3.2 North Shore, Long Island Sound and Peconic Estuary

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Species and habitats along Long Island Sound are potentially at risk because of sea level rise. This brief literature review considers this risk for the New York portion of Long Island Sound (hereafter the Sound), including the shorelines of Westchester, Bronx, Nassau, and Suffolk counties as well as the Peconic Estuary at the far eastern end of Long Island. These Long Island shorelines contain important habitats for a variety of fish, shellfish, and birds, and a great deal is known about their ecology and habitat needs (see Map 3.1). Based on existing literature and the knowledge of local scientists, this review discusses the coastal species in areas that could be at risk because of further habitat loss resulting from sea level rise and shoreline protection. There are locations in the study area with naturally steep shorelines that will interfere to varying degrees with marine transgression of tidal wetlands in response to rising seas. Although it is possible to make qualitative statements about the possible impacts if sea level rise causes a total loss of habitat, our ability to discern what the impact might be if only a portion of the habitat is lost is more limited.[168]

TIDAL MARSH

In 2003, the Long Island Sound Habitat Restoration Initiative reported that there were 8,425.6 ha (20,820 acres) of tidal wetlands in the Sound, including all tidal wetland types, with 85 percent of the total in Connecticut.[169] Most of the remaining 15 percent of tidal wetlands found in the New York State portion of the Sound are along the shores of Westchester and Bronx counties.[170] In Westchester County, ecologically important tidal wetlands occur in the county-owned Marshlands Conservancy property.[171] The Marshlands Conservancy site is the only mainland breeding area for yellow-crowned night herons in the region.[172]

Tidal wetlands are also uncommon along the north shore of Long Island because of the steep uplands and sea cliffs created by the terminal moraine of glaciers, and therefore wetlands are

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[168]EPA's ambitious goal for these reviews would have had us address the four possible outcomes resulting from different rates of sea level rise (or wetland accretion) and whether shores are protected. In a typical case where area of wetlands is 5 times the area of land that might become new wetlands as sea level rises, the four possible outcomes are:
a. Existing wetlands are lost, shore protection prevents new wetlands forming inland (100% loss).
b. Existing wetlands keep pace, shore protection prevents new wetlands forming inland (no change, in total acreage, but possible loss of plants that inhabit the upper portion of the tide range).
c. Existing wetlands lost, no shore protection allows wetlands to form inland (80% loss).
d. Existing wetlands keep pace, no shore protection allows wetlands to form inland (20% gain).
We focus on the implication of case a, because the implication of a total loss of habitat is understood at least qualitatively. The literature is often insufficient for us to distinguish whether case c is more similar to "no impact" or to the total loss implied by case a, and hence, depending on context, the prose that follows may imply either that such large scale loss is similar to total loss, or that because some wetlands will continue to survive, that the impact is similar to "no impact." In the case of beaches and possibly mudflats, the absence of shore protection generally allows the system to survive. We did not examine cases b or d at all.

[169]Holst, L, R. Rozsa, L. Benoit, S. Jacobsen, and C. Rilling, 2003, Long Island Sound Habitat Restoration Initiative, Technical Support for Habitat Restoration, Section 1: Tidal Wetlands. EPA Long Island Sound Office, Stamford, CT, p. 1-7, Available at: http://www.longislandsoundstudy.net/habitat/index.htm; and Rosza, R., 1995, "Human impacts on tidal wetlands: History and regulations, Chapter 2 in G.D. Dyer and W.A. Neiring, eds., *Tidal Marshes of Long Island Sound, Ecology History and Restoration*, The Connecticut College Arboretum, Bulletin No. 34, December. Available at: http://arboretum.conncoll.edu/publications/34/FRAME.HTM.

[170]Holst et al., 2003, p. 1-1 (see note 169).

[171]New York State (NYS) Department of State, Division of Coastal Resources, 2004, *Significant Coastal Fish and Wildlife Habitats*. Long Island Sound and Long Island, Marshlands Conservancy. Coastal Resources Online. Available at http://nyswaterfronts.com/waterfront_natural_narratives.asp.

[172]USFWS, 1997, *Significant Habitat and Habitat Complexes of the New York Bight Watershed*. USFWS, South New England, New York Bight Coastal Ecosystems Program, Charlestown, RI; The Narrows, Complex #20, pp. 611–619.

largely confined to former drowned "kettle hole" embayments such as Mount Sinai.[173] There are some notable areas of marsh in and around Stony Brook Harbor and West Meadow, bordering the Nissequogue River,[174] and along the Peconic Estuary. Some marshes around the three large bays western Long Island Sound (Little Neck Bay, Manhasset Bay, and Hempstead Harbor) provide feeding and nesting areas for green-backed heron, clapper rail, and American black duck, as well as feeding areas for wading birds.[175]

Marshes will be lost where the shorelines are backed by steep slopes or where shorelines are hardened. There has already been a significant loss of the historical area of vegetated tidal wetlands in Long Island Sound.[176] In fact, local scientists have observed marsh submergence for decades.[177] The full extent and causes of marsh losses are unknown, but some local scientists believe that sea level rise may be an important factor.[178] Authors of the Long Island Sound Habitat Restoration Initiative reported that emergent marsh, especially low marsh, is converting to intertidal flat along the shores of many of the tidal rivers that drain into the Sound, and concluded that "the biophysical changes in these marshes bear a striking resemblance to other eastern seaboard wetlands that scientists attribute to accelerated relative sea level rise."[179]

The loss of vegetated low marsh reduces habitat for several rare bird species that nest only or primarily in low marsh (e.g., seaside sparrow) (see Section 3.1). Low marsh also provides foraging areas sheltered from predators for dozens of fish species, including small resident fishes such as mummichog, striped killifish, and sheepshead minnow, and early life stages of estuarine and marine transients, which use the tidal creeks and low marsh for a nursery area (Section 3.1). Many of these transient fish species such as weakfish and winter flounder enter local commercial and recreational fisheries as adults.[180] Diamondback terrapin live in the creeks of the low marsh, where they feed on plants, mollusks, and crustaceans.[181] Marsh invertebrates of the Sound's low marsh zones include rough periwinkles, ribbed mussels, fiddler crabs, striped sea anemone, and the common clamworm.[182]

Some wetlands along Long Island Sound will be allowed to respond naturally to sea level rise, and where migration is possible, preservation of local biodiversity and some regionally rare species is possible. For example, local planners believe that Peconic Estuary shorelines around Shelter Island, Robins Island, the Conscience Point National Wildlife Reserve, the E.A. Morton National Wildlife Reserve, Novack, Sag Harbor, Orient Point and Orient Beach, and Napeague Bay will be allowed to respond naturally to sea level rise. Local planners also expect that coastal lands designated for preservation, conservation, or recreation in northern Suffolk County will remain unprotected.

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[173]Ron Rosza, coastal ecologist with the Connecticut Office of the Long Island Sound Program, email entitled Opportunity to comment on U.S. EPA-sponsored papers related to sea level rise and related impacts on habitat and species, to Karen Scott, EPA, 2/20/07 (discussing visual observations).

[174]NYS Department of State, Division of Coastal Resources, 2004 (see note 171). Wetland losses will also occur along shorelines with steep slopes, even though they are not hardened—a common characteristic of the north shore of Long Island.

[175]USFWS, 1997, The Narrows, Complex #20, p. 613 (see note 172).

[176]Holst et al., 2003, p. 1-8 (see note 169).

[177]Ron Rosza, written communication to EPA, 2/20/07 (discussing personal observations) (see note 173).

[178]Mushacke, F., 2003, "Wetland loss in the Peconic Estuary," abstract of presentation at the Long Island Sound Tidal Wetland Loss Workshop, June 24–25, Stony Brook, NY, *Workshop Proceedings and Recommendations to the Long Island Sound Study*, p. 18. Available at: http://www.longislandsoundstudy.net/habitatrestoration/more.htm. In this abstract, Fred Mushacke, a marine biologist with the New York State Department of Environmental Conservation, who has conducted GIS analyses to determine areas of marsh loss in the Peconic Estuary, stated that "the extent and causes of vegetative losses are currently unknown and can only be surmised. It is, however, a synergy of anthropogenic and natural causes, and may include, but is not limited to, sediment budget disruption, sea level rise, erosion, subsidence, and eutrophication."

[179]Holst et al., 2003, p. 1-8 (see note 169).

[180]See, for example, NYS Department of State, Division of Coastal Resources, 2004, p. 3 (see note 171).

[181]Long Island Sound Foundation, n.d., Plants & Animals of Hammonasset, available at: http://www.lisfoundation.org/coastal_access/hamm_wildlife.html The Long Island Sound Foundation has been collecting and disseminating information on the sound for the public since 1992.

[182]Warren, R.S. and P.E. Fell, 1996, "*Phragmites australis* on the lower Connecticut River: Patterns of invasion and spread. As cited on p. 1-2 of Holst et al., 2003 (see note 169).

Some preservation of species may occur where "soft" protection is the preferred protection alternative. For example, local planners believe that shore protection to hold back rising seas is "likely" or "almost certain" along the shorelines of Flanders Bay, where the Flanders Bay Wetlands occur. The New York State Department of State, Division of Coastal Resources has concluded that if protection is considered necessary, alternatives such as vegetation-based approaches should be explored. This agency has asserted that shoreline hardening "may result in loss of productive habitat areas which support the fish and wildlife resources of Flanders Bay Wetlands." Several rare bird species are found in the Flanders Bay Wetlands, including least tern, common tern, piping plover, black skimmer, osprey, and common loon. Waterfowl also feed in and around the wetlands. Midwinter aerial surveys averaged 125 birds per year in the wetlands and 700 birds per year in the adjacent bays over the period 1986–1996. Diamondback terrapin are also found in the marshes and beaches along Flanders Bay.[183]

Sea Level Fen

A sea level fen vegetation community grows along Flanders Bay.[184] This rare type of coastal wetland grows only under the unusual circumstances where there is a natural seep from a nearby slope providing nutrient-poor groundwater to support its unique vegetation, and where there is protection from nutrient-rich tidal flow (see Section 3.1). Because of the need of sea level fen vegetation for nutrient-poor waters, the Flanders Bay sea level fen may not survive inundation by sea level rise.

Estuarine Beaches

Barrier beaches are less common than tidal wetlands in the Long Island Sound study area, but beaches may be at greater risk because sea level rise will accelerate shoreline erosion. Headland erosion is the dominant type of beach development along the Sound's Long Island shoreline.[185]

Notable undeveloped barrier beaches along the north shore of Long Island include those fronting Hempstead Harbor,[186] the beach-wetland system on Eatons Neck Point,[187] the Port Jefferson Beaches near the Town of Brookhaven,[188] the Nissequogue Inlet Beaches at the mouth of the Nissequogue River in the Town of Smithtown,[189] and Cedar Point Peninsula in the Peconic Estuary.[190]

The sandy barrier-beach system fronting Hempstead Harbor is typical of these beach systems, and shows a characteristic community progression from the foreshore to the bay side, or backshore. The foreshore occurs between the highest and lowest tide zones. The abundant invertebrate fauna characteristic of this area provide forage for sanderling, semipalmated plovers, and other shorebirds that stop over during migrations.[191] Shorebirds feed on all trophic levels of beach invertebrate communities, including primary consumers (herbivorous insects, amphipods, and isopods, as well as suspension-feeding crabs and bivalves) and the secondary consumers that feed on them (crabs, isopods, polychaetes, and beetles).[192] The maritime beach community between the mean

[183]NYS Department of State, Division of Coastal Resources, 2004, Long Island Sound and Long Island, Flanders Bay Wetlands, pp. 1–4 (see note 171).
[184]NYS Department of State, Division of Coastal Resources, 2004, Flanders Bay Wetlands, p. 1 (see note 171).

[185]Long Island Sound Habitat Restoration Initiative, 2003, *Technical Support for Habitat Restoration, Section 5: Coastal Barriers, Beaches, and Dunes.* November 2003. EPA Long Island Sound Office, Stamford, CT, p. 5-1. Available at: http://www.longislandsoundstudy.net/habitat/index.htm.
[186]NYS Department of State, Division of Coastal Resources, 2004, Hempstead Harbor (see note 171).
[187]NYS Department of State, Division of Coastal Resources, 2004, Eatons Neck Point (see note 171).
[188]NYS Department of State, Division of Coastal Resources, 2004, Port Jefferson Beaches (see note 171).
[189]NYS Department of State, Division of Coastal Resources, 2004, Nissequogue Inlet Beaches (see note 171).
[190]NYS Department of State, Division of Coastal Resources, 2004, Cedar Point Peninsula (see note 171).
[191]Long Island Sound Habitat Restoration Initiative, 2003, p. 5-2 (see note 185).
[192]See, for example, Bertness, 1999 (see note 133).

high tide and the primary dune provides nesting sites for several rare bird species, including piping plover, American oystercatcher, black skimmer, least tern, common tern, roseate tern, the federally listed threatened northeastern beach tiger beetle, and horseshoe crab. Dunes and the upper limit of the backshore beach is used for nesting by diamondback terrapin.[193] They also nest on dredged sands and have been observed nesting on artificial dikes in the town of Fairfield, Connecticut.[194]

One study involving interviews with local planners found that nearly all of the Long Island shoreline of the Sound is "almost certain" to be protected in response to sea level rise. The study assumed that property owners fund their own shore protection. Moreover, the Long Island Sound Habitat Restoration Initiative cautions, "Attempts to alter the natural cycle of deposition and erosion of sand by construction of bulkheads, sea walls, groins, and jetties interrupt the formation of new beaches." [195]

Tidal Flats

Longshore drift, which usually occurs from east to west along the Sound's Long Island shoreline, carries some of the material that erodes from bluffs and later deposits it to form tidal flats and barrier spits or shoals.[196] Shoals along the Long Island shoreline, particularly around Duck Point, Baiting Hollow, and the Port Jefferson area, provide forage for numerous bird species as well as habitat for shellfish.[197] There is hard clam habitat around the northern bays.[198] One of the largest areas of tidal mudflats on the north shore is near Conscience Bay, Little Bay, and Setauket Harbor west of Port Jefferson. Large beds of hard clams, soft clams, American oysters, and ribbed mussels are found in this area.[199] In western Long Island Sound, low marsh is converting to tidal flats as seas rise.[200] As seas continue to rise and the flats become inundated, the invertebrates of tidal flats could become less accessible for feeding by the many wading birds, dabbling ducks, and shorebirds whose growth and survival depend on such invertebrate food supplies.[201] It is known, for example, that shorebird abundance is directly correlated with the abundance of invertebrate forage.[202]

NEARSHORE SHALLOW WATERS AND SUBMERGED AQUATIC VEGETATION (SAV)

Eelgrass distribution along the Sound is limited to the Peconic Estuary.[203] The Marine Program of Cornell Cooperative Extension of Suffolk County is monitoring sites in Bullhead Bay, Gardiners Bay, Northwest Harbor, Orient Harbor, Southold Bay, and Three Mile Harbor (see Map 3.1).[204] The U.S. Fish and Wildlife Service reports that eelgrass beds of statewide significance are in Orient Bay[205] and Cedar

[193]Long Island Sound Habitat Restoration Initiative, 2003, pp. 5-3, 5-4 (see note 185).
[194]Ron Rosza, email to EPA 2/20/07 (discussing visual observations) (see note 173).
[195]Long Island Sound Habitat Restoration Initiative, 2003, p. 5-7 (see note 185).
[196]Long Island Sound Habitat Restoration Initiative, 2003, pp. 5-1, 5-2 (see note 185).
[197]Important Ecological Areas in and Around Long Island Sound, Map Panel 9 of 10 – Riverhead Area and Map Panel 8 of 10 – Port Jefferson Area, n.d., produced by the USFWS Service, Coastal Ecosystems Program, Charlestown, RI, for Long Island Stewardship Initiative. Available at: www.rpa.org/maps/lismaps.html.
[198]USFWS, 1997 (see note 172)
[199]NYS Department of State, Division of Coastal Resources, 2004, Conscience Bay, Little Bay and Setauket Harbor, p. 1 (see note 171).
[200]Ron Rosza, email to EPA, 2/20/07 (discussing visual observations) (see note 173).
[201]Erwin, R.M., D.R. Cahoon, D. J. Prosser, G.M. Sanders, and P. Hensel, 2006, "Surface elevation dynamics in vegetated *Spartina* marshes versus unvegetated tidal ponds along the mid-Atlantic coast, USA, with implications to waterbirds," *Estuaries and Coasts* 29:96–106, p. 103.
[202]See, for example, Evans, P.R., and P.J. Dugan, 1984, "Coastal birds: Numbers in relation to food resources," in P.R. Evans, J.D. Goss-Custard, and W.G. Hale (eds.), *Coastal Waders and Wildfowl in Winter*, Cambridge University Press, Cambridge, U.K.
[203]Eelgrass does not occur along northern Long Island Sound because of nutrient enrichment.
[204]Schott, S. 2003. Eelgrass Monitoring: Historic Distribution and Current Trends. Presentation at the Long Island Sound Tidal Wetland Loss Workshop, June 24–25, 2003, Stony Brook, New York, Workshop Proceedings and Recommendations to the Long Island Sound Study. Available at: http://www.longislandsoundstudy.net/habitatrestoration/more.htm; Tiner, R., H. Bergquist, T. Halavik, and A. MacLachlan. 2003. Eelgrass Survey for Eastern Long Island Sound, Connecticut and New York. U.S. Fish and Wildlife Service, National Wetlands Inventory Program, Northeast Region, Hadley, MA. National Wetlands Inventory report.
[205]NYS Department of State, Division of Coastal Resources, 2004, Orient Bay, p. 1 (see note 171).

Point/Hedges Bank Shallows.[206] A recent survey found 15.7 acres of eelgrass on the north shore at Mulford Point, and 194 acres on Fisher's Island.[207]

The estuary's eelgrass beds provide food, shelter, and nursery habitats to a diversity of species, including worms, shrimp, scallops and other bivalves, crabs, and fish.[208] Horseshoe crabs reportedly forage in the eelgrass beds of Cedar Point/Hedges Bank, where they are prey for loggerhead turtles (federally listed as threatened), crabs, whelks, and sharks. Atlantic silverside is an important prey species that spawns here; silverside eggs provide an important food source for seabirds, waterfowl, and blue crab, and adults are prey for bluefish, summer flounder, rainbow smelt, white perch Atlantic bonito, and striped bass. The Cedar Point/Hedges Bank Shallows eelgrass beds are known for supporting a bay scallop fishery of statewide importance.[209]

The consequences of sea level rise for SAV are unknown. However, Short and Neckles (1999) predicted that a 50 cm (19.7 in.) increase in water depth as a result of sea level rise, which could occur in this century, could reduce the light available for seagrass photosynthesis by 50 percent, which would reduce eelgrass growth by 30–40 percent.[210] In turn, this would result in reductions in the productivity and functional values of seagrass beds. This implies that reductions in the growth and survival of eelgrass beds around the Peconic Estuary could harm local populations of scallops, which support a valuable fishery, as well as horseshoe crabs and other species that are prey for many species of commercial, recreational, and ecological value.

The movement of eelgrass beds shoreward as seas rise could be impeded by steep shores or erosion and water turbidity in front of shoreline protection structures. Local planners believe that shorelines around Shelter Island, Robins Island, the Conscience Point National Wildlife Reserve, the E.A. Morton National Wildlife Reserve, Novack, Sag Harbor, Orient Point and Orient Beach, and Napeague Bay will be allowed to respond naturally to sea level rise. Other shorelines of the Peconic Estuary are considered "likely" or "almost certain" to be protected, and if these shorelines are hardened, SAV will be unable to migrate in response to sea level rise.

MARSH AND BAY ISLANDS

Several offshore islands in western Long Island Sound are significant for their colonial wading bird rookeries. The most important are Huckleberry Island, Great Captain Island, North Brother Island, South Brother Island, and Pelican Island. These islands are rocky and mostly covered by deciduous forest; their rocky shorelines provide habitat for species such as shellfish, sea stars, and barnacles. North and South Brother islands have the largest black crowned night heron colony in New York State, along with snowy egret, great egret, cattle egret, and glossy ibis.[211] The islands' bird colonies are of regional significance, and loss of island area with sea level rise could have far-reaching consequences.

[206]NYS Department of State, Division of Coastal Resources, 2004, Cedar Point/Hedges Bank Shallows, p. 1 (see note 171).
[207]Tiner et al., 2003 (see note 204); see also http://counties.cce.cornell.edu/suffolk/habitat_restoration/projectpage/StT/eeprojectsStT.htm.
[208]Peconic Estuary Program, 2001, Peconic Estuary Comprehensive Conservation and Management Plan, sponsored by the USEPA under Sec. 320 of the Clean Water Act, Suffolk County Department of Health Services, Program Office, p. 4-4.
[209]NYS Department of State, Division of Coastal Resources, 2004, Cedar Point/Hedges Bank Shallows, p. 2 (see note 171).
[210]Short, and Neckles, 1999, p. 175 (see note 91).
[211]USFWS, 1997, pp. 612–614 (see note 172).

