Storm-induced Habitat Modifications caused by Hurricane Sandy within the U.S. Atlantic Coast Breeding Range of the Piping Plover (*Charadrius melodus*)[1]

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

The aforementioned reports inventoried the abundance and distribution of tidal inlet and sandy beach habitat, as well as anthropogenic modifications to both habitat types. This report assesses the *storm-induced* modifications to tidal inlet and sandy beach habitats caused by Hurricane Sandy, which made landfall in New Jersey on October 29, 2012. Additional future reports will assess the status of these two habitats, including new anthropogenic habitat modifications, in the U.S. Atlantic Coast breeding range of the piping plover 3 years after Hurricane Sandy.

INTRODUCTION

Hurricane Sandy made landfall as the largest Atlantic hurricane on record on October 29, 2012, as a strong Category 1 storm on the Saffir-Simpson Scale near Brigantine, New Jersey (Blake et al. 2013, Halverson and Rabenhorst 2013, Coch 2014, Sopkin et al. 2014, Schubert et al. 2015). As Hurricane Sandy moved north in the Atlantic Ocean in late October, the storm became an

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extratropical cyclone[2] with features of both a hurricane (its inner core) and a very large nor'easter (its extremely large size, ~1000 miles wide), making it a hybrid storm that was referred to by some as Superstorm Sandy (Halverson and Rabenhorst 2013).

Hurricane Sandy made landfall during a period of some of the highest tides of the year (during the fall full moon) that added to the storm's surge, resulting in record flood levels in the New York City metropolitan area (Blake et al. 2013, Halverson and Rabenhorst 2013, Schubert et al. 2015).

> *Sandy caused water levels to rise along the entire east coast of the United States from Florida northward to Maine. The highest storm surges and greatest inundation on land occurred in the states of New Jersey, New York, and Connecticut, especially in and around the New York City metropolitan area. In many of these locations, especially along the coast of central and northern New Jersey, Staten Island, and southward-facing shores of Long Island, the surge was accompanied by powerful damaging waves. (Blake et al. 2013, p. 8).*

Hurricane Sandy storm surge affected the entire U.S. Atlantic Coast breeding range of the piping plover, with peak water levels ranging from 1 to 9 feet (ft; 0.3 to 2.74 meters [m]) above ground level[3] (Blake et al. 2013, Table 1).

Tropical storm-force winds stretched from Wallops Island, VA, to Montauk, NY at the time the storm made landfall; over the entire course of the storm and its path, tropical storm-force winds affected the Atlantic coast from Maine to Florida (Blake et al 2013, Sopkin et al. 2014). Offshore waves exceeded 30 ft (9.1 m) as the storm approached and made landfall (Sopkin et al. 2014). Hurricane Sandy damaged or destroyed at least 650,000 buildings and caused at least $50 billion in damages (Blake et al. 2013, Halverson and Rabenhorst 2013). Blake et al. (2013, p. 17) found that "the extent of catastrophic damage along the New Jersey coast was unprecedented in the state's history."

Recovery Task 1.2 of the U.S. Fish and Wildlife Service (USFWS) Recovery Plan for the piping plover prioritizes the maintenance of "natural coastal formation processes that perpetuate high quality breeding habitat," specifically discouraging the "construction of structures or other developments that will destroy or degrade plover habitat" (Task 1.21), and the "interference with natural processes of inlet formation, migration, and closure" (Task 1.22) (USFWS 1996, pp. 65-66). The USFWS's most recent 5-Year Review for the piping plover recommends increasing

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[2] Blake et al. (2013, pp.3-4) describes the difference between tropical and extratropical cyclones: "The primary distinction between tropical and extratropical cyclones is their energy source. Tropical cyclones derive their energy predominantly from the release of latent heat of condensation relatively close to the center, while extratropical cyclones rely mainly on baroclinic processes (large-scale temperature contrasts between warm and cold air masses)."

[3] Peak water levels during a storm such as Hurricane Sandy can be measured and reported in various ways, including the height of floodwaters above mean high water (MHW), above sea level, above mean lower low water (MLLW), or local ground level. Using the peak water level above ground level takes into account varying land elevation and tidal ranges, and includes both the storm surge and the height of the astronomical tide. This measurement reflects the peak height of the floodwaters if a person (or bird) were standing on the barrier island or beach in that location during the storm.

Table 1. Peak water levels above ground level during Hurricane Sandy in the U.S. Atlantic Coast breeding range of the piping plover, from Blake et al. (2013).

Area	Peak water level above ground level (ft)
Maine	1 to 2
New Hampshire	1 to 2
Massachusetts	2 to 4
Rhode Island	3 to 5
Connecticut:	
Fairfield and New Haven Counties	4 to 6
Middlesex and New London Counties	3 to 5
New York:	
Staten Island and Manhattan	4 to 9
Kings County (Coney Island to Manhattan Beach)	3 to 6
Queens County (Breezy Point to Far Rockaway)	3 to 6
Nassau County	3 to 6
Suffolk County	
New Jersey:	
Monmouth County	4 to 9
Ocean County	3 to 5
Atlantic County	2 to 4
Cape May County	2 to 4
Delaware	3 to 5
Maryland	2 to 4
Virginia	2 to 4
North Carolina	3 to 5

"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).

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

Storm-induced habitat modifications are a result of natural coastal processes during a storm such as a hurricane or nor'easter, as opposed to anthropogenic habitat modifications that are caused by human activities. Storm-induced habitat modifications include the opening of new inlets or temporary storm breaches, the closure of existing inlets, alterations to the width or depth of an inlet, scarping or erosion of dunes, burial or removal of vegetation, changes in the elevation of the beach or adjacent upland area, ephemeral ponding in low-lying areas, hidden changes to the underwater areas adjacent to a beach, and overwash deposits. Cohen et al. (2009, pp. 16-17) confirmed evidence from earlier studies that "piping plover habitat area can be increased by major storms and that plover populations may respond quickly to such enhancements."

Overwash deposits sediment on the landward portion of a beach, within the dune system and adjacent upland areas, and sometimes extends across an island or barrier spit to bury marsh on the bayside shoreline, extending the shoreline farther into the bay or sound. Overwash deposits raise the elevation of the beach and/or upland area, which can reduce the likelihood of future flooding events and make those habitat areas more resilient (less vulnerable) to future flooding events and rising sea level. Overwash deposits or scour of sediments by storm surge floodwaters can expand bare sand or sparsely vegetated habitat areas, refreshing older bare sand or sparsely vegetated areas where vegetation succession was reducing the size of those areas. Ultimately overwash creates new potential nesting areas for several species of birds, including the piping plover. Where overwash extends to the bayside shoreline, new foraging habitat may be created as well. These areas can be especially valuable to piping plovers that "prefer nesting adjacent to moist substrates including bay intertidal flats" (Cohen et al. 2009, p. 17). Cohen et al. (2009) found that new storm-created bayside intertidal flats attracted piping plovers to a new nesting area and were preferentially used by for foraging by piping plover chicks, and that access to such flats may increase the carrying capacity of adjacent breeding sites.

Overwash deposits may be composed of sand, gravel or boulders. The smaller the sediment grain size (e.g., sand versus gravel or boulders), the farther inland the material can be moved and deposited as overwash (Morton 2002). Coastal vegetation impedes the impacts of storm washover because roots bind the soil together and exposed vegetation slows down overwash currents and waves; as a result, denser vegetation inhibits overwash deposits and erosion (Morton 2002). "In marshes fronting the ocean, sand can be stripped from the subaerial beach [fronting the marsh] and deposited in the adjacent marsh grasses leaving mud exposed on the beach. This response is common ... on … mud-dominated coastal regions or transgressive barriers such as along the Eastern Shore of Virginia" (Morton 2002, p. 489).

Overwash[4] deposits can be thick fanlike deposits, thin veneers of sand, widespread sheets or washover terraces[5] (Nelson 1991, Morton and Sallenger 2003). High winds drive currents in the storm surge floodwaters, influencing the types of overwash deposits that form and how far inland they penetrate. Morton (2002, p. 488) describes how "high vegetated dunes can preclude the penetration of storm surge, and simultaneously divert the high-velocity flow into adjacent low-lying areas that become washover conduits." Hall and Halsey (1991) found that overwash penetration onto and beyond a barrier beach increases significantly in areas with high long-term erosion rates[6], lower elevation landward of the beach, and large, open areas of pavement (e.g., parking lots, streets) that are oriented perpendicular to the beach.

Coastal development "can accentuate the destructive forces of [a] storm," by structures deflecting and focusing storm surge currents, increasing turbulence of the floodwaters, and thus increasing deep, local scouring of the beach and dune system (Morton 2002, p. 492). Small, wood buildings that are spaced widely apart and are elevated have minimal impacts on storm processes. But large buildings, swimming pools and shoreline stabilization structures that are closely spaced together and constructed of concrete or other hard materials increase local erosion (Morton 2002). "Because hard structures do not store and release sand like dunes, more sand erodes from the beach to satisfy the capacity of the strong waves and currents" (Morton 2002, p. 492). If developers lower or remove dunes, past storm events have shown that washover penetration is much greater than in areas where development did not lower the height of the dunes (Morton 2002). In areas where dunes have been artificially created, erosion of the sediment within the dunes is likely to be faster than in natural dunes:

> *Constructing artificial sand dunes and stabilizing them with native plants are popular activities associated with many shoreline protection and beach nourishment projects. However, artificial dunes do not necessarily respond the same way to storm processes as natural dunes. Even when indigenous species are planted on artificial dunes, the roots may remain shallow because the plants did not grow while the dunes aggraded. Consequently, artificial dunes can be less resistant to wave attack and erosion than natural dunes, and as a result they may erode more rapidly than natural dunes* …. (Morton 2002, p. 489).

Morton et al. (1994) describe four phases of beach recovery following a hurricane: (1) quick accretion of the forebeach[7] and reconstruction of the beach berm, (2) accretion of the

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[4] "Overwash" is also known as "washover."

[5] A washover terrace is an elongated deposit of sediment parallel to the beach or where a series of overwash fans merge together in a contiguous deposit. Washover terraces may be of uniform width or have highly irregular landward margins and tend to form in areas with vegetation and low and relatively uniform (low or no dunes) inland elevations (Morton 2002, Morton and Sallenger 2003).

