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[1]

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The U.S. Fish and Wildlife Service's (USFWS's) most recent 5-Year Review for the piping plover (*Charadrius melodus*) recommends increasing "efforts to restore and maintain natural coastal formation processes in the New York-New Jersey recovery unit, where threats from development and artificial shoreline stabilization are highest, and in the Southern Recovery Unit, where the plover's habitat requirements are the most stringent …. This action is also critical to reducing adverse effects of accelerating sea level rise" for the breeding range of the federally listed (threatened) Atlantic Coast population (USFWS 2009, p. 195). 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. Two previous studies (Rice 2012a, 2012b) provided these data for the U.S. continental migration and overwintering range of the piping plover, including North Carolina where the breeding and overwintering ranges overlap. This assessment provides these data for one habitat type – namely sandy oceanfront beaches from Montauk Point to Virginia along the Atlantic coast of the U.S. prior to Hurricane Sandy in October 2012. A separate report assesses tidal inlet habitat prior to Hurricane Sandy (Rice 2014). Additional separate reports will assess the northern portion of the U.S. Atlantic coast breeding range as well as the status of these two habitats immediately following and 3 years after Hurricane Sandy.

Sandy beaches are a valuable habitat for piping plovers, other shorebirds and waterbirds for nesting, foraging, loafing, and roosting. The North Atlantic Landscape Conservation Cooperative has designated the piping plover as a representative species in all three subregions, standing as a surrogate for other species using dynamic beach systems including American oystercatchers, least terns, black skimmers, seabeach amaranth and migrating shorebirds (http://www.fws.gov/northeast/science/pdf/nalcc_terrestrial_rep_species_table.pdf). Although some information is available for the number of beaches stabilized with seawalls, groins, revetments, and other hard armoring structures, these data have not been combined with other information that is available for sand placement projects and oceanfront development. Altogether this information can provide an assessment of the cumulative impacts of habitat modifications to sandy oceanfront beaches for piping plovers and other birds. This assessment does **not**, however, quantify habitat disturbances at sandy oceanfront beaches such as off-road vehicle (ORV) usage, pet and human disturbance, or disturbance to dunes or vegetation.

A description of the different types of stabilization structures typically constructed on sandy beaches – terminal groins, groins, seawalls, breakwaters, revetments and others – 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).

[1] Rice, T.M. 2015. Inventory of Habitat Modifications to Sandy Oceanfront Beaches in the U.S. Atlantic Coast Breeding Range of the Piping Plover (*Chardrius 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.

METHODS

In order to evaluate the status of sandy oceanfront beaches along the coastlines of New York (NY), New Jersey (NJ), Delaware (DE), Maryland (MD) and Virginia (VA), several methods were used. The status of sandy oceanfront beaches was evaluated through an estimation of the length and proportions of shoreline that were developed, undeveloped, in public or non-governmental organization (NGO) ownership, armored and modified with sediment placement projects. Mainland beaches were not included unless no barrier islands were located offshore and thus the mainland beaches were located directly on the Atlantic Ocean (e.g., Monmouth Beach, NJ, or Montauk, NY).

Due to a lack of published data, the oceanfront shoreline was assessed by using the most recent Google Earth imagery available prior to Hurricane Sandy (i.e., June to December 2011 except for northern New Jersey where the most recent pre-Sandy imagery was December 2010) to calculate the lengths of sandy oceanfront beaches in each geographic area as well as to distinguish the lengths that were developed versus undeveloped. A Microsoft Excel database of all data was created, with the data organized by geographic area. Data were compiled on a county-by-county or community/municipal basis to facilitate updates and replication of the data.

Where Google Earth was utilized to calculate the approximate lengths of beach shoreline that were developed versus undeveloped, no distinction was made as to the level of development. Undeveloped areas were those where no structures existed adjacent to the beach and that appeared natural in the Google Earth aerial imagery. Vacant lots that were surrounded by a high number of buildings were not counted as undeveloped areas unless they were of a sufficient size to measure (e.g., greater than 0.1 mile in oceanfront length). Parking lots and roads were not considered as developed areas unless they were developed on the landward side of the road and the road was close to the beach, preventing the sandy beach from migrating with rising sea level. Length measurements were made in miles using the “ruler” or “path” tool of Google Earth. The individual dates of Google Earth imagery and eye altitude from which measurements were made were recorded; the latter was typically 1,000-1,100 feet above ground level.

The shoreline lengths used in this report are approximations for several reasons. First is the dynamic nature of the habitat. Sandy oceanfront beaches shift in space over time and may grow (accrete) or recede (erode) on a daily, weekly, seasonal or annual basis. Thus, the measured lengths are snapshots in time and are not necessarily the same lengths that would be measured today or tomorrow. Second, only the ocean-facing segments of the inlet shorelines were included, and the demarcation lines were based on professional judgment. Finally, the measurements are approximations due to mathematical rounding to the nearest hundredth of a mile.

The amount of sandy oceanfront beach in public and/or NGO ownership (and thus protected to some degree from development) provides an approximation of how much of this habitat may be available as sea level continues to rise and climate changes. If an area is in public or NGO ownership, then it is assumed that the habitat retains the potential to migrate inland with rising sea level and to continue to provide habitat for the piping plover and other shorebirds and waterbirds over the next several decades. [Note that public and NGO-owned lands may have been, continue to be, or may be modified in the future by shoreline stabilization structures or sediment placement projects; therefore they only retain *the potential* to provide future habitat as sea level rises.] Where sandy oceanfront beaches are developed, it is assumed that the habitat is highly susceptible to being lost or significantly degraded as sea level rises (through erosion or shoreline armoring), and thus of diminishing value to the piping plover. Undeveloped sandy oceanfront beaches that are not public or NGO-owned (i.e., private) were assumed to be developable and could provide opportunities for future conservation.

Public and NGO lands in this assessment include the public lands of National Wildlife Refuges (NWRs) owned by the USFWS; National Seashores (NSs) and National Recreation Areas (NRAs) owned by the National Park Service (NPS); state, county and local parks and beaches; state Natural Areas, wildlife refuges and heritage preserves; and military bases. Sandy oceanfront beaches that have been protected by non-governmental conservation organizations, such as The Nature Conservancy preserves, were also included. Properties that have habitat conservation plans were not included because these properties typically have some level of development and are not protected, undeveloped spaces like refuges or parks. Data on the name, location, approximate shoreline length, and type of public or NGO land (e.g., wildlife refuge, park) were added to the Excel database. Shoreline lengths were obtained from published sources or websites of the individual lands wherever possible, and from Google Earth using the aforementioned methodology for measuring developed versus undeveloped areas.

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

- the presence of jetties, groins or other shoreline armoring in or adjacent to the parcel;
- dredging activities at an inlet in or near the parcel;
- beach nourishment or dredge disposal activities on beaches in the parcel;
- the presence of ORV or recreational vehicle usage;
- campgrounds, recreational facilities, and/or camping allowed on the beach;
- the maintenance and protection of coastal highways;
- the artificial creation and/or maintenance of dunes;
- artificial opening or closure of inlets, including inlet relocations;
- vegetation plantings;
- the presence of feral horses, hogs or other animals that can damage vegetation and dunes;
- waterfowl impoundments;
- the presence of private inholdings or retained rights agreements that preclude some management options; and
- the presence of historic sites or structures (e.g., historic forts on the Sandy Hook peninsula in New Jersey, military batteries at Delaware Seashore State Park in Delaware or Cape May Point State Park in New Jersey).

An assessment to estimate the length of each state's sandy oceanfront beach that has been armored with hard structures was measured by identifying and digitizing structures visible in Google Earth imagery in historic aerial photography. Because armoring structures can be buried by sediment and not readily visible in aerial imagery, imagery taken immediately following Hurricane Sandy in the first week of November 2012 was also used to identify structures that were buried before the storm but exposed after the storm. Armoring structures include shore-parallel seawalls, bulkheads, revetments, riprap, geotubes and sandbags, groins, offshore breakwaters, and jetties.

The length of shoreline modified by armoring was measured using the methodology of Coburn et al. (2010), Dallas et al (2013) and Schupp and Coburn (2015) in their recent coastal engineering inventories for the NPS, which utilized aerial imagery to identify and digitize shore protection structures within individual coastal parks. "The structure length used in calculating the percentage of shoreline armored for individual shore parallel structures was merely the length of the structure. For groin fields … the length of stabilized shore was set as the length of the groin field" (Dallas et al. 2013, p. 5). Where Dallas et al. (2013) defined a groin field as three or more groins, in this assessment a groin field was defined as two or more groins in close proximity to each other. An armoring "project was considered distinct if there was any discernible, physical separation between it and an adjacent coastal engineering project. A series of bulkheads constructed by individual interests, for example, would be classified as one structure as long as no identifiable gaps were observed between them" (Dallas et al. 2013, p. 5). The overall length of a contiguous section of seawalls, bulkheads and/or revetments was then measured and recorded as the length of shoreline armored in a given area. All armoring structures were included, even if some are periodically buried, failing, in disrepair or remnant structures. Digitization of the armoring structures within Google Earth allowed for overlapping armoring structures (i.e., a section of seawall with a groin field seaward of the wall) to be identified and the overall length of shoreline modified by the armoring to be measured without double counting.

The lengths of shoreline affected by armoring included in this report should be considered a minimum because of the difficulty in identifying structures that still may be hidden by vegetation, dunes, or beach fill. Wherever available, published sources on hard stabilization structures armoring the coast were used to verify the types of armoring and the lengths of shoreline armored in a given area. In addition, solitary shore perpendicular structures such as jetties or solitary groins were noted but not included in the lengths of shoreline armored. Although the adjacent shoreline is impacted by the solitary structure, the length of shoreline impacted is unique to the given setting and cannot be uniformly measured. Therefore the lengths of shoreline modified with armoring identified in this assessment are minimum values.

An estimate of the length of sandy oceanfront beaches that have received or continue to receive sediment placement was also compiled. Sediment placement projects include beach fill or nourishment, artificial dune construction using fill material, inlet closure, and dredge disposal placement projects. Each area of beach that has received sediment placement is counted only once, even if the site has repeatedly been modified by sediment placement, since the goal was to measure the spatial area of modification. The sediment placement information serves two purposes: 1) a basis for cumulative effects to sandy oceanfront beaches resulting from soft stabilization and dredge disposal activities, and 2) an assessment of the length of coastline where sandy beaches will attempt to be "held in place" as sea level rises. The latter increases the risk of further degrading habitat quality over time as the adverse impacts of these activities continue, perhaps in perpetuity (for a discussion of the potential adverse ecological impacts of beach nourishment and dredge disposal activities, between which "there is little to no difference" [Bush et al. 2004, p. 90], see Peterson et al. 2000, Peterson and Bishop 2005, Defeo et al. 2009, and Rice 2009). Again, published sources including peer-reviewed literature, government agency reports and permits, were used to compile the lengths of shoreline affected by beach nourishment and dredge disposal placement activities in each state (e.g., USACE 1963, 1999; USFWS 2002, 2005; Coburn et al. 2010; Dallas et al. 2013; Schupp and Coburn 2015; USACE 2013a, 2013b, 2014a, 2014b; USFWS 2014a). Where readily available published sources were absent for a geographic area, the beach nourishment database of the Program for the Study of Developed Shorelines (at http://beachnourishment.wcu.edu) was consulted and an inventory of projects in that region was added to the Excel database.

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RESULTS

As of the end of 2011 and prior to Hurricane Sandy in October 2012, 417.43 miles (671.79 kilometers [km]) of sandy oceanfront beach were present between Montauk, NY, and the Virginia-North Carolina boundary; there were an additional 4.43 miles (7.13 km) of oceanfront shoreline without sandy beaches due to either hard stabilization or erosion (Table 1). The total length of oceanfront shoreline, excluding inlets, is virtually the same on the south shore of Long Island, New York, and in New Jersey with approximately 127 miles (204.39 km) in each (Table 1). The Delaware and Maryland oceanfront shorelines are much shorter at approximately 25 and 31 miles (40.23 and 49.89 km) respectively. The New Jersey coast has the highest proportion of sandy oceanfront beaches that are developed (67%) and the Virginia coast is the least developed (16%). Although 57% of Delaware's oceanfront, sandy beaches

Table 1. The lengths of sandy oceanfront beach in each state and the proportions that are developed and undeveloped as of December 2011. The difference between the total shoreline length and the length of sandy beach is the length of shoreline that had no sandy beach present as of late 2011 according to Google Earth imagery; therefore 4.43 miles (7.13 km) of shoreline in this area lacked sandy beaches either due to the presence of armoring with hard structures (3.50 miles or 5.63 km) or erosion and/or island migration into marsh or forest (0.93 miles or 1.50 km).

State	Approximate Total Shoreline Length (miles)	Approximate length of sandy beach (miles)	Approximate Miles of Beach Developed (percent of total beach length)	Approximate Miles of Beach Undeveloped (percent of total beach length)†
NY (South Shore of Long Island)	126.51	124.88	58.23 (46%)	66.65 (54%)
NJ	127.13	125.26	84.47 (67%)	40.79 (33%)
DE	25.36	25.36	10.94 (43%)	14.42 (57%)
MD	31.10	31.10	9.00 (29%)	22.10 (71%)
VA	107.33	106.40‡	16.80 (16%)	89.60 (84%)
TOTAL	**417.43**	**413.00**	**179.44 (44%)**	**233.56 (56%)**

† Beaches classified as "undeveloped" occasionally include a few scattered structures.

‡ Wallops Island lacked a sandy beach fronting 2.34 miles of seawall as of December 2011; from April to August 2012, a beach fill project placed a beach in front of the seawall. This increased Virginia's length of sandy beach from 104.06 to 106.40 miles just prior to Hurricane Sandy in 2012.

are undeveloped with buildings, state Highway 1 runs parallel to much of the undeveloped beaches and modifies the habitat landward of the beaches at Delaware Seashore and Fenwick Island State Parks in particular. Altogether, 179.44 of 417.43 miles (288.78 of 671.79 km; 43%) of sandy oceanfront beaches from Montauk through Virginia are developed (Table 1). Slightly more than half of the total oceanfront shoreline (224.96 miles or 362.04 km, 54%) is in public or NGO ownership, with Virginia (89%) and Maryland (71%) having the highest proportions (Table 2).

For every state, the length of oceanfront shoreline that has been armored with hard erosion control structures was measured (Table 3). The total length of shoreline between Montauk, NY, and the Virginia – North Carolina boundary that has been armored is at least 117.07 miles (188.41 km; 28% of the total shoreline length). This assessment is a minimum number because some structures remain buried and are not visible in aerial imagery; in addition, historical records or inventories of hard stabilization structures may be incomplete or unavailable to indicate where buried structures may exist. The New Jersey coast has the greatest length of armored oceanfront beach by far, with 75.20 miles (121.02 km) of hard structures that line 59% of its oceanfront shoreline; the proportion is consistent with that found by Hall and Pilkey (1991), which found 51% of New Jersey's developed beaches were armored in a 1989 study. The Maryland coast is the least armored, with only 5% (1.62 miles or 2.61 km) of its oceanfront shoreline having hard stabilization structures as of the end of 2011.