The Long Island Sound Study considers Plum Island, Little Gull Island, and Great Gull Island off Orient Point "exemplary" colonial waterbird habitat, with sites "of national—if not international—significance."[212] The islands are relatively small and covered with grassy and herbaceous vegetation. According to the North Fork Audubon Society, Great Gull Island hosted 1,500 pairs of the endangered roseate tern in

1996 and 7,750 pairs of common tern.[213] The Long Island Sound Study reports that this population is the second largest breeding population of the roseate tern in North America.[214]

Gardiners Island,[215] Robins Island,[216] and Cow Neck[217] in Little Peconic Bay are in private ownership, and therefore staff of the Suffolk County Department of Planning believe that the shorelines of these properties will be left in a natural state. These islands provide habitats for many rare species such as roseate tern, common tern, least tern, northern harrier, red-tailed hawk, eastern mud turtle, and diamondback terrapin. Even if some protection of the islands' shorelines does occur, it seems likely that it will involve vegetation-based approaches rather than shoreline hardening to help preserve these valuable habitats.[218]

[212]Long Island Sound Study, LIS Stewardship Initiative**,** a cooperative effort involving researchers, regulators, user groups and other concerned organizations and individuals. Accessed December 4, 2007 at: http://www.longislandsoundstudy.net/stewardship/stewardship_sites.htm.

[213]Fact sheet by North Fork Audubon Society entitled *Great Gull Island IBA.* Accessed December 4, 2007 at: http://www.northforkaudubon.org/Gui/Content.aspx?Page=IBAGreatGull.

[214]Long Island Sound Study (see note 212).

[215]NYS Department of State, Division of Coastal Resources, 2004, Gardiners Island (see note 171).

[216]NYS Department of State, Division of Coastal Resources, 2004, Robins Island (see note 171).

[217]NYS Department of State, Division of Coastal Resources, 2004, Cow Neck (see note 171).

[218]For example, see NYS Department of State, Division of Coastal Resources, 2004, Robins Island, p. 5 (see note 171).

Map 3.1. Locations and Types of Habitat Discussed in this Report: Long Island

3.3 Long Island's South Shore Barrier Island/ Lagoon System

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Species and habitats along the south shore of Long Island are potentially at risk because of sea level rise. The large back-barrier bays of the south shore include, from west to east, Hempstead Bay, South Oyster Bay, Great South Bay, Moriches Bay, and Shinnecock Bay.[219] These bays contain regionally significant habitats for fish, shellfish, and birds, and a great deal is known about their ecology and habitat needs.

Based on existing literature and the knowledge of local scientists, this brief literature review discusses the coastal species in the region that could be at risk because of further habitat loss resulting from sea level rise and shoreline protection (see Map 3.1). Although it is possible to make qualitative statements about the possible impacts if sea level rise causes a total loss of habitat, our ability to discern what the impact might be if only a portion of the habitat is lost is more limited. A total loss of habitat is possible if shores are protected with hard structures and the wetlands are unable to keep pace with sea level rise.

Back-Barrier Salt Marshes

There are extensive salt marshes to the west of Great South Bay in southern Nassau County.[220] These marshes are particularly notable because much of the historically large area of marsh on the mainland shoreline of southern Nassau County has been lost to development and shoreline armoring, including the mainland marshes of South Oyster Bay[221] and the Hempstead Bay–South Oyster Bay habitat complex.[222]

Based on existing studies, a panel of accretion experts, convened by EPA for this report, expect that the back-barrier marshes adjacent to Jones Inlet are keeping pace with the current rate of sea level rise and may continue to keep pace if the rate increases by 2 mm/yr. Under this scenario, wider marshes may survive this modest increase in the rate of sea level rise, but fringing marshes are likely to be lost. These scientists also indicated that if the rate of sea level rise increases by 7 mm/yr, all of the marshes adjacent to Jones Inlet will be lost. To the east of Jones Inlet, the extensive back-barrier and fringing salt marshes surrounding Great South Bay, Moriches Bay, Shinnecock Bay, and Southampton are keeping pace with current rates of sea level rise, but the accretion panel predicted that their ability to keep pace will be marginal if the rate of sea level rise increases by 2 mm/yr, and marshes will be lost if rates increase by 7 mm/yr (see Reed et al., Section 2.1).

Opportunities for marsh migration along Long Island's south shore will be limited. Much of the mainland shoreline in southern Nassau County is bulkheaded, and the rural areas that remain in eastern Suffolk County are likely to be developed in the future. The state requires a 75-foot buffer around tidal wetlands to make marsh migration possible, but outside of this buffer

[219]One other back-barrier bay, Jamaica Bay, is discussed in Section 3.4, New York City, because it is most often considered as part of management programs in that area (e.g., the New York/New Jersey Harbor Estuary Program).

[220]USFWS, 1997, Great South Bay Habitat Complex #14, pp. 447–467 (see note 172).

[221]NYS Department of State and USFWS, Southern New England–New York Bight Coastal Ecosystems Program, 1998, *Shorebirds*, South Shore Estuary Reserve, Technical Report Series. Available at: http://www.nyswaterfronts.com/Final_Draft_HTML/Tech_Report_HTM/PDFs/C8A_Index_pdf.htm.

[222]USFWS, 1997, Hempstead Bay–South Oyster Bay, Habitat Complex #15, p. 483–494 (see note 172).

development and shoreline protection are permitted. Moreover, where wide areas of marsh do not keep pace, there will be a net loss even if marshes can migrate.

Increases in tidal creeks and channels with a modest increase in sea level rise (2 mm/yr) could benefit marsh fishes, including many commercially and recreationally important marine and estuarine transient species that move into the marshes for spawning and nursery habitat. However, where marshes are lost as the rate of sea level rise increases to 7 mm/yr, local populations may eventually move elsewhere in search of suitable nursery and foraging areas. An overall loss of nursery habitat and forage could reduce the productivity of the area's highly valued fishery resources.

The recovery of a number of at-risk bird species could be impeded if additional marsh area is lost as a result of sea level rise. For example, the Dune Road Marsh west of Shinnecock Inlet provides nesting sites for several species that are already showing significant declines, including clapper rail, sharp-tailed sparrow, seaside sparrow, willet, and marsh wren.[223] These marshes are also the only area in New York State where black rails are currently found on a regular basis and the only documented breeding location for sora rails on Long Island.[224]

The northern diamondback terrapin feeds and grows along marsh edges and the nearshore bays of the south shore. Sites on the south shore where terrapins reportedly are found include Captree State Park, east of the Robert Moses State Park on the Fire Island National Seashore, the marshes and ditches of Tobay Sanctuary near Guggenheim Park, and the western section of the Ocean Parkway, where there are signs announcing "Turtle Crossings" to protect terrapins from automobile traffic.[225] A local terrapin expert believes that additional marsh loss could lead to a "very serious reduction" in their already low abundance.[226]

Back-Barrier Beaches

As sea levels rise, the back-barrier beaches will erode in front of shoreline protection structures, and will be lost without continual beach nourishment. Eggs of species that nest on estuarine beaches and abundant invertebrate fauna provide forage for numerous bird species, including migratory shorebirds and species that nest on nearby barrier islands, such as the federally threatened piping plover. Shorebirds feed on all trophic levels of beach invertebrate communities, including herbivorous insects, amphipods, isopods, crabs, and bivalves.[227]

The back-barrier beaches of the south shore provide nesting sites for the northern diamondback terrapin,[228] the endangered roseate tern,[229] and horseshoe crabs.[230] Cedar Beach in Great South Bay is considered important for the recovery of roseate tern.[231] Shorebirds feed preferentially on horseshoe crab eggs during their spring migrations,[232] and local biologists believe that the large numbers of shorebirds west of Shinnecock Inlet may be due in part to horseshoe crab spawning in the area.[233] Loss of this food resource could have a significant effect on migrating shorebirds such as red knot, which feed almost exclusively on horseshoe crab eggs during their spring migration, when they must

[223]USFWS, 1997, p. 418 in Shinnecock Bay Habitat Complex #12 (see note 172).
[224]NYS Department of State, Division of Coastal Resources, 2004 (see note 171).
[225]NYS Department of State and USFWS, Southern New England-New York Bight Coastal Ecosystems Program, 1998 (see note 221).

[226]Dr. Russell Burke, Department of Biology, Hofstra University, Hempstead, NY. August 1, 2006. "Diamondback terrapin and sea level rise." Email to E. Strange, Stratus Consulting, expressing his opinion about the implications of marsh loss in southern Long Island for terrapins. (Russell Burke has operated an annual diamondback terrapin conservation project at the Jamaica Bay Wildlife Refuge in the Gateway National Recreational Area since 1998.)
[227]Dugan et al., 2003 (see note 127).
[228]NYS Department of State, Division of Coastal Resources, 2004, Great South Bay-West, p. 3 (see note 171).
[229]USFWS, 1997, p. 454 in Great South Bay, Complex #14 (see note 172).
[230]NYS Department of State and USFWS, Southern New England–New York Bight Coastal Ecosystems Program, 1998 (see note 221).
[231]USFWS, 1997, Great South Bay. Complex #14 (see note 172).
[232]USFWS, 2005, Red knot, *Calidris canutus rufa*. Fact sheet available at: http://www.fws.gov/northeast/redknot/facts.pdf.
[233]NYS Department of State and USFWS, Southern New England-New York Bight Coastal Ecosystems Program. 1998 (see note 221).

double in weight to support long-distance migrations.[234] A reduction in the area of back-barrier beach habitat would also negatively impact nesting by diamondback terrapins. Although exact numbers are unknown, a diamondback terrapin expert who has conducted field studies in the area estimates that currently only a few hundred female diamondback terrapins still nest on the back-barrier beaches of Long Island's south shore.[235]

Tidal Flats

Of the extensive tidal flats along Long Island's southern shoreline, most are found west of Great South Bay and east of Fire Island Inlet along the bay side of the barrier islands,[236] in the Hempstead Bay–South Oyster Bay complex,[237] and around the Moriches and Shinnecock inlets.[238] These flats are important foraging areas for birds and provide habitat for several edible shellfish species, including soft clam, northern quahog (hard clam), bay scallop, and blue mussel. In Shinnecock Bay, the Shinnecock Reservation has developed a subsistence aquaculture program that includes northern quahog and American oyster.[239]

Tidal flats and shallow water habitats are heavily used by shorebirds, raptors, and colonial waterbirds in spring and summer and by waterfowl during fall and winter.[240] The John F. Kennedy Bird Sanctuary is a particularly important feeding area for birds in South Oyster Bay. In summer, the state threatened least tern and a variety of herons and egrets forage here, along with the federally endangered roseate tern. The sanctuary also provides overwintering habitat for abundant waterfowl, including American black duck, blue-winged, and green-winged teal.[241] Shinnecock Bay supports populations of wintering waterfowl of statewide significance.[242]

The tidal flats around Moriches and Shinnecock inlets are particularly important foraging areas for migrating shorebirds. If shoreline waters become too deep for foraging on these flats, migrating shorebirds could have insufficient foraging areas to support their long-distance migrations. Scientists writing on behalf of the South Shore Estuary Reserve program have asserted that "because shorebirds concentrate in just a few areas during migration, loss or degradation of key sites could devastate these populations." These scientists note that local populations of black-bellied plover, whimbrel, red knot, sanderling, semipalmated sandpiper, least sandpiper, and short-billed dowitcher are already showing declines.[243]

Nearshore Shallow Waters and Submerged Aquatic Vegetation (SAV)

Seagrass beds occur along much of the southern shoreline of Long Island.[244] The consequences of sea level rise for SAV are unknown. However, Short and Neckles predicted that a 50 cm (19.7 in.) increase in water depth as a result of sea level rise, which could occur during this century, could reduce the light available for seagrass photosynthesis by 50 percent, resulting in a 30-40 percent reduction in eelgrass growth. These researchers suggested that this will, in turn, result in reduced productivity and functional values of seagrass beds.[245] The importance of eelgrass beds for the secondary production of the south shore is indicated by a study of the Great

[234]USFWS, 2005, Red knot. Fact sheet (see note 232).
[235]Dr. Russell Burke, email to E. Strange, Stratus Consulting (see note 226).
[236]USFWS, 1997, p. 449 in Great South Bay Habitat Complex #14 (see note 172).
[237]USFWS, 1997, p. 484 in Hempstead–South Oyster Bay, Habitat Complex #15 (see note 172).
[238]NYS Department of State and USFWS, Southern New England–New York Bight Coastal Ecosystems Program, 1998, p. 4 (see note 221).
[239]USFWS, 1997, Shinnecock Bay Habitat Complex #12 (see note 172).
[240]Erwin, M.R., 1996, "Dependence of waterbirds and shorebirds on shallow water habitats in the Mid-Atlantic coastal region: An ecological profile and management recommendations," *Estuaries* 19:213–219, p. 213.
[241]USFWS, 1997, p. 487 in Hempstead–South Oyster Bay, Habitat Complex #15 (see note 172).
[242]NYS Department of State, Division of Coastal Resources, 2004, Shinnecock Bay, p. 2 (see note 171).
[243]NYS Department of State and USFWS, Southern New England-New York Bight Coastal Ecosystems Program, 1998, p. 1 (see note 221).
[244]NOAA, Benthic Habitat Mapping. SAV map accessed December 4, 2007 at: http://www.csc.noaa.gov/benthic/data/northeast/longisl.htm.
[245]Short and Neckles, 1999, p. 178 (see note 91).

South Bay by Briggs and O'Connor (1971), who found that 23 of 40 recorded fish species clearly preferred naturally vegetated bottom to unvegetated areas.[246]

Marsh and Bay Islands

Increased flooding and erosion of marsh and dredge spoil islands could reduce habitat for bird species that forage and nest on these islands, particularly gulls and terns. Erosion on Warner Island is reducing nesting habitat for roseate tern and increasing flooding risk during nesting.[247] The Hempstead Bay–South Oyster Bay complex includes a network of salt marsh and dredge spoil islands that are important for nesting by herons, egrets, and ibises. Hempstead Bay is the primary nesting area in Long Island for yellow-crowned night-herons. Waterfowl such as brant and American black duck feed and rest in the shallow waters around the islands and tidal flats of the complex. An average of 25,000 waterfowl have been counted on midwinter aerial surveys.[248] Lanes Island and Warner Island in Shinnecock Bay support colonies of the state-listed common tern and the federally endangered roseate tern.[249] Carter's Island has supported nesting by the state endangered least tern.[250] Local planners have indicated that eroding marsh islands such as those in Great South Bay may need to be artificially protected to maintain the vegetated wetlands.

[246]Briggs, P.T. and J.S. O'Connor, 1971, "Comparison of shore-zone fishes over naturally vegetated and sand-filled bottoms in Great South Bay," *New York Fish and Game Journal* 18(1):15–41; cited in NYS Department of State and USFWS, Southern New England–New York Bight Coastal Ecosystems Program, 1998, *Estuarine Fish*, p. 8 (see note 221).
[247]NYS Department of State and USFWS, Southern New England–New York Bight Coastal Ecosystems Program, 1998, *Coastal Colonial Waterbirds*, p. 6 (see note 221).
[248]USFWS, 1997, p. 486 in Hempstead Bay-South Oyster Bay, Habitat Complex #15 (see note 172).
[249]USFWS, 1997, p. 418 in Shinnecock Bay, Habitat Complex #12 (see note 172).
[250]USFWS, 1997, p. 432 in Moriches Bay, Habitat Complex #13 (see note 172).

3.4 New York City, the Lower Hudson River, and Jamaica Bay

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Species and habitats in the region encompassing New York City, the lower Hudson River, the East River, and Jamaica Bay are potentially at risk because of sea level rise. Although the region is one of the most heavily urbanized areas along the U.S. Atlantic Coast, there are nonetheless regionally significant habitats for fish, shellfish, and birds in the area, and a great deal is known about the ecology and habitat needs of these species.

Based on existing literature and the knowledge of local scientists, this brief literature review discusses those species that could be at risk because of further habitat loss resulting from sea level rise and shoreline protection (see Map 3.2). Although it is possible to make qualitative statements about the ecological implications if sea level rise causes a total loss of habitat, our ability to say what the impact might be if only a portion of the habitat is lost is more limited. A total loss of habitat might be expected if shores are protected with hard structures and the wetlands are unable to keep pace with sea level rise.

Most shorelines in the New York metropolitan area are heavily modified. Because the remaining coastal land is at a premium, planners indicate that most of the shoreline is almost certain to be protected. The remaining undeveloped land along the shore continues to be developed and armored.[251] Where protection occurs, New York City's Waterfront Revitalization Program (WRP) requires the use of nonstructural alternatives such as beach nourishment, dune construction, and vegetation wherever possible. Planners expect that the only sizeable areas in the New York City metropolitan area that are unlikely to be protected are portions of the three Special Natural Waterfront Areas (SNWAs) designated by the city: Northwest Staten Island/Harbor Heron SNWA; East River–Long Island Sound SNWA; and Jamaica Bay SNWA.

TIDAL WETLANDS

Staten Island. Hoffman Island and Swinburne Island are National Park Service properties lying off the southeast shore of Staten Island; the former has important nest habitat for herons, and the latter is heavily nested by cormorants.[252] The Northwest Staten Island/Harbor Herons SNWA is an important nesting and foraging area for herons, ibises, egrets, gulls, and waterfowl.[253] The so-called Harbor Herons Complex includes three island heronries of regional significance, including Shooters Island, Pralls Island, and Isle of Meadows (see subsequent section on islands). Several tidal emergent, salt, brackish, and fresh water marshes provide foraging areas for the birds of the island heronries, including Arlington

[251] George Frame, National Park Service, in email entitled Comments on NYHarbor&RaritanBay papers EPA feb07, to Karen Scott, EPA, 2/20/07, suggests that "many urban planners are not preserving undeveloped lands along the shores of the estuary; even today they are building and hardening in many areas."

[252] George Frame, 2/20/07 email (see note 251).

[253] USFWS, 1997, p. 578 in Arthur Kill Complex, Complex #18 (see note 172).

Marsh, Sawmill Creek Marsh, Gulfport Marsh, Merrill's Marsh, Old Place Creek, Neck Creek Marsh, and Fresh Kills.[254] With the exception of Fresh Kills, shoreline protection is considered almost certain in these areas. Loss of these marshes could have a significant negative impact on the island heronries because of a lack of alternative foraging sites nearby.

The Fresh Kills wetland system is one of the largest tidal wetland systems in the region, covering an estimated 405 ha (1,000 acres).[255] Local planners expect that these wetlands will probably be allowed to respond naturally to sea level rise, but migration may not be possible because of the relatively steep slopes that have formed near the shore as a result of landfilling activities.

Manhattan. Most of the shoreline of Lower Manhattan and the Battery has been bulkheaded and filled. An exception is the natural shoreline and wetlands at the mouth of the Harlem River at New York City's Inwood Hill Park.[256] The park contains low salt marsh and a broad mudflat that runs from the marsh to the channel of the Harlem River Ship Canal. Great blue herons are found along the flat in winter and snowy and great egrets are common from spring through fall.[257]

The Lower Hudson River. Although the tidal Hudson River extends upstream to the dam at Troy, New York State's tidal wetland regulations apply to the Hudson River shoreline only up to the Tappan Zee Bridge. This is the estuarine portion of the tidal river. Along this stretch of the river there is relatively little marsh, with the exception of brackish marshes at the mouth of the Croton River, in Piermont Marsh, and in a network of marshes behind Grassy Point near Haverstraw Bay.[258]

Piermont Marsh is a 411.6 ha (1,017 acre) brackish wetland on the western shore of the lower Hudson River just below the Tappan Zee Bridge, in the town of Orangetown, in Rockland County.[259] The New York State Department of State has designated the marsh a Significant Coastal Fish and Wildlife Habitat, and it has been designated part of the Hudson River National Estuarine Research Reserve by the National Oceanic and Atmospheric Administration and the New York State Department of Environmental Conservation (NYDEC). [260]

Piermont Marsh is dominated by common reed and narrow-leaved cattail, along with some salt marsh species that include smooth cordgrass, salt-meadow cordgrass, and spike grass, making it the location of the northernmost occurrence of salt marsh species on the Hudson. Breeding birds known to use the marsh for nesting include relatively rare species such as Virginia rail, swamp sparrow, black duck, least bittern, and sora rail. A small number of osprey sometimes gather in the marsh, particularly during spring migration. Anadromous and freshwater fish use the marsh's tidal creeks as a spawning and nursery area. Killfish, mummichog, fiddler crab, and blue crab use shallow marsh areas. Diamondback terrapin, a federal species of concern, reportedly nest in upland areas along the marsh.[261]

Jamaica Bay, located between the boroughs of Brooklyn and Queens, is the largest area of protected wetlands in a major metropolitan area along the U.S. Atlantic Coast. The bay includes

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[254]USFWS, 1997, p. 579 in Arthur Kill Complex, Complex #18 (see note 172).
[255]USFWS, 1997, p. 580 in Arthur Kill Complex, Complex #18 (see note 172).
[256]USFWS, 1997, p. 630 in Lower Hudson River Estuary, Complex #21 (see note 172).
[257]Fact sheet by New York City Department Of Parks and Recreation, Inwood Hill Park—Salt Marshes in New York City Parks. Accessed December 4, 2007 at: http://www.nycgovparks.org/sub_your_park/historical_signs/hs_historical_sign.php?id=12864.