[6] Dolan and Hayden (1981) found a correlation between long-term erosion rates and how far overwash deposits penetrated inland during the Ash Wednesday Storm of 1962, which Hall and Halsey (1991) also found in South Carolina during Hurricane Hugo. Morton and Sallenger (2003) argue that the use of long-term erosion rates as an indicator of where overwash may be most significant is due to the common correlation of high erosion rates with areas of minimal to no dunes, which block overwash. Stable or accreting beaches facilitate construction of dunes, which tend to prevent overwash penetration to inland areas.

[7] The forebeach is the portion of the beach located seaward of the berm crest.

backbeach[8], (3) dune formation, and (4) expansion of the dunes and recolonization by vegetation. These four stages of recovery are only observed at undeveloped beaches, however. Developed beaches only reach stage 2 because the presence of beachfront buildings prevents the post-storm beach from being wide enough to form dunes. "Where sand is abundant and shorelines are either stable or accreting, the beach and vegetation line will eventually return to their pre-storm positions. Conversely, where sand supply is deficient and shorelines are undergoing long-term erosion, the beach and vegetation line will not recover entirely. In fact on highly erosional coasts, the vegetation line may remain in its most landward position until the next erosional event causes further landward retreat" (Morton et al. 1994, p. 900). On Galveston Island, Texas, post-hurricane recovery of the beach system took 4 to 5 years following Hurricane Alicia (category 3) in 1983. After then the beach system returned to its long-term erosional trend.

The American Littoral Society (ALS; 2012) found that one of the significant impacts of Hurricane Sandy was that the storm created new habitat and moved existing habitat in CT, NY, NJ and DE. Where storm-induced habitat modifications open and close inlets or create overwash deposits, new habitat for shorebirds and waterbirds such as the piping plover can be created. Wilcox (1959) found that major storms increased the area of nesting habitat for piping plovers on the South Shore of Long Island; the Great Hurricane of 1938 in particular created a 3 mile (4.8 km) long nesting area near the new Shinnecock Inlet and a 4 mile (6.4 km) long nesting area east of Moriches Inlet. The number of piping plovers nesting on the beach from Moriches Inlet to the village of Southampton increased after the 1938 hurricane created new nesting habitat, but gradually declined after 1942 when artificial dunes began to be constructed and stabilized with vegetation, which converted unvegetated nesting areas to vegetated sand dunes (Wilcox 1959). "After the grass covered the sand dunes again, most of the nesting plovers left the area for more suitable habitat" (Wilcox 1959, p. 135). "By 1951 there were hardly any plovers nesting at Moriches Bay in their former nesting area, in part because of the growth of grass, but mainly because of the extensive building of summer homes in this area, leaving no large dry sand areas, except one of about a mile just east of Moriches Inlet" which would become Cupsogue County Park (Wilcox 1959, p. 135). Wilcox (1959, p. 136) also found a 5 mile (8 km) stretch of beachfront between Shinnecock Inlet and Mecox Bay where piping plovers did not nest "owing to a built up section of summer homes and absence of sandy areas." Thus major storms have a positive impact by creating new nesting habitat for the piping plover, but the human response (constructing and vegetating artificial dunes) to the storm and development of the bare sand habitat negatively impacted the nesting habitat.

Hurricane Sandy was a major storm that impacted a large portion of the U.S. Atlantic Coast breeding range of the piping plover. Storms create valuable habitat for beach-nesting species such as the piping plover (Wilcox 1959, Cohen 2009) and are part of a natural process that allows beaches and barrier islands to adapt to sea level rise. Some of these storm-induced habitat modifications can be measured by comparing the distribution of sandy beach and tidal inlet habitats before (as summarized in Rice 2015d) and immediately after the storm. This study assesses the types, amount, and distribution of Hurricane Sandy's immediate changes to tidal inlet and sandy beach habitat for the piping plover and beach-dependent species. An additional

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[8] The backbeach is the portion of the beach located landward of the berm crest, generally extending to the toe of the dune or erosional scarp.

study assessing the human response to Hurricane Sandy (i.e., anthropogenic habitat modifications) during the three years after the storm will be forthcoming.

METHODS

A variety of aerial photography was taken immediately following Hurricane Sandy and is publicly available (Table 2). Google Earth contains imagery taken on November 1, 2, 3 and 5 within days of the storm, covering much of Connecticut, all of the Long Island Sound and Peconic Estuary shorelines of New York, the Atlantic Ocean shoreline of New York, and most of New Jersey. The National Geodetic Service (NGS) of the National Oceanic and Atmospheric Administration (NOAA) provides imagery of most of Connecticut, most of the Long Island Sound shoreline of New York, all of the Atlantic Ocean shorelines of New York and New Jersey, most of the Atlantic Ocean shoreline of Maryland, and the Atlantic Ocean shoreline of Virginia from the mouth of the Chesapeake Bay to the North Carolina state boundary. The NOAA-NGS imagery was flown in a series of flights on October 31 through November 6, 2012.

The United States Geological Survey (USGS) has oblique aerial photographs of the Atlantic Ocean coastline from Montauk, New York, to Beaufort Inlet / Shackleford Banks, North Carolina. The USGS aerial photographs were taken between November 4 and 6, 2012. The Program for the Study of Developed Shorelines (PSDS) at Western Carolina University also has oblique aerial photographs, along much of the South Shore of Long Island, NY, as well as New Jersey and portions of Delaware, Maryland, Virginia and North Carolina; PSDS also documented on-the-ground storm-induced landscape changes along some portions of the Long Island South Shore. The PSDS aerial photographs were taken on October 31, November 1 and November 9, 2012; the on-the-ground photographs were taken on November 26, 2012. Out of 619.04 miles (996.25 kilometers [km]) of sandy beach habitat measured by Rice (2015d) in CT, NY, NJ and MD prior to Hurricane Sandy, 589.52 miles (948.74 km; 95%) had aerial imagery available immediately after Hurricane Sandy that allowed measurement of storm-induced modifications to sandy beach habitat.

These imagery sources were surveyed to identify the location of any new tidal inlets or storm breaches, and the closure of any inlets that were open prior to Hurricane Sandy (as identified in Rice 2014 & 2015a). Google Earth placemarks were created to mark the location of all new inlets and breaches.

Overwash areas were identified and measured in Google Earth for all areas for which aerial imagery was available: CT from Old Lyme westward, along all 3 shorelines in NY, all of NJ, and all but the southernmost 3.53 miles (5.68 km) of MD. The length of sandy beach modified by overwash was calculated by measuring the length of overwash closest to the beach. This position was roughly in alignment with the dune or vegetation line that existed prior to the storm. Overwash areas may widen inland from the point of measurement, but the spatial area of overwash deposits landward of the beach was not measured and was beyond the scope of this analysis (see Hapke et al. 2013 for such an analysis for Fire Island, NY). For the purposes of this study, the focus was the length of sandy beach identified in Rice (2015b) and (2015c) that was

Table 2. Several sources of imagery taken immediately after Hurricane Sandy are publicly available and were utilized to document storm-induced habitat modifications to sandy beach and tidal inlet habitats within the U.S. Atlantic Coast breeding range of the piping plover. Each source covers different ranges of the coast from Connecticut to North Carolina.

Source	Imagery Dates (2012)	Coverage Areas
Google Earth	November 1, 2, 3 and 5	• CT from Old Lyme west • LIS shoreline of NY • Peconic Estuary shoreline of NY • Atlantic Ocean shoreline of NY • NJ from Beach Haven north
NOAA- NGS (http://storms.ngs.noaa.gov/storms/sandy/)	October 31 through November 6	• CT from Old Lyme west • LIS shoreline of NY from Baiting Hollow west • Atlantic Ocean shoreline of NY • NJ • MD from 69th Street in Ocean City to ~3.5 miles north of the VA-MD border • VA from Fisherman's Island south
USGS (http://coastal.er.usgs.gov/hurricanes/sandy/post-storm-photos/obliquephotos.html)	November 4 through 6	Atlantic Ocean shoreline from Montauk, NY, to Beaufort Inlet, NC
PSDS (https://picasaweb.google.com/psdspix)	October 31, November 1 & November 9 (aerial) November 26 (ground)	• Atlantic Ocean shoreline of NY from West Hampton Dunes to Breezy Point • NJ • Delaware Bay shoreline • DE • MD • Chincoteague, Metompkin, Cedar and Parramore Islands, VA • NC north of Ocracoke

modified by overwash. Erosion or retreat of the dune or vegetation line was not considered overwash. By focusing on the width or length of overwash paths at the backbeach, quantification of the length of new or enhanced habitat for beach-nesting birds could be calculated. In locations where bare sand or sparsely vegetated areas pre-existed landward of the beach (e.g., older overwash deposits), overwash was only counted if there was a noticeable increase in the size of the area or a decrease in the density of vegetation, resulting in significant storm-induced habitat modification to that particular location. It should be noted that because the spatial area of the overwash patches was not measured, the suitability of each overwash area as new or enhanced potential nesting habitat is variable; the nesting suitability of a small overwash fan deposited on the landward side of a beach access path at the end of a street, for instance, would not be the same as a large overwash terrace or fan deposited on an undeveloped barrier island.

Length measurements were made in feet and converted to miles using the “ruler” or “path” tool of Google Earth. The individual dates of Google Earth imagery and eye altitude (i.e., the level of zoom) from which measurements were made were recorded; the latter was typically 800 to 1,000 feet above ground level.

Where overwash occurs in a developed area, the overwash deposit loses its potential as nesting habitat and for the purposes of this assessment is considered a lost opportunity. It was assumed that an overwash deposit in a developed area would be removed or disturbed by adjacent development activities (e.g., rebuilding damaged structures) that would render the overwash area unsuitable as beach-nesting bird habitat (although that may not always be the case). In the absence of development, it is assumed that those overwash areas would have created new potential nesting habitat. Therefore the length of beach that was modified by overwash deposits was measured and subdivided into developed and undeveloped beach categories, allowing an assessment of both the amount of storm-induced habitat modifications to sandy beach habitats and the proportion of which were in developed areas where the opportunity for new habitat was precluded.