New York and New Jersey have the highest number of hard stabilization structures (Table 4). New Jersey has at least 454 groins, 150 contiguous sections of seawalls, revetments and/or bulkheads, 3 geotube

Table 2. The approximate shoreline lengths that are in public or NGO ownership in each state. These beaches include those in public ownership, ownership by non-governmental conservation organizations, and conservation easements. These miles of shoreline generally overlap with the miles of undeveloped beach but may also include some areas that have been developed with recreational facilities or other facilities (e.g., military bases).

State	Length of Shoreline in Public / NGO Ownership (miles)	Percentage of Shoreline in Public / NGO Ownership
NY (South Shore of Long Island)	60.83	48%
NJ	31.97	25%
DE	14.23	56%
MD	22.10	71%
VA	95.83†	89%
TOTAL	**224.96**	**54%**

† Wallops Island is 5.9 miles long but as of September 2011 only 3.56 miles of the island had a sandy beach; the remaining portion of the island was armored with no beach. A beach fill project created a beach in front of the seawall from April to August 2012 prior to Hurricane Sandy. The total island length is included here.
An unknown portion of Cedar Island is privately owned but undeveloped. The Chincoteague NWR owns a number of island parcels. The total island length is included here.
Cobb Island is 5.16 miles long but as of September 2011 only 4.23 miles of the island had a sandy beach; the remaining portion of the island had eroded into forest. The total island length is included here.

revetments and 6 breakwaters, construction of which Hall and Pilkey (1991) state began around 1870. New York has at least 335 groins and 39 contiguous sections of seawalls, revetments and/or bulkheads, with stabilization of the beach at Jacob Riis Park initiated in 1914, at Fort Tilden in 1918, and the majority of the groins on the Rockaway peninsula constructed between 1922 and 1927 (Dallas et al. 2013). In total there are approximately 866 oceanfront groins, 23 jetties, 173 contiguous sections of seawalls / revetments / bulkheads, 6 geotube or sandbag structures, and 30 breakwaters from Montauk, NY, to the Virginia-North Carolina boundary.

At least 239.09 miles (384.79 km; 57%) of oceanfront shoreline between Montauk, NY, and the Virginia-North Carolina boundary have received artificial sand placement via dredge disposal activities, beach nourishment or restoration, dune construction, emergency berms, inlet bypassing, and inlet closure

Table 3. Approximate shoreline miles that have been modified by armoring with hard erosion control structures for each state from Montauk, NY, to the Virginia-North Carolina state boundary prior to Hurricane Sandy in 2012. Note that these totals are minimum numbers, given missing data for some areas. Refer to the Methods section above for a description of how the lengths of armored shoreline were calculated.

State	Known Approximate Length of Armored Shoreline (miles)	Percentage of Armored Shoreline
NY (South Shore of Long Island)	25.33	20%
NJ	75.20	59%
DE	3.68	15%
MD	1.62	5%
VA	11.24	10%
TOTAL	**117.07**	**28%**

projects (Table 5). In most areas sediment placement projects are conducted in developed areas or adjacent to shoreline or inlet hard stabilization structures in order to address erosion, reduce storm damages, or ameliorate sediment deficits caused by inlet dredging and stabilization activities. The coasts of New Jersey and Maryland have the highest proportions of sediment placement activities on their oceanfront shorelines (at least 74 and 100% respectively). Virginia is the only state in this assessment that has been modified with sediment placement along less than 50% of its beaches. The totals listed in Table 5 are minimum numbers due to insufficient data on the lengths and locations of several past projects in each state (see the individual state summaries below).

Table 4. Approximate number of each type of armoring visible on the oceanfront beach in each state visible on Google Earth imagery between 1989 and November 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 3 above.

State	Number of Groins	Number of Jetties	Number of Seawalls, Bulkheads and/or Revetments	Number of Geotubes or Sandbags	Number of Breakwaters
New York	335	8	39	4	2
New Jersey	452	9	95	1	6
Delaware	29	2	4	0	0
Maryland	0	2	2	0	3
Virginia	Up to 50	2	33 +	1	19
TOTAL	**866**	**23**	**173**	**6**	**30**

Table 5. The approximate lengths of authorized constructed (existing) sediment placement projects and those proposed prior to Hurricane Sandy in October 2012 for each state; sediment placement projects include beach nourishment, artificial dune construction, inlet closure, and dredge disposal placement projects.

	Length of Shoreline Previously Modified with Sediment Placement (miles)	Length of Shoreline Proposed to be Modified with Sediment Placement (miles)	Total Length of Shoreline Modified with Sediment Placement (miles)	Percentage of Shoreline Modified with Sediment Placement
New York	65.30	5.00	70.30	56%
New Jersey	63.10	31.21	94.31	75%
Delaware	12.59†	0	12.59	50%
Maryland	31.10	0	31.10	100%
Virginia	27.69	3.1	30.79	29%
TOTAL	**199.78**	**39.31**	**239.09**	**57%**

† Following the Ash Wednesday Storm of 1962, the federal Operation Five-High reconstructed 12.59 miles (20.26 km) of beaches and dunes along the Delaware oceanfront. Current sediment placement projects total 8.66 miles (13.94 km) of beaches. Precise location information for the Operation Five-High project is unknown but presumed to overlap much of the current project areas. Therefore the higher 12.59 mile (20.26 km) figure is listed here but is likely conservative since some of the current project areas may not overlap with the Operation Five-High project areas.

Prior to Hurricane Sandy in October 2012, the Ash Wednesday Storm of 1962 was the most damaging storm to affect the New York to Virginia shoreline. Following the storm, the USACE undertook "Operation Five-High," named after the five high tides that the storm lasted. Emergency projects to reconstruct dunes and beaches and fill in storm breaches were undertaken in each of the five states covered in this assessment (USACE 1963). In New York, approximately 23 miles (37 km) of shoreline received sediment to rebuild dunes and beaches (USACE 1963, Coburn et al. 2010, USACE New York District website). In New Jersey, approximately 20 miles (32 km) of artificial dunes were constructed in 1962 (USACE 1999b) and well more than 23 miles (37 km) of beaches received fill material in 1962 and 1963, much of it overlapping the dune construction project areas (PSDS 2014). In Delaware, 12.59 miles (20.26 km) of beaches and dunes were constructed (PSDS 2014). In Maryland, two storm breaches on Assateague Island were closed and 8.00 miles (12.87 km) of beach and dune were constructed in Ocean City (PSDS 2014). In Virginia, a storm breach on Wallops Island was closed (King et al. 2010) and 5.60 miles (9.01 km) of beaches and dunes were constructed (PSDS 2014). The emergency response to the Ash Wednesday Storm of 1962 placed sediment along a total of more than 72 miles (116 km) of shoreline in these five states. Precise lengths and boundaries of all of the individual project areas are not known, however, so not all of these emergency projects are included in Table 5. Comparison of Operation Five-High projects to emergency projects constructed in response to Hurricane Sandy will be made in a subsequent report.

State-specific Results

New York

Approximately 58.23 miles (93.71 km; 46%) of the New York sandy oceanfront beach are developed and 66.65 miles (107.26 km; 54%) are undeveloped. The beaches of Kings County (Coney Island) are the most developed (93%), and those of the other three oceanfront counties are significantly less developed, with 45 to 48% of the linear oceanfront beaches developed in each (Table 6).

The beaches of New York have multiple layers of governance and management. Most of Long Island falls within Suffolk and Nassau Counties. Within the counties, there are a number of Towns such as Southampton, East Hampton, Brookhaven and Islip. These towns have multiple incorporated villages or hamlets (e.g., Montauk, Sagaponack, Westhampton Beach, and Long Beach) as well as unincorporated areas. The Dongan Patent of 1686 granted the Towns ownership of the waters and beaches (amongst other natural resources) within their boundaries, which the Towns manage via Boards of Trustees. These Boards of Trustees are separate from the Town Councils or Boards.

The sandy beaches of Long Island are therefore publicly owned by the various Towns, although their use is often restricted to residents of the Town. The property immediately adjacent to the beach, however, is most often privately owned. For example, the Town of Hempstead owns the sandy beach along eastern Long Beach Island and manages several sections as public parks. Immediately adjacent to the public beaches that are not within larger parks, however, are a number of private properties including beach clubs, beach camps, and private residences. The Town of Southampton owns the oceanfront beach within its boundaries, but private property again lines the shoreline behind the beach.

Approximately 61 miles (98.15 km) of sandy oceanfront beach from Montauk to Coney Island are in public or NGO ownership (Table 7). The public and NGO owned lands listed in Table 7 do not include Town-owned beaches unless the adjacent properties are also public or NGO lands. It is unknown 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.

Table 6. The approximate lengths of sandy oceanfront beach within each county of New York along the South Shore of Long Island and the proportions that are developed and undeveloped. The difference between the total shoreline length and the length of sandy beach is the length of shoreline that had no sandy beach present as of November 9, 2011, according to Google Earth imagery; therefore 1.38 miles of shoreline in this area was armored with hard structures with no sandy beach.

County[1]	Approximate total shoreline length in miles	Approximate length of sandy beach (miles)	Developed shoreline miles (% of total)	Undeveloped shoreline miles (% of total)
Suffolk[2]	93.56	93.11	41.46 (45%)	51.65 (55%)
Nassau	17.69	17.69	8.50 (48%)	9.19 (52%)
Queens	10.62	10.62	5.06 (48%)	5.56 (52%)
Kings	4.39	3.46	3.21 (93%)	0.25 (7%)
TOTAL	**126.26**	**124.88**	**58.23 (47%)**	**66.65 (53%)**

1 – Suffolk County, NY, stretches from Montauk Point to Babylon. Nassau County stretches from the Tobay Beach area to East Rockaway Inlet. Queens County reaches from East Rockaway Inlet to Rockaway Inlet and includes the Rockaways and Breezy Point. Kings County consists of Coney Island.

2 – The eastern end of Jones Beach Island includes the Oak Beach section of the Town of Babylon's beaches and Captree State Park; the eastern end of the island east of the "sore thumb dike" is included here so that the entire length of Jones Beach Island, a barrier island, would be assessed. This section of the island is not directly exposed to the Atlantic Ocean (although it was historically) and contributes 0.36 miles of shoreline with no beach due to armoring with hard structures, 3.56 miles of sandy beaches, 1.75 miles (49%) of which were developed and 1.81 miles (51%) of which were undeveloped prior to Hurricane Sandy.

The longest public and/or NGO owned beach is found in Fire Island National Seashore, although the seashore's oceanfront landholdings are discontinuous with 17 communities along the island. The National Park Service (NPS) also owns 4.42 miles (7.11 km) of oceanfront beach in the Jamaica Bay Unit of Gateway National Recreation Area (NRA) at Jacob Riis Park, Fort Tilden and Breezy Point.

Several state parks manage sections of oceanfront beach, with Jones Beach State Park containing 6.5 miles (10.46 km) of oceanfront beach, Robert Moses State Park 5.14 miles (8.27 km), Camp Hero State Park 1.29 miles of beach (2.08 km), Captree State Park 1.11 miles (1.79 km) and Gilgo State Park 1.12 miles (1.80 km). Suffolk County owns three oceanfront parks, with Shinnecock County Park (East and West) along 3.42 miles (5.50 km), Cupsogue County Park along 1.41 miles (2.27 km) and Silver Point County Park along 6.22 miles (10.01 km) of beach. The only National Wildlife Refuge (NWR) along the New York oceanfront coast is Amagansett NWR near Montauk that manages approximately one-third of a mile (0.53 km) of beach.

Approximately 25.33 miles (40.76 km), or 20%, of the oceanfront shoreline of New York has been armored with hard stabilization structures (Table 8). A total of 335 groins, 8 jetties, 39 sections of contiguous seawalls / revetments / bulkheads, 4 sandbag or geotube structures, 1 sore thumb dike, and 2 breakwaters were identified (Table 9).

The shoreline of Kings County (consisting of Sea Gate, Coney Island, Brighton Beach and Manhattan Beach) is 100% armored with 31 known groins, 8 sections of contiguous seawalls / revetments /

Table 7. Sandy oceanfront beaches that are in public or NGO ownership in New York, the county in which each is located, and approximate shoreline length of each. Note that only lands that exceed 0.10 mile (0.16 km) in length are listed here by name, but the contribution of 5 additional public or NGO areas with lengths of less than 0.10 mile (0.16 km) to the overall length of beaches is included in the total (therefore the total listed is greater than the sum of the individual parcels listed). Beaches owned or managed by Towns under the Dongan Patent are excluded where private property is immediately adjacent to the beach (Sources: McCormick et al. 1984, Koppelman and Forman 2008, Google Earth 2014, USACE 2014, and multiple online websites for individual public / NGO lands).

Public / NGO Land	County Location	Approximate Beach Length in Miles
Camp Hero State Park[1]	Suffolk	1.29
Rheinstein Estate Park	Suffolk	0.28
Shadmoor State Park	Suffolk	0.46
Kirk Beach Park	Suffolk	0.31
Hither Hills State Park	Suffolk	1.38
Napeague State Park	Suffolk	1.82
Atlantic Avenue Town Park	Suffolk	0.10
Amagansett NWR	Suffolk	0.37
Atlantic Double Dunes Preserve and Indian Wells Beach	Suffolk	0.53
Two Mile Hollow Beach	Suffolk	0.18
East Hampton Main Beach	Suffolk	0.43
Georgica Beach	Suffolk	0.10
Sagg Main Beach, Sagaponack	Suffolk	0.33
W. Scott Cameron Beach, Bridgehampton	Suffolk	0.12
Flying Point Beach, Water Mill	Suffolk	0.52
Shinnecock County Park East	Suffolk	0.42
Shinnecock County Park West	Suffolk	3.00
Cupsogue Beach County Park	Suffolk	1.41
Smith Point County Park	Suffolk	6.22
Fire Island NS (inholdings removed)	Suffolk	13.12
Davis Town Park	Suffolk	0.13
Atlantique Park	Suffolk	0.17
Robert Moses State Park	Suffolk	5.14
Captree State Park[2]	Suffolk	1.11
Giglo State Park	Suffolk	1.12
Town of Babylon Beaches (Gilgo, Cedar, & Overlook)	Suffolk	5.20
Tobay Beach & JFK Memorial Wildlife Sanctuary	Nassau	1.84
Jones Beach State Park	Nassau	6.50
Point Lookout Town Park	Nassau	0.56
Malibu Town Park	Nassau	0.16
Nickerson Beach Park	Nassau	0.62
Lido East Town Park	Nassau	0.38
Lido West Town Park	Nassau	0.38

Public / NGO Land	County Location	Approximate Beach Length in Miles
Silver Point County Park	Nassau	0.22
Jamaica Bay Unit - Jacob Riis Park, Fort Tilden & Breezy Point of Gateway NRA	Queens	4.42
Manhattan Beach Park	Kings	0.25
TOTAL MILES		**60.83 (48% of state shoreline)**

1 – The park also has 0.09 miles (0.14 km) of oceanfront shoreline that has a revetment with no beach, which is not included here.