[258]USFWS, 1997, p. 631 in Lower Hudson River Estuary, Complex #21 (see note 172).
[259]Fact sheet on Piermont Marsh Component of the Hudson River Reserve by the Hudson River Reserve Program, National Estuarine Research Reserve System. Accessed December 4, 2007 at:http://nerrs.noaa.gov/HudsonRiver/PiermontMarsh.html.

[260]USFWS, 1997, pp. 629, 633 in Lower Hudson River Estuary, Complex #21 (see note 172).
[261]USFWS, 1997, p. 633 in Lower Hudson River Estuary, Complex #21 (see note 172).

the Jamaica Bay Wildlife Refuge,[262] which has been protected since 1972 as part of the Jamaica Bay Unit of the Gateway National Recreation Area, administered by the National Park Service. The refuge includes numerous salt marsh islands that are sheltered from the Atlantic Ocean by the Rockaway Peninsula.

Despite extensive disturbance from dredging, filling, and development, Jamaica Bay remains one of the most important migratory shorebird stopover sites in the New York Bight region. [263] The bay provides overwintering habitat for brant, mallards, American black duck, canvasback duck, and other waterfowl, and intertidal mudflats for foraging migrants such as black skimmer, plovers, and knots.[264] The refuge and Breezy Point, at the tip of the Rockaway Peninsula, support populations of 214 species that are state or federally listed or of special emphasis, including 48 species of fish and 120 species of birds. These areas combined have been designated as a Significant Coastal Fish and Wildlife Habitat by the New York State Department of State and as a Critical Environmental Area by the NYDEC.[265]

Spring Creek Park[266] is one of only two remaining areas of salt marsh in the northern tributaries of Jamaica Bay. Yellow-crowned night heron, little blue heron, and willet are found in these marshes.[267] The nearby Four Sparrow Marsh is the other remaining salt marsh in this part of the bay. It is a particularly noteworthy as an undisturbed nesting habitat for four native species of sparrows that are in decline, the sharp-tailed, seaside, swamp, and song sparrows, and as a stopover site for some 326 species of migrating birds. Several species of ducks, gulls, and wading birds also nest in Four Sparrow Marsh and feed on marsh mollusks and crustaceans.[268]

Because of its importance as an area of significant biodiversity and its uniqueness as a wildlife sanctuary in a highly developed urban setting, planners expect that Jamaica Bay's wetlands will be allowed to respond naturally to sea level rise. However, wetlands in some parts of the bay are currently showing substantial losses. Researchers studying the salt marsh islands near the John F. Kennedy International Airport (including Yellow Bar Hassock, Black Wall Marsh, Big Egg Marsh, East High Meadow Marsh, Elders Point Marsh, and Jo Co Marsh) estimated that marsh loss in the area averaged 12 ha (29.7 acres) per year from 1974 to 1999, even though the area is a national park. [269] This represents an increase in marsh loss of 8 ha (19.8 acres) per year over preceding decades when the area was not yet part of the Gateway National Recreation Area. The estimated rate of loss has been increasing, averaging 18 ha (44.5 acres) per year over the period 1994 to 1999.[270] The reasons for this accelerating trend in marsh loss aren't completely clear, though sea level rise has been implicated as one possible cause.[271,272] However, the Jamaica Bay researchers noted that the significant marsh loss that is already occurring "implies that accretion rates in Jamaica Bay may

[262]Jamaica Bay Wildlife Refuge is managed by the National Park Service, as part of the Jamaica Bay Unit of the Gateway National Recreation Area. The refuge was originally created by the New York City Parks department in 1951. See "Brochure: The Jamaica Bay Wildlife Refuge", National Park Service, accessed November 27, 2006 at: http://www.nps.gov/archive/gate/jbu/jbu_nature.htm. Many people mistakenly call the refuge "Jamaica Bay *National* Wildlife Refuge," but national wildlife refuges are managed by the US Fish and Wildlife Service, not the National Park Service.

[263]USFWS, 1997, p. 532 in Jamaica Bay and Breezy Point, Complex #16 (see note 172).

[264]Hartig, E.K., V. Gornitz, A. Kolker, F. Mushacke, and D. Fallon, 2002, Anthropogenic and climate-change impacts on salt marshes of Jamaica Bay, New York City, *Wetlands* 22:71–89. p. 74, citing Wells (1998).

[265]USFWS, 1997, p. 532 in Jamaica Bay and Breezy Point, Complex #16 (see note 172).

[266]See fact sheet on Spring Creek Park by the New York City Department of Parks and Recreation at http://nycgovparks.org/sub_your_park/historical_signs/hs_historical_sign.php?id=11227.

[267]USFWS, 1997, p. 532 in Jamaica Bay and Breezy Point Complex #16 (see note 172).

[268]See fact sheet on the Four Sparrow Marsh Preserve by the New York City Department of Parks and Recreation, available at: http://www.nycgovparks.org/sub_about/parks_divisions/nrg/forever_wild/site.php?FWID=21.

[269]Hartig, et al., 2002 (see note 264).

[270]Hartig et al., 2002, p. 71 (see note 264).

[271]Hartig et al., 2002, p. 75 (see note 264).

[272]George Frame, 2/20/07 email (see note 251), suggests that "the catastrophic loss of salt marshes in Jamaica Bay could be due mainly to input of nutrients and contaminants from wastewater treatment plants. Also, past dredging and subaqueous borrow pits may act as a sediment sink, starving salt marshes. Sea level rise might be less important."

be insufficient, even at present rates of sea level rise, to compensate for losses due to erosion and other factors."[273]

There are significant ecological implications of marsh loss in this area. Annual marsh primary production ranges from 700 to 1,500 g/m^2 in Jamaica Bay marshes.[274] This primary production is essential for the larger estuarine food web, including the production of commercially and recreationally valuable fish species that use marshes as nursery areas.[275] Kneib (2003) developed models of marsh nekton production resulting from marsh primary production in Georgia marshes and estimated that nekton production ranges from 15 to 42 kg/ha/yr, a third of which represents the production of commercial and recreational species that use the marshes as nursery areas.[276] Thus, loss of these wetlands, even if the current rate of 18 ha/yr does not increase as sea level rise increases, would have an important impact, not just on marsh primary production but also on the production of fish and shellfish within both the marsh and the surrounding estuary. In fact, state and federal governments with holdings in the area indicate that some form of protection may be necessary to protect the significant ecological value of the bay, including applying sediment to raise the marsh surface.

Estuarine Beaches

Among the relatively few areas of beach remaining in the New York City Metropolitan Area are the beaches of the Rockaways, Coney Island, and the South Shore of Staten Island. Beach nourishment is planned or under way for all of these areas.

Jamaica Bay has been designated and mapped as a protected beach unit pursuant to the federal Coastal Barrier Resources Act.[277] Much of the bay's shoreline has been hardened with seawalls and bulkheads, so estuarine sandy beach habitat is now uncommon.[278] Remaining estuarine beaches occur off Belt Parkway (e.g., Plumb Beach) and on the bay islands.[279]

Several islands in Jamaica Bay contain mountains of dredged sand (on top of salt marshes), so they now have sandy beaches. Sandy beach also exists from Breezy Point tip to Fort Tilden (at Flatbush Avenue). Floyd Bennett Field is entirely on top of former saltmarsh and estuarine beach; this artificial island now has sandy beach along more than half of its shoreline, although portions have a bulkhead farther inland.[280]

Mud snails are common throughout this habitat, up to the high tide mark. The snails graze on sea lettuce and old horseshoe crab shells. Beach wrack, consisting primarily of straw from smooth cordgrass and common reed, with small proportions of sea lettuce, contains insects, isopods, and amphipods that also provide forage for shorebirds.[281] The abundance of shorebird species is positively correlated with the abundance of beach wrack and associated invertebrates.[282]

Horseshoe crabs lay their eggs on the small pockets of beach in the bay, many of which are found on the bay islands. The shore of Plumb Beach is a popular horseshoe crab nesting site.[283]

Diamondback terrapin also nest on sandy habitats. Diamondback terrapins are the only

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[273]Hartig et al., 2002 p. 82 (see note 264).
[274]Hartig et al., 2002, p. 71 (see note 264).
[275]Teal, 1986 (see note 10).
[276]Kneib, R.T., 2003, "Bioenergetics and landscape considerations for scaling expectations of nekton production from intertidal marshes," *Marine Ecology Progress Series* 264:279–296. (The modeled nekton production estimates were based on an estimated annual above ground primary production of 1,250 grams dry weight per square meter derived from field data, which is within the range of the annual primary production estimated for Jamaica Bay marshes.)
[277]USFWS, 1997, pp. 531–532 in Jamaica Bay and Breezy Point, Complex #16 (see note 172).
[278]Don Riepe, American Littoral Society. August 20, 2006 email to E. Strange, Stratus Consulting, entitled "Notes from phone conversation," in which he confirmed his visual observations of intertidal beaches and shoreline armoring along Jamaica Bay as discussed in an earlier phone call with E. Strange on August 11, 2006. (Mr. Riepe has served as director of the Northeast Chapter of the American Littoral Society for 25 years. He is also the organization's "Jamaica Bay Guardian," and has personally observed most of the estuarine shores in this area.)
[279]Ibid.
[280]George Frame, personal visual observations, 2/20/07 email (see note 251).
[281]Don Riepe, 2006 email (see note 278).
[282]Dugan et al., 2003 (see note 127).
[283]USFWS, 1997, p. 535 in Jamaica Bay and Breezy Point, Complex #16 (see note 172).

turtles found in brackish waters. In general, nesting terrapins show a strong preference for sandy back-barrier beaches compared to the ocean-facing beaches of barrier islands.[284,285] One reason for this may be that the back-barrier beaches are closer to the *Spartina* marshes where terrapins feed and grow.[286] In Jamaica Bay, terrapins nest in uplands, usually above the beaches; the filled wetlands of Jamaica Bay provide most of the nest sites for terrapins in this area.[287]

Nesting and migrating shorebirds feed on the invertebrates of the beaches in the study region. Many of these species nest along the marine barrier beach at Breezy Point, including the federally threatened piping plover, the state endangered least tern, and the state threatened common tern. These species feed on the small invertebrates of estuarine and ocean beaches as well as area mudflats. Breezy Point is also a concentration area for raptors, waterfowl, and landbirds passing through the area. Migrating raptors include the federally endangered peregrine falcon and the state threatened northern harrier and osprey.[288]

Because of the importance of beach species for estuarine food webs, scientists have raised concerns about the ecological implications of the loss of estuarine beaches.[289] In addition to the forage provided by the abundant mud snails and the small organisms of beach wrack, horseshoe crab eggs are a critical food source for migrating shorebirds.[290] In addition, continued loss of the few remaining sandy habitats in the study region would be particularly serious for diamondback terrapin, which only nest in these habitats. Because so few beaches remain, local planners indicate that beach nourishment in the face of sea level rise is likely for most remaining beach habitat in this area.

Tidal Flats

Relatively few tidal flats remain along the highly modified shorelines of the study region. There is only a narrow band of shallow subtidal flats along Lower Manhattan and the Battery.[291] However, tidal mudflats are increasing as salt marshes disappear.[292]

Large concentrations of shorebirds, herons, and waterfowl use the shallows and tidal flats of Piermont Marsh along the lower Hudson River as staging areas for both spring and fall migrations.[293] Tidal flats provide substrate for algae such as sea lettuce (*Ulva lactuca*), an important food for brants.[294]

Tidal flats in Jamaica Bay are frequented by shorebirds and waterfowl, and an intensive survey of shorebirds in the mid-1980s estimated more than 230,000 birds of 31 species in a single year, mostly during the fall migration.[295] The most abundant shorebirds feeding on Jamaica Bay's tidal flats in fall include plovers, sandpipers, ruddy turnstone, sanderling, dunlin, short-billed dowitcher, and greater yellowlegs. In addition to these species, red knot is seen during the spring migration. Area mudflats are also important for waterfowl in winter.[296]

Inundation with rising seas will eventually make flats unavailable to short-legged shorebirds,

[284]Roosenburg, W.M.,1991, "Nesting habitat of diamondback terrapin: A geographic comparison," *Wetland Journal* 6:8–11.
[285]Dr. Russell Burke, 2006 email to E. Strange (personal visual observation) (see note 226).
[286]Feinberg, and Burke, 2003, "Nesting ecology and predation of diamondback terrapins, *Malaclemys terrapin*, at Gateway National Recreation Area, New York," *Journal of Herpetology* 37:517–526, p. 520.
[287]George Frame, 2/20/07 email (personal visual observations) (see note 251).
[288]USFWS, 1997, p. 536 in Jamaica Bay and Breezy Point, Complex #16 (see note 172).
[289]Jackson, et al., 2002 (see note 139), reviewing the findings of J.K. Sullivan, 1994, "Habitat status and trends in the Delaware estuary," *Coastal Management* 22:49–79; and Dove and Nyman, 1995, pp. 441–447 (see note 14).
[290]Karpanty et al., 2006 (see note 160).
[291]USFWS, 1997, p. 630 in Lower Hudson River Estuary, Complex #21 (see note 172).
[292]George Frame, 2/20/07 email (personal visual observations) (see note 251).
[293]USFWS, 1997, p. 633 in Lower Hudson River Estuary, Complex #21 (discussing the ecological significance and uniqueness of Piermont Marsh) (see note 172).
[294]George Frame, 2/20/07 email (personal visual observations) (see note 251).
[295]1984 study by Joanna Burger of Rutgers University, cited on p. 3 in New York State Department of State and USFWS, 1998 (see note 221).
[296]USFWS, 1997, p. 537 in Jamaica Bay and Breezy Point Complex #16 (discussing the significance of Jamaica Bay, in particular the bay islands, as a stopover site for migratory shorebirds) (see note 172).

unless they can shift feeding to marsh ponds and pannes.[297] At the same time, disappearing saltmarsh islands in the area are transforming into intertidal mudflats. [298] This increases habitat for shorebirds at low tide, but leaves less habitat for refuge at high tide.

Shallow Nearshore Waters and Submerged Aquatic Vegetation (SAV)

There is extensive shallow water habitat and high biological productivity in the part of the Hudson River from Stony Point south to Piermont Marsh, just below the Tappan Zee Bridge in Rockland County. This wide, shallow area is where the estuary's seasonal (and annual) salt front occurs, which is the area of greatest mixing of ocean and freshwater. The salt front functions to concentrate nutrients and plankton, resulting in a high level of both primary and secondary productivity. Thus, this part of the Hudson is a major habitat area for numerous fish and bird species. It is a major nursery area for striped bass, white perch, tomcod, and Atlantic sturgeon and a wintering area for the federally endangered shortnose sturgeon. Waterfowl also feed and rest here during spring and fall migrations. Some SAV is also found here, dominated by water celery, sago pondweed, and horned pondweed.[299] Sea level rise will affect this productive area through salinity changes that will influence the composition and diversity of nearshore vegetation and associated fauna. However, changes in the upstream extent of the salt wedge as a result of sea level rise have not been analyzed, nor has anyone considered the ecological implications of such a change.

Marsh and Bay Islands

Regionally important populations of egrets, herons, and ibises are located on North and South Brother islands in the East River and on Shooter's Island, Prall's Island, and Isle of Meadows in Arthur Kill and Kill van Kull. North and South Brother islands have the largest black crowned night heron colony in New York State, along with large numbers of snowy egret, great egret, cattle egret, and glossy ibis.[300] The population of the heronries of Shooter's Island, Prall's Island, and Isle of Meadows, known collectively as the Harbor Herons Complex, constitutes about 25 percent of all nesting wading birds in New York, New Jersey, and Connecticut.[301] The available research provides no basis for expecting that these colonial nesting birds could survive if these islands were inundated.

Since 1984, an average of 1,000 state threatened common tern have nested annually in colonies on seven islands of the Jamaica Bay Wildlife Refuge, including Canarsie Pol, Jo Co Marsh, and Silver Hole Marsh, with smaller numbers at Duck Creek Marsh, East High Meadow, Ruffle Bar, and Subway Island. The heronry on Canarsie Pol also supports nesting by great black-backed gull, herring gull, and American oystercatcher. The only colonies of laughing gull in New York State, and the northernmost breeding extent of this species, occur on the islands of East High Meadow, Silver Hole Marsh, Jo Co Marsh, and West Hempstead Bay.[302]

Hoffman Island and Swinburne Island are National Park Service properties lying off the southeast shore of Staten Island; the former has important nest habitat for herons, and the latter is heavily nested by cormorants.[303]

Diamondback terrapin nest in large numbers along the sandy shoreline areas of the islands of Jamaica Bay, primarily Ruler's Bar Hassock.[304] Local experts have reported observing about

[297]Erwin et al., 2004, p. 901 (see note 16). (Discussing mudflats at Forsythe National Wildlife Refuge, New Jersey, and other northeastern Atlantic coast sites.)
[298]George Frame, 2/20/07 email (personal visual observation) (see note 251).
[299]USFWS, 1997, p. 630 in Lower Hudson River Estuary, Complex #21 (see note 172).

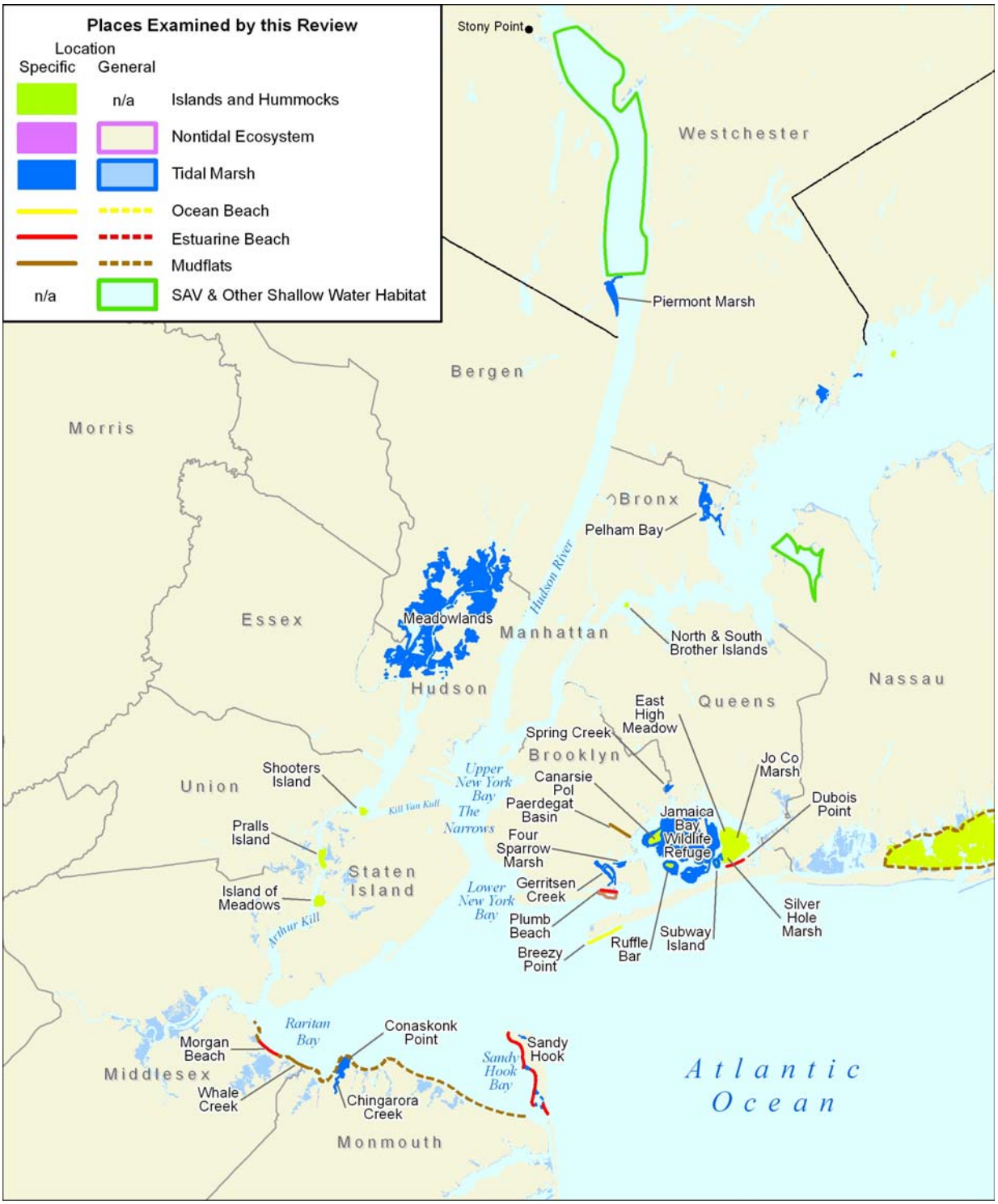
[300]USFWS, 1997, p. 614 in The Narrows, Complex #20 (see note 172).
[301]Steinberg, N. D.J. Suszkowski, L. Clark, and J. Way, 2004, Health of the Harbor: The First Comprehensive Look at the State of the NY/NJ Estuary, a report to the NY/NJ Harbor Estuary Program, Hudson River Foundation, New York, pp. 12–13.