The lengths and locations of sandy beaches following Hurricane Sandy were compared to the lengths and locations of the sandy beaches existing prior to Hurricane Sandy (as identified in Rice 2015b & 2015c). A Microsoft Excel database of all data was created, with the data organized by geographic area. Data were compiled on a community/municipal basis to facilitate comparison with the pre-hurricane data.

Published sources including peer-reviewed literature, government agency reports and permits, also were used to identify storm-induced habitat modifications throughout the U.S. Atlantic Coast breeding range of the piping plover. Numerous reviewers provided comments on a draft of this assessment in order to verify and correct details, where necessary, and are listed in the Acknowledgements section.

RESULTS

Tidal Inlet Habitat

Prior to Hurricane Sandy, 399 tidal inlets were open in the U.S. Atlantic Coast breeding range of the piping plover, from Maine to North Carolina (Rice 2015d). Hurricane Sandy opened at least 33 tidal inlets and storm breaches, 5 of which were pre-existing inlets that periodically open and close that were re-opened by the storm (Table 3, Figure 1). Four tidal inlets were closed by Hurricane Sandy – two in Connecticut, and one each New York and Virginia (Table 4, Figure 2).

The 33 new tidal inlets and storm breaches opened during Hurricane Sandy were distributed throughout the U.S. Atlantic Coast breeding range. One inlet opened in CT and another in RI. No new inlets opened along the Long Island Sound shoreline of NY. The Peconic Estuary shoreline of NY had one-third (11) of the new inlets opening along its sandy beaches. The South Shore of Long Island (NY) had 6 new inlets open. Seven (7) new inlets or storm breaches opened along the NJ coast. No new inlets opened along the DE or MD coasts. Along the Eastern Shore of Virginia, 5 new tidal inlets opened. At the southern end of the U.S. Atlantic Coast breeding range, 2 new inlets opened in NC.

Of the 33 new tidal inlets and storm breaches opened by Hurricane Sandy, more than half of them (18) were located at coastal ponds[9]. An inlet re-opened at Trustom Pond in RI, where an inlet frequently connects the pond with the ocean; when an inlet does not open naturally at

Figure 1. Hurricane Sandy opened an inlet at Chincoteague NWR in Virginia, north of the causeway. Image from USGS (2015) dated November 4, 2012.

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[9] A Google Earth .kmz file mapping the locations of all the new inlets and closures of old inlets is available on the North Atlantic LCC website at http://northatlanticlcc.org/projects/beach-resiliency/increasing-resiliency-of-beach-habitats-and-species.

Table 3. Tidal inlets and storm breaches opened by Hurricane Sandy within the U.S. Atlantic Coast breeding range of the piping plover from north to south. No new inlets are known to have opened in Maine, New Hampshire, or Massachusetts during Hurricane Sandy.

Inlet Name	State	Community	Location Description
unnamed inlet to Trustom Pond†	RI	South Kingstown	Trustom Pond NWR
unnamed inlet at Griswold Point spit	CT	Old Lyme	east end of Griswold Point spit where attached to mainland, east of Great Island and west of White Sands Beach
unnamed breach 1 at Mashomack Preserve	NY-Peconic	Shelter Island	unnamed pond on Majors Harbor on Shelter Island, Peconic Estuary
unnamed breach 2 at Mashomack Preserve	NY-Peconic	Shelter Island	less than 100 ft north of Log Cabin Creek (Inlet) on Shelter Island, Peconic Estuary
unnamed breach 3 at Mashomack Preserve	NY-Peconic	Shelter Island	approx. 200 ft north of Log Cabin Creek (Inlet) on Shelter Island, Peconic Estuary
unnamed inlet at Long Beach Bay Tidal Wetlands Area (TWA)	NY-Peconic	Orient	approx. 1,900 ft northwest of the inlet to Long Beach Bay
unnamed inlet to Tobaccolot Pond on Gardiners Island	NY-Peconic	Gardiners Island	Tobaccolot Pond, Gardiners Island, Peconic Estuary
unnamed inlet to Gales Pond on Gardiners Island	NY-Peconic	Gardiners Island	Gales Pond, Gardiners Island, Peconic Estuary
unnamed inlet to Little Pond on Gardiners Island	NY-Peconic	Gardiners Island	north end of Little Pond, Gardiners Island, Peconic Estuary
unnamed inlet to Cherry Hill Pond on Gardiners Island	NY-Peconic	Gardiners Island	Cherry Hill Pond, Gardiners Island, Peconic Estuary
unnamed inlet 1 on south spit off Gardiners Island	NY-Peconic	Gardiners Island	south spit to Cartwright Island from Gardiners Island, Peconic Estuary
unnamed inlet 2 on south spit off Gardiners Island	NY-Peconic	Gardiners Island	south spit to Cartwright Island from Gardiners Island, Peconic Estuary

Inlet Name	State	Community	Location Description
unnamed inlet to Bostwick Pond on Gardiners Island	NY-Peconic	Gardiners Island	Bostwick Pond, Gardiners Island, Peconic Estuary
Georgica Inlet†	NY-Atlantic	Wainscott & East Hampton	Georgica Pond at the boundary between Wainscott and East Hampton
Mecox Inlet†	NY-Atlantic	Water Mill & Bridgehampton	Mecox Bay at the boundary between Water Mill and Bridgehampton
Sagaponack Inlet†	NY-Atlantic	Bridgehampton & Village of Sagaponack	Sagaponack Pond at the boundary between the Village of Sagaponack and Bridgehampton
unnamed breach at Cupsogue County park	NY-Atlantic	Town of Brookhaven	approx. 1,700 ft east of the Moriches Inlet jetty at Cupsogue County Park
unnamed breach at Smith Point County Park (aka Coast Guard Cut)	NY-Atlantic	Town of Brookhaven	approx. 16,300 ft (3.1 miles) west of the Moriches Inlet jetty at Smith Point County Park
Unnamed breach in the Otis Pike Fire Island High Dune Wilderness	NY-Atlantic	Town of Brookhaven	Fire Island NS
Sea Girt Inlet	NJ	Spring Lake & Sea Girt	Wreck Pond at the boundary between Spring Lake and Sea Girt
unnamed storm breach at Lyman Street in Mantoloking	NJ	Mantoloking	Lyman Street
unnamed storm breach north of Herbert Street in Mantoloking	NJ	Mantoloking	approx. 600 ft north of the Herbert St. & Rte 35 intersection
unnamed storm breach at Herbert Street in Mantoloking	NJ	Mantoloking	Herbert Street
unnamed storm breach 1 at Holgate spit	NJ	Holgate	approx. 2,400 ft south of the Holgate - Beach Haven boundary
unnamed storm breach 2 at Holgate spit	NJ	Holgate	approx. 6,100 ft (1.16 miles) south of the Holgate - Beach Haven boundary

Inlet Name	State	Community	Location Description
unnamed storm breach 3 at Holgate spit	NJ	Holgate	approx. 9,200 ft (1.75 miles) south of the Holgate - Beach Haven boundary
unnamed inlet at Little Toms Cove at Chincoteague NWR	VA	Chincoteague	approx. 1,000 ft north of the Beach Road (2113) causeway access to Chincoteague NWR
unnamed inlet at Toms Hook, Chincoteague NWR	VA	Chincoteague	Approx., 4,000 ft (0.75 miles) southeast of Chincoteague Inlet
unnamed inlet on Hog Island	VA	Hog Island	approx. 2.5 miles south of Quinby Inlet at the south end of an unnamed pond or lagoon
unnamed inlet 1 on Fisherman Island	VA	Fisherman Island	A small coastal pond approx.. 5,500 ft (1.04 miles) southeast of the Chesapeake Bay Bridge
unnamed inlet 2 on Fisherman Island	VA	Fisherman Island	A coastal pond approx.. 4,000 ft (0.75 miles) southeast of the Chesapeake Bay Bridge
unnamed inlet at Cape Hatteras Point in Cape Hatteras NS†	NC	Buxton	A pair of connected coastal ponds immediately west of Cape Hatteras Point
New Old Drum Inlet at Cape Lookout NS	NC	Portsmouth	Approx.. 1,800 ft north of the inlet's position when it closed in 2009

† Five of the inlets opened by Hurricane Sandy are at locations where inlets periodically open and close, both naturally and artificially (Rice 2014, 2015a). Two of these inlets (Georgia and Mecox Inlets) are included in the list of 399 inlets open prior to Hurricane Sandy due to their semi-permanent status.

Table 4. Tidal inlets that were closed by Hurricane Sandy within the U.S. Atlantic Coast breeding range of the piping plover from north to south.

Inlet Name	State	Community	Location Description
Goshen Cove Inlet[1]	CT	Waterford	Harkness Memorial State Park (SP)
Nettleson Creek Inlet	CT	Milford	Silver Sands SP
Oyster Pond Inlet	NY-Peconic	Montauk	Oyster Pond
unnamed inlet on Myrtle Island	VA	Myrtle Island	Middle of Myrtle Island

1 – ALS (2012) reported that the inlet to Goshen Cove was closed by Hurricane Sandy.

Figure 2. An unnamed inlet on Myrtle Island, Virginia, was closed by Hurricane Sandy. The inlet had opened naturally in 2009 (Rice 2014). The storm overwashed the island and filled the tidal channel connected to the inlet with sediment, visible on the left side of the image. Sediment subsequently filled in the seaward portion of the inlet. Image from USGS (2015) dated November 4, 2012.

Trustom Pond, one is often cut artificially (Rice 2015a). Trustom Pond is within the Trustom Pond National Wildlife Refuge (NWR). Three new inlets were opened on coastal ponds on Shelter Island in the Peconic Estuary of NY – one at an unnamed pond and two at the pond where Log Cabin Creek (Inlet) was pre-existing; all 3 inlets were located within The Nature Conservancy's (TNC's) Mashomack Preserve. Four new inlets were opened on coastal ponds on the private Gardiner's Island in the Peconic Estuary of New York: at Tobaccolot, Gales, Little, and Bostwick Ponds. Along the South Shore of Long Island, inlets were opened to Georgica Pond, Mecox Bay and Sagaponack Pond. Each of these ponds is periodically connected to the Atlantic Ocean via inlets that open and close naturally as well as artificially (Rice 2014). Sea Girt Inlet, which historically connected Wreck Pond in NJ with the Atlantic Ocean, was re-opened by Hurricane Sandy. An inlet was opened to an unnamed pond on Toms Hook at Chincoteague NWR and another on Hog Island in Virginia. Finally, two inlets were re-opened to unnamed ponds on Fisherman Island in Fisherman Island NWR in Virginia and a third to a pair of connected coastal ponds at Cape Hatteras Point in NC.