2 – Captree State Park is included here even though its present location in Fire Island Inlet is not exposed to the Atlantic Ocean; historically the east end of Jones Beach Island was directly exposed to the ocean when the inlet was located farther east. All of Jones Beach Island was included in this assessment because the island is a barrier island.

bulkheads, and 2 breakwaters. The Manhattan Beach area is entirely armored (100%) with only two pockets of sandy oceanfront beach (totaling 0.33 mi [0.53 km]) and the majority of its shoreline (0.90 miles or 1.45 km) lined with hard structures with no sandy beach.

The shoreline of neighboring Queens County (the Rockaway peninsula) is 74% armored with 198 reported groins, 1 jetty, and 3 sections of contiguous seawalls / revetments / bulkheads. Dallas et al. (2013) located 55 groins from Breezy Point through Fort Tilden and Jacob Riis Park as visible in December 2011. Using Google Earth imagery taken immediately following Hurricane Sandy in the first few days of November 2012, an additional 17 groins (for a total of 72) were located in this inventory that had been buried but were exposed by the 2012 storm. A total of 198 groins reportedly have been constructed on the Rockaway peninsula since the mid-1920s (Dallas et al. 2013), of which 137 were located in this inventory; some of the groins historically present at Jacob Riis Park may have been removed in 1957-58 (Dallas et al. 2013).

The oceanfront shoreline of Nassau County is armored along 36% of its length, with 6.28 miles (10.11 km) of shoreline armored with 50 known groins, 2 jetties, and 7 contiguous seawalls / revetments / bulkheads (Tables 8 & 9). The majority of this armoring is found along Long Beach Island, where Lido Beach, Long Beach, East Atlantic Beach and Atlantic Beach all have varying numbers and lengths of groins and seawalls / revetments / bulkheads along their shorelines. CPE (2009b) reported 50 groins were constructed on Long Beach Island from 1930 to 1961, all of which were identified in this assessment although many of the groins are in disrepair. First proposed in 1965, the federal Jones Inlet to East Rockaway Inlet (Long Beach Island) Hurricane and Storm Damage Reduction Project proposed in 2006 to rehabilitate 17 of the existing groins and to construct up to 7 new groins at Hempstead along Long Beach Island (USACE 2006, CPE 2009b); this project was not constructed prior to Hurricane Sandy in 2012 but would armor an additional 7,800 ft (2,377 m) or 1.48 miles (2.38 km) of beach. The entire oceanfront shoreline lengths (100%) of Long Beach and East Atlantic Beach are armored.

Suffolk County, which has the longest shoreline of any of the oceanfront counties, is the least armored with hard stabilization structures with only 7% of its shoreline having hard stabilization structures, with 56 known groins, 5 jetties, 21 sections of contiguous seawalls / revetments / bulkheads, and 4 sandbag or geotube structures (Tables 8 & 9). The most well-known of these armoring structures is perhaps the Westhampton groin field, where 11 groins were initially constructed in 1965-66, 4 additional groins constructed in 1970, 2 groins tapered in 1997, and 1 intermediate groin added in 1997 (Terchunian and Merkert 1995, Rosati et al. 1999, Koppelman and Forman 2008, Bocamazo et al. 2011, and USACE

Table 8. Approximate oceanfront shoreline length (in miles) within each county of New York that were armored with hard stabilization structures visible on Google Earth imagery between 1994 and November 2012. Hard stabilization structures include groins, jetties, seawalls, bulkheads, revetments, geotubes, sandbags and breakwaters. Structures may be periodically exposed or buried and include those that are failing, in disrepair, or remnants of old structures.

County	Total Length of Shoreline (miles)	Approximate Length of Armoring (miles)	Percentage of Shoreline Armored
Suffolk[1]	93.56	6.80	7%
Nassau	17.59	6.28	36%
Queens	10.62	7.86	74%
Kings	4.39	4.39	100%
TOTAL	**126.26**	**25.33**	**20%**

1 – The eastern end of Jones Beach Island east of the "sore thumb dike" contributes 3.92 miles of shoreline to the Suffolk County total, of which 2.08 miles is armored.

Table 9. Approximate number of each type of armoring visible on the oceanfront beach in each county of New York visible on Google Earth imagery between 1994 and November 2012. 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 8 above.

County	Number of Groins	Number of Jetties	Number of Seawalls, Bulkheads and/or Revetments	Number of Geotubes or Sandbags	Number of Breakwaters
Suffolk[1]	56	5	21	4	0
Nassau[2]	50	2	7	0	0
Queens	198[†]	1	3	0	0
Kings	31	0	8	0	2
TOTAL	335	8	39	4	2

1 - Suffolk County also has the "sore thumb dike" at Fire Island Inlet which is a shore-perpendicular structure similar to a groin but is composed of sand with two armored rock tips at the end. It is not categorized here due to its unique nature. The section of shoreline east of the dike contributes 31 groins and 17 seawalls, bulkheads or revetments to the Suffolk County total.

2 - Up to 7 new groins were proposed for Hempstead on Long Beach Island by the USACE in 2006 but were not constructed prior to Hurricane Sandy in 2012 (USACE 2006, CPE 2009b).

† - Dallas et al. (2013) reported 198 groins on the Rockaway peninsula, 137 of which were located in this assessment. The higher number is used here since some structures may be buried by beach fill and not readily visible.

2014a). The most armored section of Suffolk County is the Oak Beach area of the Town of Babylon at Fire Island Inlet, where 31 groins and 17 contiguous sections of seawalls / revetments / bulkheads are visible in Google Earth aerial imagery prior to Hurricane Sandy.

The New York oceanfront shoreline between Montauk and Coney Island has been modified with at least 65.30 miles (113.13 km) of beach receiving sediment placement and another 5.00 miles (8.05 km) proposed to receive sediment placement prior to Hurricane Sandy (Table 10). Although the 1922-23 beach fill project at Coney Island is commonly cited as the oldest beach fill project in the country (e.g., Valverde et al. 1999, Campbell and Benedet 2006, Tanski 2012), beach fill was actually placed at Jacob

Riis Park before then in 1915, 1916, and 1920 (Dallas et al. 2013). The volumes of fill placed initially at Jacob Riis Park were considerably smaller (1,000 to 6,200 cubic yards) than the Coney Island project, which used 1.7 million cubic yards (mcy) of fill (Valverde et al. 1999, PSDS 2014). In 1936 the first large scale beach fill project was conducted at Jacob Riis Park with approximately 2 mcy of sediment (Dallas et al. 2013).

Operation Five-High in 1962 by the USACE reconstructed approximately 23 miles (37 km) of beach and dune in New York following the Ash Wednesday Storm of 1962 (USACE 1963, Coburn et al. 2010, USACE New York District website). Not all of these miles are included in Table 10 due to insufficient project boundary data; projects with known lengths are noted in Table 10.

Portions of Fire Island have received sediment placement on the oceanfront beach since 1933, with over 50 individual project areas (Land Use Ecological Services, Inc., et al. 2008, Suffolk County 2008, Coburn et al. 2010). Virtually the entire island (30.88 mi [49.7 km], or 98% of the island) had been modified with beach and/or dune fill prior to Hurricane Sandy, including the Otis Pike Wilderness which received fill prior to 1979 (Land Use Ecological Services, Inc., et al. 2008). Altogether over 13.7 mcy of sediment were deposited on the oceanfront shoreline of Fire Island between 1933 and 2009 (Land Use Ecological Services, Inc., et al. 2008, Suffolk County 2008, Coburn et al. 2010).

The longest on-going oceanfront beach fill project in the state is the federal East Rockaway Inlet to Rockaway Inlet project on Rockaway Beach with 6.20 miles (9.98 km) of shoreline receiving fill in a federal project since 1977 (Greene 2002, Dallas et al. 2013, PSDS 2014, USACE New York District website). Portions of Rockaway Beach have received fill since 1926, including dredge disposal from East Rockaway Inlet every two years along 4,000 ft (1219 m) of beach (Greene 2002, Dallas et al. 2013). Between 1915 and 2005, approximately 33.78 mcy of sediment were mechanically deposited on the beaches of the Rockaway peninsula (Dallas et al. 2013).

Portions of Long Beach Island have received beach fill since the 1950s, with over 3.43 mcy of sediment placed on the island's beaches since 1956 (CPE 2009b). Most of the sediment has been placed at the eastern end of the island in Point Lookout and Hempstead, although Lido Beach received fill in 1956 and 1962 (Greene 2002, CPE 2009b, PSDS 2014).

Several areas have received beach fill but precise project lengths are unknown. The Town of East Hampton places dredge spoil material at Ditch Plain beach (Town of East Hampton 1999). Prior to Hurricane Sandy in 2012, well over 28 storm breaches were closed with fill material between Montauk and Fire Island Inlet by storms in 1938, 1953, 1954, 1962, 1980, and 1992-1993; project location and length data are only known for a few of these artificial closures (USFWS 2014e).

Three storm damage reduction projects have been proposed that would modify an additional 5.00 miles (8.05 km) of sandy oceanfront beach in New York (Table 10). First proposed in 1965, the federal Jones Inlet to East Rockaway Inlet (Long Island) Hurricane and Storm Damage Reduction Project proposed in 2006 to place beach fill along two segments of beach, construct dunes in three segments, and construct a sand barrier under the City of Long Beach's boardwalk along a total of 5.49 miles (8.84 km) of Long Beach Island (USACE 2006, CPE 2009b); this project was not constructed prior to Hurricane Sandy in 2012 (Table 10). The easternmost segment of the proposed project would overlap with the Point Lookout beach area that receives dredge spoil placement from Jones Inlet, where approximately 1.591 mcy of sediment has been placed in 4 episodes from 1982 to 2008 (CPE 2009b). The western segment of the proposed project would overlap the area of Lido Beach (Town of Hempstead) that received fill in the 1956 and 1962. Therefore the total new length of beach that would be modified is 4.41 miles (7.10 km).

Table 10. The approximate lengths of authorized constructed beach nourishment and dredge disposal placement projects on New York oceanfront beaches from Montauk to Coney Island. Shaded rows with a "P" in the length column are projects proposed prior to Hurricane Sandy but not yet constructed (Sources: Greene 2002, Hanc 2007, Koppelman and Forman 2008, Land Use Ecological Services, Inc., et al. 2008, Suffolk County 2008, CPE 2009, Town of East Hampton 1999, Coburn et al. 2010, Bocamazo et al. 2011, Dallas et al. 2013, PSDS 2014, USACE 2014a, USFWS 2014b, USFWS 2014e and the USACE New York District website).

Location	Project Length (miles)
Montauk	0.59 P
Ditch Plains[1]	unknown
Easthampton (Hook to Georgica Ponds)	2.37
Sagaponack Pond area (Operation Five-High)	0.60
Mecox Bay area (Operation Five-High)	1.30
Dune Road, east of Shinnecock Inlet	0.27
Shinnecock County Park East	0.57
Shinnecock County Park West	0.76
Tiana Beach	0.57
Southampton (Operation Five-High)	1.00
Quogue	0.02
Westhampton Beach to Cupsogue Beach County Park	4.06
Cupsogue Beach County Park	1.10
Moriches Inlet Area	0.42
Smith Point County Park	5.66
Fire Island National Seashore[2]	20.08
Davis Park	These recent local projects overlap the historic Operation Five-High Project area on Fire Island
Water Island	
Fire Island Pines	
Point O'Woods	
Seaview	
Ocean Bay Park	
Ocean Beach	
Lonelyville	
Dunewood	
Fair Harbor	
Saltaire	
Robert Moses State Park[3]	5.14
Oak Beach	unknown
Gilgo Beach	3.41
Jones Beach State Park	6.50
Jones Inlet to East Rockaway Inlet (Long Beach)[4]	4.41 P
Point Lookout (Town of Hempstead)	0.57
Lido Beach (Operation Five-High)	0.80
Rockaway Beach	6.20
Jacob Riis Park	0.43
Coney Island	3.47
TOTAL MILES[5]	**70.30 (56% of state beaches)**

1 – The Town of East Hampton has placed dredge spoil material on the Ditch Plains beach, but precise locations and project length(s) are unknown.

2 – The federal Operation Five-High project following the Ash Wednesday Storm of 1962 placed beach fill and reconstructed dunes along approximately 7.01 miles of Fire Island. Combined with other sediment placement projects, a total of 30.88 miles (49.70 km) of Fire Island at one time or another have received fill, with the most recent episodes at Smith Point County Park, 11 of the private communities, and Robert Moses State Park (Land Use Ecological Services, Inc., et al. 2008).

3 – Robert Moses State Park currently receives dredged material from Fire Island Inlet and the Great South Bay Federal Navigation Project periodically; historically, the entire park has received fill at one time or another (Land Use Ecological Services, Inc., et al. 2008).

4 – The proposed project area proposes two segments of beach fill and construction of three segments of dune plus a sand barrier under the Long Beach boardwalk totaling 30,500 ft or 5.78 miles (9.30 km); the proposed project area overlaps the dredge spoil placement area at Point Lookout / Hempstead Beach and the previous beach fill placements in Lido Beach. Therefore only 4.41 miles (6.63 km) of new fill areas are listed here.

5 – The federal Operation Five-High project following the Ash Wednesday Storm of 1962 placed beach fill and reconstructed dunes along approximately 23 miles (37 km) of New York beaches (USACE 1963, USACE New York District website), but the precise locations and/or lengths of sections outside of Sagaponack Pond, Mecox Bay, Southampton, Fire Island, and Lido Beach are unknown and not included in this total.

The second storm damage reduction project that would modify additional beach with sediment placement is in Montauk, where the most recent project plan prior to Hurricane Sandy proposed to place beach fill along 0.59 miles (0.95 km) of beach (USACE 2014c). The third proposal is the federal Interim Storm Damage Protection Project, Fire Island Inlet to Moriches Inlet, which has been proposed for Fire Island; the project would place beach fill and construct dunes along 11.7 miles (18.83 km) of Fire Island (USACE 1999a), but the project is not listed in Table 10 since it overlaps with other previous sediment placement projects on Fire Island. Altogether the more than 65.30 miles (113.13 km) of sandy oceanfront beach modified by historical and existing sediment placement projects has modified approximately 52% of the sandy oceanfront shoreline; including proposed projects would increase the proportion of sandy oceanfront beaches modified by sediment placement projects to 56% and projects with unknown location and length data would increase the total further.

New Jersey

Approximately 84.47 miles (135.94 km; 67%) of the New Jersey sandy oceanfront beach are developed and 40.79 miles (65.65 km; 33%) are undeveloped. The beaches of Cape May County are the most developed (73%), and those of the other three oceanfront counties are slightly less developed, with 56 to 68% of the linear oceanfront beaches developed in each (Table 11).

Nearly 32 miles (51.50 km) of sandy oceanfront beach in New Jersey are in public or NGO ownership (Table 12). The longest of these is found Island Beach State Park (9.68 miles, or 15.58 km), although the park has extensive sand fencing and a jetty at its southern end. The National Park Service owns 6.00 miles (9.66 km) of oceanfront beach in the Sandy Hook Unit of Gateway NRA. The Edwin B. Forsythe NWR manages nearly 7 miles (11.27 km) of beach at Holgate and Little Beach Island.

