary and Atlantic Ocean shorelines of New York plus New Jersey. The Southern Recovery Unit includes Delaware, Maryland, Virginia and North Carolina.

Altogether the six detailed habitat inventories can provide an assessment of the cumulative impacts of habitat modifications at tidal inlets and sandy ocean beaches for piping plovers and other birds, including overlapping portions of the wintering and migration range of the recently listed rufa red knot (*Calidris canutus rufa*). These assessments did **not**, however, include habitat disturbances at tidal inlets and sandy beaches such as off-road vehicle (ORV) usage, pet and human disturbance, or disturbance to dunes or vegetation on inlet shoulders.

Inlets and sandy beaches are highly valuable habitats for piping plovers, red knots, other shorebirds, and waterbirds for nesting, foraging, loafing, and roosting (Harrington 2008, Kisiel 2009, Lott et al. 2009, Maddock et al. 2009). The North Atlantic Landscape Conservation Cooperative has designated the piping plover as a representative species in all three subregions, standing as a surrogate for other species using dynamic beach systems including American oystercatchers, least terns, black skimmers, seabeach amaranth and migrating shorebirds (http://www.fws.gov/northeast/science/pdf/nalcc_terrestrial_rep_species_table.pdf). Sandy beaches and/or dunes are designated as a key habitat in the state Wildlife Action Plans for all of the states in the U.S. Atlantic Coast breeding range; the piping plover is listed as a species in greatest conservation need by each of those states as well (CTDEP 2005, DE DNREC 2006, MD DNR 2005, MDIFW 2005, NJ DEP 2008, NYDEC 2005, RDFW 2005, MDFW 2006, NC WRC 2005, NHFG 2006, VA DGIF 2015). The Long Island Sound Study lists both beach and dune habitat and piping plovers as environmental indicators for the health of the Long Island Sound ecosystem (LISS 2015). The Peconic Estuary Program also has designated piping plover nests and nesting productivity as an environmental indicator, as well as the extent of shoreline hardening from shoreline stabilization structures (Balla et al. 2005).

INVENTORY METHODS AND RESULTS

For a complete description of the methods used to identify the abundance, distribution and status of modifications to the tidal inlet and sandy beach habitats in the U.S. Atlantic Coast breeding range of the piping plover, see the individual reports for each habitat and geographic area. Inventory results include the overall lengths of sandy beaches present prior to Hurricane Sandy and the proportions of sandy beach that had been modified by development, armoring with hard shoreline stabilization structures, and sediment placement. The length of sandy beach in public and/or non-governmental organization (NGO) ownership is also included. Results are presented by county and state. Inventory results for tidal inlets include the number and location of tidal inlets open in each state at the time of Hurricane Sandy in October 2012, and the numbers of tidal inlets that had been modified by armoring with hard shoreline stabilization structures, dredging and sediment mining. The numbers and locations of known historical inlets and those that had been artificially opened, closed or relocated are also included.

For a description of the inventory methods used in ME, NH, MA, RI, CT, and along the Long Island Sound and Peconic Estuary shorelines of NY, see:

- pages 2 to 9 of Rice (2015a) for tidal inlets, and
- pages 2 to 6 of Rice (2015b) for sandy beaches.

For a description of the inventory methods used along Atlantic Ocean shoreline of NY, NJ, DE, MD and VA, see:

- pages 2 to 5 of Rice (2014) for tidal inlets, and
- pages 2 to 4 of Rice (2015c) for sandy beaches.

For a description of the inventory methods used in North Carolina, see:

- pages 1 to 6 of Rice (2012a) for tidal inlets, and
- pages 1 to 4 of Rice (2012b) for sandy beaches.

The habitat modification databases 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 tidal inlets or sandy beaches contained within the U.S. Atlantic Coast breeding range of the piping plover. These reports and databases will be posted on-line at the North Atlantic LCC Hurricane Sandy Science Coastal Resiliency Projects website (http://northatlanticlcc.org/projects).

SUMMARY RESULTS

New England Recovery Unit

The New England Recovery Unit is the northernmost recovery unit of the U.S. Atlantic Coast breeding range of the piping plover and includes the coasts of Maine, New Hampshire, Massachusetts, Rhode Island, and Connecticut. Prior to Hurricane Sandy, there were approximately 920 miles (1,481 kilometers [km]) of sandy beaches from Georgetown, ME, south through Connecticut (Table 1). Forty-three percent (43%) of these sandy beaches were developed along their beachfront before Hurricane Sandy. New Hampshire and Maine's sandy beaches were the most developed (87% and 68% respectively), and Rhode Island's sandy beaches were the least developed (29%).

Over 26% (242.78 miles or 390.72 km) of the sandy beaches in the New England Recovery Unit were armored with hard shoreline stabilization structures; this number is conservative since groin fields in Massachusetts were excluded (see Rice 2015b for a full discussion). New Hampshire's sandy beaches were significantly more armored (72%) than any other state in the New England Recovery Unit, with Rhode Island's sandy beaches the least modified by hard shoreline stabilization structures (8%). Massachusetts has the longest length of sandy beaches lined with hard shoreline stabilization structures by far, with at least 180.24 miles (290.07 km) of sandy beaches modified with shore-parallel structures (groin fields were excluded – see the Massachusetts section of Rice 2015b for a full discussion). As of the date(s) of the most recent aerial imagery prior to Hurricane Sandy in October 2012, there were at least 20.12 miles (32.38 km) of New England shoreline where all sandy beach habitat had been lost seaward of armoring.

Table 1. Known habitat modifications to exposed sandy beach habitat in the New England Recovery Unit of the piping plover. Note that the approximate length of armored shoreline with no sandy beach (habitat loss) column reflects the length of armored shoreline without sandy beach as of the most recent imagery prior to Hurricane Sandy.

State	Approx. Length of Sandy Beach (miles)	Sandy Beaches Developed (miles)	Known Approximate Length of Armored Sandy Beach Shoreline (miles)	Approximate Length of Armored Shoreline with No Sandy Beach (miles)	Known Length of Shoreline Previously Modified with Sediment Placement (miles)
ME[1]	48.88	33.11	14.51	0.48	6.30
NH	9.58	8.35	6.91	0.19	1.37
MA	729.94	300.26	180.24+	Unknown	14.79
RI[2]	49.56	14.62	4.21	1.42	6.00
CT	82.16	35.96	36.91	18.03	15.32
TOTAL[3]	**920.12**	**392.3 (43%)**	**242.78 (26%)**	**20.12 (2%)**[4]	**> 43.78 (> 5%)**[5]

1 – The area of Maine shoreline included in this assessment is from Georgetown south.
2 – Upper Narragansett Bay is not included; see the Rhode Island section of Rice (2015b) for precise details.
3 – Totals may differ due to rounding.
4 – The percentage of sandy beach habitat lost was calculated by dividing by the sum of the length of armored shoreline with no beach and the length of sandy beach.
5 – The length and percentage of sandy beach habitat modified by sediment placement is a minimum due to a lack of project location and length data for 69 of 237 projects in this recovery unit.