A few of the new tidal inlets, such as the storm breaches at Holgate within the Edwin B. Forsythe NWR in NJ, were in the process of closing naturally when the aerial imagery was taken within days of the storm. Some of the inlets were closed artificially within days or weeks of the storm. The status of all of the new tidal inlets and storm breaches opened and closed by Hurricane Sandy will be assessed in a future report(s) that inventories habitat modifications to tidal inlet habitat within the U.S. Atlantic Coast breeding range of the piping plover 3 years after Hurricane Sandy.

Prior to Hurricane Sandy, each of the 33 inlets and breaches were sandy beach habitat. Each of these locations shifted habitat types from sandy beach to tidal inlet following Hurricane Sandy. Most of the new inlets and breaches were small and narrow, with only 14 of them exceeding 100 ft (30 m) or more in width immediately after the storm opened them. Altogether, ~11,560 ft (2.19 miles) of sandy beach habitat was converted to open water tidal inlet habitat at 32 locations[10]. This conversion from beach to inlet habitat is a snapshot of the habitat changes immediately following the storm. The new inlets often form recurved spits on their shoulders and tidal shoal deposits that can regain and even increase the amount of sandy beach habitat available at the location after the storm. If the new inlet naturally closes within days to months, the inlet's recurved spits and shoal deposits can increase bayside unvegetated habitat in the long-term. These changes will be assessed in the forthcoming study summarizing habitat changes three years after Hurricane Sandy.

The four inlets that were closed during Hurricane Sandy were small and narrow. Where the four inlets were closed, tidal inlet habitat was converted to ~407 ft (0.08 miles) of sandy beach habitat. In sum, the 32 (of 33) new inlets and 4 closed inlet resulted in a decrease of ~11,150 ft (2.19 miles) of sandy beach habitat immediately following the storm. Because some of the inlets shifted in size and position over time, or as some closed naturally, this ~11,150 ft decrease in sandy beach habitat was ephemeral and represents a snapshot in time of a storm-induced habitat modification within 8 days of Hurricane Sandy.

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[10] Imagery was not available for Rhode Island's shoreline immediately following Hurricane Sandy; therefore the inlet opened at Trustom Pond is not included in this measurement.

Sandy Beach Habitat

Sandy beach habitat in the U.S. Atlantic Coast breeding range of the piping plover was naturally modified by Hurricane Sandy in several ways. In addition to the conversion of some sandy beach habitat to tidal inlet habitat described above, sandy beach habitat was modified by storm-induced changes to the presence or absence of dry sandy beach, the lengths of sandy beach on inlet shoulders and barrier spits, and overwash. Modifications to the beach profile, nearshore bathymetry, and any adjacent dune systems were beyond the scope of this assessment.

Hurricane Sandy made landfall near Atlantic City / Brigantine, New Jersey, and as a result the most modifications to the sandy beach habitat in the U.S. Atlantic Coast breeding range of the piping plover occurred closest to the storm. No significant modifications to sandy beach habitat were observed in Maine (Slovinsky et al. 2013; Mark McCollough and Kate O'Brien, USFWS, pers. communication, October 29, 2015). It is assumed no significant overwash occurred in New Hampshire, either, due to the distance of those beaches from the storm. Storm-induced habitat modifications occurred in MA and RI, but aerial imagery was not available for those states and thus the modifications were not quantifiable. Birchler et al. (2014) reported flooding and overwash in Falmouth, MA. Storm reports submitted to MyCoast.org[11] documented some overwash (both sand and gravel) and/or minor structural damages in Salisbury, Rockport, Westport, Mashpee, Falmouth, Fairhaven, Martha's Vineyard and Nantucket. Significant beach erosion occurred along the south shores of Martha's Vineyard, Nantucket and in some locations in Buzzards Bay (Rebecca Haney, MA Office of Coastal Zone Management, pers. communication, October 29, 2015). No significant modifications to the sandy beaches of Cape Cod, MA, were observed (Kate Iaquinto, USFWS, pers. communication, October 29, 2012).

The RI Office of Housing and Community Development (2013) reported that the southern coastal communities of Westerly, New Shoreham (Block Island), Charlestown, South Kingstown, Narragansett and Newport suffered the most damage from Hurricane Sandy in Rhode Island, including some areas of overwash. The sandy beaches in Westerly and South Kingstown, particularly those in Misquamicut and Roy Carpenter Beach respectively, had extensive overwash. Due to a lack of post-storm aerial imagery, this overwash could not be quantified, however.

In Connecticut, there were 82.16 miles (132.22 km) of sandy beach habitat prior to Hurricane Sandy, for which 65.56 miles (105.51 km; 80%) have aerial imagery available immediately following the storm (Table 5). Of the 65.56 miles (105.51 km) of sandy beach habitat for which imagery is available, 24.94 miles (40.14 km; 38%) were modified by the storm. Overwash modified 20.18 miles (32.48 km) of sandy beach habitat[12], of which 27% was located in developed beachfront areas and 73% in undeveloped beachfront areas (Table 5). Another 4.76

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[11] MyCoast.org is an online database to document coastal conditions and damages during storms and seasonally high (king) tides. The public can submit photographs and geo-referenced observations of coastal conditions. Database partners include state and municipal agencies. As of October 2015, the states of Maine, New Hampshire, Massachusetts, Rhode Island, Connecticut and South Carolina participate in MyCoast.org.

[12] ALS (2012) reported that areas of eastern Connecticut for which imagery was not available also were modified by Hurricane Sandy, including the beaches at Bluff Point Coastal Reserve and Mumford Cove in Groton; Harkness Memorial State Park in Waterford; Rocky Neck State Park and Pattagansett Marsh Preserve in East Lyme; and Hatchetts Point Natural Area in Old Lyme.

Table 5. Hurricane Sandy modified sandy beaches within the U.S. Atlantic Coast breeding range of the piping plover by depositing overwash on and directly adjacent to the beaches. Overwash modifications occurred in both developed and undeveloped beachfront areas. Where overwash modified sandy beaches in developed areas, it is assumed that the development precludes use of the new bare sand or sparsely vegetated habitat as nesting habitat for shorebirds and waterbirds; thus the proportion of overwash located in developed areas represents a lost opportunity to increase the amount of nesting habitat available following Hurricane Sandy.

State	Proportion of Sandy Beaches with Imagery	Approximate Length of Sandy Beach Modified by Overwash (miles)		Total Approximate Length of Sandy Beach Modified by Overwash (miles)	Proportion of Sandy Beach Length Modified by Overwash
		Developed Beachfront	Undeveloped Beachfront		
CT	65.56 of 82.16 miles (80%)	5.48	14.70	20.18	31%
NY - LIS	111.27 of 120.66 miles (92%)	0.71	3.41	4.12	4%
NY - Peconic	134.98 of 134.98 miles (100%)	0.14	10.64	10.78	8%
NY - Atlantic	124.88 of 124.88 miles (100%)	13.84	15.00	28.84	23%
NJ	125.26 of 125.26 miles (100%)	23.34	9.64	32.98	26%
MD	27.57 of 31.10 miles (88%)	0.19	5.74	5.93	22%
TOTAL	**589.52 of 619.04 (95%)**	**43.70**	**59.13**	**102.83**	**17%**

miles (7.66 km) of sandy beach habitat was modified through movements of inlet shoulders and spits, loss or gain of dry sandy beach habitat seaward of hard shoreline stabilization structures[13], and the opening and closure of inlets. The net change in the length of sandy beach in the areas of Connecticut for which aerial imagery was available was a decrease of 1.23 miles (1.98 km).

There were 120.66 miles (194.18 km) of sandy beach habitat along the Long Island Sound shoreline of NY prior to Hurricane Sandy, for which 111.27 miles (179.07 km; 92%) have aerial imagery available immediately following the storm (Table 5). Of the 111.27 miles (179.07 km) of sandy beach habitat with imagery, ~6.78 miles (10.91 km; 6%) were modified by the storm. Overwash modified an estimated 4.12 miles (6.63 km) of sandy beach habitat, of which 17% was

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[13] In many areas dry sandy beach habitat was lost seaward of hard stabilization structures including seawalls, bulkheads and revetments following Hurricane Sandy. In other areas a dry sandy beach was present after Sandy seaward of hard stabilization structures where sandy beaches had not been observed prior to the storm (Rice 2015b, 2015d). Because the most recent aerial imagery available for this area prior to Hurricane Sandy was March 2012 (except for NJ where it was December 2010 or July 2011), some of these gains and losses in sandy beach habitat seaward of hard stabilization structures may be due to seasonal changes and may not be directly attributable to Hurricane Sandy.

located in developed beachfront areas and 83% in undeveloped beachfront areas. Overwash along the Long Island Sound beaches of NY is restricted to those beaches without bluffs, because the high elevation of the bluffs prevents overwash from occurring. As a result, the only overwash that occurred along the Long Island Sound shoreline of NY was located at or near inlets and barrier spits. Another ~2.65 miles (4.26 km) of sandy beach habitat was modified through movements of inlet shoulders and spits, plus loss or gain of dry sandy beach habitat seaward of hard shoreline stabilization structures (see footnote 12, page 16). No sandy beach habitat was converted to tidal inlet habitat (or vice versa) along the Long Island Sound shoreline of NY. The net change in the length of sandy beach in the areas of the Long Island Sound shoreline of New York for which aerial imagery was available was an increase of ~1.52 miles (2.45 km).