Approximately 59% (75.20 miles or 121.02 km) of New Jersey's shoreline is armored with hard stabilization structures (Table 13). There are roughly 454 oceanfront groins, 9 jetties, 150 contiguous sections of seawalls / revetments / bulkheads, 3 geotube structures and 6 submerged breakwaters along New Jersey's oceanfront (Table 14). This assessment (Table 13) confirms the conclusion of Farrell et al.

Table 11. The approximate lengths of sandy oceanfront beach within each county of New Jersey and the proportions that are developed and undeveloped. The difference between the total shoreline length and the length of sandy beach is the length of shoreline that had no sandy beach present as of December 30, 2010 (north of Holgate) or June or August 2011 (south of Holgate) according to Google Earth imagery; therefore 1.87 miles (3.00 km) of shoreline in this area was armored with hard structures with no sandy beach.

County†	Approximate total shoreline length in miles	Approximate length of sandy beach (miles)	Developed shoreline miles (% of total)	Undeveloped shoreline miles (% of total)
Monmouth	26.74	26.05	17.35 (67%)	8.70 (33%)
Ocean	45.15	45.15	30.90 (68%)	14.25 (32%)
Atlantic	18.48	18.48	10.42 (56%)	8.06 (44%)
Cape May	36.76	35.58	25.80 (73%)	9.78 (27%)
TOTAL	**127.13**	**125.26**	**84.47 (67%)**	**40.79 (33%)**

†Monmouth County stretches from Sandy Hook to Manasquan Inlet. Ocean County stretches from Manasquan Inlet to Little Egg Inlet. Atlantic County reaches from Little Egg Inlet to Great Egg Harbor Inlet. Cape May County stretches from Great Egg Harbor Inlet to Cape May.

Table 12. Sandy oceanfront beaches that are in public or NGO ownership in New Jersey, the county in which each is located, and approximate shoreline length of each. (Sources: Hall and Pilkey 1991, Farrell et al. 1999, Kennish 2001, Dallas et al. 2013, and multiple online websites for individual public / NGO lands).

Public / NGO Land	County Location	Approximate Beach Length in Miles
Sandy Hook Unit, Gateway NRA	Monmouth	6.00
Seven Presidents Oceanfront Park	Monmouth	0.46
Island Beach State Park	Ocean	9.68
Holgate Unit, Edwin B. Forsythe NWR	Ocean	3.25
Brigantine Unit, Edwin B. Forsythe NWR	Atlantic	3.68
North Brigantine Natural Area	Atlantic	2.70
Corson's Inlet State Park	Cape May	0.97
Strathmere Natural Area	Cape May	0.26
Stone Harbor - The Point Conservation Management Area	Cape May	1.30
Two Mile Beach Unit, Cape May NWR	Cape May	0.70
USCG LORAN Station	Cape May	0.52
USCG Cape May Training Center	Cape May	1.10
Lower Cape May Meadows: TNC South Cape May Meadows Preserve & Cape May State Park	Cape May	1.35
	TOTAL MILES	**31.97 (26% of state shoreline)**

Table 13. Approximate oceanfront shoreline length (in miles) within each county of New Jersey that were armored with hard stabilization structures visible on Google Earth imagery between March 1991 (south of Margate) or March-April 1995 (north of Margate) and November 2012. Hard stabilization structures include groins, jetties, seawalls, bulkheads, revetments, geotubes, sandbags and breakwaters. Structures may be periodically exposed or buried and include those that are failing, in disrepair, or remnants of old structures.

County	Total Length of Shoreline (miles)	Approximate Length of Armoring (miles)	Percentage of Shoreline Armored
Monmouth	26.74	21.75	81%
Ocean	45.15	19.90	44%
Atlantic	18.48	9.05	49%
Cape May	36.76	24.50	67%
TOTAL	**127.13**	**75.20**	**59%**

Table 14. Approximate number of each type of armoring visible on the oceanfront beach in each county of New Jersey visible on Google Earth imagery between March 1991 (Cape May County) or March-April 1995 (the remaining counties) and November 2012. 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 and its overall length is counted in Table 13 above.

County	Number of Groins	Number of Jetties	Number of Seawalls, Bulkheads and/or Revetments	Number of Geotubes	Number of Breakwaters
Monmouth	200†	4	44	0	1
Ocean	119	2	34	1	0
Atlantic	39	1	6	0	0
Cape May‡	96	2	12	0	5
TOTAL	**454**	**9**	**95**	**1**	**6**

†Four of these structures are actually stormwater outfalls that have been armored; due to their armoring they are counted as groins here. USACE (1989) identified 185 groins from Sea Bright to Manasquan, 162 of which were located in this assessment. The USACE (1989) total is used here and added to the 4 armored stormwater outfalls and 11 groins identified within Sandy Hook NRA.

‡At Cape May Point State Park, Battery 223 is a concrete bunker on the beach that may act like armoring along ~0.03 miles (180 ft) of oceanfront beach.

(1999, p. 52) that found "Ocean County is the least intensely stabilized New Jersey oceanfront county in terms of coastal protection structures made from timber, stone or concrete." (Table 13).

NJDEP (1981) found 306 groins and 21.27 miles (34.23 km) of seawalls / bulkheads / revetments along the New Jersey oceanfront. Hall and Pilkey (1991) found more than 300 groins and 18.85 miles (30.33 km) of seawalls, revetments and bulkheads in New Jersey in 1989. This assessment identified 454 oceanfront groins and approximately 46.34 miles (74.58 km) of seawalls, revetments and bulkheads in New Jersey as of 2011. The greater numbers and lengths of structures found in this assessment is most likely due to the exposure of previously buried structures (by Hurricane Sandy) but also may include new structures built since the 1981 and 1989 surveys. Coburn and Griffith (2014) also identified a greater length of shore-parallel structures - 48.78 miles (78.50 km) - along New Jersey's oceanfront, which is only slightly higher than the total length identified in this assessment. Hall and Pilkey (1991) found that groins were present along 37.14 miles (59.77 km) of shoreline, although many of these areas overlapped the areas where walls were present because "most of [the] beaches with seawalls, revetments and bulkheads also have groins. Only five beach segments (Seaside Park, mid-Atlantic City, Ventnor, Margate, and South Ocean City) were backed with shore parallel structures and no groins" (p. 776). Altogether Hall and Pilkey (1991) found 51% of New Jersey shoreline was armored in 1989, as compared to 59% armoring identified in this assessment.[2]

The entire length of Monmouth County shoreline outside of the Sandy Hook Unit of the Gateway NRA is armored with hard stabilization structures, representing 81% of the county's sandy oceanfront beaches (Table 14). Dallas et al. (2013) reported 145 groins along the oceanfront from the Sandy Hook park boundary to Manasquan Inlet, but Donohue et al. (2004), citing a 1985 site inspection survey by the USACE and reported in USACE (1989), identified 185 groins in the same area. This assessment identified 162 groins plus 4 stormwater outfalls with armoring visible on Google Earth imagery from March 1995 to November 2012. Comparison of the groins identified in this assessment with the USACE (1989) and Donohue et al. (2004) groin numbers indicates that the majority of the groins not located in this assessment should be in Sea Bright and Monmouth Beach. The section of Sea Bright and Monmouth Beach shorelines "missing" groins in this assessment are armored with a seawall and lacked a sandy beach prior to construction of the federal beach fill project in 1995. Therefore the groins may still be present but may have been submerged in Google Earth imagery in March 1995 and then buried by beach fill later in 1995. The initial beach fill project constructed by the USACE included notching 35 groins between Sea Bright and Manasquan Inlet in order to minimize impacts to the longshore sediment transport system (and increase the longevity of the fill). Since no groins were reported to have been removed during initial construction, Table 14 assumes that all 185 groins are still in place in Monmouth County (although many may be buried by beach fill).

Dallas et al. (2013) reported 10.7 miles (17.2 km) of seawall in Monmouth County stretching from the Sandy Hook boundary to Manasquan Inlet, and this study identified 13.51 miles (21.74 km) of seawalls / bulkheads / revetments visible on Google Earth imagery from April 1995 to November 2012. The higher number in this assessment is most likely due to the availability of aerial imagery taken immediately after Hurricane Sandy, when structures that were previously buried became visible and could be identified.

Armoring of the Monmouth County shoreline began over a century ago, as described by Donohue et al. (2004, pp. 199-200):

> *The earliest groins were constructed of timber in 1915, to protect a large stone seawall at the northern section of the project area. Groin construction continued through the 1960's, with most of the construction occurring in the 1920's and the late 1940's. Groin construction consisted of various combinations of stone, timber, asphalt and concrete. … Originally constructed by a private interest (the Central Railroad of New Jersey), local interests, such as the State of New Jersey, Monmouth County and the local municipalities constructed the remainder of the groins. As of 1985, 37 of the groins held sand fillets, primarily on their southern or updrift sides. These sand fillets were the main location of*

[2] In the USFWS's proposed listing of the red knot (USFWS 2013), New Jersey is stated as having 43% of its shoreline armored with hard stabilization structures, including nearly 27 miles of shore-parallel structures, 24 jetties, 368 groins and 1 breakwater. This assessment was able to identify approximately 46 miles of shore-parallel structures, 9 jetties, 454 groins and 6 breakwaters primarily by using updated imagery from Google Earth that showed structures that had been buried under sand and/or vegetation but were exposed by Hurricane Sandy. The higher number of jetties cited in USFWS (2013) likely includes those found on the Delaware Bay shoreline, which was not included in this assessment.

recreational use of the section's shoreline, and the only protection upland infrastructure had from destructive coastal storm waves.

For the Asbury Park to Manasquan section, a complete site inspection of coastal structures was conducted in 1987 (US Army Engineers, 1989), with a follow-up inspection in 1992. Along with three inlet jetties, timber and steel bulkheads and limited lengths of rock revetment and stone sea wall, there exist 82 groins in this section of the project …. The groins are constructed of timber, steel and timber, timber and stone at the outer ends, or all stone. … The groins were constructed by state, county or municipal authorities. The groins were constructed from 1915 to 1967, with five stone groins in Bradley Beach extended in 1990.

Ocean County's sandy oceanfront beaches are 44% armored (Table 13). USACE (1999b) states that a total of 112 groins existed on Long Beach Island by the early 1970s, but only 98 were found to be visible in 1996, with another in the Holgate area of Long Beach Township recorded with zero length and 2 additional groins known to be buried in Barnegat Light (for a total of 101). Farrell et al. (1999) reported that groin construction in Ocean County began in the 1880s and 1890s and no new groins have been built since the 1970s. The groin structures on Long Beach Island are spaced 750 to 1,000 ft (228.6 – 304.8 m) apart along 16.70 miles (26.88 km) of oceanfront beach; the groins are constructed of stone, timber or both materials (USACE 1999b, 2013). Two additional groins were buried in Barnegat Light in a 1990 survey by the accretionary fillet at the inlet jetty (USACE 1999b). Both NJ DEP (1981) and this assessment identified all 98 of the visible groins. Most of the groins (86 of 101) were constructed in the 1960s following the damaging Ash Wednesday Storm of 1962, with 69 of them constructed immediately following the storm in 1963-64 (USACE 1999b, 2013). USACE (1999b) found that most of the island's bulkheads were destroyed or severely damaged in the 1962 storm and only remnants remained, and those remnants were generally buried in dunes and not visible. Using aerial imagery taken immediately following Hurricane Sandy, this assessment identified approximately 0.58 miles (0.93 km) of remnant bulkheads exposed by the hurricane.

Atlantic County is slightly more armored than Ocean County, with armoring along 49% of its sandy oceanfront beaches (Table 13). This armoring includes approximately 39 groins, 1 jetty, and 22 contiguous sections of seawalls / revetments / bulkheads (Table 14). The armoring is concentrated on Absecon Island, where 100% of Atlantic City, 80% of Margate City and 86% of Longport are armored. Ventnor City is only 1% armored.

Cape May County is 52% armored with approximately 96 groins, 2 jetties, 48 sections of contiguous seawalls / revetments / bulkheads and 5 submerged breakwaters (Tables 13 and 14). In the northern part of the county, Ocean City is 96% armored, Strathmere is 100% armored (not including the Strathmere Natural Area), Sea Isle City is 82% armored, and Stone Harbor is 100% armored (not including Stone Harbor Point). Avalon are less heavily armored with 13% armoring. In the southern part of the county, North Wildwood is 87% armored, the USCG Cape May Training Center is 47% armored, Cape May City is 88% armored, and Cape May Point is 100% armored. Lower Cape May Meadows, consisting of the TNC South Cape May Meadows Preserve and Cape May State Park, is 10% armored and the Two Mile Beach Unit of Cape May NWR is 67% armored with 4 remnant groins (with 3 of the 4 visible in imagery from 1991 to 2002 but not after). The only armoring at the USCG LORAN Station is a jetty at Cape May Inlet.

Six submerged breakwaters have been constructed as experimental projects in New Jersey. The first submerged breakwater was installed in northern Avalon in 1993, where it was attached to the terminal groin on Townsends Inlet; the breakwater was subsequently buried by beach fill in 1995 (Stauble and

Tabar 2003). Another submerged breakwater was installed in Belmar / Spring Lake in 1994 (Stauble and Tabar 2003). Two experimental submerged breakwater structures were installed in the groin field at Cape May City in 1994, a stone seawall in groin cell 5 in 1999-2000, and another two experimental breakwater type structures were installed in 2002 (Stauble and Giovannozzi 2003, Stauble and Tabar 2003, Morang et al. 2014).

More miles of sandy oceanfront beach have received sediment placement in New Jersey than in any other state covered in this assessment. Three-quarters (75%) of the state's shoreline has received sediment placement or is proposed for sediment placement (Table 15). Existing sediment placement projects have modified 63.10 miles (101.55 km) of shoreline and another 31.21 miles (50.23 km) have been proposed to be modified in this way. The longest of these projects is the federal Sandy Hook to Barnegat Inlet Beach Erosion Control Project which extends along 34.54 miles (55.59 km) of beach in Monmouth and Ocean Counties (USFWS 2002, 2005). The federal beach fill project is separated into three sections and several reaches between two Districts of the USACE and as of 2011, 17.56 miles (28.26 km)[3] of the project have been constructed and another 16.98 miles (27.33 km) have been authorized but not constructed. In the area that has been proposed for federal beach fill, more than 2.33 miles (3.75 km) previously received fill from 1953 to 1978 (PSDS 2014).