Table 2. Approximate number of each type of armoring on the each section of coast both with sandy beaches and where sandy beach habitat had been lost that was visible on Google Earth imagery between 1991 and May 2012 and/or reported in published documents. Note that multiple seawalls, bulkheads or revetments are counted as one structure if they are continuous with no separations; for example, if five individual properties each have an individual seawall protecting their property and the seawalls are attached to each other with no gaps, the armoring is counted as one seawall structure (Dallas et al. 2013) and its overall length is counted in Table 1 above.

State	Number of Groins	Number of Jetties	Number of Seawalls, Bulkheads and/or Revetments	Number of Breakwaters
Maine	0	8	118	0
New Hampshire	14	2	45	2
Massachusetts[1, 2]	up to 2,030	73	up to 5,378	up to 21
Rhode Island	12	11	58	1
Connecticut	653	24	275	18
TOTAL	**up to 2,709**	**118**	**up to 5,874**	**up to 42**

1 – MA DCR (2009) and Fontenault et al. (2013) provide inventories of public and private shoreline stabilization structures for the entire Commonwealth of Massachusetts but do not provide data on how many of the structures are on sandy beaches versus rocky shorelines. A very small number of these structures may be found on rocky shorelines; an additional unknown number occur on sandy shorelines along inner bays and harbors that were not included in the sandy beach assessment.

2 – MA DCR (2009) and Fontenault et al. (2013) identified a combined total of 2,103 groins and jetties along the entire Massachusetts coast. Rice (2015a) identified 73 jetties in Massachusetts, which was subtracted from the 2,103 total to estimate up to 2,030 groins.

There were up to 2,709 groins along sandy beaches in the New England Recovery Unit (excluding MA) before Hurricane Sandy, with the vast majority of the known groins found in Massachusetts and Connecticut (Table 2). MA DCR (2009) and Fontenault et al. (2013) identified 2,103 groins and jetties in Massachusetts, but did not distinguish those that were located on sandy beaches versus those located on rocky sections of coastline (although it may be safe to assume nearly all of them are on sandy beaches because their intended purposes are to trap and retain sediment). Up to 42 breakwaters and 118 jetties were along sandy beaches in New England before October 2012. Up to 5,874 contiguous sections of seawalls, bulkheads and/or revetments lined the sandy beaches of the New England Recovery Unit, the vast majority in Massachusetts, before Hurricane Sandy.

At least 5% (43.78 miles or 70.46 km) of the sandy beaches in the New England Recovery Unit had been modified by sediment placement projects prior to Hurricane Sandy, but project length data were lacking for a significant proportion of projects (69 of 237) and the actual number of miles of beaches modified by sediment placement is considerably higher. Nearly all of the sediment placement projects modifying sandy beaches in the New England Recovery Unit are the placement of dredged material from nearby inlets and navigation channels; projects with the primary intent of beach nourishment or storm damage reduction are relatively uncommon and where they do occur they tend to be conducted by county, municipal or private interests. There are no on-going large-scale federal storm damage reduction projects involving beach or dune fill in the New England Recovery Unit as there are in the other two recovery units. The locations and known lengths of individual sediment placement projects for each state can be found in Rice (2015b).

The New England Recovery Unit had 219 tidal inlets open prior to Hurricane Sandy, with over two-thirds (68%) of them modified in at least one manner (Table 3). The majority (63%) of the inlets were stabilized with hard structures along at least one shoreline. More than one-third (36%) of the tidal inlets were dredged at least once, including 51 inlets in Massachusetts and 2 of the 3 inlets in New Hampshire. Twenty (20) of the inlets had been opened artificially, with 13 of those artificial inlets located in Massachusetts. Only 3 inlets had been mined for sediment and 2 had been relocated. Thirteen (13) inlets had been closed artificially in Massachusetts (6) and Connecticut (7). The list of inlets open in each state and the modifications to each prior to Hurricane Sandy can be found in Rice (2015a).

Nearly 300 miles (483 km) of sandy beaches in the New England Recovery Unit were in public and/or NGO ownership (Table 4). Massachusetts had the highest amount of public and/or NGO-owned sandy beaches, with over 217 miles (349 km), but both New Hampshire and Rhode Island had over half of their sandy beaches in public and/or NGO ownership. These lands are not free from habitat modification(s), however, as some public lands such as Wallis Sands, Jenness Beach and North Hampton State Parks in NH all have been modified by shoreline armoring and/or sediment placement.

Table 3. The number of open tidal inlets, inlet modifications, and artificially closed inlets in each state of the New England Recovery Unit 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	13	6
RI	17	9	6	8	0	0	7	0
CT	56	48	47	11	0	0	0	7
TOTAL	219	150 (68%)	139 (63%)	78 (36%)	2 (1%)	3 (1%)	20 (9%)	13 (n/a)

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

‡ One additional inlet in MA and three additional inlets in RI have been artificially created but were not open in October 2012.

Table 4. Approximate lengths of sandy beach in public and/or NGO ownership in the New England Recovery Unit of the U.S. Atlantic Coast breeding range of the piping plover by state.

State	Approx. Length of Sandy Beach (miles)	Length of Sandy Beach Shoreline in Public / NGO Ownership (miles)
Maine	48.88	13.9 (28%)
New Hampshire	9.58	5.11 (53%)
Massachusetts	729.94	217.49 (30%)
Rhode Island	49.56	27.27 (55%)
Connecticut	82.16	35.09 (43%)
UNIT TOTAL	**920.12**	**298.86 (32%)**

In summary, piping plover habitat within the New England Recovery Unit had been significantly modified, with 43% of its 920 miles (1,480 km) of sandy beaches developed, at least 26% armored, and at least 3% modified by sediment placement, and 68% of the 219 tidal inlets modified in at least one manner. An additional 20+ miles (32 + km) of sandy beach habitat were absent seaward of shoreline stabilization structures shortly before Hurricane Sandy. Nearly one-third of the sandy beaches were in public and/or NGO ownership.

<u>New York – New Jersey Recovery Unit</u>

The New York – New Jersey Recovery Unit is the central recovery unit of the U.S. Atlantic Coast breeding range of the piping plover and includes the New Jersey coast plus three coastline segments of New York – the Long Island Sound (LIS) or North Shore shoreline, the Peconic Estuary shoreline, and the Atlantic Ocean or South Shore shoreline. While the Atlantic Ocean coasts of Long Island and New Jersey are dominated by barrier islands and spits separated by large inlets, the LIS and Peconic Estuary shorelines of NY lack barrier islands and tend to be dominated instead by glacial bluffs with narrower beaches and shorter spits separated by more frequent and smaller inlets.

Prior to Hurricane Sandy, there were approximately 506 miles (814 km) of sandy beaches in New York and New Jersey (Table 5). Slightly over half (52%) of the sandy beaches in the recovery unit were developed along their beachfront before Hurricane Sandy. The sandy beaches of oceanfront New Jersey and the Long Island Sound shoreline of New York were the most developed (67% and 61% respectively), and New York's Peconic Estuary beaches were the least developed (33%).

The length of sandy beach was fairly evenly divided between the four sections of shoreline in the recovery unit, but their levels of modification were not evenly divided (Table 5). The New Jersey oceanfront beaches were much more modified than the three sections of New York shoreline.

New Jersey's oceanfront beaches were 67% developed, 60% armored and 50% modified by sediment placement. The New Jersey beaches have had one-quarter to one-third of the recovery unit's breeding pairs of piping plovers since 1996 (USFWS 2014).