There were 134.98 miles (217.23 km) of sandy beach habitat along the Peconic Estuary shoreline of NY prior to Hurricane Sandy, with aerial imagery available immediately following the storm for all of the sandy beach habitat described in Rice (2015b; Table 5). Of the 134.98 miles (217.23 km) of sandy beach habitat, ~14.19 miles (22.84 km; 11%) were modified by the storm. Overwash modified ~10.79 miles (17.36 km) of sandy beach habitat, of which 99% was located in undeveloped beachfront areas. Overwash along the Peconic Estuary beaches of NY is restricted to those beaches without bluffs, because the high elevation of the bluffs prevents overwash from occurring. As a result, the only overwash that occurred along the Peconic Estuary shoreline of NY was located at or near inlets and barrier spits. Another ~3.40 miles (5.47 km) of sandy beach habitat was modified through movements of inlet shoulders and spits, loss or gain of dry sandy beach habitat seaward of hard shoreline stabilization structures (see footnote 12, page 16), and the opening and closure of inlets. Where 11 new inlets were opened along sandy beaches on the Peconic Estuary shoreline of NY, ~0.91 miles (1.46 km) of sandy beach habitat was converted to tidal inlet habitat; where Oyster Pond Inlet closed, ~0.01 miles (0.02 km) of sandy beach habitat was gained through the conversion from tidal inlet habitat. The net change in the length of sandy beach in the Peconic Estuary of New York was an increase of ~0.15 miles (0.24 km).

There were 124.88 miles (200.97 km) of sandy beach habitat along the Atlantic Ocean shoreline of New York prior to Hurricane Sandy, with aerial imagery available immediately following the storm for all of the sandy beach habitat described in Rice (2015c, Table 5). Of the 124.88 miles (200.97 km) of sandy beach habitat, ~29.26 miles (47.09 km; 23%) were modified by the storm. Overwash modified ~28.83 miles (46.40 km) of sandy beach habitat, of which 48% was located in developed beachfront areas and 52% in undeveloped beachfront areas. Another ~0.43 miles (0.69 km) of sandy beach habitat was modified through movements of inlet shoulders, loss or gain of dry sandy beach habitat seaward of hard shoreline stabilization structures (see footnote 12, page 16), and the opening of new inlets. Where 6 new inlets were opened along sandy beaches on the South Shore of NY, ~0.18 miles (0.29 km) of sandy beach habitat was converted to tidal inlet habitat. The net change in the length of sandy beach along the Atlantic Ocean shoreline of New York was an increase of ~0.06 miles (0.10 km). In general the beaches of Suffolk County at the eastern end of Long Island had less damage and coastal change than those located at the western end of the South Shore and close to New York City (Sopkin et al. 2014, Schubert et al. 2015).

There were 125.26 miles (201.59 km) of sandy beach habitat along the Atlantic Ocean shoreline of New Jersey prior to Hurricane Sandy, with aerial imagery available immediately following the storm for all of the sandy beach habitat described in Rice (2015c, Table 5). Of the 125.26 miles (201.59 km) of sandy beach habitat, ~37.04 miles (59.61 km; 30%) were modified by the storm. Overwash modified ~32.98 miles (53.08 km) of sandy beach habitat, of which 71% was located in developed beachfront areas and 29% in undeveloped beachfront areas. Another ~4.06 miles (6.53 km) of sandy beach habitat was modified through movements of inlet shoulders, loss or gain of dry sandy beach habitat seaward of hard shoreline stabilization structures (see footnote 11, page 16), and the opening of new tidal inlets and storm breaches. Where 7 new inlets and storm breaches were opened along sandy beaches of New Jersey, ~0.54 miles (0.87 km) of sandy beach habitat was converted to tidal inlet habitat. The net change in the length of sandy beach in New Jersey was a decrease of ~3.65 miles (5.87 km). ALS (2012) found that 65% of New Jersey's beach and dune habitat experienced moderate to high damage, defined as having evidence of overwash, new inlets, moderate (50 – 100 ft) to major (> 100 ft) thinning or migration of the beach, and/or loss of dune vegetation including the creation of new bare sand areas. Sopkin et al. (2014) found the greatest impacts from Hurricane Sandy in terms of coastal change (dune height, shoreline position, land elevation) were located along the New Jersey shore from Island Beach State Park through Mantoloking.

The only aerial imagery available for the Delaware ocean coast[14] immediately following Hurricane Sandy is two series of oblique photographs taken by the USGS and PSDS (PSDS 2015, USGS 2015). These photographs show that there were a few small areas of overwash that modified the sandy beaches at Cape Henlopen SP and within the developed communities along the DE coast. The most significant area of storm-induced habitat modifications via overwash was located at Delaware Seashore SP, where overwash was deposited on the roadway north of Indian River Inlet and one overwash fan reached the bayside shoreline (Figure 3). Measurements of the length of sandy beach modified by overwash deposits could not be made due to the oblique angle of the USGS and PSDS photographs, which were taken by fixed wing aircraft flying offshore of the shoreline.

In Maryland, there were 31.10 miles (50.05 km) of sandy beach habitat prior to Hurricane Sandy, with aerial imagery available immediately following the storm for all but the southernmost 3.53 miles (5.68 km) of the sandy beach habitat described in Rice (2015c, Table 5). Of the 27.57 miles (44.37 km) of sandy beach habitat with post-storm imagery available, ~5.94 miles (9.56 km; 22%) were modified by the storm. Overwash modified ~5.93 miles (9.56 km) of sandy beach habitat, 97% of which was located in undeveloped beachfront areas and 3% of which was located in developed Ocean City. Overwash reached across the island and was deposited on the bayside shoreline in some locations (Sopkin et al. 2014). Only ~60 ft (0.01 miles) of sandy beach was gained in Maryland following Hurricane Sandy, when a bulge of sediment accreted into Ocean City Inlet on the inlet side of the south jetty No sandy beach habitat was converted to tidal inlet (or vice versa) habitat along the Atlantic Ocean shoreline of MD. The net change in the length of sandy beach in the areas of Maryland for which aerial imagery was available was an increase of 0.01 miles (0.02 km).

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[14] Note that only the oceanfront shoreline of Delaware is considered here. For impacts to the Delaware Bay shoreline, see the American Littoral Society's summary for the National Fish and Wildlife Foundation (ALS 2012).

Figure 3. Overwash occurred in limited areas in Delaware, most notably north of Indian River Inlet in Delaware Seashore State Park. Nearly all of the overwash deposits were scraped back onto the beach to form artificial dunes within one week of the storm, as seen in this image from near the Indian River Marina where the overwash extended across both roadways on the barrier spit to the bayside. Image from USGS (2015) dated November 6, 2012.

Figure 4. The southern end of Chincoteague NWR in Virginia was overwashed by Hurricane Sandy. The narrow spit connecting Toms Hook to rest of Chincoteague / Assateague Island was overwashed completely, from ocean (the bottom of the photo) to the Toms Cove (the top of the photo), forming sheetwash type overwash deposits. Image from USGS (2015) dated November 4, 2012.

Figure 5. The barrier islands along Virginia's Eastern Shore were extensively overwashed by Hurricane Sandy. On some islands, overwash modified virtually all of the sandy beach habitat such as at Metompkin Island, seen here looking from north to south. Image from USGS (2015) dated November 4, 2012.

Figure 6. The barrier islands along Virginia's Eastern Shore were extensively overwashed by Hurricane Sandy. On some islands, overwash modified virtually all of the sandy beach habitat such as at the north end of Ship Shoal Island as seen here. Image from USGS (2015) dated November 4, 2012.

Figure 7. Overwash breached the dunes protecting North Carolina Highway 12 (NC 12) at Pea Island NWR in North Carolina, crossing the roadway and depositing an overwash fan in one of the refuge's impoundments. In this USGS (2015) image from November 6, 2012, the NC Department of Transportation has already removed the overwash from the roadway and piled the sediment on the beach as an artificial dune.

Figure 8. Hurricane Sandy deposited overwash in Rodanthe, NC, creating overwash fans in a developed area along NC 12. NC 12 is buried by overwash on the left side of the photo and undermined by erosional scour at the right side of the photo, where sandbags had been placed to protect the roadway. The sandy beach habitat has been modified by the storm to retreat landward and to remove any dunes. Image from USGS (2015) dated November 4, 2012.

Sopkin et al. (2014) plus a review of oblique aerial photographs taken by the USGS and PSDS indicates that Hurricane Sandy naturally modified sandy beach habitat in VA and NC as well. Overwash was extensive at the southern end of Chincoteague NWR and along the VA Eastern Shore barrier islands (Figures 4, 5 and 6). In North Carolina, significant overwash occurred at Pea Island NWR (Figure 7) and nearby Rodanthe (Figure 8), as well localized areas of Cape Hatteras and Cape Lookout National Seashores (NS). Measurements of the length of sandy beach modified by overwash deposits could not be made due to the oblique angle of the USGS and PSDS photographs, which were taken by fixed wing aircraft flying offshore of the shoreline.

DISCUSSION

Hurricane Sandy was a major storm that impacted a significant portion of the U.S. Atlantic coast breeding range of the piping plover. Both sandy beach and tidal inlet habitats were modified by the storm, with overwash creating new potential nesting habitat, barrier spits and inlet shoulders shifting position, new inlets opening, and existing inlets closing. Sandy beach habitat was also modified at and near hard shoreline stabilization structures, including jetties, seawalls, bulkheads and revetments. Where aerial imagery was available immediately following the storm, storm-induced modifications to tidal inlet and sandy beach habitats were identified at 241 locations from RI to NC; overwash modified sandy beaches at an additional ~1,017 locations in CT, NY, NJ and MD (see Appendix A for a complete list of overwash areas within each community in these 4 states).

Hurricane Sandy created small areas of new sandy beach habitat adjacent to jetties at 8 inlets, where sediment accreted on the inside (within the inlet) of jetties. This storm-induced habitat modification resulted in an increase of 0.09 miles (0.14 km) of new bare (unvegetated) sediment habitat on inlet shoulders for shorebirds and waterbirds. At 4 other inlets, sandy beach habitat detached from hard shoreline stabilization structures, resulting in a decrease of 0.05 miles (0.08 km) of bare sediment habitat on inlet shoulders. Overall there was a small net increase in sandy beach habitat at inlets with hard shoreline stabilization structures.

At inlets without hard shoreline stabilization structures, sandy beach habitat on inlet shoulders increased in 26 locations and decreased at 14 locations. The accretion where these shifts in inlet shoulders increased sandy beach habitat resulted in a gain of 0.64 miles (1.03 km) of bare sand habitat. Where inlet shoulders retreated, there was a decrease of 0.45 miles (0.72 km) of sandy beach habitat. Overall there was a small net increase in sandy beach habitat on inlet shoulders without jetties immediately following Hurricane Sandy. Nelson (1991) found localized accretion near inlets in South Carolina following Hurricane Hugo as well.