The federal Barnegat Inlet to Little Egg Inlet (Long Beach Island) Storm Damage Reduction Project is partially constructed, with sections at Harvey Cedars, Surf City, Ship Bottom and the Brant Beach section of Long Beach Township constructed between 2006 and 2011 (USACE 2013, NMFS 2014). These constructed sections total 4.39 miles (7.07 km) of oceanfront beach and dune fill. The remaining 12.51 miles (20.13 km) are proposed and authorized for federal beach fill but were not constructed by the end of 2011 (USACE 1999b, 2013), the end of the survey period for this assessment. Several areas within the proposed federal project area have historically received beach fill, with more than 5.26 miles (8.47 km) having received beach and/or dune fill from 1956 to 2010 (USACE 1999b, PSDS 2014). Prior to construction of the Barnegat Inlet to Little Egg Inlet (Long Beach Island) Storm Damage Reduction Project, more than 6.019 mcy of sediment had been placed on Long Beach Island, most of it from 1954 to 1963 (USACE 1999b). The federal Operation Five-High project, for example, reconstructed dunes with fill material along 17.4 miles (28.00 km) of Long Beach Island following the Ash Wednesday Storm of 1962 (USACE 1999b). The Barnegat Light and Holgate project areas constructed with Operation Five-High are included in Table 15, but due to a lack of project boundaries for the other areas of the island the remaining 14.27 miles (22.97 km) of the 1962-63 projects are not included but are assumed to overlap other fill episode project areas. Therefore the proposed length of beach to be modified for the proposed Long Beach Island project listed in Table 15 is 7.25 miles (11.67 km), which is the length of new beach that would be modified by the new federal project.

Federal beach fill projects have also been proposed and partially constructed on Brigantine, Absecon Island, Ocean City, Avalon, Stone Harbor and Cape May. The Brigantine Inlet to Great Egg Harbor Inlet - Brigantine Island project initiated construction in 2006 along 1.80 miles (2.90 km) of northern Brigantine using material mined from Brigantine Inlet, although more of the island has historically been modified by sediment placement including the federal Operation Five-High that extended along 3.40 miles (5.47 km) of the island in 1962-63 (USFWS 2005, NMFS 2014, PSDS 2014). The entire length of Absecon Island is included in the Brigantine Inlet to Great Egg Harbor Inlet Storm Damage Reduction

[3] Note that the shoreline length of Section 1 of the Sandy Hook to Barnegat Inlet Beach Erosion Control Project, which extends from Sea Bright to Ocean Township, is frequently cited as 12 miles (e.g., Donohue et al. 2004). The southernmost reach of this project from Elberon to Loch Arbour was authorized but had not been constructed prior to Hurricane Sandy "due to a lack of public access, lack of support by the local municipalities and, as a result, NJDEP's inability to acquire the necessary real estate" (USACE 2014b, p. ES-1). This unconstructed reach is 3.22 miles (5.18 km) long and thus the actual constructed length of Section 1 of the project is 8.56 miles (13.78 km).

Project, with sections at Atlantic City and Ventnor City (5.06 miles or 8.14 km) initially constructed in 2003-04 with material mined from Absecon Inlet and sections at Margate and Longport proposed (3.05 miles or 4.91 km). Atlantic City has a long history of sediment placement, with the first known episode occurring in 1936 and an estimated 21 total placement episodes prior to Hurricane Sandy in October 2012 (Farrell et al. 1989, Pilkey and Clayton 1989, USFWS 2005, Campbell and Benedet 2006, NMFS 2014, PSDS 2014).

Ocean City, also known as Peck Beach, has a long history of modification with sediment placement on its beaches as well. First modified with beach fill in 1950, the beaches of Ocean City have been modified with fill 34 times prior to Hurricane Sandy in 2012 (Nordstrom 1988, Greene 2002, USFWS 2005, Campbell and Benedet 2006, NMFS 2014, PSDS 2014). The federal Great Egg Harbor and Peck Beach Project – Ocean City project was initially constructed from 1991-93 and extends along 4.70 miles (7.56 km) of beach using material mined from Great Egg Harbor Inlet. A southern extension of the project area has been authorized along an additional 2.60 miles (4.18 km) of beach but has not been constructed (USFWS 2005).

Over 3 miles (4.83 km) of Strathmere and Sea Isle City have been modified by sediment placement projects, primarily through state-funded projects. Strathmere was first modified by beach fill in 1966 and Sea Isle City in 1962 (USFWS 2005, NJDEP 2009a & 2009b, PSDS 2014). The federal Great Egg Harbor to Townsends Inlet Project – Strathmere and Sea Isle City project has been authorized for 6.55 miles (10.54 km) of the island's beaches (USFWS 2005), but the project was not constructed prior to Hurricane Sandy in 2012.

Avalon and Stone Harbor have been modified with sediment placement since 1962 and 1967 respectively. The federal Townsends Inlet to Cape May Inlet Project initially constructed 1.44 miles (2.32 km) of beach fill in Avalon and 2.30 miles (3.70 km) in Stone Harbor in 2003 (USFWS 2005, Hafner 2012, NMFS 2014, PSDS 2014). In 2006 a pilot project "backpassed" 50,000 cy sediment from a beach area with a "surplus" of sand to an erosional hotspot within Avalon (Hafner 2012). In 2009 both communities received beach fill in a state project (NJDEP 2009a, 2009b). An environmental restoration project has been proposed for Stone Harbor Point with an artificial dune with a geotube core, beach fill and additional artificial dunes, but the project has not been constructed (USFWS 2005).

The federal Cape May Inlet to Lower Township Project extends from the south jetty at Cape May Inlet to 3rd Avenue in Cape May City and was initially constructed in 1989 and 1991 in two reaches. Cape May City has been modified with sediment placement since 1962 (Greene 2002, USFWS 2005, NMFS 2014, PSDS 2014). The Lower Cape May Meadows – Cape May Point project was a federal ecosystem restoration project at Cape May Point State Park and TNC's South Cape May Point Preserve initially constructed in 2004-05 along 1.35 miles (2.17 km) of beach. An additional 1.05 miles (1.69 km) of beach at Cape May Point is also a part of the federal project and received fill in 2004-05, but historically has been modified with sediment placement since 1967 (USFWS 2005, PSDS 2014).

Altogether the more than 63.10 miles (101.55 km) of New Jersey sandy oceanfront beaches that received sediment placement prior to Hurricane Sandy represent 50% of the state's beaches (Table 15). The projects authorized but not constructed prior to Hurricane Sandy represent an additional 25% of the state's oceanfront beaches. If all of the proposed projects were constructed, 75% of the sandy oceanfront beaches in New Jersey would be modified by sediment placement, many of them repeatedly as projects are renourished every few years. In addition, the Five Mile Beach area of the Wildwoods in Cape May County is under investigation for a potential federal storm damage reduction project but no projects have been proposed yet (USACE and NJDEP 2005).

Table 15. The approximate lengths of authorized constructed beach nourishment and dredge disposal placement projects on New Jersey oceanfront beaches from north to south. Shaded rows with a "P" in the length column are projects proposed prior to Hurricane Sandy but not yet constructed (Sources: Nordstrom 1988, Farrell et al. 1989, Pilkey and Clayton 1989, USACE 1999b, Greene 2002, USACE 2002b, USFWS 2002, Donohue et al. 2004, USFWS 2005, Campbell and Benedet 2006, NJDEP 2009a & 2009b, Beck and Kraus 2010, Coburn et al. 2010, Hafner 2012, Dallas et al. 2013, USACE 2013, NMFS 2014, PSDS 2014, USACE 2014b and the websites of the USACE New York and Philadelphia Districts and NJDEP Coastal Engineering Shore Protection Projects).

Location	Project Length (miles)
Sandy Hook, Gateway NRA	1.16
Sandy Hook to Barnegat Inlet Beach Erosion Control Project: Section 1 – Sea Bright to Ocean Twp.	8.56
Sandy Hook to Barnegat Inlet Beach Erosion Control Project: Section 1, Elberon to Loch Arbour Reach	3.22 P
Sandy Hook to Barnegat Inlet Beach Erosion Control Project: Section 2 - Asbury Park to Manasquan	9.00
Sandy Hook to Barnegat Inlet Beach Erosion Control Project: Section 3 - Point Pleasant, Bay Head, Mantoloking, Brick, Dover, Lavallette, Seaside Heights, Seaside Park, and Berkeley Twp.	11.43[†] P
Bay Head	0.68
Lavallette	0.96
Seaside Heights	0.38
Seaside Park	0.31
Berkeley Twp.[1]	Unknown
Island Beach State Park	0.47
Barnegat Light (Operation Five-High)	1.61
Loveladies (Long Beach Twp.)[2]	Unknown
Barnegat Inlet to Little Egg Inlet: Long Beach Island – Harvey Cedars	1.93
Barnegat Inlet to Little Egg Inlet: Long Beach Island – Surf City and Ship Bottom	1.53
Ship Bottom	1.23
Brant Beach (Long Beach Twp.)	0.62
Barnegat Inlet to Little Egg Inlet: Long Beach Island – Brant Beach	0.98
Beach Haven	1.88
Long Beach Twp.	1.50
Barnegat Inlet to Little Egg Inlet: Long Beach Island (unconstructed sections)	7.25 P
Holgate (Operation Five-High)	1.52
Brigantine Island[3]	3.40
Brigantine / Absecon Inlet North Shore	0.37
Brigantine Inlet to Great Egg Harbor Inlet Project: Absecon Island (Atlantic City & Ventnor City)	5.06
Brigantine Inlet to Great Egg Harbor Inlet Project: Absecon Island (Margate & Longport)	3.05 P
Longport[4]	Unknown
Great Egg Harbor and Peck Beach: Ocean City	4.70

Location	Project Length (miles)
Great Egg Harbor and Peck Beach: Southern Ocean City	2.60 P
Strathmere (Upper Twp.)	1.47
Great Egg Harbor to Townsends Inlet Project: Strathmere (Upper Twp.) & Sea Isle City	3.46‡ P
Sea Isle City	1.62
Avalon (Operation Five-High)	
Townsends Inlet to Cape May Inlet: Avalon	1.44
Townsends Inlet to Cape May Inlet: Stone Harbor	2.30
Stone Harbor Point	0.20 P
North Wildwood	1.43
Wildwood[5]	Unknown
Cape May to Lower Township	3.61
Lower Cape May Meadows	1.35
Cape May Point	1.05
TOTAL MILES	**94.31 (75% of state beaches)**

† The full proposed project area is 13.76 miles (22.14 km) but 2.33 miles (3.75 km) of beach within the proposed project area have received fill in the past; thus only 11.43 miles (18.39 km) of fill would be new modifications.
1 – Berkeley Township received beach fill in 1962, 1966 and 1968 but the project lengths and precise locations are unknown.
2 – The Loveladies section of Long Beach Township has received beach fill in 1962, 1978 and 1992 but the project lengths and precise locations are unknown.
3 – The federal Brigantine Inlet to Great Egg Harbor Inlet: Brigantine Island project has a project length of 1.80 miles (2.90 km) but other beach fills dating to 1962 have extended along 3.40 miles (5.47 km) of beach.
4 – Longport received federal dredge disposal in 1990 but the project length and precise location are unknown.
‡ The full proposed project area is 6.55 miles (10.54 km) but 3.09 miles (4.97 km) of beach within the proposed project area have received fill in the past; thus only 3.46 miles (5.57 km) of fill would be new modifications.
5 – Wildwood received beach fill in 1963 and 1991 but the project lengths and precise locations are unknown.

Delaware

In Delaware, approximately 10.94 miles (17.61 km, 43%) of the sandy oceanfront beaches are developed and 14.42 miles (23.21 km, 57%) are undeveloped (Table 16). The oceanfront beaches of Dewey Beach, Bethany Beach, South Bethany and Fenwick Island 100% developed. The only undeveloped areas of linear oceanfront beach in Delaware are within the state's three state parks and a small portion of Rehoboth Beach.

Over 14 miles (22.5 km) of sandy oceanfront beach in Delaware are in public or NGO ownership in three state parks (Table 17). Delaware Seashore State Park is the longest of the three oceanfront state parks with approximately 6.33 miles (10.19 km) of sandy beach. Fenwick Island State Park is the shortest with just over 3 miles (4.8 km) of sandy beach.

In Delaware there are approximately 3.68 miles (5.92 km) of sandy oceanfront beach shoreline that are armored with hard stabilization structures (Table 18). This 15% of the shoreline includes 20 groins north of Indian River Inlet and 9 groins south of the inlet, dual jetties at Indian River Inlet, and 2 sections of contiguous seawalls / revetments / bulkheads both north and south of the inlet (Table 19). Daniel (2001) mentions a revetment as being present in South Bethany, but no hard structures are visible in Google

Earth imagery from 1992 – 2011 despite the absence of any significant dunes for most of that period of time.

Table 16. The approximate lengths of sandy oceanfront beach within each county of Delaware and the proportions that are developed and undeveloped as of June 29, 2011, according to Google Earth imagery; there no miles of shoreline in this area armored with hard structures with no sandy beach.

County	Approximate total shoreline length in miles	Approximate length of sandy beach (miles)	Developed shoreline miles (% of total)	Undeveloped shoreline miles (% of total)
Sussex	25.36	25.36	10.94 (43%)	14.42 (57%)
TOTAL	**25.36**	**25.36**	**10.94 (43%)**	**14.42 (57%)**

Table 17. Sandy oceanfront beaches that are in public or NGO ownership in Delaware, the county in which each is located, and approximate shoreline length of each (Source: Delaware State Parks website).

Public / NGO Land	County Location	Approximate Beach Length in Miles
Cape Henlopen State Park	Sussex	4.89
Delaware Seashore State Park	Sussex	6.33
Fenwick Island State Park	Sussex	3.01
	TOTAL MILES	**14.23 (56% of state shoreline)**

Table 18. Approximate oceanfront shoreline length (in miles) within each county of Delaware that were armored with hard stabilization structures visible on Google Earth imagery between March 1992 and June 2011 prior to Hurricane Sandy. Hard stabilization structures include groins, jetties, seawalls, bulkheads, revetments, geotubes, sandbags and breakwaters. Structures may be periodically exposed or buried and include those that are failing, in disrepair, or remnants of old structures.

County	Total Length of Shoreline (miles)	Approximate Length of Armoring (miles)	Percentage of Shoreline Armored
Sussex‡	25.36	3.68	15%

‡At Cape Henlopen State Park, there are two World War II towers on the beach that may act like armoring along.

Table 19. Approximate number of each type of armoring visible on the oceanfront beach in Sussex County, Delaware, north and south of Indian River Inlet visible on Google Earth imagery between March 1992 and June 2011 prior to Hurricane Sandy. 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 and its overall length is counted in Table 18 above.

County	Number of Groins	Number of Jetties	Number of Seawalls, Bulkheads and/or Revetments	Number of Geotubes	Number of Breakwaters
Sussex – North of inlet	20	1	2	0	0
Sussex – South of inlet	9	1	2	0	0
TOTAL	**29**	**2**	**4**	**0**	**0**

PSDS (2014) records indicate about half (12.59 out of 25.36 miles, or 20.26 km) of the Delaware coast received federal emergency beach fill following the destructive Ash Wednesday Storm of 1962. Precise locations are not available but exceed the length of current beach fill projects (Table 20). Three federal projects place beach fill in Rehoboth Beach and Dewey Beach (since 2005), Bethany and South Bethany Beaches (since 2008), and Fenwick Island (since 2005). Prior to the start of the federal projects, widespread state-sponsored fill projects were constructed in 1989, 1992, 1994 and 1998 (Daniel 2001, Greene 2002). There is a sediment bypassing plant at Indian River Inlet that bypasses sediment (since 1990) from south to north, depositing material on 0.66 miles (1.06 km) of beach annually; periodically a larger area north of the inlet receives supplemental nourishment fill. Altogether approximately 8.66 miles (13.94 km; 34%) of Delaware's sandy oceanfront beaches have received sediment placement in recent years.