The South Shore of Long Island was significantly modified overall, with 47% of its beachfront developed, 20% armored and 52% modified by sediment placement. USFWS (2014, p. 74) found that from 2000 to 2013, "the south shore Atlantic Ocean Beaches [of Long Island] supported between 63 and 71% of the Long Island-wide population [of breeding piping plovers]. Abundance levels in the Peconic and Long Island Sound beaches are fairly close, [together] accounting for between 29 and 37% of the Long Island-wide population. The

Table 5. Known habitat modifications to exposed sandy beach habitat in the New York – New Jersey Recovery Unit of the piping plover. Note that the approximate length of armored shoreline with no sandy beach column reflects the length of armored shoreline without sandy beach as of the most recent imagery prior to Hurricane Sandy.

State	Approx. Length of Sandy Beach (miles)	Sandy Beaches Developed (miles)	Known Approximate Length of Armored Sandy Beach Shoreline (miles)	Approximate Length of Armored Shoreline with No Sandy Beach (miles)	Known Length of Shoreline Previously Modified with Sediment Placement (miles)
NY - LIS	120.66	73.28	6.08	6.07	0.57+
NY - Peconic	134.98	45.06	27.05	17.24	1.44+
NY - Atlantic	124.88	58.23	25.58	1.38	65.30
NJ	125.26	84.47	75.20	1.87	63.10
TOTAL	**505.78**	**261.04 (52%)**	**133.91 (26%)**	**26.56 (5%)†**	**130.41 (26%)**

† The percentage of sandy beach habitat lost was calculated by dividing by the sum of the length of armored shoreline with no beach and the length of sandy beach.

distribution is patchy and reflective of habitat types and quality which is affected by land use patterns, which are in and of themselves affected in large part by stabilization projects." Thus even though the amount of sandy beach habitat may be roughly equal between the three sections of Long Island coastline and not withstanding the amount of modification, the South Shore appears to be significantly more valuable to breeding piping plovers.

Over 26% (133.91 miles or 215.51 km) of the sandy beaches of New York and New Jersey were armored with hard shoreline stabilization structures (Table 5). New Jersey's oceanfront beaches were significantly more armored (60%) than any other section of shoreline in the New York - New Jersey Recovery Unit, with New York's Long Island Sound beaches the least modified by hard shoreline stabilization structures (5%). New Jersey had the longest length of sandy beaches lined with hard shoreline stabilization structures by far, with approximately 75.20 miles (121.02 km) of sandy beaches modified with armoring. As of the date(s) of the most recent aerial imagery prior to Hurricane Sandy in October 2012, there were at least 26.56 miles (43.15 km) of shoreline in New York and New Jersey where all sandy beach habitat had been lost seaward of armoring. Nearly two-thirds of sandy beach habitat lost due to shoreline armoring was found along the Peconic Estuary shoreline of New York where 17.24 miles (27.75 km) was absent as of early 2012.

There were 2,424 groins along sandy beaches in the New York – New Jersey Recovery Unit before Hurricane Sandy, with the vast majority of the known groins found along the Peconic Estuary shoreline of NY (Table 6). At least 88 jetties and 26 breakwaters were along sandy

Table 6. Approximate number of each type of armoring on each section of coast both with sandy beaches and where sandy beach habitat had been lost that was visible on Google Earth imagery between 1991 and March 2012 and/or reported in published documents. Note that multiple seawalls, bulkheads or revetments are counted as one structure if they are continuous with no separations; for example, if five individual properties each have an individual seawall protecting their property and the seawalls are attached to each other with no gaps, the armoring is counted as one seawall structure (Dallas et al. 2013) and its overall length is counted in Table 5 above.

State	Number of Groins	Number of Jetties	Number of Seawalls, Bulkheads and/or Revetments	Number of Breakwaters
NY - LIS	577	21	255	4
NY - Peconic	1,060	50	306	14
NY - Atlantic	335	8	43	2
NJ	452	9	96	6
TOTAL	**2,424**	**88**	**700**	**26**

Table 7. The number of open tidal inlets, inlet modifications, and artificially closed inlets in each state of the New York - New Jersey Recovery Unit 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‡	
NY - LIS	28	21	20	5	0	1	1	0
NY - Peconic	96	63	56	33[c]	2	0	5	0
NY - Atlantic	9	9	6	9	0	3	4	4
NJ	11	10	9	9	1	8	1	5
TOTAL	144	103 (71%)	91 (63%)	56 (16%)	3 (2%)	12 (8%)	11 (8%)	9 (n/a)

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

‡ At least one additional inlet in NY was artificially created but was not open in 2012 prior to Hurricane Sandy.

beaches in NY and NJ before October 2012. At least 700 contiguous sections of seawalls, bulkheads and/or revetments lined the sandy beaches of the recovery unit before Hurricane Sandy.

At least 26% of the sandy beaches in the New York – New Jersey Recovery Unit had been modified by sediment placement projects prior to Hurricane Sandy (Table 5). Although available information makes it appear that equal proportions of the sandy beaches (26%) have been modified with hard stabilization structures and sediment placement, data on sediment placement projects on the Long Island Sound and Peconic Estuary shorelines of New York are so sparse that the recovery unit's actual level of modification by sediment placement is almost certainly significantly higher. The lengths of beach modified by sediment placement are only known for 3 of 12 project areas on Long Island Sound and 3 of 47 project areas on the Peconic Estuary. Roughly half of the South Shore (52%) and New Jersey (50%) beaches had been modified with sediment placement before Hurricane Sandy, totaling about 128.40 miles (206.64 km) of sandy beach. The locations and known lengths of individual sediment placement projects for each state can be found in Rice (2015b) for the Long Island Sound and Peconic Estuary shorelines and in Rice (2015c) for the South Shore of Long Island and New Jersey shorelines.

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, and increases to the west so that the tidal range is three times as high at the western end of Long Island Sound as the tidal range in Block Island Sound; the mean tidal range at Plum Island, for example, is 2.6 ft (0.8 m) but it increases to 7.3 ft (2.2 m) at Hempstead Harbor (Morgan et al. 2005). 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 and barrier islands 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). In contrast to the North and South Shores, the Peconic Estuary shoreline of New York is “highly convoluted,” but is also composed of glacial sediment and lined with headland bluffs that are typically less than 20 ft (6 m) high on the north fork but up to 240 ft (73 m) high on the south fork (Eisel 1977, p. 1). The New Jersey shoreline is very similar to that of the South Shore, Atlantic Ocean shoreline of New York.

As a result of these geological differences in the three segments of New York shorelines, the distribution of the recovery unit’s tidal inlets is not uniform. The New York – New Jersey Recovery Unit had 144 tidal inlets open prior to Hurricane Sandy, with two-thirds (67%) of them located along the Peconic Estuary shoreline of New York (Table 7). Thirteen (13) of the inlets, or 9%, were opened artificially; 7 of the 13 artificial inlets were located on the Peconic Estuary shoreline.

Over three-quarters (76%) of the tidal inlets in New York and New Jersey were modified in at least one manner (Table 7). The majority (63%) of the inlets were stabilized with hard structures along at least one shoreline. Half of the tidal inlets had been dredged at least once, and 13 of the inlets had been opened artificially. All (100%) of Long Island’s South Shore inlets had been modified, and only one inlet in New Jersey had *not* been modified prior to Hurricane Sandy.