[302]USFWS, 1997, p. 537 in Jamaica Bay and Breezy Point, Complex #16 (see note 172).
[303]George Frame, 2/20/07 email (personal visual observation) (see note 251).
[304]USFWS, 1997, p. 538 in Jamaica Bay and Breezy Point, Complex #16 (see note 172).

2,000 females nesting in the area.[305] Although bay islands may offer more protection from predators than the mainland, in recent years a large percentage of terrapin eggs have been depredated.[306] Other possible causes of low egg survivorship include so-called “root predation,” whereby the roots of beach plants “invade” a nest and penetrate the eggs and absorb their nutrients.[307]

It is estimated that between 1974 and1994, the smaller islands of Jamaica Bay lost nearly 80 percent of their vegetative cover.[308] There has been an accelerating trend in the loss of marsh area, reaching an average annual rate of 18 ha (44.5 acres) per year between 1994 and 1999.[309] Further loss of bay island habitat with rising seas could eliminate nesting sites for island-nesting birds, having significant impacts on the populations of these species, particularly those with already diminished population sizes such as the state threatened common tern. A local terrapin expert has speculated that marsh loss, combined with loss of beach nesting sites, could greatly reduce the remaining local population of diamondback terrapin.[310]

[305]Dr. Russell Burke, 2006 email to E. Strange (see note 226). See also Feinberg, J.A., and R.L. Burke, 2003 (see note 286), and Ner, S.E., and R.L. Burke, n.d., Direct and indirect effects of urbanization on diamond-back terrapins of the Big Apple: Distribution and predation in a human-modified estuary, Unpublished manuscript, Department of Biology, Hofstra University, Hempstead, NY.
[306]Ner and Burke, n.d. (see note 305).
[307]Feinberg and Burke, 2003, pp. 517 and 523, and references therein (see note 286).
[308]Hartig et al., 2002, p. 71 (see note 264).
[309]Hartig et al., 2002, p. 78 (see note 264).
[310]Dr. Russell Burke, 2006 email to E. Strange (see note 226).



Map 3.2 Locations and Types of Habitat Discussed in this Report: New York Harbor and Raritan Bay

3.5 Raritan Bay and the Hackensack Meadowland, New Jersey

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Species and habitats in the tidal marshes of Raritan Bay and the Hackensack Meadowlands are potentially at risk because of sea level rise. Raritan Bay is part of the Raritan Bay–Sandy Hook Bay habitat complex at the "apex" of the New York Bight. The apex is where the east-west oriented coastline of New England and Long Island intersects the north-south oriented coastline of the mid-Atlantic at Sandy Hook. This is very significant ecologically, because the two coastlines tend to concentrate species migrating between the two areas.[311]

Based on existing literature and the knowledge of local scientists, this brief literature review discusses the coastal species in the region that could be at risk because of further habitat loss resulting from sea level rise and shoreline protection (see Map 3.2). Although it is possible to make qualitative statements about the possible impacts if sea level rise causes a total loss of habitat, our ability to discern what the impact might be if only a portion of the habitat is lost is more limited. A total loss of habitat is possible if shores are protected with hard structures and the wetlands are unable to keep pace with sea level rise.

Tidal Marshes

Tidal marshes in this region are mostly estuarine marsh or saline fringing marsh, with small areas of freshwater tidal marsh along South River and Raritan River. According to a panel of accretion experts, the dominant accretionary processes in these marshes are peat accumulation and inputs of river sediments, both of which they anticipate will increase in the future depending on marsh type and local conditions.

As a result of the high productivity and the potential for peat accumulation of tidal freshwater marshes in the region, the accretion panel believes that freshwater tidal marshes along the South and Raritan rivers will accumulate sufficient sediment to accrete and even expand as sea level rise increases, even with a 7 mm/yr increase in the current rate (Section 2.1).

However, the accretion panel anticipates that peat accumulation in estuarine and saline fringe marsh will increase only up to a threshold level, which is currently unknown. The panel projects that beyond that threshold these marshes will become marginal if the rate of sea level rise increases by 2 mm/yr, and will not survive if the rate increases by 7 mm/yr. Even at the modest rate of increase of 2 mm/yr, these marshes will be lost if hardened shorelines prevent migration or the marshes are degraded by human activities (see Section 2.1).

The shorelines of Raritan Bay have the most natural estuarine and saline fringing marsh remaining in the region. The southern portion of Raritan Bay includes large tracts of fringing salt marsh at Conaskonk Point and from Flat Creek to Thorn's Creek.[312] Local planners expect that much of the region's shoreline will be protected from sea level rise; in developed areas, bulkheading is already common. Therefore, migration of brackish and saline fringing marsh will not be possible along most, if not all, of the shoreline.

As estuarine and saline fringing marshes are lost, there will be increasing competition for habitat among the species found in these marshes, and eventually all of the marsh inhabitants that

[311]USFWS, 1997, p. 553 in Raritan Bay-Sandy Hook Bay Complex, Complex #17 (see note 172).

[312]Ibid.

depend on these marshes for nesting and other critical activities will need to move to similar habitat elsewhere to survive. Marsh loss will also eliminate the high primary production and detrital food web of the marsh, which are important for secondary production throughout the surrounding estuary.[313]

These marshes are critical for numerous nesting and migrating bird species. The salt marsh at Conaskonk Point provides breeding areas for green heron, clapper rail, willet, American oystercatcher, marsh wren, seaside sparrow, and saltmarsh sharp-tailed sparrow, as well as feeding areas for herons, egrets, common tern, least tern, and black skimmer. In late May and early June, sanderlings, ruddy turnstones, semipalmated sandpipers, and red knots feed on horseshoe crab eggs near the mouth of Chingarora Creek. [314] Diamondback terrapin feed in the marshes and creeks in this area.[315]

Saltmarsh along the backside of the Sandy Hook spit is dominated by low marsh cordgrass.[316] Characteristic fauna of low marsh include invertebrates such as ribbed mussel and marsh fiddler crab, and resident marsh fish species such as mummichog and sheepshead minnow. [317] The young of a number of marine fish species find forage and protection in low marsh, including winter flounder, Atlantic menhaden, bluefish, and striped bass.[318] Characteristic bird species of the low marsh also inhabit the area, including clapper rail, willet, and marsh wren.[319]

New Jersey's Hackensack Meadowlands, in Hudson and Bergen counties, are renowned for containing the largest single tract of estuarine tidal wetland in the New York/New Jersey Harbor Estuary.[320] Before European settlement, the area included a combination of fresh, brackish, and saline wetlands as well as large areas of forest. Subsequently, the Meadowlands were dramatically altered by a variety of human activities. Of the remaining wetlands in Hudson and Bergen counties, only about 1,928 ha (4,763 ac) are tidal wetlands.

The tidal marshes that remain provide regionally significant habitat for a number of federally or state-listed species. Diamondback terrapin, a federal species of concern, is common in the Sawmill Wildlife Management Area.[321] The state-listed endangered least tern, black skimmer, and pied-billed grebe use Kearney Marsh as a feeding area.

Much of the tidal marsh of the Meadowlands are dominated by the invasive common reed (*Phragmites*), a species found in degraded wetlands with decreased tidal flow.[322] As a result of recent restoration activities, parts of Harrier Meadow and the Riverbend Wetlands Preserve now support a mixture of open water and native high saltmarsh vegetation.[323]

One result of sea level rise in the Meadowlands may be conversion of some *Phragmites*-dominated marshes into salt marshes dominated by the native cordgrass, *Spartina alterniflora*. This may benefit some bird species, because the dense physical structure of *Phragmites* limits access to the marsh surface by foraging shorebirds, waders, waterfowl, and other taxa.[324,325]

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[313]Teal, 1986 (see note 10).
[314]Barnes, S., n.d., New Jersey Audubon Society, Sandy Hook Bird Observatory, *Guide to Birding in Raritan Bay*. Available at: http://www.njaudubon.org/Centers/SHBO/Conaskonk.html.
[315]USFWS, 1997, p. 556 in Raritan Bay–Sandy Hook Bay Complex, Complex #17 (see note 172).
[316]USFWS, 1997, p. 554 in Raritan Bay–Sandy Hook Bay Complex, Complex #17 (see note 172).
[317]USFWS, 1997, pp. 554–555 in Raritan Bay–Sandy Hook Bay Complex, Complex #17 (see note 172); Rader, D.N., 1984, Salt-marsh benthic invertebrates: Small-scale patterns of distribution and abundance, *Estuaries* 7(4A):413–420.
[318]Boesch, D.F., and R. E. Turner, 1984, "Dependence of fishery species on salt marshes: The role of food and refuge," *Estuaries* 7(4A):460–468, p. 465.
[319]USFWS, 1997, p. 556 in Raritan Bay–Sandy Hook Bay Complex, Complex #17 (see note 172).
[320]USFWS, 1997, p. 595 in Hackensack Meadowlands, Complex #19 (see note 172).
[321]USFWS, 1997, p. 599 in Hackensack Meadowlands, Complex #19 (see note 172).
[322]USFWS, 1997, p. 597 in Hackensack Meadowlands, Complex #19 (see note 172).
[323]See, for example, Seigel, A., C. Hatfield, and J. M. Hartman, 2005, "Avian response to habitat restoration of urban tidal marshes in the Hackensack Meadowlands, New Jersey," *Urban Habitats* 3:87–116. Available at: http://www.urbanhabitats.org.
[324]Seigel et al., 2005, p. 88 and references therein (see note 323).
[325]However, George Frame, 2/20/07 email (see note 251), noted that common reed provides habitat for some species, e.g., birds such as red-winged blackbirds and spring peepers (*Hyla crucifer*) and other amphibians and reptiles.

Estuarine Beaches

A local marine biologist with the National Marine Fisheries Service reports that there are small areas of estuarine beach all along the shorelines of this region where there is no shoreline hardening or marsh, except in low current areas where mud flats predominate.[326] Portions of the estuarine beaches of Sandy Hook are bulkheaded or armored.[327] Sandy beaches are common along the shores of Staten Island from Tottenville to Ft. Wadsworth, whereas hardened shores are more common on the New Jersey side of Raritan Bay. The southern shoreline of Raritan Bay includes a number of beaches along Sandy Hook Peninsula and from the Highlands to South Amboy. There are also beaches on the Perth Amboy side, some of which (e.g., Keansburg) are popular summer amusement beach areas. Other beaches are found on some of the shorelines around small islands within the Shrewsbury-Navesink River system.[328]

The estuarine beaches in the region are extremely important spawning areas for horseshoe crabs, and the dry, upper beach is used by nesting terrapins. Many other coastal birds such as terns, gulls, and black skimmers use the open sandy areas of beaches for resting and some nest on the beaches as well.[329] The New Jersey Audubon Society reports that its members have observed gulls and terns at the Raritan Bay beach at Morgan on the southern shore, including some rare species such as black-headed gull, little gull, Franklin's gull, glaucous gulls, black tern, sandwich tern, and Hudsonian godwit.[330] Recently, area beaches, especially those on Sandy Hook Bay, have become important resting places for several species of seals that frequent the area during the winter.[331]

Beaches are also important foraging grounds for birds, especially migrating shorebirds such as sanderlings, yellowlegs, and oystercatchers looking for clams and other invertebrates. Red knots, ruddy turnstones, and laughing gulls feed on horseshoe crab eggs in the sand of area beaches. [332] Mud snails are common on estuarine beaches, and beach wrack contains insects, isopods, and amphipods. The abundance of shorebird species is positively correlated with the abundance of beach wrack and associated invertebrates.[333] Recent research indicates that beach wrack traps horseshoe crab eggs, making them more available for shorebirds.[334]

Local planners anticipate that most of the shoreline along the beach/dune systems of Raritan Bay and Sandy Hook are almost certain to be protected as sea level rises. However, it is uncertain whether beach nourishment or shoreline armoring will be more common.

If the beaches are armored, beaches will erode and sediments will not be available for natural replenishment of sand,.[335] This will eliminate the beach nesting areas of terrapins and horseshoe crabs and the forage provided to birds by small beach organisms. The loss of horseshoe crab eggs will be especially critical for red knot, which feed almost exclusively on crab eggs during their spring migration.

If beaches are nourished, their geomorphic characteristics may be altered in ways that some scientists believe are unsuitable for many beach invertebrates, including horseshoe crabs.[336] Sandy Hook is considered almost certain to be protected using approaches that retain natural shores. The Park Service is currently planning to build a sand bypass system to replenish a narrow section of the spit.

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[326]Frank Steimle, National Marine Fisheries Service marine biologist. In July 14, 2006 email to E. Strange, Stratus Consulting, entitled "Comments on draft report on HRE-Hackensack/Raritan Bay," describing the area's estuarine beaches. Frank Steimle has closely observed the New York/New Jersey Harbor Estuary for over two decades.
[327]George Frame, 2/20/07 email (personal visual observations) (see note 251).
[328]Frank Steimle, 2006 email to E. Strange (see note 326).
[329]Ibid.
[330]Barnes, n.d., New Jersey Audubon Society (see note 314).
[331]USFWS, 1997, pp. 555–-556 in Raritan Bay–Sandy Hook Bay Complex, Complex #17 (see note 172).

[332]Frank Steimle, 2006 email to E. Strange (personal visual observations) (see note 326).
[333]Dugan et al., 2003, p. 32 (see note 127).
[334]Jackson et al., 2002, p. 418 (see note 139).
[335]Nordstrom, 2005 (see note 153).
[336]Jackson, et al., 2002, p. 420 (see note 139), reviewing the findings of Nelson, W.G, 1993, "Beach restoration in the southeastern U.S.: Environmental effects and biological monitoring," *Ocean and Coastal Management*, 19:157–182, and Rudloe, A., 1981, Aspects of the biology of juvenile horseshoe crabs, *Limulus polyphemus. Bulletin of Marine Sciences* 31:125–133.

Tidal Flats

We have been unable to find any papers analyzing whether the tidal flats in this region could keep pace with accelerated sea level rise. Therefore, in this discussion we consider the species that would be at risk if the flats are unable to keep pace.

The area's flats are known foraging grounds for numerous bird species, diamondback terrapin,[337] and horseshoe crabs.[338] The thousands of birds that pass through or reside in and around Raritan and Sandy Hook bays depend on intertidal invertebrate food resources as well as the many small adult and juvenile fishes that feed in these areas.

The south shore of the Raritan and Sandy Hook bays, from the confluence of the Shrewsbury and Navesink rivers west to the mouth of the Raritan River, consists of a narrow band of salt marsh habitat, tidal creek, beaches, dunes, and remnant forests. Some 1,460 ha (3,600 acres) of intertidal flats extend offshore from these habitats an average of 0.4 km (0.25 miles).[339] The flats are important foraging and staging areas for migrating shorebirds, averaging more than 20,000 birds, mostly semipalmated plover, sanderling, and ruddy turnstone.[340] Tidal flats are also habitat for hard and soft shell clams, which are important for recreational and commercial fishermen where not impaired by poor water quality.

The flats at the mouth of Whale Creek near Pirate's Cove (see Map 3.2) attract gulls, terns, and shorebirds year-round.[341] The intertidal and shallow water macroalgae beds provide forage for brant and dabbling ducks.[342] Midwinter waterfowl surveys indicate that an average of 60,000 birds migrate through the area in winter.[343]

Shallow Waters and Submerged Aquatic Vegetation (SAV)

Little eelgrass is found in this region, primarily because of poor water quality resulting from high levels of nutrients and suspended solids.[344] Therefore, in this region sea level rise is not an impact of concern for SAV. Sea lettuce and other algae substitute for eelgrass as an important food for Brants and as habitat for invertebrates and small fishes.[345]

[337]Dr. Russell Burke, email to E. Strange (personal visual observations of terrapins) (see note 226).
[338]Frank Steimle, July 14, 2006 email to E. Strange (personal visual observations of numerous species) (see note 326).
[339]USFWS, 1997, p. 553 in Raritan Bay–Sandy Hook Bay Complex, Complex #17 (see note 172).
[340]USFWS, 1997, pp. 553 and 556 in Raritan Bay–Sandy Hook Bay Complex, Complex #17 (see note 172).
[341]Barnes, n.d. (see note 314).
[342]Frank Steimle, July 14, 2006 email to E. Strange (personal visual observations) (see note 326).
[343]USFWS, 1997, p. 556, Raritan Bay–Sandy Hook Bay Complex, Complex #17 (see note 172).
[344]USFWS, 1997, p. 559,Raritan Bay–Sandy Hook Bay Complex, Complex #17 (see note 172).
[345]George Frame, 2/20/07 email (personal visual observations) (see note 251).

3.6 New Jersey's Coastal Bays

Author: ***Elizabeth M. Strange, Stratus Consulting Inc.***

Species and habitats along the Atlantic Coast of south-central New Jersey are potentially at risk because of sea level rise. This region encompasses the barrier islands, barrier spits, and back-barrier lagoons of New Jersey's Ocean, Atlantic, and Cape May counties. The region contains important habitats for a wide variety of fish, invertebrates, terrapins, and birds, and a great deal is known about the ecology and habitat needs of these species. Based on existing literature and the knowledge of local scientists, this summary discusses those species that could be at risk because of further habitat loss resulting from sea level rise and shoreline protection (see Map 3.3). Although it is possible to make qualitative statements about the ecological implications if sea level rise causes a total loss of habitat, our ability to say what the impact might be if only a portion of the habitat is lost is more limited. A total loss of habitat might be expected if shores are protected with hard structures and the wetlands are unable to keep pace with sea level rise.

Ocean County has two coastal barrier islands, Island Beach to the north and Long Beach Island to the south. Behind these barrier islands are the bays of the Barnegat Estuary, including Barnegat Bay, Manahawkin Bay, and Little Egg Harbor; three inlets; several tidal creeks; and numerous finger canals.[346] The Barnegat Bay National Estuary Program (BBNEP) includes the shoreline from the Point Pleasant Canal south to the Little Egg Harbor Inlet.[347]

Atlantic County has the back-barrier bays and tidal wetlands of the Brigantine Bay and marsh complex, which extends from Little Egg Inlet south to the Great Egg Harbor Inlet,[348] and the Great Egg Harbor Estuary[349] contained within southern Atlantic County and northern Cape May County. Cape May County has the important environmental areas of the Cape May Peninsula, which include the coastal ponds of Cape May Meadows at the tip of the peninsula and a network of salt marsh islands and small, shallow bays connected by a network of channels and tidal creeks on the peninsula's Atlantic Ocean side.[350]

There have been many efforts to conserve and restore species and habitats in the barrier island/back-barrier lagoon system of the study region. Some of the larger parks and wildlife areas in the region are Island Beach State Park, Great Bay Boulevard State Wildlife Management Area, and the E.B. Forsythe National Wildlife Refuge (Forsythe Refuge) in Ocean and Atlantic counties. Parts of the Cape May Peninsula are protected by the Cape May National Wildlife Refuge,[351] the Cape May Point State Park,[352] and TNC's Cape May Migratory Bird Refuge.[353] The peninsula is renowned as one of the primary stopover sites for migrating birds along the U.S. Atlantic Coast. The North Brigantine Natural

[346] See USFWS, 1997, Barnegat Bay Complex, Complex #6. pp. 317–330 (see note 172) .

[347] The website for the Barnegat Bay National Estuary Program is http://www.bbep.org/.

[348] See USFWS, 1997, Brigantine Bay and Marsh Complex, Complex #4. pp. 281–307 (see note 172).

[349] See USFWS, 1997, Great Egg Harbor Estuary, Complex #3. pp. 261–268 (see note 172).

[350] See USFWS, 1997, Cape May Peninsula, Complex #1. pp. 177–195 (see note 172).

[351] See http://www.fws.gov/northeast/capemay/.

[352] See http://www.state.nj.us/dep/parksandforests/parks/capemay.html.

[353] See http://www.nature.org/wherewework/northamerica/states/newjersey/work/art17205.html.

Area is a critical nesting area for least terns and piping plovers and a critical stopover habitat for a number of migrating shorebirds. Corson's Inlet State Park and Strathemere Natural Area, which straddle Corson's Inlet, have historically provided critical habitat area for black skimmers, least terns, and piping plovers, and in an important stopover habitat for migratory shorebirds. Stone Harbor Point and Champagne Island, part of the Hereford Inlet system, are critical nesting areas for least terns, black skimmers, piping plovers, common terns, and American oystercatchers, and provide critical resting and feeding habitat for migrating shorebirds, including red knot. Marsh islands behind this inlet system and behind Stone Harbor host the largest concentration of nesting laughing gulls in the world.[354] The TNC refuge alone supports an estimated 317 bird species, 42 mammal species, 55 reptile and amphibian species, finfish, shellfish, and other invertebrates.[355] All of these areas are likely to be placed at increased risk by rising sea levels.