Table 20. The approximate lengths of authorized constructed beach nourishment and dredge disposal placement projects on Delaware oceanfront beaches from north to south (Sources: USACE 2000, Daniel 2001, Greene 2002, NMFS 2014, and PSDS 2014).

Location	Project Length (miles)
Rehoboth Beach and Dewey Beach Storm Damage Reduction Project	2.56
North Indian River Inlet area beach	0.93
North Indian River Inlet Sediment Bypassing	0.66
Bethany Beach and South Bethany Beach Storm Damage Reduction Project	2.83
Sea Colony (Bethany Beach)	0.45
Fenwick Island Storm Damage Reduction Project	1.23
TOTAL MILES	**8.66**[†] **(34% of state beaches)**

[†]Federal emergency beach fill following the 1962 Ash Wednesday Storm extended along 12.59 miles (20.26 km) of Delaware beaches but their precise locations are unknown and are assumed to overlap many if not all of these project areas. Historically, therefore, significantly more than 8.66 miles (13.94 km) of Delaware oceanfront beaches have received beach fill.

Maryland

Of the approximately 31.1 miles (50.05 km) of sandy oceanfront beach in Maryland, 29% (9.00 miles or 14.48 km) has been developed and 71% (22.1 miles or 35.57 km) is undeveloped (Table 21). The development is limited to the beaches of Ocean City and southern Fenwick Island north of Ocean City Inlet, however, where 100% of those 9 miles (14.48 km) of beach is developed. South of Ocean City Inlet, on the other hand, the beaches are 100% undeveloped and entirely in public ownership with Assateague Island National Seashore and Assateague Island State Park (Table 22).

The Maryland oceanfront is the least armored of the states in this assessment, with only 5% (1.62 miles or 2.61 km) of the sandy oceanfront beaches having hard stabilization structures (Table 23). There are two jetties and three breakwaters at Ocean City Inlet (Table 24). A federal hurricane protection project constructed a 1.52 mile (2.45 km) long seawall from 4th to 27th Streets in Ocean City as part of a massive beach fill project that was initiated in 1993 (Schechtman and Brady 2013). The only other armoring structure is a bulkhead on Assateague Island that is thought to have been constructed between 1929 and 1942 along the estuarine shoreline but which is now buried mid-island as the island has migrated landward; it was briefly exposed when an inlet was cut on the northern part of the island during the Ash Wednesday Storm of 1962 (Schupp and Coburn 2015).

Table 21. The approximate lengths of sandy oceanfront beach within each county of Maryland and the proportions that are developed and undeveloped as of November 2011 according to Google Earth imagery; there were no miles of shoreline in this area armored with hard structures with no sandy beach.

County	Approximate total shoreline length in miles	Approximate length of sandy beach (miles)	Developed shoreline miles (% of total)	Undeveloped shoreline miles (% of total)
Worcester	31.10	31.10	9.00 (29%)	22.10 (71%)
TOTAL	**31.10**	**31.10**	**9.00 (29%)**	**22.10 (71%)**

Table 22. Sandy oceanfront beaches that are in public or NGO ownership in Maryland, the county in which each is located, and approximate shoreline length of each (Sources: Schupp et al. 2013, Schupp and Coburn 2015, and the Maryland DNR website).

Public / NGO Land	County Location	Approximate Beach Length in Miles
Assateague State Park	Worcester	2.00
Assateague Island National Seashore	Worcester	20.10
	TOTAL MILES	**22.10 (71% of state shoreline)**

Table 23. Approximate oceanfront shoreline length (in miles) within each county of Maryland that were armored with hard stabilization structures visible on Google Earth imagery between April 1989 and November 2011 prior to Hurricane Sandy and/or identified in Schupp and Coburn (2015). Hard stabilization structures include groins, jetties, seawalls, bulkheads, revetments, geotubes, sandbags and breakwaters. Structures may be periodically exposed or buried and include those that are failing, in disrepair, or remnants of old structures.

County	Total Length of Shoreline (miles)	Approximate Length of Armoring (miles)	Percentage of Shoreline Armored
Worcester	31.1	1.62	5%

Table 24. Approximate number of each type of armoring visible on the oceanfront beach in Worcester County, Maryland, north and south of Ocean City Inlet visible on Google Earth imagery between April 1989 and December 2011 prior to Hurricane Sandy and/or identified in Schupp and Coburn (2015). 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 and its overall length is counted in Table 23 above.

County	Number of Groins	Number of Jetties	Number of Seawalls, Bulkheads and/or Revetments	Number of Geotubes	Number of Breakwaters
Worcester – North of inlet	0	1	1	0	0
Worcester – South of inlet	0	1	1†	0	3‡
TOTAL	**0**	**2**	**2**	**0**	**3**

† The bulkhead located on Assateague Island is presumed to be an old bayside structure that is now buried within the island as the island has migrated landward; it was briefly exposed in 1962 when a breach in the island revealed it (Schupp and Coburn 2015).

‡Note that the three breakwaters are on the Assateague Island shoulder of Ocean City Inlet and are not oceanfront structures; thus their lengths are not included in the total listed in Table 23 above. One breakwater is attached to the southern jetty.

The entire length (100%) of Maryland's oceanfront shoreline has received sediment placement in one form or another (Table 25). A federal hurricane protection project was initially constructed in phases along the full 9.00 mile (14.48 km) long Ocean City shoreline starting in 1988, including the construction of the aforementioned seawall and an artificial dune (Greene 2002, Krantz et al. 2009, PSDS 2014). From 1988 to 2006, Ocean City beaches received approximately 11.92 mcy of beach fill (Krantz et al. 2009). Beach scraping began in Ocean City in the late 1970s when the mayor personally bulldozed sand on the beach in front of threatened condominiums and other structures, initiating a city program of beach scraping while waiting for a federal shore protection project (Morgan 2011). During the 1920s and 1930s sand (including overwash sand that had inundated city streets following a 1933 hurricane) was actually removed from Ocean City for inland construction projects until the city passed and strictly enforced an ordinance requiring one truck load of mainland dirt be deposited on the island for every truck load of sand removed (Morgan 2011).

The entire length of Assateague Island (37.00 miles [59.50 km], 22.10 miles [35.57 km] of which are in MD) has been modified historically, with an artificial dune constructed along virtually its entire length (Schupp and Coburn 2015; Table 25). On the Maryland portion of Assateague Island, the Ackerman / Ocean Beach Club built an artificial foredune in 1950; the 1962 Ash Wednesday Storm damaged the artificial dune line and it was reconstructed in 1963 (Schupp and Coburn 2015). Although only portions of the dune line are currently maintained by the Assateague State Park (2.00 miles or 3.21 km) and the NPS to protect 1.9 miles (3.1 km) of their developed zone, remnants of the historic dune line were still present prior to Hurricane Sandy and interfere with natural coastal processes on the island (Schupp and Coburn 2015). From 1971 to 1986, the USACE deposited dredged material (approximately 300,000 cy total) from Ocean City Inlet channels on Assateague Island, creating spoil dunes southwest of the south jetty; these artificial dunes still are the highest on the island (Schupp and Coburn 2015).

In recent years the long-term erosional impacts caused by the Ocean City Inlet jetties has resulted in a number of restoration projects on Assateague Island. In 1998 a temporary emergency foredune was constructed along 1.5 miles (2.4 km) of the north end of the island. Notches intentionally were cut in the foredune in 2008 and 2009 to allow overwash to periodically penetrate the interior of the island to restore sparsely vegetated habitat for the piping plover (Schupp et al. 2013). In 2002 Phase 1 of the North End Restoration Project was constructed with a one-time beach fill along 6.87 miles (11.05 km) of Assateague Island and was placed seaward of the mean high water line with the intention of replacing approximately 15% of the sediment captured by the inlet and not bypassed to the island since 1934 (Schupp and Coburn 2015). Phase 2 of the North End Restoration Project began in 2004 with sediment dredged from the flood and ebb tidal deltas of Ocean City Inlet and mechanically bypassed by placing the material on the nearshore bar crest and just seaward of the bar along 1.6 miles (2.5 km) of northern Assateague Island; the material is placed approximately 1.5 miles (2.5 km) south of the inlet downdrift of where the ebb shoal attaches to the island. Material has been bypassed twice annually since 2004 (Schupp and Coburn 2015). Although the entire Maryland portion of Assateague Island has been modified with sediment placement historically, since 1998 only 6.87 miles (11.06 km) of the island have been modified in this way.

Table 25. The approximate lengths of authorized constructed beach nourishment and dredge disposal placement projects on Maryland oceanfront beaches from north to south (Sources: Greene 2002, Krantz et al. 2009, Schupp et al. 2013, PSDS 2014, and Schupp and Coburn 2015).

Location	Project Length (miles)
Ocean City	9.00
Assateague Island[1, 2]	21.10
TOTAL MILES	**31.10 (100% of state beaches)**

1 – The Ackerman / Ocean Beach Club constructed an artificial foredune along the entire Maryland portion of Assateague Island in 1950 and rebuilt it in 1963; a federal beach fill project following the Ash Wednesday Storm of 1962 closed storm breaches and constructed dunes along 4.15 miles (6.68 km) of the island. Portions of the island more recently have received fill as part of an emergency storm berm built in 1998 (1.64 miles, or 2.64 km), North End Restoration Project in 2002 (6.87 miles, or 11.06 km), and surf zone / nearshore sediment bypassing annually since 2004 (1.60 miles, or 2.57 km). In addition, the Assateague Island State Park maintains an artificial dune along 2.00 miles (3.21 km) of beach through beach fill, beach scraping, sand fencing, vegetation planting and other methods.

2 - The USFWS constructed an artificial dune along the Green Run / Fox Hills area of the island in Maryland to the southern tip of the island in Virginia for migratory waterfowl management in 1963 for a total project length of 21.85 miles (35.16 km), 7.55 miles (12.15 km) of which are in Maryland.

Virginia

In Virginia, the vast majority of the sandy oceanfront beaches are undeveloped (84%, 89.60 miles or 144.20 km) and only a portion of Wallops Island in Accomack County and then the majority (51%) of the City of Virginia Beach (which is equivalent to a county) are developed (Table 26). The oceanfront beaches of Northampton County along the Eastern Shore barrier islands are 100% undeveloped.

The majority (89%, 95.83 miles, or 154.22 km) of Virginia's sandy oceanfront beaches are in public and/or NGO ownership (Table 27). The Nature Conservancy (TNC) owns and manages most of the barrier islands along the Eastern Shore as part of its Virginia Coast Reserve: Hog Island, Ship Shoal Island, Mink Island, Myrtle Island, Smith Island, Parramore island, Cobb Island, and portions of Metompkin and Cedar Islands. The Chincoteague NWR owns and/or manages the Virginia portion of Assateague Island (16.4 miles or 26.39 km), the Assawoman Island portion of Wallops Island, and sections of Metompkin and Cedar Islands (USFWS 2014d). The state manages the Wreck Island Natural Area Preserve. Fishermans Island NWR is the southernmost of the Eastern Shore barrier islands in public and/or NGO ownership. Just north of the North Carolina state boundary, the state owns False Cape State Park and the USFWS owns Back Bay NWR, together protecting approximately 10 miles (16.09 km) of sandy oceanfront beach.

The length of sandy oceanfront beach found on the Virginia barrier islands is constantly changing with additions and losses in recent years. Wallops Island did not have a beach in front of most of its seawall in late 2011, but a beach fill project in 2012 placed sediment in front of the seawall prior to Hurricane Sandy in October. Nebel et al. (2012) found that Cedar Island has been retreating at an accelerating rate since 1980, possibly due to an increased frequency of tropical storms (Nebel et al. 2013). The long-term (1852-2007) average rate of erosion on Cedar Island is 13.5 feet / year (ft/yr; 4.1 meters / year [m/yr]) but the short-term retreat rate is triple that at 41.3 ft/yr (12.6 m/yr; Nebel et al. 2012). Gaunt (1991), as cited in Nebel et al. (2012), found that Cedar Island is narrowing and lost 32% of its subaerial area between 1910 and 1986. Overwash is actively moving sediment towards the marsh on the backside of the island and

Table 26. The approximate lengths of sandy oceanfront beach within each county of Virginia and the proportions that are developed and undeveloped. The difference between the total shoreline length and the length of sandy beach is the length of shoreline that had no sandy beach present as of September 2011 according to Google Earth imagery; 0.93 miles (1.50 km) of Cobb Island in Northampton County had no sandy beach due to shoreline erosion into forest.

County	Approximate total shoreline length in miles	Approximate length of sandy beach (miles)	Developed shoreline miles (% of total)	Undeveloped shoreline miles (% of total)
Accomack[1]	48.44	48.44	2.78 (6%)	45.66 (94%)
Northampton	31.34	30.41	0 (0%)	30.41 (100%)
Virginia Beach	27.55	27.55	14.02 (51%)	13.53 (49%)
TOTAL	**107.33**	**106.40**	**16.80 (16%)**	**89.60 (84%)**

1 - Wallops Island, which merged with Assawoman Island when Assawoman Inlet closed, is 5.9 miles (9.50 km) long but as of September 2011 only 3.56 miles (5.73 km) of the island had a sandy beach; the remaining portion of the island was armored with no beach. A beach fill project created a beach in front of the seawall from April to August 2012 prior to Hurricane Sandy. The total island length is included as having a sandy beach here.

creates extensive overwash fans (Nebel et al. 2012, 2013, and Gaunt 1991 and Newman and Munsart 1968 as cited in Nebel et al. 2013), indicating that the island is migrating landward. Richardson and McBride (2007), as cited in Nebel et al. (2012), found that erosion rates on Parramore Island have also accelerated since 1994, from a long-term rate (1852-2006) of 11.8 ft/yr (3.6 m/yr) to a short-term (1998-2006) rate of 28.9 ft/yr (8.8 m/yr). "Cedar and Parramore Islands are retreating at a rate that is anomalously high for the mid-Atlantic shoreline" (Nebel et al. 2012, p. 339).

Table 27. Sandy oceanfront beaches that are in public or NGO ownership in Virginia, the county in which each is located, and approximate shoreline length of each (Sources: USFWS 2010, USFWS 2014d, and multiple online websites for individual public / NGO lands).