Thirteen (13) inlets had been mined for sediment, more than in any other recovery unit; 8 of these 13 inlets were in NJ and have been targeted as sediment sources for beach fill projects. The 2 inlets along the North Shore of Long Island that have been mined were commercially mined for sand and gravel prior to the early 1970s. Three (3) inlets in the recovery unit had been relocated. An additional 9 inlets had been closed artificially, all of them on the Atlantic Ocean coastlines of NY and NJ. The list of inlets open in each state and the modifications to each prior to Hurricane Sandy can be found in Rice (2015a) for the Long Island Sound and Peconic Estuary shorelines of NY and Rice (2014) for the South Shore of Long Island and New Jersey.

Nearly 190 miles (306 km) of sandy beaches in the New York – New Jersey Recovery Unit were in public and/or NGO ownership (Table 8). The Peconic Estuary and Atlantic Ocean shorelines of New York each had roughly 61 miles (98 km) of public and/or NGO-owned sandy beaches, with the New Jersey (32 miles or 51 km) and North Shore (~35 miles or 56 km) coasts considerably less.

Table 8. Approximate lengths of sandy beach in public and/or NGO ownership in the New York – New Jersey Recovery Unit of the U.S. Atlantic Coast breeding range of the piping plover by state.

State	Approx. Length of Sandy Beach (miles)	Length of Sandy Beach Shoreline in Public / NGO Ownership (miles)
New York – LIS	120.66	34.96 (29%)
New York – Peconic	134.98	60.99 (45%)
New York – Atlantic	124.88	61.03 (49%)
New Jersey	125.26	31.97 (26%)
UNIT TOTAL	**505.78**	**188.95 (37%)**

In summary, piping plover habitat within the New York – New Jersey Recovery Unit had been significantly modified, with 52% of its ~506 miles (~872 km) of sandy beaches developed, at least 26% armored, and at least 26% modified by sediment placement, and 71% of the 144 tidal inlets modified in at least one manner. An additional ~27 miles (~43 km) of sandy beach habitat were absent seaward of shoreline stabilization structures shortly shortly before Hurricane Sandy. Over one-third (37%) of the sandy beaches were in public and/or NGO ownership.

Southern Recovery Unit

The Southern Recovery Unit is the southernmost recovery unit of the U.S. Atlantic Coast breeding range of the piping plover and includes the coasts of Delaware, Maryland, Virginia and North Carolina. Prior to Hurricane Sandy, there were approximately 489 miles (787 km) of oceanfront, sandy beaches from Delaware south through North Carolina (Table 9). Forty percent (40%) of these sandy beaches were developed along their beachfront before Hurricane Sandy. North Carolina and Delaware’s sandy beaches were the most developed (49% and 43% respectively), and Virginia’s oceanfront beaches were the least developed (16%).

Over 3% (16.54 miles or 26.62 km) of the sandy beaches of the Southern Recovery Unit were armored with hard shoreline stabilization structures (Table 9), excluding North Carolina where the length of beach modified by sandbag revetments is unknown. Delaware and Virginia’s oceanfront beaches were more armored (15 and 11% respectively) than Maryland (5%), and Virginia had the highest length of beach modified by armoring with over 11 miles (18 km) of hard stabilization structures found predominantly at Wallops Island and the Virginia Beach area.

Table 9. Known habitat modifications to exposed sandy beach habitat in the Southern Recovery Unit of the piping plover. Note that the approximate length of armored shoreline with no sandy beach column reflects the length of armored shoreline without sandy beach as of the most recent imagery prior to Hurricane Sandy.

State	Approx. Length of Sandy Beach (miles)	Sandy Beaches Developed (miles)	Known Approximate Length of Armored Sandy Beach Shoreline (miles)	Approximate Length of Armored Shoreline with No Sandy Beach (miles)	Known Length of Shoreline Previously Modified with Sediment Placement (miles)
DE	25.36	10.94	3.68	0	12.59
MD	31.10	9.00	1.62	0	31.10
VA	106.40	16.8	11.24	0†	27.69
NC	326.00	159.00	unknown	unknown	91.30
TOTAL	**488.86**	**195.74 (40%)**	**16.54 (3%)**	**0 (0%)**	**162.68 (33%)**

† Sandy beach habitat had been lost along 3.56 miles (5.73 km) of seawall on Wallops Island as of September 2011, but a beach fill project in August 2012 replaced the lost beach just prior to Hurricane Sandy.

As of September 2011, sandy beach habitat along approximately 3.56 miles (5.73 km) of Wallops Island, VA, was not present seaward of a seawall, but a beach fill project in August 2012 created a beach in front of the seawall just prior to Hurricane Sandy in October. The total amount of sandy beach habitat in the recovery unit that was lost due to shoreline armoring prior to Hurricane Sandy, however, is unknown due to the lack of data from North Carolina, where a number of sandbag revetments had no sandy beach as of 2011 but have not been measured.

There were 100 groins along sandy beaches in the Southern Recovery Unit before Hurricane Sandy, with half of the known groins found along the Virginia shoreline along Wallops Island and south of Chesapeake Bay (Table 10). At least 8 jetties and 22 breakwaters were along sandy beaches of the recovery unit before October 2012. At least 392 contiguous sections of seawalls, bulkheads, revetments and/or sandbags lined the sandy beaches of the recovery unit before Hurricane Sandy.

Approximately one-third (33%) of the sandy beaches in the Southern Recovery Unit had been modified by sediment placement projects prior to Hurricane Sandy (Table 9). North Carolina accounts for the majority of the beaches modified with sediment placement, with 91.30 of the 162.68 miles (146.93 of 261.81 km) of modified beach. The entire Maryland oceanfront coast has been historically or is currently modified by sediment placement projects along its sandy beaches and/or dunes, and at least 50% of Delaware's oceanfront beaches have been modified by sediment placement. The locations and known lengths of individual sediment placement projects for each state can be found in Rice (2015c) for DE, MD and VA and in Rice (2012b) for NC.

Table 10. Approximate number of each type of armoring on each section of oceanfront coast both with sandy beaches and where sandy beach habitat had been lost that was visible on Google Earth imagery between 1989 and August 2012 and/or reported in published documents. Note that multiple seawalls, bulkheads or revetments are counted as one structure if they are continuous with no separations; for example, if five individual properties each have an individual seawall protecting their property and the seawalls are attached to each other with no gaps, the armoring is counted as one seawall structure (Dallas et al. 2013) and its overall length is counted in Table 9 above.

State	Number of Groins	Number of Jetties	Number of Seawalls, Bulkheads and/or Revetments	Number of Breakwaters
Delaware	29	2	4	0
Maryland	0	2	2	3
Virginia	50	2	34	19
North Carolina	21	2	352†	0
TOTAL	**100**	**8**	**392**	**22**

† The number of seawalls, bulkheads and/or revetments for North Carolina includes an estimated 350 temporary sandbag revetments reported in NC DENR (2011). The total length of these structures is unknown and not included in Table 7.