Tidal Marshes and Nearshore Nontidal Marshes

There are 18,440.7 ha (71.2 mi^2), 29,344.6 ha (113.3 mi^2), and 26,987.7 ha (104.2 mi^2) of tidal salt marsh in Ocean, Atlantic, and Cape May counties, respectively. Based on a review of available studies, a panel of accretion experts convened for this report concluded that marshes in the study are keeping pace with current local rates of sea level rise of 4 mm/yr, but will become marginal with a 2 mm/yr acceleration, and will be lost with a 7 mm/yr acceleration except where they are near local sources of sediments (e.g., rivers such as the Mullica and Great Harbor rivers in Atlantic County) (see Section 2.1).

There is potential for wetland migration in the unprotected parts of Island Beach State Park, the Forsythe Refuge, and other parks and wildlife management areas in Ocean County.[356] Wetlands may also be allowed to migrate along the undeveloped shorelines of the Mullica and Great Egg Harbor rivers in Atlantic County.[357]

However, with the exception of beaches and a few areas such as the Forsyth Refuge, most estuarine shorelines are hardened.[358] Local planners indicate that the developed mainland and barrier island shorelines of Ocean, Atlantic, and Cape May counties will almost certainly be protected. The narrow fringing salt marshes along protected shorelines north of Barnegat Inlet could be lost even with a 2 mm/yr acceleration in rate of sea level rise. Below Barnegat Inlet natural shorelines are considered likely to remain because the sea would have to rise many feet before it would reach US Highway 9.[359] With continued sea level rise, natural sedimentary processes will be increasingly disrupted and lead to "drowning" of marshes. Many typical back-bay areas will likely become lakes. The invasive common reed may spread into areas where higher sea levels cause groundwater discharge to migrate up slope with greater volume.[360]

As marshes along protected shorelines experience increased tidal flooding, there may be an initial benefit to some species. This is because as tidal creeks become wider, deeper, and more abundant, fish species may benefit because of increased access to forage on the marsh surface.[361] Fish species such as Atlantic silverside, mummichog, and bay anchovy move into the creeks during low tide, but have greater access and are more common on the marsh surface during high tide. Sampling of larval fishes in high salt marsh on Cattus Island, Beach

[354]Dave Jenkins, acting chief, New Jersey Division of Fish and Wildlife, Endangered and Nongame Species Program, Trenton, NJ. E-mail entitled Opportunity to comment on a US EPA-sponsored paper concerning sea level rise, to Karen Scott of EPA, 7/18/07. (personal visual observations).
[355]Fact sheet by National Park Service on the New Jersey Coastal Heritage Trail Route. Accessed December 4, 2007 at: http://www.nps.gov/archive/neje/migsites.html.
[356]Ibid.
[357]Ibid.
[358]Stanton Hales, Richard Stockton College, Biology & Marine Sciences Programs, Pomona, NJ. E-mail entitled Reviews of USEPA-sponsored papers, to Karen Scott of EPA 7/25/07. (personal visual observations).
[359]Ibid.
[360]Barry Truitt, The Nature Conservancy. Email entitled Review of Atlantic coast side of the VES, to Karen Scott of EPA, 7/25/07.
[361]Weinstein, M.P., 1979, "Shallow marsh habitats as primary nurseries for fishes and shellfish, Cape Fear River, North Carolina," *U.S. Fisheries Bulletin* 77:339–357.

Haven West, and Cedar Run in Ocean County showed that high marsh is important for production of mummichog, rainwater killfish, spotfin killifish, and sheepshead minnow. The flooded marsh surface and tidal and nontidal ponds and ditches appear to be especially important for the larvae of these species.[362] However, as sea levels continue to rise, and marshes along hardened shorelines convert to open water, marsh fishes will lose access to these marsh features and the protection from predators, nursery habitat, and foraging areas provided by the marsh.

Loss of marsh area would also have negative implications for the dozens of bird species that forage and nest in the region's marshes. Initially, deeper tidal creeks and marsh pools will become inaccessible to short-legged shorebirds such as plovers.[363] Long-legged waterbirds such as yellow-crowned night heron, which forages almost exclusively on marsh crabs (fiddler crab and others), will lose important food resources. High marsh nesting birds such as northern harrier, black rail, clapper rail, and willet may be most at risk.[364] Eventually, complete conversion of marsh to open water will affect the hundreds of thousands of shorebirds that stop in these areas to feed during their migrations. The New Jersey Coastal Management Program estimated that some 1.5 million migratory shorebirds stop over on New Jersey's shores during their annual migrations.[365] Waterfowl also forage and overwinter in area marshes. Midwinter aerial waterfowl counts in Barnegat Bay alone average 50,000 birds.[366] The tidal marshes of the Cape May Peninsula provide stopover areas for hundreds of thousands of shorebirds, songbirds, raptors, and waterfowl during their seasonal migrations.[367] The peninsula is also an important staging area and overwintering area for seabird populations. Surveys conducted by the U.S. Fish and Wildlife Service from July through December 1995 in Cape May County recorded more than 900,000 seabirds migrating along the coast.[368]

As feeding habitats are lost, local bird populations may no longer be sustainable. For example, avian biologists suggest that if marsh pannes and pools continue to be lost in Atlantic County as a result of sea level rise, the tens of thousands of shorebirds that feed in these areas may shift to feeding in impoundments in the nearby Forsythe Refuge, increasing shorebird densities in the refuge by tenfold and reducing population sustainability because of lower per capita food resources and disease from crowding.[369]

Local populations of marsh-nesting bird species will also be at risk where marshes drown. This will have a particularly negative impact on rare species such as seaside and sharp-tailed sparrows, which may have difficulty finding other suitable nesting sites. According to syntheses of published studies in Greenlaw and Rising, and Poole and Gill, densities in the region ranged from 0.3 to 20 singing males per hectare and 0.3 to 4.1 females per hectare for the seaside and sharp-tailed sparrows, respectively.[370] Loss and alteration of suitable marsh habitats are the primary conservation concerns for these and other marsh-nesting passerine birds.[371] Nonpasserine marsh nesting

[362]Talbot, C.W., and K.W. Able, 1984, "Composition and distribution of larval fishes in New Jersey high marshes," *Estuaries* 7:434–443.
[363]Erwin et al., 2004 (see note 16).
[364]Dave Jenkins (see note 354).
[365]Cooper, M.J.P., M.D. Beevers, and M. Oppenheimer, 2005, *Future Sea Level Rise and the New Jersey Coast,* Science, Technology, and Environmental Policy Program, Woodrow Wilson School of Public and International Affairs, Princeton University, Princeton, NJ, p. 3, citing the New Jersey Coastal Management Program.
[366]USFWS, 1997, Barnegat Bay Complex, Complex #6. p. 323 (see note 172).
[367]See USFWS, 1997, Cape May Peninsula, Complex #1. pp. 177–195 (see note 172).
[368]USFWS, 1997, Barnegat Bay Complex, Complex #6. p. 324 (see note 172).
[369]Erwin et al., 2006 (see note 58).
[370]Greenlaw, J.S., and J.D. Rising, 1994, "Sharp-tailed sparrow (*Ammodramus audacutus*)," in Poole, A. and F. Gill, (eds.), *The Birds of North America,* No. 127, The Academy of Natural Sciences, Philadelphia and the American Ornithologists' Union, Washington, DC; and Post, W. and J. S. Greenlaw, 1994, Seaside sparrow (*Ammodramus maritimus*), in Poole and Gill, as cited in Chapter 6 of *The Barnegat Bay Estuary Program Characterization Report*. Prepared by the Barnegat Bay National Estuary Program (Scientific and Technical Advisory Committee), January 2001. Available at: http://www.bbep.org/char_rep.htm
[371]Chapter 7 of *The Barnegat Bay Estuary Program Characterization Report.* Prepared by the Barnegat Bay National Estuary Program (Scientific and Technical Advisory

birds may also be at risk, particularly high marsh species such as northern harrier and black rail, which are state-listed as endangered. Species that nest in other habitat but rely on marshes for foraging, such as herons and egrets, will also be affected as marshes drown.

Bulkheading is also under way to protect the vulnerable freshwater ecosystems of the Cape May Meadows (The Meadows), which is located behind the eroding dunes of the Cape May Canal. Freshwater coastal ponds in The Meadows are found within a few hundred feet of the shoreline and therefore could easily be inundated as seas rise. The ponds provide critical foraging and resting habitat for a variety of bird species, primarily migrating shorebirds.[372] Among the rare birds seen in The Meadows by local birders are buff-breasted sandpipers, arctic tern, roseate tern, whiskered tern, Wilson's phalarope, black rail, king rail, Hudsonian godwit, and black-necked stilt.[373] Because of its vulnerability to sea level rise and its status as an ecologically important area, local planners expect that The Meadows will continue to be protected in the future.

Estuarine Beaches

Estuarine beaches could largely disappear as a result of erosion and inundation of sandy habitat as seas rise. This would eliminate the billions of invertebrates that are found within or on the sandy substrate or beach wrack along the tide line of estuarine beaches.[374] These species provide a rich and abundant food source for bird species. Small beach invertebrates include isopods and amphipods, blood worms, and beach hoppers, and beach macroinvertebrates include soft shell clams, hard clams, horseshoe crabs, fiddler crabs, and sand shrimp (see details in Section 3.1).

To protect estuarine beaches, beach nourishment is being implemented in developed portions of the Ocean County shore, particularly in the northern part, while bulkheading continues to be used on the bayside shores of the county. TNC, the U.S Army Corps of Engineers (USACE), and the New Jersey Department of Environmental Protection (NJDEP) are undertaking beach replenishment to protect a mile-long stretch of sandy beach found in the Cape May Migratory Bird Refuge that provides nesting habitat for the rare piping plover and least tern.[375]

Loss of horseshoe crab eggs as a result of beach erosion or beach nourishment could have important implications for the 1.5 million migratory shorebirds that stop over on New Jersey's shores to refuel during their annual migrations.[376] Many shorebirds feed preferentially on horseshoe crab eggs in spring (e.g., red knot),[377,378] and loss of this food source could reduce the growth and survival of migrants if there are insufficient alternative foraging sites nearby.[379] Sanderling, red knot, and ruddy turnstone prefer sandy beaches for foraging.[380] In spring these migrants must feed nearly continuously to gain sufficient weight for nesting and to continue their long-distance migrations.[381]

Northern diamondback terrapin nests on estuarine beaches in the Barnegat Bay area.[382] Loss of these habitats will make terrapins even more dependent on areas modified by humans (roadways). Local scientists consider coastal

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Committee), January 2001. Available at: http://www.bbep.org/char_rep.htm/Ch7/Chapter%207.htm.

[372] Fact sheet by New Jersey Department of Environmental Protection on Cape May Point State Park. Accessed December 5, 2007 at: http://www.state.nj.us/dep/parksandforests/parks/capemay.html.

[373] Fact sheet by Paul Kerlinger, Outdoors Columnist, entitled "Birding, The Cape May Migratory Bird Refuge." Accessed December 5, 2007 at: http://www.capemaytimes.com/birds/capemay-meadows.htm.

[374] Bertness, 1999, pp. 256–257, gives an estimate of more than 2 billion microscopic invertebrates per square meter (see note 133).

[375] Fact sheet by The Nature Conservancy on the Cape May Migratory Bird Refuge. Accessed December 5, 2007 at: http://www.nature.org/wherewework/northamerica/states/newjersey/work/art17205.html.

[376] Cooper et al., 2005, p.3, citing the New Jersey Coastal Management Program (see note 365).

[377] USFWS, 2005 (see note 232).

[378] Karpanty et al., 2006 (see note 160).

[379] Although in spring the principal food source of shorebirds is typically horseshoe crab eggs, the BBNEP reports that in Barnegat Bay shorebirds feed on invertebrates in marsh mudflats and beaches. See Chapter 7 of *The Barnegat Bay Estuary Program Characterization Report* (see note 371).

[380] Chapter 7 of *The Barnegat Bay Estuary Program Characterization Report* (see note 371).

[381] USFWS, 2005 (see note 232).

[382] Chapter 7 (and references therein) of *The Barnegat Bay Estuary Program Characterization Report* (see note 371).

development, which destroys terrapin nesting beaches and access to nesting habitat, one of the primary threats to diamondback terrapins, along with predation, roadkills, and crab trap bycatch.[383]

Loss of estuarine beach could also have negative impacts on rare tiger beetles. Two subspecies of *Cicindela dorsalis* are found on New Jersey's coastal shoreline: the northeastern beach tiger beetle, *C. dorsalis dorsalis*, which is a federally listed threatened species and a state species of special concern and regional priority, and *C. dorsalis media*, which is considered rare, though it has not been considered for state listing. In the mid-1990s, the northeastern beach tiger beetle was observed on the undeveloped ocean beaches of Holgate and Island Beach. The USFWS does not know whether this species is also found on the area's estuarine beaches, but studies indicate that it feeds and nests in a variety of habitats.[384] The current abundance and distribution of the northeastern beach tiger beetle in the coastal bays is a target of research.[385] At present, there are plans to reintroduce the species in the study region at locations where natural ocean beaches remain.[386]

Tidal Flats

The tidal flats of New Jersey's back-barrier bays are critical foraging areas for hundreds of species of shorebirds, passerines, raptors, and waterfowl. Tidal flats are found in almost all of the coastal bays, and support invertebrates such as insects, worms, clams, and crabs that provide an important food source for these and other birds that forage in the study region. Some shorebirds such as semipalmated sandpiper, dunlin, and dowitcher forage preferentially on mudflats and shallow impoundments.[387]

Important shorebird areas in the study region include the flats of Great Bay Boulevard Wildlife Management Area, North Brigantine Natural Area, and the Brigantine Unit of the Forsythe Refuge.[388,389] The USFWS estimates that the extensive tidal flats of the Great Bay alone total 1,358 ha (3,355 acres). Inundation of tidal flats with rising seas would eliminate critical foraging opportunities for the area's abundant avifauna. As tidal flat area declines, increased crowding in remaining areas could lead to exclusion and mortality of many foraging birds.[390, 391] Some areas may become potential sea grass restoration sites, but whether or not "enhancing" these sites as eelgrass areas is feasible will depend on their location, acreage, and sediment type.[392]

Shallow Nearshore Waters and Submerged Aquatic Vegetation (SAV)

The Barnegat Estuary is distinguished from the lagoons to the south by more open water and SAV and less emergent marsh. Within the Barnegat Estuary, dense beds of eelgrass are found at depths under 1 meter (3.28 feet), particularly on sandy shoals along the backside of Long Beach Island and Island Beach, and around Barnegat Inlet, Manahawkin Bay, and Little Egg Inlet. Eelgrass is relatively uncommon from the middle of Little Egg Harbor south to Cape May,[393] particularly locations where water depths are above 1 meter (3.28 feet), such as portions of Great South Bay.[394]

Seagrass surveys from the 1960s through the 1990s revealed an overall decline in seagrass in Barnegat Estuary from 6,823 ha (16,847 acres) in

[383]See the website of the Wetlands Institute's terrapin conservation program at http://www.terrapinconservation.org.
[384]USFWS, 1997, Barnegat Bay Complex, Complex #6, pp. 317–330 (see note 172).
[385]State of New Jersey, 2005, New Jersey Comprehensive Wildlife Conservation Strategy for Wildlife of Greatest Conservation Need, August 2005 Draft, Table C1, p. 61, available at: http://www.njfishandwildlife.com/ensp/waphome.htm.
[386]State of New Jersey, 2005 (see note 385).
[387]Chapter 7 of *The Barnegat Bay Estuary Program Characterization Report* (see note 371).
[388]See USFWS, 1997, Barnegat Bay Complex, Complex #6, p. 317 (see note 172).
[389]USFWS, 1997, Brigantine Bay and Marsh Complex, Complex #4, p. 281 (see note 172).
[390]Galbraith et al., 2002, p. 173 (see note 50).
[391]Erwin et al., 2004, p. 892 (see note 16).
[392] Stanton Hales (expert judgment based on a career largely devoted to these issues) (see note 358).
[393]USFWS, 1997, Barnegat Bay Complex, Complex #6. pp. 317–330 (see note 172).
[394]USFWS, 1997, Mullica River-Great Bay Estuary, Complex #5. pp. 295–307 (see note 172).

a 1968 survey to an average of 5,677 ha (14,029 acres) of seagrass beds from 1996 to 1998.[395, 396]

Numerous studies indicate that eelgrass has high ecological value as a source of both primary[397] and secondary production[398] in estuarine food webs. In Barnegat Estuary eelgrass beds provide habitat for invertebrates, birds, and fish that use the submerged vegetation for spawning, nursery, and feeding habitat. In addition, many species graze on eelgrass, including gastropods, fishes, ducks, and muskrats.[399]

Short and Neckles suggested that a 50 cm (19.7 in.) increase in water depth as a result of sea level rise could reduce the light available for eelgrass photosynthesis by 50 percent, resulting in a 30–40 percent reduction in seagrass growth. The researchers suggested that this will, in turn, result in reduced productivity and functional values of eelgrass beds.[400]

Results of a study in Barnegat Bay indicated that shoreline protection may exacerbate this problem. The study found that where shorelines are bulkheaded, SAV, woody debris, and other features of natural shallow water habitat are rare or absent. These bulkheaded areas have reduced abundances of fishes compared to sites that were not bulkheaded sites.[401]

The Barnegat Estuary has 14 yacht clubs, with 4 on Long Beach Island alone. Sailing and sailboat racing are less popular in Atlantic and Cape May counties,[402] with their relatively small and shallow bays. One possible benefit of the conversion of marsh to open water would be increased recreational sailing in the larger barrier bays that might form. On the other hand, deeper water would make Little Egg Harbor Bay less hospitable to windsurfing.[403]

Marsh and Bay Islands

Large bird populations are found on marsh and dredge spoil islands of the back-barrier bays in the study region. These islands include nesting sites protected from predators for several species of conservation concern, including gull-billed tern, common tern, Forster's tern, least tern, black skimmer, American oystercatcher, and piping plover. Diamondback terrapin, a state species of special concern and a regional priority, is also known to feed on marsh islands in the bays.[404]

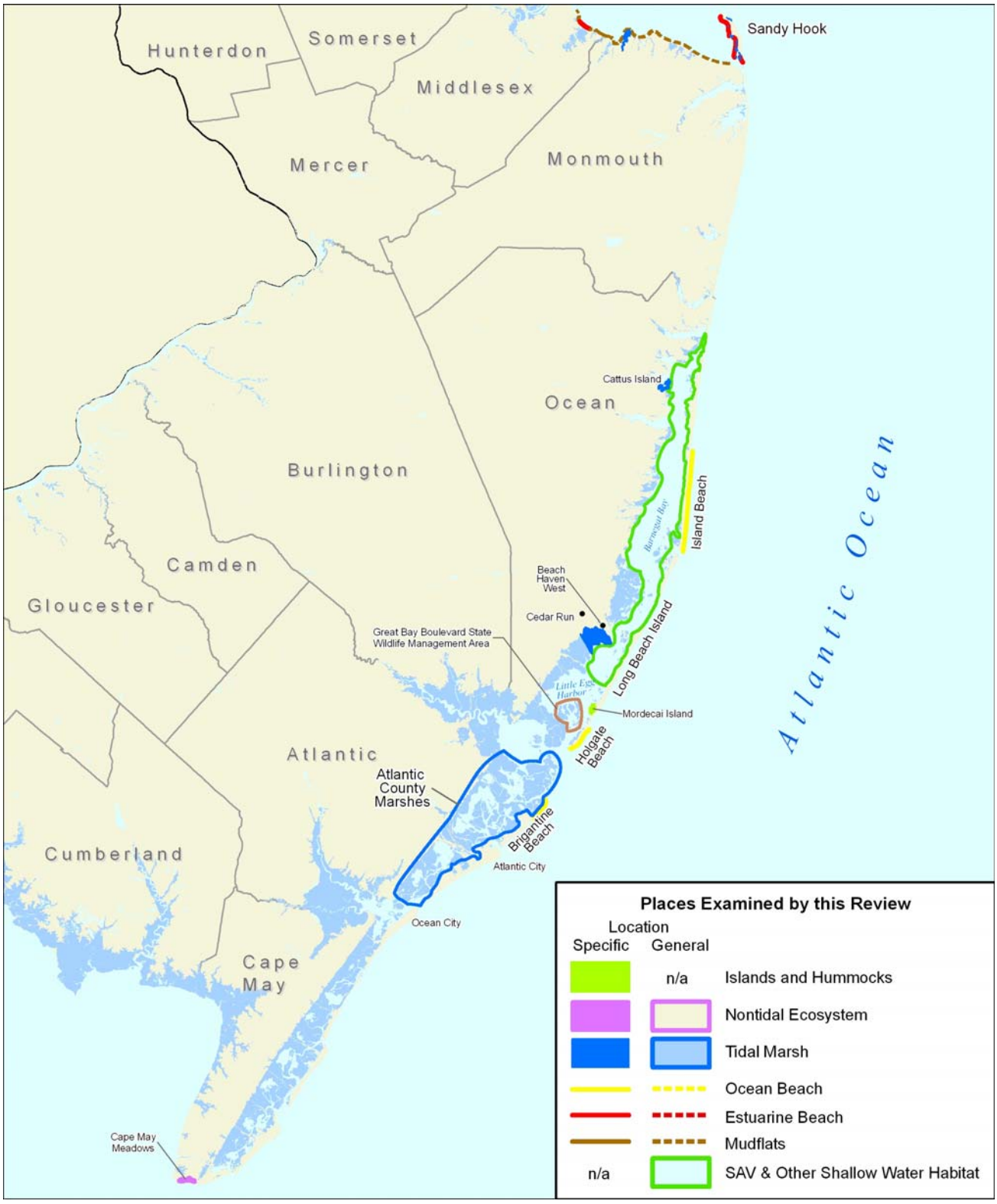
Some of the small islands in Barnegat Bay and Little Egg Harbor are several feet above mean spring high water,[405] but portions of other islands are very low, and some low islands are currently disappearing. Many of these vulnerable islands are used by nesting common terns, Forster's terns, black skimmers, and American oystercatchers.[406] With the assistance of local governments, the Mordecai Land Trust is actively seeking grants to halt the gradual erosion of Mordecai Island, a 45-acre island just west of Beach Haven on Long Beach Island. Members of the land trust have documented a 37 percent loss of island area since 1930. The island's native salt marsh and surrounding waters and SAV beds provide habitat for a variety of aquatic and avian species. NOAA Fisheries considers the island and its waters essential fish

[395]Chapter 7 of *The Barnegat Bay Estuary Program Characterization Report* (see note 371).
[396]According to an 7/21/06 email to E. Strange, Stratus Consulting, from Dr. Paul A. X. Bologna of the Department of Biology and Molecular Biology at Montclair State University, Dr. Bologna has conducted SAV monitoring in the Barnegat Estuary since 1998, but these data are not yet analyzed.
[397]Thayer, G.W., W.J. Kenworthy, and M.S. Fonseca, 1984, The Ecology of Eelgrass Meadows of the Atlantic Coast: A Community Profile, U.S. Fish and Wildlife Service, FWS/OBS-84/02.
[398]Jackson, E.L., A.S. Rowden, M.J. Attrill, S. Bossey, and M. Jones, 2001, The importance of seagrass beds as habitat for fishery species, *Oceanography and Marine Biology Annual Review* 39:269–303.
[399]Chapter 7 of *The Barnegat Bay Estuary Program Characterization Report* (see note 371).
[400]Short and Neckles, 1999 (see note 91).
[401]Byrne, 1995 (see note 112).