Public / NGO	County / City Location	Approximate Beach Length in Miles
Chincoteague NWR	Accomack	16.40
Wallops Island NASA Flight Center[1]	Accomack	5.90
Assawoman Island Unit, Chincoteague NWR	Accomack	3.16
unnamed islet in Gargathy Inlet	Accomack	0.10
Metompkin Island - Chincoteague NWR & TNC Virginia Coast Reserve	Accomack	6.75
Cedar Island Unit, Chincoteague NWR & TNC[2]	Accomack	7.78
Dawson Shoals (islet in Wachapreague Inlet)	Accomack	0.54
Parramore Island Natural Area Preserve, TNC	Accomack	7.81
Hog Island, TNC Virginia Coast Reserve	Northampton	7.81
Cobb Island, TNC Virginia Coast Reserve[3]	Northampton	5.16
Wreck Island Natural Area Preserve	Northampton	3.48
Ship Shoal Island, TNC Virginia Coast Reserve	Northampton	2.51
Mink Island, TNC Virginia Coast Reserve	Northampton	0.25
Myrtle Island, TNC Virginia Coast Reserve	Northampton	1.68
Smith Island, Virginia Coast Reserve	Northampton	7.45
Fishermans Island NWR	Northampton	3.00
Joint Expeditionary Base Little Creek, Fort Story	City of Virginia Beach	1.54
Naval Air Station Oceana Dam Neck Annex	City of Virginia Beach	4.00
Little Island Park	City of Virginia Beach	0.55
Back Bay NWR	City of Virginia Beach	4.30
False Cape State Park	City of Virginia Beach	5.66
	TOTAL MILES	**95.83 (89% of state shoreline)**

1 –Wallops Island, which merged with Assawoman Island when Assawoman Inlet closed, is 5.9 miles (9.50 km) long but as of September 2011 only 3.56 miles (5.73 km) of the island had a sandy beach; the remaining portion of the island was armored with no beach. A beach fill project created a beach in front of the seawall from April to August 2012 prior to Hurricane Sandy. The total island length is included here.

2 - An unknown portion of Cedar Island is privately owned but undeveloped. The Chincoteague NWR and TNC own a number of island parcels. The total island length is included here.

3 - Cobb Island is 5.16 miles (8.30 km) long but as of September 2011 only 4.23 miles (6.81 km) of the island had a sandy beach; the remaining portion of the island had eroded into forest. The total island length is included here.

Approximately 11.24 miles (18.09 km; 10%) of the Virginia coast is armored with hard erosion control structures (Table 28). Wallops Island has a long history of hard stabilization, or armoring, efforts to protect federal facilities on the island (King et al. 2010). A seawall was first constructed on the island in 1945-46 with steel sheet pile; the seawall has been rebuilt and expanded several times since then. Between 1956 and 1972, 47 groins were constructed on the island. King et al. (2010) found that several of the groins, most of which were failing or in poor condition, were removed when the seawall was improved in the mid-1990s. King et al. (2010) does not specify how many of the groins were removed. Google Earth imagery from March 1994 shows 45 groins or portions of groins present on the island, but more recent imagery only shows a portion of the southernmost groin at the southern end of the runway; it is not known whether the other 46 groins were removed or if they are still present but buried in sand, fully submerged, or detached from the island as the southern shoreline eroded landward. A geotube revetment or seawall initially was constructed in 2006 south of the existing seawall and subsequently has been repaired or rebuilt in sections (King et al. 2010). From August 2011 to March 2012, the rock seawall was extended by 1,415 ft (431.29 m) to the south and future extensions were proposed as funds became available up to 4,600 ft (1,402.08 m; BOEM 2012). After completion of the extension, the stone seawall extended for approximately 3.12 miles (5.02 km) and the geotube revetment or seawall extended south from the seawall another approximate 0.62 miles (1.00 km).

Other areas of Virginia that have armoring are Joint Expeditionary Base Little Creek (JEB), Fort Story, where there is a revetment, 3 groins and 19 detached breakwaters; Virginia Beach which has a 3.79 mile (6.10 km) long seawall; dual jetties at Rudee Inlet and a revetment on the Croatan inlet shoulder; and a 1 mile (1.61 km) buried seawall at the Naval Air Station Oceana Dam Neck Annex. In addition, Sandbridge in the City of Virginia Beach has a long history of private bulkheads and seawalls. Basco (1992) found 4.8 miles (7.7 km) of seawalls / bulkheads in 15 contiguous sections, but a number of these seawalls were in poor condition or failed prior to the construction of a beach fill project in 1998. At least 29 sections of contiguous seawalls / bulkheads were identified in this assessment totaling approximately 1.17 miles (1.88 km); more may exist but are not visible in aerial imagery through 2011 due to burial by the beach fill project. An additional 6 detached breakwaters covering 0.25 miles (0.40 km) of sandy oceanfront beach were proposed in 2011 for construction at JEB Fort Story.

Approximately 30.79 miles (49.55 km; 29%) of sandy oceanfront beach in Virginia have received sediment placement in one form or another since 1951. The Virginia portion of Assateague Island, consisting of Chincoteague NWR, was modified with an artificial dune line constructed for migratory

Table 28. Approximate oceanfront shoreline length (in miles) within each county of Virginia that were armored with hard stabilization structures visible on Google Earth imagery between March 1989 and September 2011 prior to Hurricane Sandy. Hard stabilization structures include groins, jetties, seawalls, bulkheads, revetments, geotubes, sandbags and breakwaters. Structures may be periodically exposed or buried and include those that are failing, in disrepair, or remnants of old structures.

County / City	Total Length of Shoreline (miles)	Approximate Length of Armoring (miles)	Percentage of Shoreline Armored
Accomack	48.44	4.08	8%
Northampton	31.34	0	0
Virginia Beach	27.55	7.16†	26%
TOTAL	**107.33**	**11.24**	**10%**

†An additional 0.25 miles (0.40 km) of shoreline were proposed for armoring in 2011 at JEB Fort Story.

Table 29. Approximate number of each type of armoring visible on the oceanfront beach in coastal Virginia prior to Hurricane Sandy (visible on Google Earth imagery between March 1989 and September 2011). Note that multiple seawalls, bulkheads or revetments are counted as one structure if they are continuous with no separations; for example, if five individual adjacent 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 and its overall length is counted in Table 28 above.

County / City	Number of Groins	Number of Jetties	Number of Seawalls, Bulkheads and/or Revetments	Number of Geotubes	Number of Breakwaters
Accomack	Up to 47	0	1	1	0
Northampton	0	0	0	0	0
Virginia Beach	3	2	32 +	0	19†
TOTAL	**Up to 50**	**2**	**33 +**	**1**	**19**

†An additional 6 breakwaters were proposed for JEB Fort Story by the Navy in 2011.

waterfowl management purposes first built in the 1950s and then expanded to the oceanfront in 1963 along the refuge's entire length (~14.3 miles or 23.01 km) plus approximately 7.5 additional miles (12.07 km) along the Maryland portion of the island (Schupp and Coburn 2015, USFWS 2014d). Refuge staff maintained the artificial dune line from the 1960s to the 1990s. Approximately 2.5 miles (4.02 km) of the artificial dune that were eroded in a 1992 storm near the north beach parking lot were rebuilt and planted with beach grass in 1993 (Schupp and Coburn 2015, USFWS 2014d). Then Chincoteague NWR's 1993 Master Plan "de-emphasized" maintenance of the artificial dune and has since then limited its maintenance to "selected areas to provide protection to facilities and wildlife habitat" (USFWS 2014d, p. N-6). "At present, Assateague Island's artificial dune system ranges from non-existent south of the beach parking lots, to well-developed with small gaps ocean-side of North Wash Flats and Old Fields Impoundments" (USFWS 2014d, p. N-6).

Historical information in Barnes and Truitt (1997) indicate that Cobb Island may have been modified with sediment placement in the 1840s when Nathan F. Cobb initially purchased and developed the island. Barnes and Truitt (1997, p. 74) reprinted an 1877 account from Joseph F. Morgan, in which the latter wrote "In 1840, there was not five acres of the Island that the sea did not wash over at high tide. A greater part of the Island has been reclaimed by Mr. Cobb, by bringing boat loads of earth from the main land of Virginia." If this account is accurate, it would very likely make Cobb Island the oldest sediment placement project on the East Coast. No other sediment placement has taken place on the island, which is currently owned by TNC.

Portions of the Virginia Beach shoreline have received sediment placement on an annual basis since 1951 (Fenster and Dolan 1999, PSDS 2014), perhaps the most frequently nourished beach on the East Coast. Ward et al. (1989, p. 152) describe Virginia Beach's operation as the "oldest, continuous beach nourishment program on the East Coast." Over 12.89 mcy of material was deposited on the beaches of Virginia Beach between 1951 and 1996. Sediment is bypassed annually across Rudee Inlet from south to north, and material dredged and stockpiled from Lynnhaven Inlet on the Chesapeake Bay shoreline frequently is hauled by truck to Virginia Beach beaches. The federal Beach Erosion and Hurricane Protection Plan was initially constructed along 6.00 miles (9.66 km) of oceanfront from 1996 to 2002, with an improved seawall from the inlet north to 58th Street and beach fill and/or dune construction along the entire project length (Fenster and Dolan 1999, Virginia Beach Beaches and Waterways Advisory Commission 2002, USACE Norfolk District website).

Dune breaches at the Back Bay NWR are to be closed as soon as possible immediately east of the impoundment complex, but no specific episodes are provided in the refuge's Comprehensive Conservation Plan (USFWS 2010). A beach fill project for the Wallops Island Flight Facility was proposed in 2010 (King et al. 2010) and was constructed from April to August 2012 prior to Hurricane Sandy (BOEM 2013). The project constructed 3.73 miles (6.00 km) of beach fill with approximately 3.2 mcy of material dredged from offshore and placed in front of an extended seawall that had no sandy beach plus in front of a geotube revetment that had some sandy beach; portions of the seawall were buried under an artificial dune as part of the project (King et al. 2010, BOEM 2013).

Table 30. The approximate lengths of authorized constructed beach nourishment and dredge disposal placement projects on Virginia oceanfront beaches from north to south. Shaded rows with a "P" in the length column are projects proposed prior to Hurricane Sandy but not yet constructed (Sources: Lillycrop et al. 1988, Fenster and Dolan 1999, Greene 2002, Virginia Beach Beaches and Waterways Advisory Commission 2002, King et al. 2010, NMFS 2012, PSDS 2014, Schupp and Coburn 2015, and the USACE Norfolk District website).

Location	Project Length (miles)
Assateague Island / Chincoteague NWR[1]	14.3
Wallops Island[2]	3.10
Wallops Island breach closure	0.43
Virginia Beach Beach Erosion and Hurricane Protection Project	6.00
Naval Air Station Oceana Dam Neck Annex	1.76
Sandbridge Hurricane Protection and Beach Nourishment Project	5.00
TOTAL MILES	**30.79 (29% of state beaches)**

1 – The USFWS constructed an artificial dune along the Green Run / Fox Hills area of the island in Maryland to the southern tip of the island for migratory waterfowl management in 1963 for a total project length of 21.85 miles (35.16 km), 14.30 miles (23.01 km) of which are in Virginia.

2 – The total project length of beach fill extended for 3.73 miles (6.00 km) of beach but overlaps an artificial breach closure at its southern end that was completed after the Ash Wednesday Storm of 1962; therefore only 3.10 miles (4.99 km) are beach fill in new areas.

DISCUSSION

A substantial proportion of the sandy oceanfront beaches within the Montauk, NY, through Virginia section of the breeding range of the piping plover have been developed (44%), filled with sediment (at least 57%) and armored (28%). These habitat modifications tend to occur in the same locations as each other, resulting in localized adverse cumulative effects. When combined with the habitat modifications to the tidal inlets within the same region (results of Rice 2014), significant cumulative loss and degradation of piping plover habitat has resulted; for example on areas such as the New York – New Jersey oceanfront coast where 95% of the inlets have been armored and/or dredged, 56% of the oceanfront beach has been developed, at least 65% has received sand placement, and 40% of the beach has been armored. The number of beach nourishment projects is increasing in virtually every state (Trembanis et al. 1998, Bush et al. 2004, USFWS 2009), resulting in an increasing magnitude of habitat modification. This assessment did not include other forms of habitat modification, such as dune building and maintenance (using non-fill methods), vegetation plantings, beach scraping (using bulldozers to push up artificial levees or "dunes" with sediment from the beach), the maintenance and protection of coastal roads, and the alterations caused by driving ORVs on beaches and dunes. However, all of these activities occur throughout the assessment area and cumulatively they increase the adverse effects on habitats used by piping plovers and other wildlife that use sandy oceanfront beach habitat.

Many oceanfront communities in this assessment area have 100% development along their oceanfronts. In New York, 24 communities are completely developed. Another 33 communities in New Jersey are 100% developed along their oceanfront. Four of the five oceanfront communities in Delaware are 100% developed. Maryland's Ocean City is 100% developed. Only one community in Virginia (Sandbridge) is 100% developed along its oceanfront. Development modifies sandy oceanfront beach habitat, leading to habitat loss, fragmentation and degradation. McCormick et al. (1984, p. 73) state that "From Long Beach [NY] west to the tip of Coney Island, unrestrained development has buried marsh, dunes and beach beneath a layer of pavement and buildings … The city of Long Beach is a remarkable example of the speed with which a natural barrier can be obliterated by development."

In the *National Assessment of Shoreline Change: Historical Shoreline Change along the New England and Mid-Atlantic Coasts*, Hapke et al. (2010, p. 52) state that:

> *As coastal communities continue to grow along the New England and Mid-Atlantic coast, potential conflicts will continue to arise between preservation of property (typically privately owned) and conservation of the beach (typically publicly owned). Past social responses indicate that these conflicts will likely be resolved through a combination of beach nourishment projects and shoreline protection structures. Both of these engineering responses to erosion alter the natural beach processes and eventually lead to artificial shoreline positions. … Many beaches are already altered by shoreline protection projects and more are likely to be altered in the future.*

Mitteager et al. (2006, p. 890) describe how private oceanfront property owners in developed areas of New Jersey have modified the natural dune system and its vegetation, including how structures such as bulkheads, boardwalks and walls "interrupt the natural environmental gradient." They found that "The landward portions of natural dunes and their vegetation were eliminated in many municipalities to accommodate development. Dunes that are now seaward of buildings are truncated portions of natural dunes or, more commonly, new dunes created artificially using sand fences, vegetation plantings, or earth-moving equipment" (Mitteager et al. 2006, p. 890). "Dunes on private lots are generally lower and less mobile than municipally managed foredunes, and contain more shrubs than natural dunes would have at similar distances from the sea" (Mitteager et al. 2006, p. 890). Although only some of these types of modifications (i.e., armoring structures) are included in this assessment, all of these types of modifications contribute to the cumulative impacts of human modifications to sandy oceanfront beaches on which the piping plover and many other species depend. Mitteager et al. (2006) provides recommendations on how to minimize some of these impacts on a local, lot-by-lot, basis.

Several barrier islands in this assessment area have been modified with sediment placement since their first development, in massive projects that modified entire landscapes. In the 1840s, Cobb Island, VA, was reportedly modified with large volumes of sediment imported from the mainland to raise the island's elevation for development by Nathan Cobb (Barnes and Truitt 1997). In 1908-09, dredges pumped marsh and bay sediments onto Long Beach Island, NY, to construct the foundation for its development; the massive sediment placement regraded the island to a 10 ft (3 m) elevation on the ocean side and a 4 ft (1.2 m) elevation on the bayside (McCormick et al. 1984). "The dredging operation was regarded as the biggest ever undertaken with the exception of the Panama Canal, and the amount of lumber moved was so great that elephants were employed in the task" (McCormick et al., p. 75). In 1926, Jones Island received over 40 mcy of sediment dredged from South Oyster Bay (which created the State Boat Channel), raising the mid-line elevation of the island to 14 ft (4.3 m) as the new Jones Beach State Park was constructed with “one of the biggest dredging jobs in America” (Hanc 2007, p. 14). Tanski (2012) estimated that 128 mcy of sediment have been placed on Long Island’s oceanfront beaches since the 1920s.