Barrier spits and small islands (e.g., the Norwalk Islands of CT) shifted position and/or size at 23 locations (excluding the changes at inlets described above). Sandy beach habitat increased by 0.38 miles (0.61 km) at 7 of these locations and decreased by 1.22 miles (1.96 km) at the other 16 locations. This resulted in a net decrease of 0.84 miles (1.35 km) of sandy beach habitat available immediately following Hurricane Sandy. It should be noted that in areas where multiple dates of imagery were available in the aftermath of the storm, several of the barrier spits connected to small islands that were submerged by Hurricane Sandy had re-emerged within days of the storm; thus at least a portion of this net decrease in sandy beach habitat was temporary.

Approximately 103 miles (166 km) of sandy beaches in CT, NY, NJ and MD were modified by Hurricane Sandy overwash. Although this represented 17% of the sandy beach habitat for which aerial imagery was available, the length of sandy beach modified by overwash varied from 4% to 31% within the six individual shorelines in those four states (Table 5). Connecticut's sandy beaches were the most modified by storm overwash with 31% of the sandy beaches for which imagery was available altered. The sandy beaches of Maryland, the South Shore of New York, and New Jersey were 22-26% modified by storm overwash. The sandy beaches of the Long Island Sound and Peconic Estuary shorelines of New York, on the other hand, were only 4 and 8% modified respectively. This is due primarily to the geologic nature of those shorelines, where bluffs line much of the beaches and prevent overwash; but the more sheltered orientations of the Long Island Sound and Peconic Estuary shorelines also minimized overwash from Hurricane Sandy, which approached from the south.

Within individual sections of shoreline, storm-induced modifications to sandy beaches by overwash occurred in both developed and undeveloped beachfronts (see Appendix A for a complete list). On the Peconic Estuary shoreline of NY, 99% of the overwash was located in undeveloped areas. Similarly, 97% of the overwash in Maryland occurred on the undeveloped sandy beaches of Assateague Island NS. Along the Long Island Sound shorelines of NY and CT, 83% and 73% of the overwash locations respectively were along undeveloped beachfronts. On the South Shore of Long Island, NY, slightly more than half (52%) of the overwash occurred on undeveloped beaches.

In contrast, along the New Jersey coast only 29% of the overwash was located in undeveloped beachfront areas. Hurricane Sandy overwash modified sandy beaches in NJ at approximately 453 locations (see Table A-5 in Appendix A). Roughly one-third of these locations (148) were on Long Beach Island, where 142 of the 148 sites were located in developed beachfront areas, the vast majority of which were very small areas of overwash at beach access points at the ends of streets oriented perpendicular to the beach. The remaining 6 overwash locations were within the undeveloped area of Barnegat Light adjacent to the Barnegat Inlet jetty and within the Holgate Unit of the Edwin B. Forsythe NWR; these 6 overwash areas in undeveloped areas were significantly larger areas of overwash than those that were located in developed areas. Overall there were ~5.48 miles (8.82km) of sandy beach modified by overwash on Long Beach Island, NJ, but 45% (2.49 miles or 4.01 km) was located in developed areas and is a lost opportunity for new potential nesting habitat for beach-nesting birds. Along the entire NJ oceanfront, only ~9.64 miles (15.51 km) of sandy beach modified by overwash were located in undeveloped areas and provided the opportunity for new potential nesting habitat, versus ~23.34 miles (37.56 km) of modified sandy beach in developed beachfront areas where the opportunity for new potential nesting habitat was lost. Furthermore, the beaches modified by the storm in developed areas will be prevented from long-term recovery of the beach and dune system by the position of the first row of development where the natural dune line would be most likely to reform in the years following the storm (Morton et al. 1994).

In the 4 states for which imagery was available, 42% of the total ~103 miles (166km) of sandy beach modified by overwash was in developed areas where the new bare sand or sparsely vegetated areas would not be available to beach-nesting birds as a result of the development. Therefore although Hurricane Sandy created at least ~103 miles (166 km) of new or enhanced potential nesting habitat for the piping plover and other beach-nesting birds, only 58% of those beaches were potentially available to the birds as a direct result of development along the other 42%. On Fire Island, Hapke et al. (2013, p. 20) also found that the incursion distance, or how far overwash penetrates inland beyond the beach, "was limited in many locations by private homes and other community infrastructure in the developed stretches of coast."

Hall and Halsey (1991) found that parking lots and streets that are oriented perpendicular to and adjacent to the beach acted as overwash channels during Hurricane Hugo in South Carolina. Hurricane Sandy overwash areas appear to have penetrated inland on paved areas as well. Indeed, of the 1,017 total locations where overwash modified the sandy beaches within the 4 states with suitable imagery (see Appendix A), at 590 (58%) of those locations, overwash sediments were deposited on paved areas such as roadways, driveways and parking lots. Many of these locations were beach access points at the ends of streets oriented perpendicular to the beachfront, especially in NJ. In several locations heavy equipment was visible in the aerial imagery already removing the overwash material from the paved areas and placing the sediment back on the beach. In the ALS's assessment for the National Fish and Wildlife Foundation (NFWF) shortly after Hurricane Sandy, the authors noted that municipalities and other entities pursuing immediate recovery efforts do not recognize overwash areas as (new) habitat, rendering those areas "extremely vulnerable to damage from the bulldozing and moving of sand … as towns attempt to replace dunes and shore up their beaches" (ALS 2012, p. 5). These activities to remove overwash from paved and developed areas resulted in the direct (and immediate) habitat loss of new bare sand habitat areas created by Hurricane Sandy in those locations. This loss of storm-induced habitat modification as a result of the human response occurred in both developed and undeveloped areas, since a number of undeveloped beachfronts include parking lots and roadways.

The beach changes captured in the datasets may reflect processes that preceded, and were unrelated to, Hurricane Sandy and its impacts. Rice (2015b) and Rice (2015c) described the distribution of sandy beaches prior to Hurricane Sandy, but the aerial imagery available used in those inventories was several months before the storm and generally taken during the winter months. Aerial imagery immediately following the hurricane showed changes to the presence or absence of dry sandy beach habitat seaward of hard shoreline stabilization structures at 130 locations. Due to the gap in time between the before- and after-Sandy imagery, however, at least some of these modifications may be due to seasonal changes in the local sediment supply and not directly attributable to Hurricane Sandy. Nelson (1991) found that beaches in northern South Carolina accreted, or built up, in the days immediately prior to Hurricane Hugo in September 1989 due to the strong southwesterly winds, large amplitude long period waves, and unusually high spring tides; beaches seaward of seawalls also built up significantly. Thus the presence of dry sandy beaches seaward of armoring following Hurricane Sandy where previously there had been none could be a result of the storm *or* seasonal changes (i.e., summer accretion) since the pre-storm imagery was taken.

Finally, the presence of hard shoreline stabilization structures can influence storm impacts to beach systems, increasing damages to adjacent structures (Coch and Wolff 1991, Nelson 1991, Coch 2015). In this assessment, the presence and absence of dry sandy beaches seaward of shore-parallel hard stabilization structures (i.e., seawalls, bulkheads, revetments) may have been modified by Hurricane Sandy. At 56 locations dry sandy beach was present following the storm where it had not been present before the storm; these new sections of sandy beach accounted for an increase of ~4.80 miles of sandy beach. At 74 locations dry sandy beach was absent following Hurricane Sandy, for a loss of ~5.77 miles of sandy beach. Altogether there was a net decrease in the length of dry sandy beach seaward of hard stabilization structures of ~0.97 miles in the four states for which imagery was available following the storm. Overwash in areas where seawalls and similar structures were present was uncommon but did occur in some areas where structures were overtopped by the storm.

Nelson (1991) found that seawalls and riprap revetments in South Carolina did not appear to increase erosion of the beach seaward of the structures during Hurricane Hugo (a Category 4 storm) in 1989, regardless of whether the seawall survived, was overtopped, or failed during the storm. The authors attribute this to the littoral transport alongshore during the storm overpowering the expected negative effects of the structures as well as the positive effects of local sand sources (the dunes). The presence of seawalls or riprap revetments did, however, affect the natural recovery of the beach by reflecting waves and scouring the base of the walls, preventing the natural accretion of sediment. Thus, the presence of hard shoreline stabilization structures prevents the natural recovery of the beach system by preventing the landward migration of the beach and dune profile, rendering those areas less resilient to future storms (Nelson 1991, Morton et al. 1994, Morton 2002).

ALS (2012) also found that natural systems were resilient to Hurricane Sandy’s impacts, as opposed to man-made structures that were heavily damaged. In many locations they found that natural dune systems protected both natural and man-made features, even in areas where the dunes were breached, eroded or flattened into overwash deposits. “[S]ome locations, such as Avalon Dunes [NJ], which have a natural beach, in part because they are managed for nesting shorebirds, and utilize a less intensive beach maintenance regimen (i.e., less mechanical beach raking and sand transfers [as compared to other beaches in NJ]), appear to have been more resilient than nearby of adjacent beaches that were subject to more heavy maintenance activities” (ALS 2012, p. 27).

Coch and Wolff (1991) and Thieler and Young (1991) found that dunes, particularly natural ones, were the most effective protection for beachfront development to hurricane waves and storm surge. Natural dunes were found to be more resistant, or resilient, to erosion during Hurricane Hugo in 1989 in South Carolina (Coch and Wolff 1991). Natural dunes have a tighter packing of sand grains with lower porosity compared to artificial, bulldozed dunes where the sand grains are more loosely packed and more porous, rendering them more susceptible to wave erosion; natural dunes also tend to be higher and more vegetated, also making them more resistant to erosion (Coch and Wolff 1991).

Table 6. Changes in the length of sandy beach within each state for which aerial imagery was available immediately following Hurricane Sandy, from north to south.