Although far fewer in number than those in the New England and New York-New Jersey Recovery Units, the 36 tidal inlets in the Southern Recovery Unit open prior to Hurricane Sandy typically were larger than the inlets in New England and along the North Shore and Peconic Estuary shorelines of New York (Table 12). Tidal inlets along the Atlantic Ocean shoreline south of Montauk, NY, tend to be considerably farther apart and separated by barrier islands or longer barrier spits. In the Southern Recovery Unit, Delaware and Maryland each had only one inlet along their oceanfront coastlines, with the rest of the inlets divided between Virginia and North Carolina.

Over two-thirds (68%) of the 36 inlets were modified in at least one manner (Table 12). The majority (58%) of the inlets were stabilized with hard structures along at least one shoreline. More than half of the inlets (20 of 36) were found in NC, where 85% of the state's inlets had been modified by 2012. In contrast, only 14% of Virginia's 14 tidal inlets had been modified. Less than one-third (28%) of the recovery unit's tidal inlets were dredged at least once, and 3 of the inlets had been opened artificially. Six (6) inlets had been mined for sediment and 3 had been relocated (all 3 in NC). Fifteen (15) inlets had been closed artificially, 11 of them in NC. The list of inlets open in each state and the modifications to each prior to Hurricane Sandy can be found in Rice (2012a) for NC and Rice (2014) for the other states.

Table 12. The number of open tidal inlets, inlet modifications, and artificially closed inlets in each state of the Southern Jersey Recovery Unit 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‡	
DE	1	1	1	1	0	1	1	0
MD	1	1	1	1	0	1	0	3
VA	14	2	1	2	0	0	0	1
NC	20	17	7	16	3	4	2	11
TOTAL	36	21 (58%)	10 (28%)	20 (56%)	3 (8%)	6 (17%)	3 (8%)	15 (n/a)

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

‡ One additional inlet in MD was artificially created but was not open in 2012 prior to Hurricane Sandy.

Table 13. Approximate lengths of sandy beach in public and/or NGO ownership in the Southern Recovery Unit of the U.S. Atlantic Coast breeding range of the piping plover by state.

State	Approx. Length of Sandy Beach (miles)	Length of Sandy Beach Shoreline in Public / NGO Ownership (miles)
Delaware	25.36	14.23 (56%)
Maryland	31.10	22.10 (71%)
Virginia	106.40	95.83 (90%)
North Carolina	326	178.70 (55%)
UNIT TOTAL	**488.86**	**310.86 (64%)**

Over 310 miles (499 km) of sandy beaches in the Southern Recovery Unit were in public and/or NGO ownership (Table 13). North Carolina had the highest amount of public and/or NGO-owned sandy beaches, with over 178 miles (286 km), but Virginia had 90% of its sandy beaches in public and/or NGO ownership due primarily to the preservation of all or significant portions of 13 barrier islands along the Eastern Shore.

In summary, piping plover habitat within the Southern Recovery Unit had been significantly modified, with 40% of its 489 miles (787 km) of sandy beaches developed, at least 3% armored, and at least 33% modified by sediment placement, and 58% of the 36 tidal inlets modified in at least one manner. An unknown amount of sandy beach habitat was absent seaward of shoreline stabilization structures shortly before Hurricane Sandy. Nearly two-thirds (64%) of the sandy beaches were in public and/or NGO ownership.

U.S. Atlantic Coast Breeding Range

The total length of sandy beach habitat in the U.S. Atlantic Coast breeding range of the piping plover, from Maine to North Carolina, was approximately 1,915 miles (3,081 km) as of late 2011 and early 2012 (Table 14). Beachfront development had modified 44% of the breeding range beach habitat. Armoring with hard shoreline stabilization structures had modified at least 21% of the beaches in the breeding range. Altogether the U.S. Atlantic Coast breeding range of the piping plover had up to 5,233 groins, 214 jetties, up to 6,966 contiguous sections of seawalls, bulkheads and/or revetments, and up to 90 breakwaters prior to Hurricane Sandy (Table 15). At least 18%, or over 338 miles (544 km), of sandy beaches in the U.S. Atlantic Coast breeding range of the piping plover had been modified by sediment placement activities.

As of the date(s) of the most recent aerial imagery prior to Hurricane Sandy in October 2012, there were at least 47 miles (76 km) of shoreline in the U.S. Atlantic Coast breeding range where all sandy beach habitat had been lost seaward of armoring. The actual percentage is higher since the lengths of habitat lost at that time in Massachusetts and North Carolina are unknown, with the former likely to be significant and the latter insignificant.

Historically the amount of sandy beach habitat absent seaward of hard stabilization structures in the NY-NJ Recovery Unit was higher, but large-scale beach fill projects constructed since 1995 have replaced beaches that had been lost in front of some seawalls in New Jersey. As sea level continues to rise with climate change, the long-term risk of additional habitat loss due to shoreline armoring is high, with nearly 400 miles (644 km) of hard shoreline stabilization structures at risk of causing increased habitat loss throughout the breeding range, mostly in the New England and New York - New Jersey Recovery Units where 96% of the armoring is located.

Throughout the U.S. Atlantic Coast breeding range of the piping plover, 274 of the 399 inlets (69%) open prior to Hurricane Sandy had been modified in at least one manner (Table 16). Massachusetts and New York had an order of magnitude more inlets than the other states in the U.S. Atlantic Coast breeding range with 122 and 133 inlets respectively, although only 9 (7%) of New York's inlets were on the South Shore (all 9 of which were modified in at least one

Table 14. Known habitat modifications to exposed sandy beach habitat in the U.S. Atlantic Coast breeding range of the piping plover by recovery unit.

Recovery Unit	Approx. Length of Sandy Beach (miles)	Sandy Beaches Developed (miles)	Known Approximate Length of Armored Sandy Beach Shoreline (miles)	Approximate Length of Armored Shoreline with No Sandy Beach (miles)	Known Length of Shoreline Previously Modified with Sediment Placement (miles)
New England	920.12	392.3	242.78	20.12 +	43.78
NY – NJ	505.78	261.04	133.91	26.56	131.52
Southern	488.86	195.74	16.54	0 +	162.68
TOTAL	**1,914.76**	**849.08 (44%)**	**393.23 (21%)**	**46.68 + (2.4%)†**	**337.98 (18%)**

† The percentage of sandy beach habitat lost was calculated by dividing by the sum of the length of armored shoreline with no beach and the length of sandy beach.

Table 15. Approximate number of each type of armoring on the exposed sandy beaches in each recovery unit (excluding Massachusetts from the New England Recovery Unit) visible on Google Earth imagery between 1989 and August 2012 and/or reported in published documents. Note that multiple seawalls, bulkheads or revetments are counted as one structure if they are continuous with no separations; for example, if five individual properties each have an individual seawall protecting their property and the seawalls are attached to each other with no gaps, the armoring is counted as one seawall structure (Dallas et al. 2013) and its overall length is counted in Table 14 above.

Recovery Unit	Number of Groins	Number of Jetties	Number of Seawalls, Bulkheads and/or Revetments	Number of Breakwaters
New England	up to 2,709	118	up to 5,874	up to 42
New York – New Jersey	2,424	88	700	26
Southern	100	8	392	22
TOTAL	**up to 5,233**	**214**	**up to 6,966**	**up to 90**

Table 16. The number of open tidal inlets, inlet modifications, and artificially closed inlets in each Recovery Unit of the U.S. Atlantic Coast breeding range of the piping plover prior to Hurricane Sandy in October 2012.