Artificial dunes are often constructed to protect development along the oceanfront. Artificial dunes were constructed along entire barrier islands in the 1950s and 1960s, including both the Maryland and Virginia portions of Assateague Island. The federal Operation Five-High rebuilt more than 72 miles (116 km) of beaches and dunes following the Ash Wednesday Storm of 1962. Artificial dune lines are maintained and protected by local or state laws in many places. Federal sediment placement projects typically include the construction of artificial dunes. Local communities construct artificial dunes with fill material hauled in by truck or pumped in with dredged material, use armoring to protect dune faces, or scrape sand from the beach to rebuild dunes. Miles of sand fencing and vegetation plantings are used to maintain these artificial dunes in place. (Sand fencing is also utilized to trap windblown sediment and build dunes in a more natural method, but those efforts are not included in the sediment placement projects described in this assessment but will be included in the post-Sandy assessments.) Mitteager et al. (2006, p. 892) state that the regulation in New Jersey protecting dunes “is written for shore protection, not habitat, aesthetic or heritage value. Direct disturbance to the dunes that would reduce their dimensions is prohibited, but sand can be added by earth-moving equipment, and vegetation may be planted.”

Magliocca et al. (2011, p. 918) describe these type of modifications to sandy oceanfront barrier islands:

> *Interactions between human manipulations and landscape processes can form a dynamically coupled system because landscape-forming processes affect humans, and humans increasingly manipulate landscape-forming processes. Despite the dynamic nature of sandy barrier islands, economic incentive and recreational opportunities attract humans and development. Storm-driven sediment-transport events that build barrier islands constitute hazards to humans and infrastructure, and manipulations aimed at preventing or mitigating such events link human actions and long-term island morphodynamics.*

Magliocca et al. (2011, p. 918) investigated “how the behavior of a natural barrier island differs from one in which humans are dynamic system constituents,” focusing on the impacts of removing overwash deposits following storms and rebuilding artificially high and continuous dunes. They conclude that (Magliocca et al. 2011, p. 928):

> *(1) Artificially high dunes filter out high-frequency, small-scale storm impacts, which result in less overwash deposition over time. The introduction of artificially high dunes drives the overwash regime toward less-frequent and higher-amplitude overwash events. Storms that finally overtop artificial dunes impact a back-barrier environment that is lower than it would otherwise have been, which amplifies the severity of the overwash or inundation.*
>
> *(2) The long-term exclusion of overwash from the back-dune environment tends to amplify the effects of sea level rise because island elevation landward of the dune line is fixed despite continuously rising sea levels. Reconstruction of artificial dunes, by mining the overwash deposits, reinforces relatively low island elevations for long periods. In the [human/barrier island] coupled system, flooding frequency increases as the difference between storm-induced water levels and island elevations relative to sea level grows.*
>
> *(3) The obstruction of overwash decreases the availability of on-site sand for dune reconstruction. As the heights of maintained dunes increase, sand must be imported from off-site and at a higher rate …. Road relocation— the consequence of*

significant coverage or washout of the roadbed due to overwash—occurs more frequently as artificial dune height increases ….

(4) The natural system migrates landward relatively continuously …, but the [human/barrier island] coupled system's back-barrier shoreline is fixed for long periods. The disruption of overwash promotes thinning of the island as the seaward shoreline migrates landward (caused by sea-level rise, gradients in alongshore sediment flux, and low-frequency overwash events), whereas the back-barrier shoreline moves very little.

The authors found that the construction and maintenance of artificial dunes block minor and moderate overwash events, resulting in a narrower and lower island in the long-term. Then "when dunes are overtopped, the sediment redistributions are more severe. …Increasing the height of artificially maintained dunes increases the rate of island narrowing and, therefore, infrastructure relocation, and increases the need for sediment to be imported from outside the system" (Magliocca et al. 2011, p. 918).

Large scale sediment placement projects may have similar long-term impacts. Tanski (2012, p. 23) states that for Long Island's oceanfront beaches, "Since inlets are the primary mechanisms for transferring sediment landward along Long Island's barrier island systems, nourishment projects that cover large areas and are maintained for very long periods of time could lower the rate of cross shore sand transport and, eventually, affect barrier island migration … [but] it [is] very difficult to determine how a nourishment project might alter long-term barrier migration rates or how long it would take." These so-called "soft" stabilization methods of using fill material to modify sandy oceanfront beaches and dunes therefore may result in long-term impacts to the natural system.

In recent years, sediment placement projects have been constructed in front of armoring. The impacts of shoreline armoring can be adverse, far-reaching and long-term. The impacts of hard stabilization structures on oceanfront beaches have been described by McCormick et al. (1984), Kraus (1988), Pilkey and Wright (1988), Terchunian (1988), Weggel (1988), Ward et al. (1989), Hall and Pilkey (1991), Bush et al. (1996), USACE (2002) and many others. Shore-parallel structures such as seawalls, bulkheads and revetments often lead to the loss of the beach in front of the seawall (McCormick et al. 1984, Pilkey and Wright 1988, Hall and Pilkey 1991, Bush et al. 1996, USACE 2002, Hapke et al. 2010). Ward et al. (1989, p. 59) state that "In most settings, if a beach is desired in front of a wall, it most likely will have to be nourished from time to time, as the wall cuts off the immediate sand source for the beach."

Tanski (2012, p. 21) states that while shore parallel structures like seawalls, bulkheads and revetments may not have adverse impacts on natural beach processes in areas where the shoreline is accreting or stable in the long-term and the sediment supply is adequate, in areas where there is a sediment deficit and chronic erosion, "armoring the shoreline can adversely affect the beach and adjacent areas unless other measures are also taken to mitigate their impacts. These measures might include bringing in additional sand to make up for the sand impounded or retained by the structure. … [S]hore armoring structures usually lead to a narrowing of loss of the beach … because they prevent the beach from migrating landward." When the shore parallel structure is eventually flanked by a receding shoreline on either side, the wall structure then protrudes onto the beach and can act as a groin and cause downdrift erosion by blocking sediment transport along the beach (Tanski 2012).

"The New Jersey shoreline, in many places stabilized for longer than a century, provides evidence of the degradational effect of hard stabilization on recreational beaches. The impact is apparent whether structures involved are shore parallel or shore perpendicular. On the other hand, there are a number of areas where no beach would exist at all if it were not for sand retention behind groins or jetties" (Hall and Pilkey 1991, p. 782). In their New Jersey study, Hall and Pilkey (1991, p. 782) concluded that:

For the open ocean coast of New Jersey, the dry beach width is narrower on beaches stabilized by hard structures compared to unstructured beaches. The width of dry beach also appears to be a function of the density of hard stabilization: the greater the density of stabilizing structures, the narrower the beach. Dry beaches with seawalls, bulkheads, and revetments are the narrowest. Groins are also present on most of these seawalled beaches. Due to simultaneous occurrences of both types of structures, we were not able to separate the effects of shore parallel from shore perpendicular structures, it is interesting to note that approximately 51% of areas that are seawalled have no beach, except in a few cases where groins have trapped sand on the updrift side.

It should be noted that the Hall and Pilkey (1991) findings predate the large scale beach fill projects on the New Jersey shore, which reconstructed beaches in the most of the areas they surveyed. Pilkey and Wright (1988, p. 41) also found that "dry beach width is consistently and significantly narrower in front of walls. The more dense the hard stabilization, the narrower the beach."

McCormick et al. (1984) describes a process they call the "New Jerseyization" of beaches, where shoreline armoring leads to more and larger armoring until eventually the shoreline is lined with armored structures with no beaches or only small pockets of beaches on the updrift sides of groins. "Each groin, each seawall, each revetment reduces the sand supply, which results in increased shoreline erosion somewhere else in the system" (McCormick et al. 1984, p. 31). McCormick et al. (1984, p. 38) list a series of "Truths of the Beach," one of which is "Shoreline engineering destroys the beach it was intended to save."

Weggel (1988, p. 32) states that "It is clear that the shoreline at Seabright [sic] would today be significantly different if the seawall had not been built. It would undoubtedly be located much further landward and the existing houses and roadway would long ago have been destroyed … [but] it can be deemed a success from an engineering viewpoint" since the wall's purpose was to protect buildings and the roadway. "By halting erosion at Seabright [sic], the wall has reduced the supply of sediment reaching Sandy Hook and caused erosion there" (Weggel 1988, p. 33). This finding was made prior to the massive beach fill project, which constructed a new beach in front of the seawall in 1995.

Terchunian (1988, p. 65) characterizes the coastal armoring issue by stating "On a chronically eroding shoreline, coastal armoring structures may lead to degradation of the beach/dune system in front of and adjacent to these structures resulting in a loss of both the recreational and natural protective values of the beaches and dunes." Terchunian (1988, p. 65) outlines a process for calculating "the amount of beach sand which would be required to mitigate the potential adverse impacts of the coastal armoring structures," thereby allowing for beach fill requirements to be estimated in advance to offset the erosion impacts of the structures.

Many seawalls, bulkheads and revetments in New York and New Jersey are a century old, as noted by Hall and Pilkey (1991) and Dallas et al. (2013), clearly documenting that the impacts of shore-parallel armoring structures can be long-term. In more recent decades, sediment placement projects have been undertaken to reconstruct lost beaches in front of these walls. Large scale sediment placement projects modify sandy, oceanfront beaches as well as those downdrift from the individual project areas. Beck and Kraus (2010), for example, describe how the stabilization, dredging and geologic setting of Shark River Inlet, NJ, precluded the inlet from having an ebb tidal delta until adjacent beaches began to receive beach fill in 1997 (beaches to the south) and 2000 (beaches to the north). This led to the formation of an ebb tidal delta in the early 2000s, which has formed a sediment transport pathway around the dual jetties at the inlet. The beach fill altered the system from sediment-starved to one in which shoaling has increased maintenance dredging needs at the inlet. The authors predict that it will take more than a decade for the ebb tidal delta to reach equilibrium, noting that the periodic dredging with mechanical bypassing to the beaches to the north interrupts the delta's evolution. Thus the beach fill project generated positive and negative downdrift impacts – positive in that sediment transport is being restored at a stabilized inlet and restoring adjacent habitats, negative in the increased dredging needs and their concomitant habitat disturbances.

Armoring structures that are built perpendicular to the beach, namely groins and jetties, also adversely impact sandy, oceanfront beaches. Groins cause downdrift erosion (McCormick et al. 1984, Ward et al. 1989, USACE 2002, Rankin et al. 2004). This invariably results in groins being constructed in fields, where the downdrift impact can be shifted farther down the beach. Tanski (2012, p. 20) discusses the impacts of groins, stating that "The magnitude of the impact increases as the length and height of the [groin] structure and the rate of longshore transport increase. To help minimize adverse impacts of these structures, sand should be placed on the … updrift side of the [groin] structure to create a protective beach. This helps minimize the disruption of the flow of sand along the coast (but does not necessarily eliminate all the impacts)." McCormick et al. (1984) and Rankin et al. (2004) also describe how the larger a groin is, the greater the downdrift erosion impacts.

Rankin et al. (2004, p. 237) states that "Unacceptable erosion of the downdrift beaches can occur if the groins are sufficiently long so that alongshore-moving sediment cannot bypass the structure. Attempts have been made to reduce the erosion in the lee of a groin by shortening, notching, or removing the entire groin to increase the bypassing of sand to downdrift beaches." The USACE *Coastal Engineering Manual* (USACE 2006, pp. V-3-59 to V-3-78) describes the downdrift impact of groins and states that even when filled with beach fill, groins will still cause some amount of downdrift erosion.

Ward et al. (1989) recommend that if groins are constructed, they should be low-profile; that is, the groins are highest in elevation on land and their height tapers lower as you move offshore. In this way, longshore sediment transport can be less interrupted after the groin cell is roughly half full, decreasing downdrift erosion impacts.

Another recent method to reduce the downdrift impacts of groins is to notch them. Donohue et al. (2004) and Rankin et al. (2004) monitored the effectiveness of notching 35 groins that were located within the Sandy Hook to Barnegat Inlet Beach Erosion Control Project, Section 1 – Sea Bright to Ocean Township, New Jersey. The New York District of the USACE notched groins that were identified as too long and potentially deleterious to the massive fill project along 8.56 miles of shoreline. The groins were notched in order to minimize their downdrift erosional impacts and increase the groins' ability to allow sediment to move downdrift. The monitoring concluded that notching can be effective in bypassing sediment depending on the location and design of the notches.

Rice (2009) and USFWS (2012) provide additional best management practices and conservation measures to avoid, minimize and mitigate the adverse impacts of sediment placement and armoring projects on sandy oceanfront beaches.

Finally, ~ 225 miles (362 km) of sandy oceanfront beaches between Montauk, NY, and the Virginia-North Carolina border are in public and/or NGO ownership. These lands are not uniformly distributed throughout this area however. Virginia has the highest number of miles of land in public or NGO ownership, covering 89% of the state's shoreline. From Ocean City Inlet, MD, to the mouth of the Chesapeake Bay, the Delmarva Peninsula has 13 contiguous barrier islands in public and/or NGO ownership. Federal and state lands have been especially important as limiting development of sandy oceanfront beach habitat in this assessment area. For example, the Fire Island and Assateague Island National Seashores and Gateway National Recreation Area contribute over 43.64 miles (70.23 km) of protected sandy beaches. National Wildlife Refuges have also preserved sandy oceanfront beaches in the assessment area, most notably on Edwin B. Forsythe (NJ), Chincoteague (VA), Fishermans Island (VA) and Back Bay NWRs. State parks total over 51 miles (83 km) of sandy oceanfront beaches between Montauk, NY, and the Virginia-North Carolina state line. State Natural Areas add another approximately 15 miles (24 km) of sandy oceanfront beach in public ownership. This protection does not equate to pristine, undisturbed, and unmodified habitat, however, because many public lands have been and continue to be modified by armoring, beach nourishment and placement of dredge disposal, permitted ORV use, protection and maintenance of coastal roadways and historic structures, the potential for incompatible activities on non-federal inholdings, creation and maintenance of artificial dune ridges, and closure of new inlets. Although they are generally shorter in length than the federal and state lands, lands owned by county and local governments collectively make an important contribution to the total inventory of publicly and NGO-owned lands.

The area with the least modified habitat is on the Virginia barrier islands, which stands in stark contrast to the highly modified beaches in the other states to the north. The Virginia barrier islands historically have eroded much faster than the rest of the mid-Atlantic coast, however (Nebel et al. 2013). Fenster et al. (2011) theorize that as sea level rise continues to accelerate, tidal inlets may widen, more sand may be sequestered in ebb shoals, and the Virginia barrier islands in particular may fragment as new inlets open and the islands rapidly retreat. Thus the extent of sandy beach habitat provided by the Virginia barrier islands may change in the future with sea level rise. This inventory of public and NGO-owned lands can be used to identify geographic gaps where conservation efforts may be prioritized to maintain and increase overall habitat availability and quality as sea level rises and climate changes.

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