[402]Of 32 yacht clubs in New Jersey, 14 are in Ocean County, and 6 are in Atlantic and Cape May counties combined. The other 12 are evenly divided between Delaware River, Monmouth County, and North Jersey. Don Robertson's Marine Marketplace: Yacht Clubs with Web Sites. Available at: http://www.yachtsales.com/yclubs/nj.html.
[403]Titus, J., 1998, Windsurfing in a warmer world, *Windsurfing Magazine*, March (Windsurfing is more convenient when water is 3–4 ft deep than when over one's head.)
[404]USFWS, 1997, Barnegat Bay Complex, Complex #6. pp. 317–330 (see note 172).
[405]Personal visual observation by James G. Titus, U.S. EPA.
[406] Dave Jenkins (personal visual observation) (see note 354).

habitat for spawning and all life stages of winter flounder as well as juvenile and adult stages of Atlantic sea herring, bluefish, summer flounder, scup, and black sea bass.[407] The island is also a strategically located nesting island for many of New Jersey's threatened and endangered species, and it contains a moderate-size black skimmer colony, common terns, and most recently, a very small colony of royal terns.[408]

[407] Mordecai Land Trust web site, available at: http://www.mordecaimatters.org.
[408] Dave Jenkins (personal visual observation) (see note 354).



Map 3.3 Locations and Types of Habitat Discussed in this Report: New Jersey Shore

3.7 Delaware Bay

Authors: ***Danielle Kreeger, Partnership for the Delaware Estuary Inc., and James G. Titus, U.S. Environmental Protection Agency***

Delaware Bay is part of the larger Delaware Estuary Ecosystem, the second largest estuary in North America and home to hundreds of species of ecological, commercial, and recreational value. Unlike other estuaries in the Mid-Atlantic, the Delaware estuary's tide range is greater than the ocean tide range, generally about 2 meters. Beaches account for 52 percent of the bay's shore, with marsh and eroding peat accounting for most of the remainder.[409]

This brief literature review discusses species that could be at risk because of further habitat loss resulting from sea level rise and shoreline protection.

Tidal Marshes

Much of the land along Delaware Bay, and for several kilometers inland, is tidal wetland (see Map 3.4). The Delaware Estuary has one of the largest freshwater tidal prisms in the world. As result, the tidal wetlands vegetation must be adapted for a wide range in salinity. Delaware Bay and its tributary creeks have tidal freshwater, brackish, and salt marshes. These wetlands are characterized by zones of different vegetation types, which reflect small differences in topography and tidal flooding regimes. All three classes are essential habitat for wildlife, waterfowl, fish, and other living resources.

In the salt marshes fringing Delaware Bay, the low marsh is flooded at least once daily and is generally found between the mean tide level and mean high water. The bay's low marsh is dominated by smooth cordgrass, *Spartina alterniflora*. The less frequently flooded high marsh zone has higher plant diversity, and typically includes *Spartina patens, Iva frutescens*, and *Baccharis halimifolia*. High marsh is less common than low marsh and is likely to be much more vulnerable to sea level rise. Black rail and the coastal plain swamp sparrow depend on high marsh habitat. Almost the entire breeding range of the coastal swamp sparrow is in the Delaware Estuary.

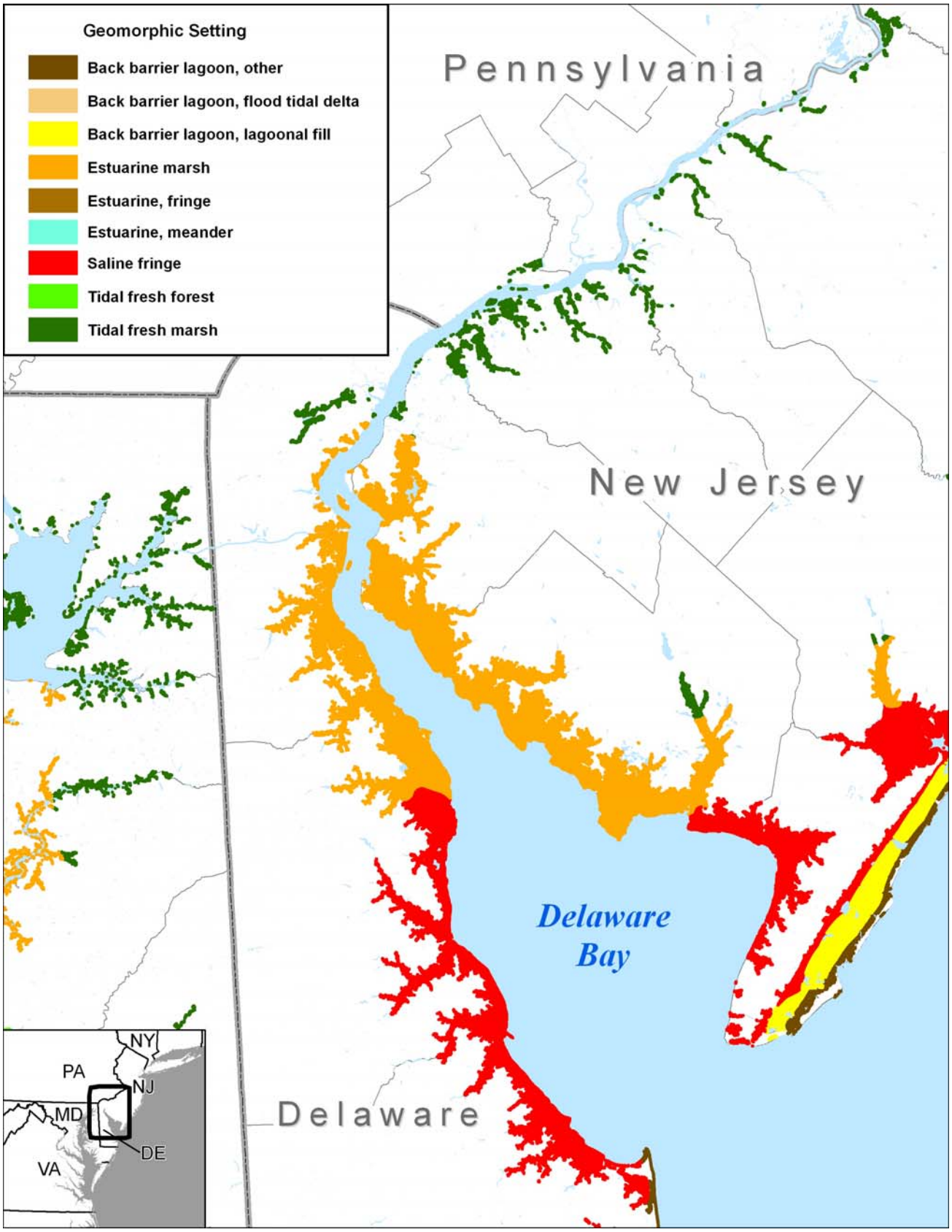
Historically, much of the bay's shoreline was diked to reclaim wetlands for farming. However, in recent decades, dikes have been removed to support wetland restoration.[410] At the same time, there has been an expansion of the common reed, *Phragmites australis*, at higher elevations and in many of the formerly diked areas.[411] Marsh areas dominated by common reed are thought to provide lower quality wildlife and fishery habitat compared to natural cordgrass marshes.[412]

[409]Lathrop, R., M. Allen, and A. Love, 2006, Mapping and Assessing Critical Horseshoe Crab Spawning Habitats in Delaware Bay, Grant F. Walton Center for Remote Sensing and Spatial Analysis, Cook College, Rutgers University, p.15, Table 8, accessed on November 15, 2006 at: http://deathstar.rutgers.edu/projects/delbay/.

[410]See Weinstein, M.P., K.R. Philip, and P. Goodwin, 2000, "Catastrophes, near-catastrophes and the bounds of expectation: Success criteria for macroscale marsh restoration," in *Concepts and Controversies in Tidal Marsh Ecology*, M.P. Weinstein and D.A. Kreeger (eds.), Kluwer Academic Publishers, Dordrecht, The Netherlands, pp. 777–804; and Able, K.W., D.M. Nemerson, P.R. Light, and R.O. Bush, 2000, "Initial response of fishes to marsh restoration at a former salt hay farm bordering Delaware Bay," in Weinstein and D.A. Kreeger, pp. 749–776.

[411]Ibid.

[412]Philip, K., 1995, Tidal Wetlands Characterization – Then and Now. Delaware Estuary Program, Final Report to the Delaware River Basin Commission.



Map 3.4. Tidal Wetlands Along the Delaware Estuary. Source: Titus et al. (Section 2.2), using science assessment of Reed et al. (Section 2.1).

Can Marshes Keep Pace with Rising Sea Level?

The sustainability of tidal marshes in response to relative sea level rise depends on the supply of sediment and organic matter to raise the marsh surface, the tide range, and the ability of wetlands to migrate inland, which depends on both the slope of the nearby lowland and whether people allow the wetland migration or block it with shore protection (Section 2.1). The 2 meter daily tide range enables low and high marsh to each subsist over an elevation range of close to 1 meter. Hence it would take a 1 meter rise to submerge all the existing low marsh, or to flood all of the existing high marsh at the frequency that defines low marsh. In much of Delaware Bay, however, tidal marshes appear to be at the low end of their potential elevation range, increasing their vulnerability.[413] Unlike the marshes along the back-barrier bays of Delaware and New Jersey, the tidal marshes of Delaware Bay grow upward primarily through the accretion of organic matter, not sediment.

Evidence of wetland loss can be seen in many areas, such as just inside the mouth of the Maurice River near Port Norris, New Jersey (see Map 3.4). In this location, the effects of sea level rise appear to be acting synergistically with increased erosive energy to lead to significant marsh losses over the past 100 years. One contributing factor here might have been the loss of the oyster reefs near the mouth during the 1950s and 1960s, which might have afforded some protection against storm surge and wave energy. Today, the energy from winter Nor'easters and other storms directly enters the mouth, eroding at the marsh edge across a new embayment and threatening to breach to the river upstream of the town of Bivalve.[414] This idea is attracting some interest as a possible strategy for combating shoreline erosion by restoring nearshore reefs in concert with rehabilitating intertidal mussel and oyster communities along marsh edges as a form of natural armoring. Nevertheless, it is unlikely that such efforts will be widespread enough to ensure that all tidal wetlands accrete vertically at a rate to offset sea level rise, and seaward losses of marsh are certain to continue. In other areas of Delaware Bay, wetlands do not appear to be vanishing as quickly or at all, and so one must consider the possibility that some wetlands will keep pace with rising sea level but others will not.

Considering these factors, Reed et al. (Section 2.1) concluded that with a 2 mm/yr acceleration in sea level rise, most of the Delaware Bay wetlands would be marginal, and that the wetlands will probably convert to open water along Bombay Hook National Wildlife Refuge on the Delaware side, and between Fortescue and the Salem Nuclear Generating Station on the New Jersey side (see Map 3.5).

Can Wetlands Migrate Inland as Sea Level Rises?

As a general rule, where the bay's shoreline is armored, the landward migration of the marsh will be impeded. Along Delaware Bay, most of the shore is undeveloped and unlikely to be armored. Each acre of land submerged, however, would not necessarily correspond to an acre of increased wetland habitat: landward migration of tidal wetlands would occur at the expense of existing nontidal wetlands along much of the shore. Moreover, no one has established that the tidal inundation of the freshwater wetlands would lead to creation of salt marsh; in many areas such inundation converts the wetlands to open water instead.

The Partnership for the Delaware Estuary is directing attention to the landward fringe of tidal wetlands, where conversion of nontidal natural lands to tidal natural lands appears imminent and important to safeguard against further losses of tidal wetlands. The Partnership (a National Estuary Program) is currently leading an assessment of land use patterns in the landward buffers adjacent to tidal wetlands to identify locations where landward migration of tidal

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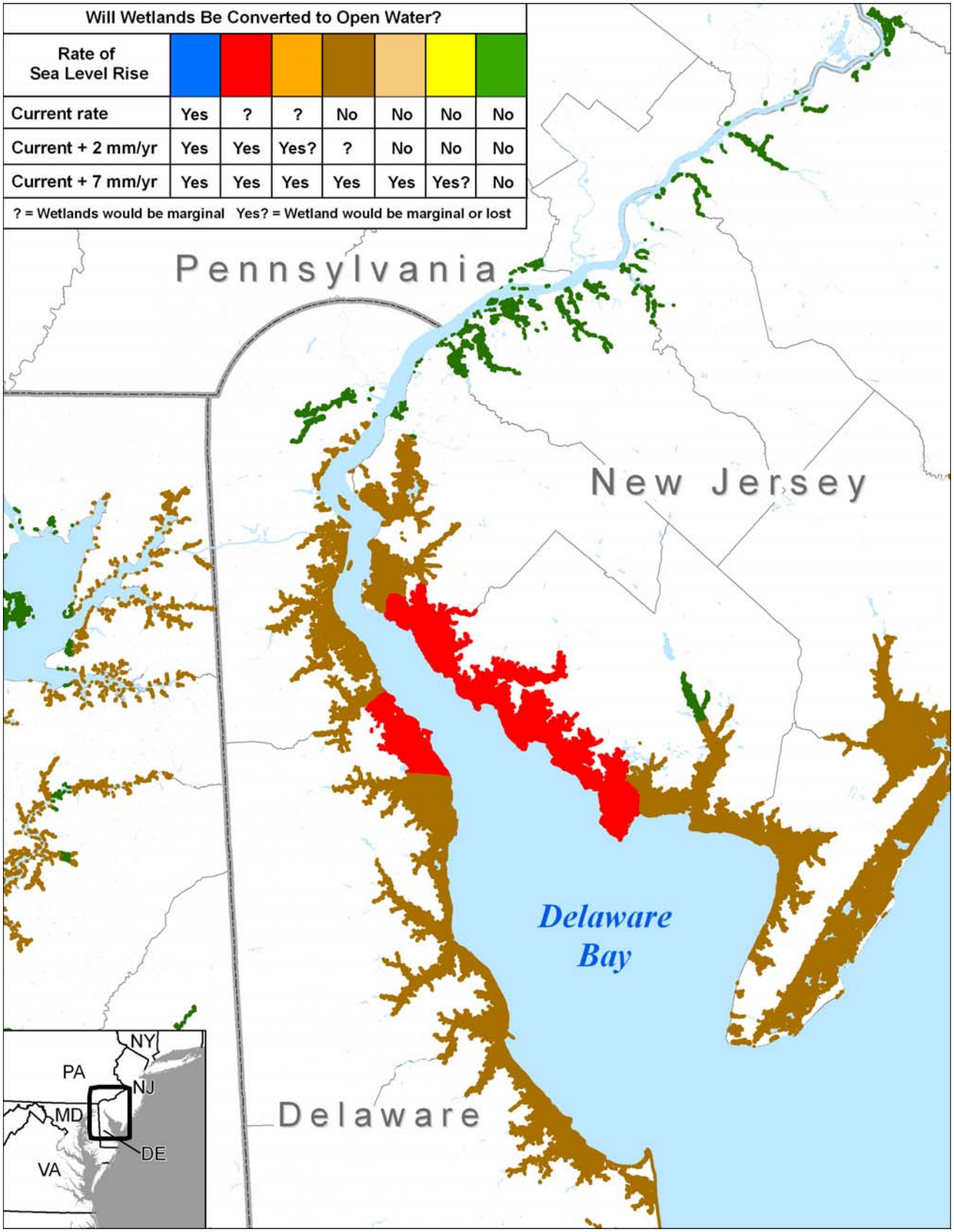
[413]Kearney, M.S., A.S. Rogers, J.R.G. Townsend, E. Rizzo, D. Stutzer, J.C. Stevenson, and K. Sundborg, 2002, "Landsat imagery shows decline of coastal marshes in Chesapeake and Delaware bays," *Eos* 83(16):173.

[414]This case demonstrates how the effects of sea level rise must be considered in a local context that considers multiple physical and ecological factors.



Map 3.5. Potential for Tidal Wetlands along the Delaware Estuary to Keep Pace as Sea Level Rises.
Source: Titus et al. (Section 2.2), using science assessment of Reed et al. (Section 2.1)

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marshes might be encouraged, such as undeveloped agricultural lands and natural woodlands.

Implications of Habitat Change

The loss of tidal marsh as sea level rises would harm species that depend on these habitats for food, shelter, or spawning and nursery habitat, including macroinvertebrates, finfish, and wintering waterfowl. Although effects on marsh biota have not been studied directly, current understanding of marsh ecology suggests that changes within the marsh will affect the ecology of not only the marsh itself but also the entire estuary.[415]

Many bird species use or depend on these marshes, including great blue herons, black duck, blue and green-winged teal, northern harrier, osprey, rails, red winged blackbirds, widgeon, and shovelers. Aquatic species such as diamondback terrapin, blue crab, killifish, mummichog, perch, weakfish, flounder, bay anchovy, silverside, herring, and rockfish rely on tidal marshes for a nursery area or for feeding on mussels, fiddler crabs, and other invertebrates.[416]

Research indicates that fishes and birds feeding in the marsh are critical for the export of marsh production to the wider estuarine food web.[417] Any reduction of cordgrass habitat would probably reduce populations of the important macroinvertebrate species. Macroinvertebrates associated with cordgrass stands in the low intertidal include grass shrimp, ribbed mussel, coffee-bean snail, and fiddler crabs.[418] Blue crab, sea turtles, and shorebirds are among the many species that prey on ribbed mussels; fiddler crabs are an important food source for bay anchovy and various species of shorebirds.[419] In turn, the depletion of these organisms would reduce the numbers of marsh birds. Wading birds such as the glossy ibis feed on marsh invertebrates.[420] Waterfowl, particularly dabbling ducks, use low marsh areas as a wintering ground. The black duck is already in decline, and is considered a species of special concern by EPA's Delaware Estuary Program.[421] The winter snow goose population in the bay is currently the largest population in the eastern flyway, and a primary source of food for snow geese is the root system of the smooth cordgrass.[422] Diamondback terrapin, listed as a species of conservation concern by the Northeast Regional Technical Committee and as a species of greatest conservation need in Delaware's Wildlife Action Plan, would also be impacted both by loss of wetlands, which are nursery areas for young turtles, and by loss of nesting beaches.

Tidal creeks and shallow water areas of the low marsh provide spawning and nursery areas for finfish that are seasonal residents, year-round residents, and transients from the wider estuary that enter tidal marshes only periodically. The most common fish species of the marsh are mummichog, spot, white perch, Atlantic menhaden, Atlantic silverside, bay anchovy, and sheepshead minnow.[423] The abundance of these species may be affected not only by a loss of habitat but also by reductions in invertebrate food supplies.