Recovery Unit	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‡	
New England	219	150	139	78	2	3	20	13
NY - NJ	144	103	91	56	3	12	11	9
Southern	36	21	10	20	3	6	3	15
TOTAL	399	274 (69%)	240 (60%)	154 (39%)	8 (2%)	21 (5%)	34 (9%)	37 (n/a)

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

‡ One additional inlet in MA, three additional inlets in RI, one in NY and one in MD have been artificially created but were not open in 2012 prior to Hurricane Sandy.

manner). The majority of the inlet modifications were hard stabilization structures, with 60% of the inlets having at least one hard structure. More than one-third (39%) of the inlets had been dredged at least once. At least 34 inlets had been artificially opened and another 37 artificially closed. Eight (8) inlets are known to have been relocated and at least 21 mined for sediment.

Inlets from Montauk, NY, through Virginia tend to be larger but fewer in number compared to tidal inlets from southern Maine through the North Shore and Peconic Estuary shorelines of New York. The latter inlets are more numerous, generally smaller, and may be anchored on one shoulder with resistant outcrops that do not let the inlets migrate as much as typical barrier island inlets to the south. Of the 343 inlets from southern Maine to Montauk, NY, 68% (234) had been modified, with 63% (215) stabilized with hard structures. Of the 56 inlets south of Montauk, NY, 71% (40) had been modified, with 44% (25) stabilized with hard structures. The stabilized inlets south of Montauk, NY, were concentrated in the north, however, with 26 of the 31 inlets that had *not* been stabilized located in VA and NC at the south end of the range.

Altogether 42% of the sandy beaches, or about 800 miles (1,287 km), in the U.S. Atlantic Coast breeding range were in public or NGO ownership (not including public beaches in several states where private property is immediately adjacent to the beach; Table 17). The Southern Recovery Unit had the highest proportion of lands in public or NGO ownership, with nearly two-thirds (64%) of its sandy beaches in public or NGO ownership. The New England and New York – New Jersey Recovery Units each had approximately one-third of their sandy beaches in public or NGO ownership, slightly more than half the level of the Southern Recovery Unit. Although New England had the lowest proportion of sandy beach in public or NGO ownership, the actual

Table 17. Approximate lengths of sandy beach in public and/or NGO ownership in the U.S. Atlantic Coast breeding range of the piping plover by recovery unit.

Recovery Unit	Approx. Length of Sandy Beach (miles)	Length of Sandy Beach Shoreline in Public / NGO Ownership (miles)
New England	920.12	298.86 (32%)
New York – New Jersey	505.78	188.95 (37%)
Southern	488.86	310.86 (64%)
TOTAL	**1,914.76**	**798.67 (42%)**

length (~300 miles or 483 km) is nearly the same as the total miles (~311 miles or 500 km) in the Southern Recovery Unit and much more than the ~189 miles (~304 km) in the New York – New Jersey Recovery Unit.

The sandy beaches of the New England Recovery Unit appear to be most threatened by armoring, the sandy beaches of the Southern Recovery Unit by sediment placement, and the beaches of the New York – New Jersey Recovery Unit by development, armoring and sediment placement. The New England Recovery Unit contains the most sandy beach habitat for the piping plover, nearly half (48%; ~920 miles or 1481 km) of the entire U.S. Atlantic Coast breeding range sandy beach habitat, but over 243 miles (391 km) of those beaches were armored (Table 10). The Southern Recovery Unit, by contrast, had roughly 17 miles (27 km) of armoring, excluding North Carolina.

The Southern Recovery Unit is the most modified and threatened by sediment placement projects (33%), but data for the Long Island Sound and Peconic Estuary shorelines of New York are sparse and the actual proportion of sandy beaches modified by sediment placement in the NY – NJ Recovery Unit is higher and could approach that of the Southern Recovery Unit (Table 10). The New England Recovery Unit is the least modified (at least 3%) by sediment placement projects but missing data from most projects means that the quantified modification is an underestimate. Nevertheless, over 162 miles (261 km) of sandy beaches in the Southern Recovery Unit have been modified by sediment placement activities.

The sandy beach habitat of the New York – New Jersey Recovery Unit faces a triple threat of development, armoring and sediment placement. The New York – New Jersey Recovery Unit had the most developed beachfront prior to Hurricane Sandy (52%) and also had been modified by both armoring (26%) and sediment placement (at least 26%). Roughly 134 miles (217 km) of sandy beaches in NY and NJ were armored with hard shoreline stabilization structures and at least 132 miles (212 km) had been modified with sediment placement. In addition, the tidal inlets of the recovery unit are heavily modified, with 72% of the inlets modified in at least one way (Table 7), with 19 of the 20 inlets (95%) on the New York South Shore and New Jersey shorelines modified.

DISCUSSION

A substantial proportion of the sandy beaches within the U.S. Atlantic Coast breeding range of the piping plover had been developed (44%), filled with sediment (at least 18%) and armored (at least 21%). At least 46.68 miles (75.12 km) of sandy beach habitat was absent seaward of armoring just prior to Hurricane Sandy. These habitat modifications tend to occur in the same locations as each other, resulting in localized adverse cumulative effects. When combined with the habitat modifications to the tidal inlets, significant cumulative loss and degradation of piping plover habitat has resulted. In New Hampshire, for example, 100% of the inlets had been armored and/or dredged, 87% of the beachfront had been developed, 72% of the beach had been armored, and at least 14% of the beaches had received sediment placement prior to Hurricane Sandy. In New Jersey, all but one inlet had been armored and/or dredged, 67% of the beachfront had been developed, 60% of the beach had been armored, and at least 50% of the beaches had received sediment placement.

Seven of the 11 states in the U.S. Atlantic Coast breeding range of the piping plover allow the construction of new hard shoreline stabilization structures on oceanfront or soundfront beaches, and two others (Maine and North Carolina) allow sandbags that act as revetments (Table 18). North Carolina also passed legislation allowing the construction of up to 4 terminal groins in 2011. Connecticut revised its regulations in 2012 to allow more buildings to potentially construct seawalls and other hard structures, updating the building construction date from 1980 to 1995 where erosion control structures could be installed. As a result, future additional habitat modifications due to shoreline armoring threatens all three recovery units and may pose an increasing threat in the future as state regulators face increasing pressure to allow more armoring as sea level rises.

The preference for nonstructural alternatives[2] to erosion control by most of the states in the U.S. Atlantic Coast breeding range of the piping plover (Table 18) suggests that sediment placement projects, including the building and maintenance of artificial dunes and beach nourishment projects, will increase as sea level continues to rise at an accelerating rate and storm intensity is expected to increase with climate change.

The beneficial use of dredged material by placement on nearby beaches may also increase with increasing recognition of the importance to retain sediment within the local coastal system, as has occurred throughout the New England Recovery Unit. As part of the development of a

[2] Nonstructural alternatives to hard shoreline stabilization structures (i.e., bulkheads, seawalls, revetments, groins) typically include relocation of structures, elevation of structures, beach fill, dune building or vegetation planting, or the construction of "living shorelines" which include marsh creation, slope grading, creation or restoration of oyster reefs, the installation of offshore sills with marsh plantings and/or fill landward of the sill(s), and may also include the use of coir fiber logs in some states. In several states, including RI, CT, NY, NJ, DE, MD and VA, the use of nonstructural alternatives must be shown to be infeasible or impractical before hard shoreline stabilization alternatives may be considered.