State	Increase in Length of Sandy Beach (miles)	Decrease in Length of Sandy Beach (miles)	Net Change in Length of Sandy Beach (miles)
CT	1.76	3.00	-1.23
NY - LIS	2.09	0.57	1.52
NY - Peconic	1.77	1.63	0.15
NY - Atlantic	0.25	0.19	0.06
NJ	0.20	3.86	-3.65
MD	0.01	0.00	0.01
TOTAL	**6.09**	**9.23**	**-3.14**

Beaches are storm-dependent systems where natural processes such as overwash and the opening and closing of inlets periodically modify the landscape and its habitats. Overwash deposits and the shoals associated with inlet complexes allow barrier islands and spits to migrate with rising sea level. Overwash deposits raise the elevation of the beach and islands or spits, making those areas more resilient (less vulnerable) to future flooding events and sea level rise. The flood tidal shoal deposits associated with migrating and closed inlets provide a platform onto which a barrier island or spit can migrate with sea level rise. Hurricane Sandy had widespread effects on tidal inlet and sandy beach habitat within the U.S. Atlantic Coast breeding range of the piping plover, creating new or improved potential nesting habitat along ~103 miles (166 km) of sandy beach, new tidal inlet habitat at 33 locations, and new bare sand habitat at 4 closed inlet locations.

The length of sandy beach increased about 6 miles (9.66 km) in some areas and decreased by about 9.23 miles (14.85 km) in other areas, resulting in an overall net decrease of ~3.14 miles (5.05 km) within the ~590 miles (950 km) of sandy beach for which aerial imagery was available immediately following the storm (Table 6). This modification to sandy beach length resulted in only a -0.5% change. Connecticut and New Jersey had overall small declines in the amount of sandy beach habitat, while the 3 shorelines of NY and the shoreline of MD had slight increases. The cumulative impacts of development and hard shoreline stabilization on tidal inlet and sandy beach habitat, however, decreased the magnitude of the storm-induced habitat creation, reducing the potential new or improved potential nesting habitat created by overwash by at least 42%.

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APPENDIX A

The length of sandy beach modified by Hurricane Sandy overwash in each community for which aerial imagery was available in Connecticut, New York, New Jersey and Maryland

Table A-1. The total length of sandy beach modified by overwash and the proportion that is within developed and undeveloped beachfront areas in each community (from east to west) within Connecticut where aerial imagery immediately following Hurricane Sandy was available. Overwash that was located in developed beachfront areas is assumed to be a lost opportunity to create new nesting habitat for the piping plover.

State	Community[1]	Number of Overwash Locations	Approximate Length of Sandy Beach Modified by Overwash (miles)		Total Length of Sandy Beach Modified by Overwash (miles)
			Developed Beachfront	Undeveloped Beachfront	
CT	Old Lyme[2]	6	0.150	1.108	1.258
			12%	88%	
CT	Old Saybrook	5	0	0.303	0.303
			0%	100%	
CT	Westbrook	6	0.543	0.024	0.567
			96%	4%	
CT	Clinton	4	0.321	0.521	0.841
			38%	62%	
CT	Madison	14	0.365	0.602	0.967
			38%	62%	
CT	Guilford	1	0	0.109	0.109
			0%	100%	
CT	Branford	2	0.140	0.200	0.340
			41%	59%	
CT	East Haven	2	0.505	0	0.505
			100%	0%	
CT	New Haven	1	0	0.118	0.118
			0%	100%	
CT	West Haven	4	0	1.360	1.360
			0%	100%	
CT	Milford	19	0.793	1.376	2.169
			37%	63%	
CT	Stratford	6	0.734	2.012	2.746
			27%	73%	
CT	Bridgeport[3]	7	0	1.628	1.628
			0%	100%	
CT	Fairfield[4]	4	0.263	0.195	0.458
			57%	43%	
CT	Westport	13	0.544	1.327	1.871
			29%	71%	
CT	Norwalk	22	0.296	2.575	2.871
			10%	90%	

State	**Community**[1]	**Number of Overwash Locations**	**Approximate Length of Sandy Beach Modified by Overwash (miles)**		**Total Length of Sandy Beach Modified by Overwash (miles)**
			Developed Beachfront	**Undeveloped Beachfront**	
CT	Darien	4	0.256	0.153	0.409
			63%	37%	
CT	Stamford	15	0.505	0.835	1.341
			38%	62%	
CT	Greenwich	5	0.062	0.255	0.317
			20%	80%	
TOTAL		**140**	**5.477**	**14.703**	**20.179**
			27%	**73%**	

1 – No aerial imagery was available for the communities of Stonington, Groton, New London, Waterford and East Lyme.

2 – No aerial imagery was available for 2.27 miles (3.65 km) of eastern Old Lyme.

3 – No aerial imagery was available for 0.33 miles (0.54 km) of western Bridgeport.

4 – No aerial imagery was available for 3.12 miles (5.02 km) of eastern Fairfield.

Table A-2. The total length of sandy beach modified by overwash and the proportion that is within developed and undeveloped beachfront areas in each community (from east to west) along the Long Island Sound shoreline of New York where aerial imagery immediately following Hurricane Sandy was available. Overwash that was located in developed beachfront areas is assumed to be a lost opportunity to create new nesting habitat for the piping plover.

State	Community[1]	Number of Overwash Locations	Approximate Length of Sandy Beach Modified by Overwash (miles)		Total Length of Sandy Beach Modified by Overwash (miles)
			Developed Beachfront	Undeveloped Beachfront	
NY-LIS	Plum Island	2	0	0.159	0.159
			0%	100%	
NY-LIS	Orient	0			0
NY-LIS	East Marion	0			0
NY-LIS	Greenport	0			0
NY-LIS	Southold	1	0	0.142	0.142
			0%	100%	
NY-LIS	Peconic	0			0
NY-LIS	Mattituck	0			0
NY-LIS	Jamesport	1	0	0.063	0.063
			0%	100%	
NY-LIS	Riverhead	0			0
NY-LIS	Baiting Hollow	0			0
NY-LIS	Wading River	0			0
NY-LIS	East Shoreham	0			0
NY-LIS	Shoreham	0			0
NY-LIS	Rocky Point	0			0
NY-LIS	Sound Beach	0			0
NY-LIS	Miller Place	0			0
NY-LIS	Mt. Sinai	2	0	0.296	0.296
			0%	100%	
NY-LIS	Port Jefferson	0			0
NY-LIS	Belle Terre	0			0
NY-LIS	Town of Brookhaven	0			0
NY-LIS	Old Field	6	0	0.692	0.692
			0%	100%	
NY-LIS	Stony Brook	0			0
NY-LIS	Nissequogue	1	0	0.028	0.028
			0%	100%	
NY-LIS	Fort Salonga	2	0	0.369	0.369

State	**Community[1]**	**Number of Overwash Locations**	**Approximate Length of Sandy Beach Modified by Overwash (miles)**		**Total Length of Sandy Beach Modified by Overwash (miles)**
			Developed Beachfront	**Undeveloped Beachfront**	
			0%	100%	
NY-LIS	Town of Huntington	2	0	0.419	0.419
			0%	100%	
NY-LIS	Eatons Neck	1	0	0.457	0.457
			0%	100%	
NY-LIS	Huntington Bay	2	0.218	0.078	0.296
			74%	26%	
NY-LIS	Lloyd Harbor	1	0	0.391	0.391
			0%	100%	
NY-LIS	Cold Spring Harbor	0			0
NY-LIS	Laurel Hollow	0			0
NY-LIS	Cove Neck	0			0
NY-LIS	Center Island	1	0.125	0	0.125
			100%	0%	
NY-LIS	Bayville	1	0.062	0	0.062
			100%	0%	
NY-LIS	Locust Valley	0			0
NY-LIS	Lattingtown	5	0.141	0.315	0.455
			31%	69%	
NY-LIS	Glen Cove	2	0.114	0	0.114
			100%	0%	
NY-LIS	Sea Cliff	0			0
NY-LIS	Port Washington	0			0
NY-LIS	Sands Point	1	0.054	0	0.054
			100%	0%	
TOTAL		**31**	**0.715**	**3.408**	**4.123**
			17%	**83%**	

1 – No aerial imagery was available for Fishers Island.

Table A-3. The total length of sandy beach modified by overwash and the proportion that is within developed and undeveloped beachfront areas in each community (clockwise from Montauk to Orient) along the Peconic Estuary shoreline of New York where aerial imagery immediately following Hurricane Sandy was available. Overwash that was located in developed beachfront areas is assumed to be a lost opportunity to create new nesting habitat for the piping plover.

Community	Number of Overwash Locations	Approximate Length of Sandy Beach Modified by Overwash (miles)		Total Length of Sandy Beach Modified by Overwash (miles)
		Developed Beachfront	Undeveloped Beachfront	
Montauk	8	0	0.641	0.641
		0%	100%	
Napeague	0			0
Amagansett	0			0
Springs	5	0.111	0.431	0.541
		20%	80%	
Northwest Harbor	3	0	0.472	0.472
		0%	100%	
Sag Harbor	1	0	0.042	0.042
		0%	100%	
North Haven	0			0
Noyack	1	0	0.179	0.179
		0%	100%	
North Sea	0			0
Tuckahoe	0			0
Hampton Bays	2	0	0.442	0.442
		0%	100%	
Flanders	0			0
Riverhead	0			0
Aquebogue	0			0
Jamesport	0			0
Laurel	0			0
Mattituck	0			0
Cutchogue	1	0	0.030	0.030
		0%	100%	
New Suffolk	0			0
Robins Island	0			0
Peconic	2	0.020	0.348	0.368
		5%	95%	
Southold	3	0.013	0.460	0.473
		3%	97%	

Community	**Number of Overwash Locations**	**Approximate Length of Sandy Beach Modified by Overwash (miles)**		**Total Length of Sandy Beach Modified by Overwash (miles)**
		Developed Beachfront	**Undeveloped Beachfront**	
Greenport West	1	0	0.086	0.086
		0%	100%	
Greenport	0			0
East Marion	0			0
Orient	10	0	1.900	1.900
		0%	100%	
Shelter Island	10	0	1.663	1.663
		0%	100%	
Gardiners Island	12	0	3.949	3.949
		0%	100%	
TOTAL	**59**	**0.143**	**10.643**	**10.787**
		1%	**99%**	

Table A-4. The total length of sandy beach modified by overwash and the proportion that is within developed and undeveloped beachfront areas in each community (from east to west) along the Atlantic Ocean shoreline of New York where aerial imagery immediately following Hurricane Sandy was available. Overwash that was located in developed beachfront areas is assumed to be a lost opportunity to create new nesting habitat for the piping plover.