High marsh is an important habitat for raptors such as the short-eared owl and for various species of songbirds that breed or pass through the high marsh during their migrations to northern breeding areas.[424] Seaside sparrows are characteristic of cordgrass areas, and sharp-tailed sparrows are more common in upland areas dominated by salt hay.[425] If marsh migration is

[415]Kneib, R.T., 2000, "Salt marsh ecoscapes and production transfers by estuarine nekton in the southeastern United States," in Weinstein and Kreeger, pp. 267–292 (see note 410).
[416]See Dove and Nyman, 1995 (see note 14).
[417]Deegan, L.A., J.E. Hughes, and R.A. Rountree, 2000, "Salt marsh ecosystem support of marine transients," in Weinstein and Kreeger, pp. 333–368 (see note 410); and Kneib, 2000 (see note 415).
[418]Kreamer, 1995, pp. 81–90 (see note 19); and Kreeger, D. A. and R. I. E. Newell, 2000, "Trophic complexity between primary producers and invertebrate consumers in salt marshes," Chapter 11 in Weinstein and Kreeger, pp. 183–216 (see note 410).
[419]Kreamer, 1995, pp. 81–90 (see note 19).
[420]See Dove and Nyman, 1995 (see note 14).
[421]Ibid.
[422]Ibid.
[423]Rountree and Able, 1992 (see note 22).
[424]See Dove and Nyman, 1995 (see note 14).
[425]Ibid.

impeded by shoreline protection structures and the area of high marsh is reduced, birds of the high marsh will decline and species already in low numbers may be lost.

Beaches

Sandy beaches and foreshores account for 54 percent of the Delaware and New Jersey shores of Delaware Bay, respectively (see Table 3.1). Table 3.1 shows additional estimates of the status of the bay's shoreline, with an emphasis on the vulnerability of beach habitat. As sea level rises, beaches can be lost if shores are armored or if the land behind the existing beach has too little sand to sustain a beach as the shore retreats.[426] So far, only 4–6 percent of the natural shore had been replaced with shoreline armoring. Another 15 and 4 percent of the shore is developed. However, planners expect that approximately half of (nonwetland) shores will eventually require some sort of shore protection. Although conservation areas encompass 58 percent of Delaware Bay's shores, they include only 32 percent of beaches that are optimal or suitable habitat for horseshoe crabs.

Many Delaware Bay beaches have a relatively thin veneer of sand. Although these small beaches have enough sand to protect the marshes immediately inland from wave action, there is some question about whether some beaches would survive accelerated sea level rise even without shoreline armoring.

Beach nourishment has been relatively common along the developed beach communities on the Delaware side of the bay. Although beach nourishment can diminish the quality of habitat for horseshoe crabs, nourished beaches are more beneficial than armored shores. In a few cases, Delaware has nourished beaches with the primary purpose to restore horseshoe crab habitat.[427]

he loss of Delaware Bay's beaches would harm horseshoe crabs, migratory birds, and other wildlife. For example, on their annual migrations from South America to the Arctic, nearly a million shorebirds move through Delaware Bay, where they feed heavily on infaunal benthic invertebrates in tidal mudflats (see subsequent discussion) and particularly on horseshoe crab eggs on the bay's sandy beaches and foreshores.[428] The Delaware Estuary is home to the largest spawning population of horseshoe crabs in the world, and although these animals can lay eggs in tidal marshes, their preferred nesting sites are the mid- and high intertidal zones of sandy beaches. Map 3.6 depicts the suitability of the Delaware Bay shore for horseshoe crab habitat. A sea level rise modeling study estimated that a 2-ft rise in relative sea level over the next century could reduce shorebird foraging areas in Delaware Bay by 57 percent or more by 2100,[429] with likely impacts to horseshoe crabs as well. If these foraging habitats are lost and prey species such as horseshoe crab decline, there could be substantial reductions in the numbers of shorebirds supported by the bay.[430]

Numerous other animals rely on the sandy beaches of Delaware Bay to lay eggs or forage on invertebrates such as amphipods and clams. These include diamondback terrapins, Kemp's and Ridley sea turtles, red fox, raccoons, and opossum. When tides are high, numerous fish also forage along the sandy beaches, such as killifish, mummichogs, rockfish, perch, herring, silversides, and bay anchovy.

Tidal Flats

Areas of exposed tidal flats in Delaware Bay occur between mean sea level (MSL) and mean low water, and extend primarily along the bay's shorelines. Intertidal flats are known to be important foraging areas for finfish as

[426]Cites in Nordstrom, 2005 (see note 153).
[427]See, e.g., Smith et al., 2002 (see note 155).
[428]Smith et al., 2002 (see note 155).
[429]Galbraith et al., 2002 (see note 50).
[430]Ibid.

Table 3.1: The Shores of Delaware Bay: Habitat Type, Likelihood of Shore Protection, and Conservation Status of Shores Suitable for Horseshoe Crabs

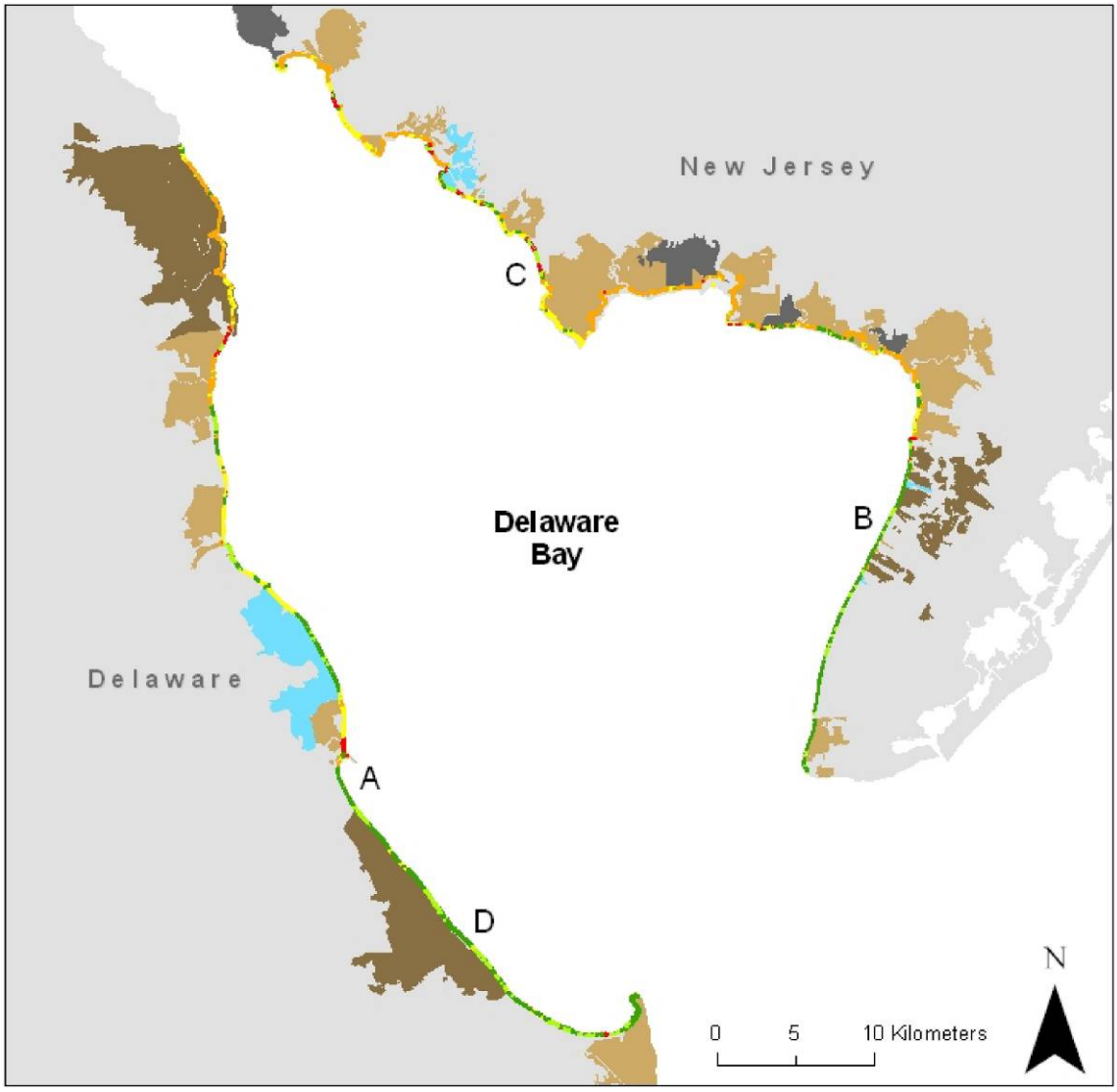
Shoreline Length	Delaware		New Jersey		NJ+DE
…by Habitat Type (percentage of bay shoreline)[a]	km	%	km	%	%
Beach	68	74	62	42	54
Armored Shore	3.7	4	8.3	6	5
Organic	20	22	78	53	41
Total Shoreline	91	100	148	100	100
…by Indicators of Future Shore Protection					
Protection Structures set back from shore[a]	2.7	2.9	5.1	3.4	3
Development[a]	13	15	5.7	3.8	8
...by Likelihood of Shore Protection (percentage of nonwetland shores)					
Shore Protection Almost Certain	35	45	17	29	39
Shore Protection Likely	4	5	3	5	5
Shore Protection Unlikely	17	22	18	31	26
No Shore Protection	21	27	20	34	30
…by Suitability for Horseshoe Crab (percentage of bay shoreline)					
Optimal Habitat[b]	31.3	34	26.0	18	24
Suitable Habitat[b]	10.5	12	5.1	3.5	6.6
Less Suitable Habitat[b]	29.0	32	49.0	33	33
Unsuitable Habitat[b]	20.0	22	67.0	46	37
…Within Conservations Lands by Suitability for Horseshoe Crab (percentage of equally suitable lands)					
Optimal Habitat[c]	12.9	41	9.6	37	39
Optimal and Suitable Habitat[c]	13.6	33	9.8	32	32
Optimal, Suitable, and Less Suitable Habitat[c]	32.2	46	43.3	54	50
All Shores[c]	44.7	49	92.7	63	58

[a] Delaware and New Jersey results from Lathrop et al., Table 8 (see text note 409).
[b] Delaware and New Jersey results from Lathrop et al. (see text note 409) at p.16, Table 9. "Unsuitable" includes both "avoided" and "disturbed."
[c] From Lathrop et al. (see text note 409) at p.18, Table 1. Lathrop et al. report results for the categories separately; we aggregate the categories.

well as migrating shorebirds, including red knot, ruddy turnstone, sanderling, and semipalmated sandpiper.[431] Although the benthic ecology of the system is poorly described, rich mudflat communities of polychaetes and bivalves are thought to sustain blue crabs, grass shrimp, killifish, mummichogs, rockfish, perch, herring, bay anchovy, skates, rays, black ducks, blue and green-winged teal, mallards, northern harriers, rails, and great blue herons. These communities are characteristic of the lower estuary region and Delaware Bay where salinities are greater than about 10 ppt. In the lower salinity areas, polychaetes are replaced with oligochaetes on the mudflats. At low tide, numerous mammals forage on mudflats, such as muskrat, opossum, raccoon, and red fox. Beyond their trophic roles, the ecological importance of these shallow subtidal and intertidal habitats is not well understood in the Delaware Estuary, where little research and assessment has been devoted to aquatic bottom habitats.[432] The greatest loss of mud flats generally occurs where migration is prevented by the presence of shore protection structures. In the Delaware Estuary, extensive mudflats exist in many areas, particularly along sections of the Delaware coastline and within some of the larger marshland tracts in New Jersey.

[431] Dove and Nyman, 1995 (see note 14).

[432] Kreeger, D., R. Tudor, J. Sharp, S. Kilham, D. Soeder, M. Maxwell-Doyle, J. Kraeuter, D. Frizzera, J. Hameedi and C. Collier,. 2006, White Paper on the Status and Needs of Science in the Delaware Estuary, Partnership for the Delaware Estuary Report #06-01, 72 pp. Accessed on November 2, 2006 at http://www.delawareestuary.org/scienceandresearch/datasetsandreports/localandregional.asp.



Map 3.6. Delaware Bay Shore: Conservation Status and Suitability for Horseshoe Crabs
Source: Lathrop et al. (see text note 409).

Shallow Waters

Although the direct effect of sea level rise will be to deepen these waters, shallow water habitat may increase if wetlands convert to open water. Therefore, we cannot currently say whether this type of habitat will increase or decrease.

Even if we knew the direction of change, the resulting impacts on the fish and shellfish of Delaware Bay have not been studied. Nevertheless, many of the finfish and shellfish species of nearshore waters and the shore zone are well known, and habitat changes and loss of habitat area affect species distribution, diversity, and abundance. One of the best known and most popular species of the nearshore waters is the blue crab, *Callinectes sapidus*. Another signature species in the shallow waters of the Delaware Estuary is the eastern oyster, *Crassostrea virginica.* It is not clear how sea level rise might affect these animals, but in the case of oyster reefs there is some concern that natural reef-building is not occurring fast enough to sustain population losses from a variety of other factors.[433]

De Sylva et al. conducted an extensive survey of finfish in the Delaware Estuary, and found that bay anchovy, alewife, Atlantic menhaden, striped bass, hogchoker, and Atlantic croaker use these shallow waters as a nursery area.[434] Other species, including blueback herring, mummichog, banded killifish, silverside, and white perch, spawn in these nearshore areas and move in and out of tidal marshes. Blueback herring spawn in shallow waters of creeks over sand or gravel substrate. The ocean-going bluefish moves into the bay in summer, where the young congregate in nearshore areas. Sand, peat/mud, and mud beaches are also important habitat for some fish species, including alewife, American.

[433]Ibid.

[434]De Sylva, D.P., F.A. Kalber Jr., and C.N. Shuster, 1962, Fishes and Ecological Conditions in the Shore Zone of the Delaware River Estuary, with Notes on Other Species Collected in Deeper Waters. Information series, Publication No. 5, University of Delaware Marine Laboratories, Lewes.

3.8. Maryland and Delaware Coastal Bays

Author: ***Elizabeth M. Strange, Stratus Consulting Inc.***

Species and habitats along in the back-barrier bays of Maryland and Delaware (hereafter referred to collectively as the Coastal Bays) are potentially at risk because of sea level rise. The Maryland Coastal Bays include Chincoteague, Sinepuxent, Newport, Isle of Wight, and Assawoman bays. The Delaware Inland Bays are three interconnected bays (Little Assawoman Bay, Indian River Bay, and Rehoboth Bay). The shorelines of the Coastal Bays contain important habitats for a variety of fish, shellfish, and birds, and a great deal is known about their ecology and habitat needs. Based on existing literature and the knowledge of local scientists, this brief literature review discusses the coastal species in the region that could be at risk because of further habitat loss resulting from sea level rise (see Section 3.1, Overview) and shoreline protection (see Map 3.7). Although it is possible to make qualitative statements about the possible impacts if sea level rise causes a total loss of habitat, our ability to discern what the impact might be if only a portion of the habitat is lost is more limited. A total loss of habitat is possible if shores are protected with hard structures and the wetlands are unable to keep pace with sea level rise.

Back-Barrier Salt Marshes

There are an estimated 6,718 ha (16,600 acres) of salt marsh along Maryland's Coastal Bays, mostly along the mainland shorelines of Sinepuxent, Newport, and Chincoteague bays; there are about 1,012 ha (2,500 acres) of salt marsh in the northern bays.[435] There are an estimated 5,510 ha (13,600 acres) of vegetated estuarine wetlands in the Delaware Inland Bays, most of which are tidal salt marshes.[436] These tidal salt marshes are mostly fringing marshes, but there are also large acreages of back-barrier marshes, especially in Rehoboth Bay.[437]

The Delaware's Inland Bays provide one of the few areas in Delaware for colonial nesting waterbirds, including herons, egrets, gulls and terns. The rate of development within the bays' drainage and associated shoreline hardening would likely severely limit marsh migration during sea level rise. Loss of the fringing marshes and islands of the bays would significantly reduce or eliminate nesting habitat for these species in Delaware.[438]

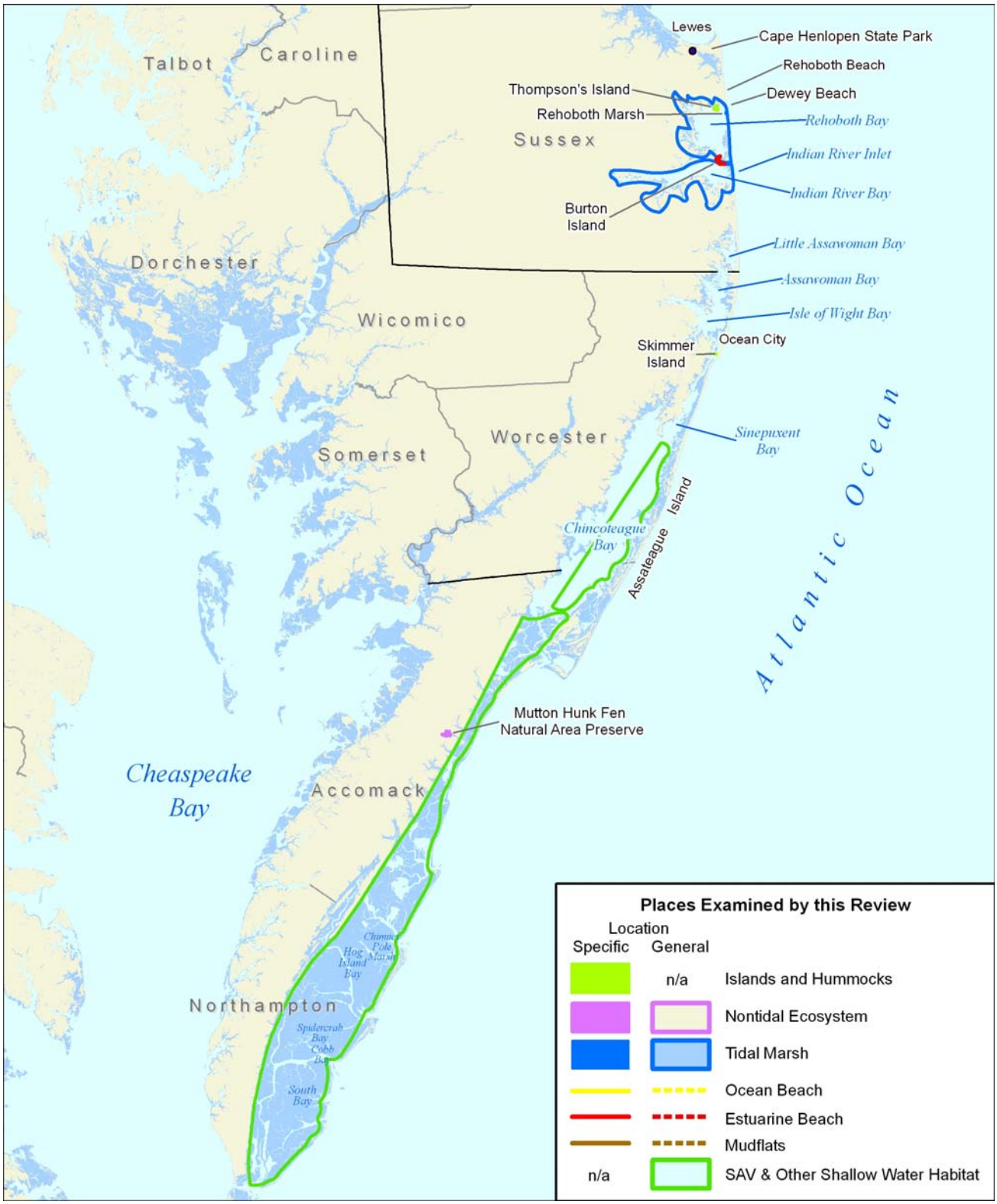
The Maryland Coastal Bays Program considers shoreline erosion due to sea level rise and shoreline hardening major factors contributing to a decline in the amount of natural shoreline habitat available for estuarine species in the

[435]Bleil, D., D. Clearwater, and B. Nichols, 2005, "Status of the wetlands in the Maryland coastal bays," Chapter 6.4 in Wazniak, C.E., and M.R. Hall (eds.), 2005, *Maryland's Coastal Bays: Ecosystem Health Assessment 2004*, DNR-12-1202-0009, Maryland Department of Natural Resources, Tidewater Ecosystem Assessment, Annapolis, MD, p. 6-33.

[436]Tiner, R.W., 2001, Delaware's Wetlands: Status and Trends. U.S. Fish and Wildlife Service, Ecological Services, Region 5, Hadley, MA. Prepared for the Delaware Department of Natural Resources and Environmental Control, Watershed Assessment Section, Division of Water Resources, Dover, DE. Cooperative National Wetlands Inventory Publication, Figure p. 9, text p. 16.

[437]Chris Bason, Center for the Delaware Inland Bays, email communication to Karen Scott, EPA, 5/14/07 (personal visual observation).

[438]Kevin Kalasz, wildlife biologist, Natural Heritage & Endangered Species Program, Delaware Division of Fish and Wildlife, in email entitled Opportunity to comment on U.S. EPA-sponsored papers related to sea level rise and related impacts on habitat and species, to Karen Scott of EPA, 2/16/07 (expert judgment based on official duty).