Table 18. Regulations regarding the construction and maintenance of hard shoreline stabilization structures on sandy beaches in the U.S. Atlantic Coast breeding range vary by state and are listed here.

State	New Hard Shoreline Stabilization Structures Allowed?
ME	• NO new structures since 1983 • Sandbags or riprap may be allowed in emergency situations • Maintenance or repair of existing structures with <50% damage does not require a permit
NH	• YES with conditions
MA	• POSSIBLE with conditions†
RI	• NO for Type 1 Waters (all oceanfront beaches) • POSSIBLE with conditions for other Type Waters • Repair of existing structures allowed by permit if >50% damaged
CT	• NO for buildings constructed after 1980 • Nonstructural methods preferred, including dune creation and sandbags • New rules in 2012 modified the regulations‡
NY	• YES if designed to have at least a 30 year effective lifespan • Nonstructural methods preferred
NJ	• YES with conditions • Nonstructural methods preferred
DE	• YES with conditions • Nonstructural methods preferred, including beach fill
MD	• YES with conditions • Nonstructural methods and "living shorelines" preferred
VA	• POSSIBLE – regulations are local • State-preferred "living shorelines" methods since 2011
NC	• NO new structures since 1974 with the exception of up to 4 terminal groins allowed since 2011 • Temporary sandbag revetments allowed

† The Massachusetts Wetlands Protection Act contains specific conditions under which erosion control structures may be considered and generally prohibits groins in areas designated "barrier beaches," limits jetties to those areas with existing navigation channels, and has performance standards for seawalls, revetments and bulkheads that may prevent their approval in many areas (MA Barrier Beach Task Force 1994). Shoreline stabilization structures may be approved by local permits for buildings constructed prior to August 1978 along coastal banks or bluffs if the shoreline stabilization structures are the only feasible means of protection and if adverse impacts to adjacent and downdrift beaches such as reduced sediment supply are minimized (O'Connell and Leatherman 1999, O'Connell 2010).

‡ In 2012 Connecticut modified its regulations to define less environmentally damaging preferred alternatives, including relocation, elevation of structures, dune creation and/or vegetation, and "living shorelines" methods; buildings constructed prior to 1995 are now allowed to construct hard shoreline stabilization structures with conditions, including mitigation such as beach fill intended to offset anticipated sediment source losses and to have no net increase in armoring (i.e., removal of other erosion control structures).

Dredged Material Management Plan (DMMP) for Long Island Sound, for example, Battelle (2009) conducted an inventory of potential sites where dredged material could be beneficially placed. The inventory identified 195 municipal, county and state beaches in Connecticut, Rhode Island and Long Island as potential sites for placement of dredged material. Of the 195 potential beach sites, 104 indicated a need for dredged material when contacted (Battelle 2009). Seven (7) beaches were identified in RI, 16 in CT, and 81 in NY; Appendix A contains a full list of the beach sites that indicated a need for dredged material. Only 53 of these beaches are known to have received sediment placement prior to Hurricane Sandy, indicating that the remaining 61 would be new beaches that could be modified in the future under the DMMP. All 7 of the potential dredged material disposal sites in Rhode Island have previously been modified by sediment placement according to Rice (2015b). Five (5) of the 16 potential sites in Connecticut are known to have been modified previously with sediment placement (Rice 2015b). Of the 81 potential sites in New York (located on all three shorelines of Long Island), 30 have been previously modified with sediment placement according to Rice (2015b) and (2015c).

Although less than half (44%) of the sandy beachfront from Maine to North Carolina was developed prior to Hurricane Sandy, 60 communities were 100% developed and another 69 were at least 75% developed along their beaches, excluding North Carolina. In Maine, Old Orchard Beach was completely developed. All of the sandy beaches in New Castle, NH, were developed. Twelve communities in Massachusetts were more than 75% developed. On New York's Long Island Sound shoreline, the beachfronts of Shoreham, Rocky Point, Belle Terre and Port Jefferson were 100% developed. Eight communities along the Peconic Estuary of New York were more than 75% developed along their beachfronts. Along the South Shore of New York, 19 communities were completely developed. Another 29 communities in New Jersey were 100% developed along their oceanfront. Four of the five oceanfront communities in Delaware were 100% developed. Maryland's Ocean City was 100% developed. Although these communities are located in all three recovery units, development appears to be especially threatening to sandy beaches in the New York – New Jersey Recovery Unit where 91 communities were at least 75% developed, with 52 of those 100% developed. Altogether 55% of the 166 beachfront communities in the New York - New Jersey Recovery Unit were at least 75% developed along their beachfronts, as compared to 27% of the 114 communities in the New England Recovery Unit and 30% of the 27 communities (excluding NC) in the Southern Recovery Unit.

In 5 states ownership of coastal property (including lands owned by public entities) extends to the mean low water mark or tide line, whereas state ownership begins at the mean high water mark or tide line (regardless of the upland ownership) in the other 6 states (Table 19). In some areas individual deeds specify a particular property boundary line on a map instead of a dynamic water line as the seaward boundary of beachfront property, and as sandy beaches erode or migrate onto adjacent private property with rising sea level, development and private beach ownership may increasingly threaten the sustainability of sandy beach habitat. Feagin et al. (2010, p. 988) found that "static legal definitions of the coastal zone enforce linear restrictions to the natural interplay of sediments and represent a threat to ecosystem functioning. Also, inevitable conflicts ensue once sea levels rise or [extreme episodic storm events] strike." Instead, Feagin et al. (2010) recommend ecologically defined boundaries between public and private property on beaches, such as the one used in Texas where the native

Table 19. Coastal property ownership of beaches in the U.S. Atlantic Coast breeding range of the piping plover. In some states, state ownership of the beach begins at the mean high water or tide line, and in other states it begins at the mean low water or tide line. Note that public entities or non-governmental organizations may own extensive sections of beach but not the adjacent upland properties, providing public access to the beach in many areas.

State	Upland Ownership to Mean High Water (MHW)	Upland Ownership to Mean Low Water (MLW)
Maine		X
New Hampshire		X
Massachusetts		X
Rhode Island	X	
Connecticut	X	
New York†	X	
New Jersey	X	
Delaware‡	X	X
Maryland	X	
Virginia		X
North Carolina	X	

† The Andros Patent of 1676 granted the Town of Southold ownership of the lands under its creeks, inlets, bays and harbors as well as other common lands and natural resources. The Dongan Patent of 1686 granted several of the Towns ownership of the waters and beaches (amongst other natural resources) within their boundaries, which the Towns manage via Boards of Trustees. We were unable to determine whether the Towns' ownership and management of the beaches (through the Dongan Patent) will move along with the beaches as they migrate with rising sea level, or if the adjacent private property will affect that ownership and/or management of the sandy beaches.

‡ Private property may extend to the high water line, lower water line, or some other location specified in a deed in Delaware.

vegetation line serves as the public-private property line, which is allowed to shift landward with natural processes.