Community	Number of Overwash Locations	Approximate Length of Sandy Beach Modified by Overwash (miles)		Total Length of Sandy Beach Modified by Overwash (miles)
		Developed Beachfront	Undeveloped Beachfront	
Montauk	7	0.068	0.036	0.104
		65%	35%	
Napeague	6	0.134	0.025	0.159
		84%	16%	
Amagansett	4	0.119	0.016	0.134
		88%	12%	
East Hampton	9	0.086	0.201	0.287
		30%	70%	
Wainscott	5	0.026	0.220	0.246
		11%	89%	
Sagaponack	3	0.177	0.226	0.402
		44%	56%	
Bridgehampton	4	0.112	0.145	0.256
		44%	56%	
Water Mill	3	0.020	0.073	0.094
		22%	78%	
Village of Southampton	2	0.014	0.061	0.075
		19%	81%	
Hampton Bays	12	0.313	0.613	0.926
		34%	66%	
Quogue	0			0
Westhampton Beach	0			0
Town of Southampton	0			0
West Hampton Dunes[1]	7	0.020	0.244	0.264
		8%	92%	
Smith Point County Park	11	0.009	1.541	1.550
		1%	99%	
Fire Island NS	28	0	2.709	2.709
		0%	100%	
Ocean Ridge/Davis Park (Brookhaven)	1	0.044	0	0.044
		100%	0%	

Community	Number of Overwash Locations	Approximate Length of Sandy Beach Modified by Overwash (miles)		Total Length of Sandy Beach Modified by Overwash (miles)
		Developed Beachfront	Undeveloped Beachfront	
Water Island (Brookhaven)	0			0
Fire Island Pines (Brookhaven)	2	0.019	0	0.019
		100%	0%	
Cherry Grove (Brookhaven)	0			
Point o'Woods (Brookhaven)	4	0.338	0.006	0.343
		98%	2%	
Ocean Bay Park (Brookhaven)	1	0.434	0	0.434
		100%	0%	
Seaview (Islip)	1	0.032	0	0.032
		100%	0%	
Ocean Beach	1	0.122	0	0.122
		100%	0%	
Fire Island Summer Club / Corneille Estates (Islip)	1	0.170	0	0.170
		100%	0%	
Robbins Rest (Islip)	0			0
Atlantique (Islip)	3	0.154	0.109	0.263
		59%	41%	
Lonelyville (Islip)	0			0
Dunewood (Islip)	0			0
Fair Harbor (Islip)	0			0
Saltaire	3	0.069	0	0.069
		100%	0%	
Kismet (Islip)	1	0.148	0	0.148
		100%	0%	
Robert Moses SP	16	0.193	0.444	0.637
		30%	70%	
Gilgo SP	4	0	0.291	0.291
		0%	100%	
Town of Babylon (Gilgo - Cedar - Overlook Beaches)	6	0.184	0.838	1.023
		18%	82%	
Tobay Beach (Town of Oyster Bay)	2	0	0.049	0.049
		0%	100%	
Jones Beach SP	15	0.302	3.317	3.619
		8%	92%	
Town of Hempstead	20	0.542	0.281	0.823
		66%	34%	

Community	Number of Overwash Locations	Approximate Length of Sandy Beach Modified by Overwash (miles)		Total Length of Sandy Beach Modified by Overwash (miles)
		Developed Beachfront	Undeveloped Beachfront	
Long Beach	21	1.885	0	1.885
		100%	0%	
East Atlantic Beach	8	0.411	0	0.411
		100%	0%	
Atlantic Beach	13	1.007	0.201	1.208
		83%	17%	
Far Rockaway	2	0.501	0.209	0.710
		71%	29%	
Arverne	11	0.766	0.708	1.474
		52%	48%	
Rockaway Park	10	2.991	0.442	3.433
		87%	13%	
Breezy Point	13	0.398	1.762	2.160
		18%	82%	
Manhattan Beach	2	0.057	0.232	0.289
		20%	80%	
Brighton Beach	5	0.317	0	0.317
		100%	0%	
Coney Island - West Brighton	8	1.574	0	1.574
		100%	0%	
Sea Gate	3	0.081	0	0.081
		100%	0%	
TOTAL	**278**	**13.837**	**14.998**	**28.834**
		48%	**52%**	

1 – This includes adjacent Cupsogue County Park.

Table A-5. The total length of sandy beach modified by overwash and the proportion that is within developed and undeveloped beachfront areas in each community (from north to south) within New Jersey where aerial imagery immediately following Hurricane Sandy was available. Overwash that was located in developed beachfront areas is assumed to be a lost opportunity to create new nesting habitat for the piping plover.

Community	Number of Overwash Locations	Approximate Length of Sandy Beach Modified by Overwash (miles)		Total Length of Sandy Beach Modified by Overwash (miles)
		Developed Beachfront	Undeveloped Beachfront	
Sandy Hook	10	0	2.590	2.590
		0%	100%	
Sea Bright	14	2.862	0.110	2.973
		96%	4%	
Monmouth Beach	3	0.611	0	0.611
		100%	0%	
Long Branch	8	1.277	0.226	1.503
		85%	15%	
Deal	3	0.259	0	0.259
		100%	0%	
Allenhurst	0			0
Loch Arbour	1	0.193	0	0.193
		100%	0%	
Asbury Park	7	0.244	0.141	0.384
		63%	37%	
Ocean Grove	2	0.386	0	0.386
		100%	0%	
Bradley Beach	3	0.424	0	0.424
		100%	0%	
Avon-by-the-Sea	3	0.325	0	0.325
		100%	0%	
Belmar	1	1.355	0	1.355
		100%	0%	
Spring Lake	17	0.842	0.018	0.860
		98%	2%	
Sea Girt	5	0.352	0	0.352
		100%	0%	
Manasquan	3	0.898	0	0.898
		100%	0%	

Community	Number of Overwash Locations	Approximate Length of Sandy Beach Modified by Overwash (miles)		Total Length of Sandy Beach Modified by Overwash (miles)
		Developed Beachfront	Undeveloped Beachfront	
Point Pleasant Beach	10	0.869	0	0.869
		100%	0%	
Bay Head	4	0.695	0	0.695
		100%	0%	
Mantoloking	10	1.320	0	1.320
		100%	0%	
Brick (Normandy Beach)	6	1.284	0	1.284
		100%	0%	
Dover Beaches North	3	1.388	0	1.388
		100%	0%	
Lavallette	7	1.215	0	1.215
		100%	0%	
Ortley Beach	3	0.594	0	0.594
		100%	0%	
Seaside Heights	2	0.143	0	0.143
		100%	0%	
Seaside Park	15	0.468	0	0.468
		100%	0%	
Berkeley Township (South Seaside Park & Island Beach SP)	26	0.010	1.651	1.661
		1%	99%	
Barnegat Light	3	0	0.356	0.356
		0%	100%	
Loveladies	6	0.249	0	0.249
		100%	0%	
Harvey Cedars	10	0.122	0	0.122
		100%	0%	
North Beach	2	0.311	0	0.311
		100%	0%	
Surf City	5	0.031	0	0.031
		100%	0%	
Ship Bottom	3	0.015	0	0.015
		100%	0%	
Long Beach Township (North Beach Haven et al.)	83	0.727	0	0.727
		100%	0%	
Beach Haven	22	0.284	0	0.284

Community	Number of Overwash Locations	Approximate Length of Sandy Beach Modified by Overwash (miles)		Total Length of Sandy Beach Modified by Overwash (miles)
		Developed Beachfront	Undeveloped Beachfront	
		100%	0%	
Long Beach Township (including Holgate Unit of Forsythe NWR)	14	0.750	2.635	3.384
		22%	78%	
Galloway Township (Little Beach Island, Forsythe NWR)	6	0	0.551	0.551
		0%	100%	
Brigantine	20	0.048	1.104	1.152
		4%	96%	
Atlantic City	0			0
Ventnor City	1	0.0169	0	0.017
		100%	0%	
Margate City	30	0.584	0	0.584
		100%	0%	
Longport	23	0.384	0	0.384
		100%	0%	
Ocean City	26	1.273	0	1.273
		100%	0%	
Strathmere	2	0.021	0	0.021
		100%	0%	
Sea Isle City	13	0.083	0.030	0.113
		73%	27%	
Avalon	0			0
Stone Harbor	5	0.023	0.014	0.037
		61%	39%	
North Wildwood	0			0
Wildwood	0			0
Wildwood Crest	0			0
Lower Township (Two Mile Beach Unit, Cape May NWR & USCG LORAN Station)	0			0
Cape May	12	0.404	0	0.404
		100%	0%	
Lower Township (South Cape May Meadows & Cape May Point SP)	1	0	0.214	0.214
		0%	100%	

Community	**Number of Overwash Locations**	**Approximate Length of Sandy Beach Modified by Overwash (miles)**		**Total Length of Sandy Beach Modified by Overwash (miles)**
		Developed Beachfront	**Undeveloped Beachfront**	
Cape May Point	0			0
TOTAL	**453**	**23.343**	**9.639**	**32.982**
		71%	**29%**	

Table A-6. The total length of sandy beach modified by overwash and the proportion that is within developed and undeveloped beachfront areas in each community (from north to south) within Maryland where aerial imagery immediately following Hurricane Sandy was available. Overwash that was located in developed beachfront areas is assumed to be a lost opportunity to create new nesting habitat for the piping plover.

Community	Number of Overwash Locations	Approximate Length of Sandy Beach Modified by Overwash (miles)		Total Length of Sandy Beach Modified by Overwash (miles)
		Developed Beachfront	**Undeveloped Beachfront**	
Ocean City	1	0.194	0	0.194
		100%	0%	
Assateague Island NS[1]	55	0%	5.739	5.739
		0%	100%	
TOTAL	**56**	**0.194**	**5.739**	**5.933**
		3%	**97%**	

[1] No aerial imagery was available for the southernmost 3.53 miles (5.68 km) of Assateague Island NS in Maryland.