Feagin et al. (2010) also recommend the public purchase of the remaining undeveloped coastal barriers to preserve their ecological sustainability. The inventory of public and NGO-owned sandy beaches within the U.S. Atlantic Coast breeding range of the piping plover (see Rice 2011b, 2015b and 2015c for lists of individual public and NGO beach tracts for each state) can serve as a basis for future conservation opportunities to maximize the sustainability of sandy beach and tidal inlet habitat as sea level rises and climate changes.

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Appendix A

Table A-1. Sandy Beaches within the New England Recovery Unit of the U.S. Atlantic Coast breeding range of the piping plover identified as potential sites for the beneficial use of dredged material as part of the Long Island Sound DMMP under development (from Battelle 2009). Beaches that are known to have been previously modified with sediment placement project(s) are noted, from Rice (2015b).

State	Town	Site Name	Existing Sediment Placement Site	New Sediment Placement Site
CT	Fairfield	Southport Beach	X	
CT	Fairfield	Sasco Hill Beach	X	
CT	Fairfield	Penfield Beach		X
CT	Fairfield	Jennings Beach		X
CT	Milford	Silver Sands State Park	X	
CT	Guilford	Jacobs Beach	X	
CT	Madison	Surf Club Beach		X
CT	Madison	West Wharf Beach		X
CT	Madison	East Wharf Beach		X
CT	Madison	Hammonasset State Park	X	
CT	East Lyme	Rocky Neck State Park		X
CT	Waterford	Kiddie Beach		X
CT	Waterford	Jordan Cove Beach		X
CT	Waterford	Pleasure Beach		X
CT	Waterford	Waterford Beach Park		X
CT	Groton	Bluff Point State Park		X
RI	Westerly	Napatree Point Beach	X	
RI	Westerly	Watch Hill Beach	X	
RI	Westerly	Wuskenau (New Town) Beach	X	
RI	Westerly	Atlantic Beach Park	X	
RI	Westerly	Westerly Town Beach	X	
RI	South Kingstown	Town Beach	X	
RI	Narragansett	Town Beach	X	

Table A-2. Sandy Beaches within the New York - New Jersey Recovery Unit of the U.S. Atlantic Coast breeding range of the piping plover identified as potential sites for the beneficial use of dredged material as part of the Long Island Sound DMMP under development (from Battelle 2009). Beaches that are known to have been previously modified with sediment placement project(s) are noted, from Rice (2015b and 2015c).

State	Town	Site Name	Existing Sediment Placement Site	New Sediment Placement Site
NY	Rye	Oakland Beach / Rye Town Beach[1]		X
NY	Rye	Playland Beach[1]		X
NY	New Rochelle	Glen Island Beach[1]		X
NY	New Rochelle	Harbor Island Beach[1]		X
NY	New Rochelle	Hudson Park Beach[1]		X
NY	Glen Cove	Morgan Park Beach		X
NY	Glen Cove	Crescent Beach		X
NY	Glen Cove	Pryibil Beach		X
NY	Huntington	West Neck Beach		X
NY	Huntington	Gold Star Battalion Beach[1]		X
NY	Huntington	Crescent Beach		X
NY	Huntington	Fleet's Cove Beach[1]		X
NY	Huntington	Centerport Beach[1]		X
NY	Huntington	Hobart Beach		X
NY	Huntington	Asharoken Beach	X	
NY	Huntington	Crabmeadow Beach		X
NY	Smithtown	Callahan's Beach		X
NY	Smithtown	Sunken Meadow State Park	X	
NY	Kings Park	Kings Park Bluff Beach[1]		X
NY	Smithtown	Short Beach	X	
NY	Smithtown	Schubert's Beach		X
NY	Smithtown	Long Beach		X
NY	Riverhead	Wading River Beach	X	
NY	Riverhead	Wildwood State Park		X
NY	Riverhead	Reeves Beach		X
NY	Riverhead	Iron Pier Beach		X
NY	Riverhead	South Jamesport Beach	X	
NY	Southold	Breakwater Park Beach[2]		X
NY	Southold	Bailie's Beach	X	
NY	Southold	Goldsmith Inlet Park	X	
NY	Southold	Kenney's Beach	X	
NY	Southold	McCabe's Beach		X
NY	Southold	Horton's Point Lighthouse Park Beach		X

State	Town	Site Name	Existing Sediment Placement Site	New Sediment Placement Site
NY	Southold	Town Beach		X
NY	Southold	Truman’s Beach		X
NY	Southold	New Suffolk Beach	X	
NY	Southold	Gull Pond Beach (Norman E. Klipp Park)	X	
NY	Southold	Aldrich Lane Park Beach		X
NY	Southold	Mattituck Park District Beach (“Yacht Club Beach”)		X
NY	Southold	Veteran’s Memorial Park Beach	X	
NY	Southold	Bay Avenue Park Beach	X	
NY	Southold	Pequash Avenue Beach (Fleets Neck Beach)	X	
NY	Southold	Nassau Point Beach	X	
NY	Southold	Emerson Park Beach	X	
NY	Southold	Triangle Park Beach		X
NY	Southold	Goose Creek Beach	X	
NY	Southold	Founder’s Landing Beach		X
NY	Southold	Orient Beach State Park		X
NY	East Hampton	Gin Beach	X	
NY	East Hampton	East Lake Beach	X	
NY	East Hampton	Hither Hills State Park		X
NY	East Hampton	Alberts Landing Beach		X
NY	East Hampton	Louse Point Beach	X	
NY	East Hampton	Maidstone Park Beach	X	
NY	East Hampton	Montauk Point State Park		X
NY	East Hampton	Camp Hero State Park		X
NY	East Hampton	Ditch Plain Beach	X	
NY	East Hampton	Shadmoor State Park		X
NY	East Hampton	Essex Street Beach		X
NY	East Hampton	Kirk Park Beach		X
NY	East Hampton	Atlantic Avenue Beach		X
NY	East Hampton	Indian Wells Beach		X
NY	East Hampton	Two Mile Hollow Beach		X
NY	East Hampton	Egypt Beach		X
NY	East Hampton	Wiborg’s Beach		X
NY	East Hampton	Main Beach	X	
NY	East Hampton	Georgica Beach	X	
NY	East Hampton	Beach Lane Beach		X
NY	Southampton	Quogue Village Beach		X
NY	Southampton	Rogers Beach		X

State	Town	Site Name	Existing Sediment Placement Site	New Sediment Placement Site
NY	Southampton	Lashley Beach	X	
NY	Islip	Hecksher State Park[1]		X
NY	Babylon	Robert Moses State Park	X	
NY	Bablyon	Gilgo State Park	X	
NY	Hempstead	Jones Beach State Park	X	
NY	Hempstead	Town Park at Point Lookout	X	
NY	Hempstead	Town Park at Sands		X
NY	Hempstead	Lido West Town Park Beach	X	
NY	Hempstead	Harbor Isle Beach[1]		X
NY	Hempstead	Hewlett Point Park Beach[1]		X
NY	Queens	Rockaway Beach	X	

1 – This beach was not included in Rice (2015b) or Rice (2015c) and information regarding its previous modification from sediment placement is from PSDS (2015).

2 – Note that although Breakwater Beach has not been modified previously with sediment placement, historically it has been modified by commercial sand and gravel mining (Rice 2015b).