Map 3.7. Locations and Types of Habitat Discussed in this Report: Atlantic Coast of the Delmarva Peninsula

northern bays.[439] There has been significant shoreline hardening in Maryland's northern coastal bays (Isle of Wight and Assawoman), but little or no hardening in the three southernmost bays (Sinepuxent, Newport, and Chincoteague).[440] Planners expect shores in the southern part of Maryland's coastal bays to remain unprotected. Where natural shorelines remain, marshes in low-lying areas may expand inland as seas rise. Much of the shoreline of Maryland's northern coastal bays is protected using bulkheads or stone riprap, resulting in unstable sediments and loss of wetlands and shallow water habitat.[441] Armoring of these shorelines will prevent inland migration of marshes, and any remaining fringing marshes will ultimately be lost. The Maryland Coastal Bays Program estimated that more than 607 ha (1,500 acres) of salt marshes have already been lost in the Coastal Bays as a result of shoreline development and stabilization techniques.[442]

Loss of marshes will reduce habitat for many bird species that use the marshes for roosting, nesting, or foraging. Such species include black-bellied plover, dunlin, and horned grebe, wading birds such as herons and egrets, migratory shorebirds, rail species, including Virginia, king, and clapper rails, and many species of waterfowl.[443] Ducks and geese, including mallards, pintails, blue and green winged teals, gadwalls, canvasbacks, loons, buffleheads, mergansers, and golden eyes, overwinter in the bays' marshes.[444] A large colony of American brant winters in Rehoboth and Indian River bays.[445] The Rehoboth marsh is known as an important area for colonies of nesting shorebirds and a food source for young birds.[446] The bays' marshes also provide nesting habitat for many species of concern to federal and state agencies, including northern harrier, American black duck, Nelson's sparrow, salt marsh sharp-tailed sparrow, seaside sparrow, coastal plain swamp sparrow, black rail, Forster's tern, gull-billed tern, black skimmers, and American oystercatchers. There is particular concern for Forster's tern because most of its breeding range is in the salt marshes of the mid-Atlantic.[447]

Marsh loss will also reduce habitat for resident and transient fish and shellfish species. Marsh resident fishes include mummichog, Atlantic silverside, and naked goby. A number of marine transients, including recreationally and commercially important species such as black drum, striped bass, bluefish, Atlantic croaker, sea trout, and summer flounder, depend on the marshes for spawning and nursery habitat. Important forage fish that move into the bays for spawning include spot, menhaden, silver perch, and bay anchovy, which are currently declining all along the Atlantic Coast. Shellfish species found in the bays' marshes include clams, oysters, shrimps, ribbed mussels, and blue crabs.[448]

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[439]Maryland Coastal Bays Program, 1999, *Today's Treasures for Tomorrow: Towards a Brighter Future; The Comprehensive Conservation and Management Plan for Maryland's Coastal Bays*, Maryland's Coastal Bays Program, Berlin, MD, Final Draft, June, p. 45.
[440]Hennessee, L., 2005, Status of the shorelines in the Maryland coastal bays, Chapter 6.5 in Wazniak and Hall (see note 435), p. 6-42.
[441]Maryland Coastal Bays Program, 1999, p. 6 (see note 439).
[442]Maryland Coastal Bays Program, 1999, p. 67 (see note 439).
[443]Dave Wilson, Maryland Coastal Bays Program. In June 13, 2006 email to E. Strange, Stratus Consulting, entitled "Follow up to my visit," providing review of draft text and recounting personal observations reported in a meeting on 16 May 2006. (Dave Wilson is the outreach coordinator for the Maryland Coastal Bays Program.)
[444]"Discover Delaware's Inland Bays," n.d., fact sheet, Document No. 40-01-01/03/03/01 produced with funding from NOAA by the Delaware Department of Natural Resources and Environmental Control, Delaware Coastal Programs. Available at: www.dnrec.state.de.us/dnrec2000/Library/Misc/InlandBays.pdf; and personal observations of Chris Bason (see note 437).
[445]"Discover Delaware's Inland Bays" (see note 444).
[446]Delaware Inland Bays Comprehensive Conservation and Management Plan, June 1995, Chapter 2: The State of the Inland Bays, p. 86.
[447]Erwin et al., 2006, p.16 (see note 58).
[448]Casey, J., and S. Doctor, 2005, Status of finfish populations in the Maryland Coastal Bays, Chapter 8.4 in Wazniak and Hall (see note 435), p. 8-34.

Forested Wetlands

Forested wetlands occur along both tidal and nontidal creeks. Increasing instances of crown dieback and tree mortality in these wetlands are generally considered a result of sea level rise and an upstream shift in the salinity gradient. Where inland migration is not possible, the understory is being filled in with marsh plants, resulting in loss of tree habitats that are critical for many bird species, including bald eagles and a variety of breeding songbirds.[449]

Sea Level Fen

A rare sea level fen vegetation community grows in the Angola Neck Natural Area along Rehoboth Bay.[450] This extremely rare type of coastal wetland grows only under the unusual circumstances where there is a natural seep from a nearby slope providing nutrient-poor groundwater to support its unique vegetation and where there is protection from nutrient-rich tidal flow (see Section 3.1, Overview, for detailed description of sea level fens).[451] Because of its location, the Angola Neck sea level fen could be lost as rising seas move inland, bringing nutrient-rich waters that are not tolerated by sea level fen vegetation.

Coastal Plain Ponds

Coastal plain ponds are small, groundwater-fed ponds that contain many rare plant species. Because they are near sea level, these unique plant communities are particularly vulnerable to sea level rise. Such areas occur in the Delaware Inland Bays, especially within Assawoman Wildlife Management Area on Little Assawoman Bay.[452]

Back-Barrier Beaches

The back-barrier beaches of the Coastal Bays have a number of important ecological functions. Horseshoe crabs spawn on these beaches, [453]

and their eggs are an important food source for migrating shorebirds in spring.[454] *Photuris bethaniensis* is a globally rare firefly located only in interdunal swales on Delaware barrier beaches. The firefly's habitat is at risk because of beach stabilization and shoreline hardening, which limits dune migration and the formation of interdunal swales. Local ecologists favor research to ascertain whether protecting infrastructure from sea level rise might also increase erosion and further limit the formation of new interdunal swales.[455]

Northern diamondback terrapin spend most of their time in the marsh creeks and open waters of the Coastal Bays, but move onto the back-barrier beaches to nest and deposit their eggs along the upper beach.[456] Diamondbacks nest on back-barrier beaches and most types of estuarine beaches. In Delaware, they are known to next on beaches of Burton Island.[457] They also regularly nest in residential areas, which may result from their natal imprint leading them back to former dune habitat that is now developed.[458] A natural instinct to get to the most suitable nesting habitat in the dunes nearer the ocean may be the reason some terrapins cross Route 1.[459] This has become a major management concern because many are killed by traffic.[460]

Loss of additional beach habitat due to sea level rise and erosion below bulkheads and other protective structures could have a number of negative consequences for species that use these beaches for egg-laying, foraging, or other critical

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[449]Gary Fleming (personal visual observation) (see note 76).
[450]Delaware Department of Natural Resources and Environmental Control, Inland Bay Report. Accessed December 5, 2007 at: http://www.dnrec.state.de.us/DNREC2000/Admin/WholeBasin/InlandBays/living.pdf.

[451]Westerfelt, K., E. Largay, R. Coxe, W. McAvoy, S. Perles, G. Podniesinski, L. Sneddon, and K. Starkosch Walz, 2006, *A Guide to the Natural Communities of the Delaware Estuary*: *Version 1*, NatureServe, Arlington, VA, p. 258.
[452]Kevin Kalasz (see note 438) (personal visual observation) and Chris Bason (see note 437) (personal visual observation).

[453]Dave Wilson, personal visual observation (see note 443).
[454]Delaware Audubon Society. *Important Bird Areas in the Delaware*. Summary available at: http://www.delawareaudubon.org/birding/globaliba.html.
[455]Kevin Kalasz (see note 438).
[456]Dave Wilson (personal visual observation (see note 443).
[457]"Discover Delaware's Inland Bays" (see note 444).
[458]Chris Bason (personal visual observation) (see note 437).
[459]Ibid.
[460]"Discover Delaware's Inland Bays" (see note 444).

activities. Because terrapins bury their eggs deep within sandy sediment, where the eggs are protected against predators and other dangers, it is unlikely that they could reproduce in alternative habitats where it is more difficult to dig into the sediment to bury their eggs. Horseshoe crabs rarely spawn unless sand is at least deep enough to nearly cover their bodies, about 10 cm (4 in.).[461] Shoreline protection structures designed to slow beach loss can also block horseshoe crab access to beaches and can entrap or strand spawning crabs when wave energy is high.[462]

Erosion and inundation may reduce or eliminate beach wrack communities of the upper beach, especially in developed areas where shores are protected. Beach wrack contains insects and amphipod crustaceans such as fleas and beach hoppers that provide food for many species, including migrating shorebirds.[463] In addition, horseshoe crab eggs are sometimes ensnared in the wrack, where they are more accessible to foraging shorebirds.[464] Loss of wrack will decrease these food sources (for a more detailed description, see Section 3.1, Overview).

Tidal Flats

Tidal flats are found at the seaward edge of the shorelines of both the Delaware and Maryland Coastal Bays. The benthic invertebrates of tidal flats typically include bivalves, small crabs, worms, and snails, which are important forage for shorebirds.[465]

The low-lying coastal plain and the fine unconsolidated sediments of the bays makes their tidal flats particularly susceptible to inundation from sea level rise.[466] In areas where sediments accumulate in shallow waters and shoreline protection prevents landward migration of salt marshes, flats may become vegetated as low marsh encroaches seaward, which will further increase sediment deposition and lead to an increase in low marsh and a reduction in tidal flats.[467] Where sediment deposition is comparatively low, marsh may revert to unvegetated flat, at least in the short term, before the area becomes fully inundated.[468]

Reduction in the area of tidal flats will reduce invertebrate food supplies for wading birds, shorebirds, and dabbling ducks such as mallards and the American black duck. As rising seas cover flats with more and more water, they will become less available to foraging species, particularly short-legged shorebirds.[469] Tidal flats are critical for migrating shorebirds. Some researchers predict that as inundation increases and the area of tidal flats declines, increased crowding in remaining areas will lead to exclusion and mortality of shorebirds.[470]

Shallow Waters and Submerged Aquatic Vegetation (SAV)

There are currently about 4,629 ha (11,438 acres) of SAV in Maryland's coastal bays, mostly eelgrass. Nearly 85 percent of eelgrass beds are found along the bayside of Assateague Island. Eelgrass in Maryland's coastal bays is generally limited to a maximum depth of about 1.5 m (5 feet).[471] Thus, unless conditions change, a 50–100 cm (20–40 in.) rise in sea level could potentially make areas where water depths are greater than 50–100 cm (20–40 in.) inhospitable to SAV.[472]

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[461]Weber, R.G., 2001, Preconstruction horseshoe crab egg density monitoring and habitat availability at Kelly Island, Port Mahon, and Broadkill Beach Study areas, Prepared for the Philadelphia District Corps of Engineers, Philadelphia, PA, p. 4.
[462]Doctor, S., and C.E. Wazniak, 2005, "Status of horseshoe crab, *Limulus polyphemus*, populations in Maryland coastal bays," Chapter 8.7 in Wazniak and Hall (see note 435), p. 8-92.
[463]Dugan et al., 2003, p. 32 (see note 127).
[464]Jackson et al., 2002, p. 418 (see note 139).
[465]Burger, J., L. Niles, and K.E. Clark, 1997, "Importance of beach, mudflat, and marsh habitats to migrant shorebirds in Delaware Bay," *Biological Conservation* 79:283–292, p. 284.
[466]Johnson, Z.P., 2000, *A Sea Level Rise Response Strategy for the State of Maryland*, Maryland Department of Natural Resources, Coastal Zone Management Division, p. 9 and Figure 2.
[467]Redfield, 1972 (see note 132).
[468]Brinson et al., 1995, p. 655 (see note 23).
[469]Erwin, no date (see note 136).
[470]Galbraith et al., 2002 (see note 50).
[471]Wazniak, C., L. Karrh, T. Parham, M. Naylor, M. Hall, T. Carruthers, and R.J. Orth, 2005, Seagrass abundance and habitat criteria in the Maryland Coastal Bays, Chapter 6.1 in Wazniak and Hall (see note 435), p. 6-5.
[472]Short and Neckles, 1999, p. 175 (see note 91).

Researchers are uncertain whether the natural overwash process will keep water depths constant by providing enough sediment for the bay bottoms to rise as fast as the sea rises. Nor does anyone know whether inundated marsh on the mainland would be replaced by SAV. As a result, we are unable to say whether SAV in this area will increase or decrease as sea level rises.

The fate of SAV is very important for secondary productivity in the back-barrier bays of Maryland. Eelgrass beds are considered essential habitat for summer flounder and bay scallop and critical habitat for blue crab, which support substantial recreational and commercial fisheries in the coastal bays.[473] Therefore, the possibility of a net loss of eelgrass as sea level rises implies a risk to the local populations of flounder, scallop, and crab that are harvested in the coastal bays of Maryland. SAV is also important for many nongame species such as sticklebacks, pipefishes, and seahorses.

At present, SAV is almost absent from the Delaware Inland Bays because of eutrophication and turbid conditions in the bays' shallow waters.[474] However, reestablishment of eelgrass beds has been successful near Indian River Inlet, where ocean-influenced water quality supports growth.[475] In the future, poor water quality combined with increasing depth with sea level rise could impede SAV recovery in other parts of the bays.

Marsh and Bay Islands

Islands within the coastal bays are important nesting areas for herons, egrets, black skimmers, gulls and terns. Laughing gulls, herring gulls, and great black-backed gulls nest on the marsh islands of Delaware's Inland Bays. Forster's terns nest on dead marsh grasses on the islands.[476]

Marsh islands within the bays are undergoing rapid erosion. Big Piney Island in Rehoboth Bay experienced erosion rates of 30 ft/yr between 1968 and 1981, and is now gone.[477] Little Piney Island is another historical island in Rehoboth Bay that is completely eroded. Currently, Seal Island in Little Assawoman Bay is eroding rapidly after being nearly totally devegetated by greater snow geese.[478] The erosion of the these island and their potential submergence due to an inability to keep pace with sea level rise are of particular concern because these islands protect other natural and developed shorelines and marshes from increased erosion.

Hundreds of horned grebes stage for migration at the north end of Rehoboth Bay near Thompson's Island. Thompson's Island, part of the Delaware Seashore State Park, is located between Rehoboth and Dewey Beach, and is a significant birding area. Located only a half mile from the beach is the last stand of mature forest of white oak and loblolly pine along the Delaware coast. The island has several other habitat zones, including salt marsh. Resident species include some that are difficult to find along the coast, such as hairy woodpecker and belted kingfisher. The island is especially significant as a "migration trap," where migrating birds are funneled onto the island and "trapped" by 7 miles of inland bays and coast.[479]

Royal tern is a species that nests only on low-lying islands.[480] Although royal terns visit Delaware's Inland Bays in the summer, they do not nest there.[481] In the Maryland bays, royal

[473]Maryland Coastal Bays Program, 1999, p. 56 (see note 439).
[474]Delaware Department of Natural Resources and Environmental Control, 2001, Inland Bays/Atlantic Ocean Basin Assessment Report, June, p. 39.
[475]Delaware Department of Natural Resources and Environmental Control, n.d., Inland Bays/Atlantic Ocean Environmental Profile. Section on Water Quality: Water Resource Issues. Available at: http://www.dnrec.state.de.us/water2000/Sections/Watershed/ws/ib_atlantic_env_profile.pdf.

[476]"Discover Delaware's Inland Bays" (see note 444).
[477]Swisher, M.L., 1982, The rates and causes of shore erosion around a transgressive coastal lagoon, Rehoboth Bay, Delaware, M.S. Thesis, College of Marine Studies, University of Delaware, Newark.
[478]Chris Bason (personal visual observation) (see note 437).
[479]Ednie, A.P., n.d., *Birding Delaware's Prehistoric Past: Thompson's Island at Delaware Seashore State Park.* Available at: http://www.dvoc.org/DelValBirding/Places/ThompsonsIsland.htm.
[480]Buckley, P.A., and F.G. Buckley, 2002, Royal tern (*Sterna maxima*), in Poole and Gill (see note 370).
[481]"Discover Delaware's Inland Bays" (see note 444).

terns nest only on Skimmer Island, which is currently only about 10 cm (4 in) above sea level.

There are numerous small islands in Maryland's Chincoteague Bay. However, stabilization of the Ocean City inlets and efforts by the U.S. Army Corps of Engineers to prevent formation of new inlets have inhibited the natural formation of new islands. The Corps has created many small dredge spoil islands, but most have disappeared as a result of erosion. These islands typically provide good nesting habitat for gulls, egrets, herons, American oystercatchers, glossy ibis, American black duck, American bald eagle, and osprey.[482]

Many of the small islands in the coastal bays are currently eroding, and may disappear altogether as rising seas inundate low-lying areas. Further loss of these islands because of erosion and sea level rise could result in severe reductions in island bird populations. [483]

The highest number of nesting American oystercatchers in Delaware are found nesting in the Inland Bays. They primarily nest on small sandy beaches and wrack on islands. Loss of nesting habitat for this species would dramatically reduce the population of American oystercatcher in Delaware.[484]

[482]Erwin, 1996, p. 216 (see note 240).

[483]Ibid.

[484]Kevin Kalasz (see note 438) (expert judgment based on official duty).

3.9 The Atlantic Side of the Virginia Eastern Shore

*Author: **Elizabeth M. Strange, Stratus Consulting Inc.***

Species and habitats in the tidal marshes of the Atlantic Coast side of the Virginia Eastern shore are potentially at risk because of sea level rise. This region contains the largest stretch of natural coastline along the U.S. Atlantic Coast, almost all of which is owned by either TNC or the federal government. The region includes extensive back-barrier lagoonal marshes and areas of estuarine beach behind a chain of barrier islands. Fringing salt marshes occur on the mainland side of the lagoons.

Based on existing literature and the knowledge of local scientists, this brief literature review discusses the coastal species in the region that could be at risk because of further habitat loss resulting from sea level rise and shoreline protection (see Section 3.1, Overview) (see Map 3.7). Although it is possible to make qualitative statements about the possible impacts if sea level rise causes a total loss of habitat, our ability to discern what the impact might be if only a portion of the habitat is lost is more limited. A total loss of habitat is possible if shores are protected with hard structures and the wetlands are unable to keep pace with sea level rise.

Back-Barrier Salt Marshes

Salt marsh adaptation to sea level rise. Salt marshes occupy thousands of acres in eastern Accomack and Northampton counties.[485] Marsh accretion experts believe that most of these marshes are keeping pace with current rates of sea level rise, but may be unable to continue to do so if the rate of sea level rise increases by another 2 mm/yr (see Section 2.1). Some local field measurements indicate that accretion rates may be insufficient to keep pace even with current rates of sea level rise. Accretion rates as low as 0.9 mm/yr (Phillips Creek Marsh) and as high as 2.1 mm/yr (Chimney Pole Marsh) have been reported,[486] and the average relative sea level rise along the Eastern Shore is estimated as 2.8–4.2 mm/yr.[487]

The dominant accretion processes in eastern Accomack and Northampton counties are storm sedimentation and overwash from the beaches of the barrier islands. A panel of accretion experts recently suggested that if the rate of sea level rise increases by 2 mm/yr, the survival of marshes in this area will depend on the future frequency of storms supplying sediments (see Section 2.1). Other scientists have suggested that the ability of the marshes of the Eastern Shore to keep pace may be constrained by the generally low sediment supply provided by the small watersheds of the area.[488,489] In 2004, annual losses of 0.2 and 0.67 percent were reported for Curlew Bay and Gull Marsh, respectively, mostly as a result of perimeter erosion to open water.[490] However, in Mockhorn Wildlife Refuge in southern Northampton County, where elevations are lower, sediments have accumulated in shallow waters, and low marsh is encroaching on adjacent tidal flats.[491,492]

[485]Fleming et al., 2006 (see note 67).

[486]Kastler, J.A., and P.L. Wiberg, 1996, "Sedimentation and boundary changes of Virginia salt marshes," *Estuarine, Coastal and Shelf Science* 42:683–700, p. 691.

[487]May, M.K., 2002, Pattern and Process of Headward Erosion in Salt Marsh Tidal Creeks, Master's Thesis, Department of Biology, Eastern Carolina University, Greenville, NC, p. 4, reviewing the findings of G.F. Oertel, T.F. Wong, and J.D. Conway, 1989, "Sediment accumulation at a fringe marsh during transgression, Oyster, Virginia., *Estuaries* 12:18–26, and B.P. Hayden, D. Dueser, J.T. Callahan, and H.H. Shugart, 1991, "Long-term research at the Virginia Coast Reserve," *BioScience* 41:310–318.

[488]Christiansen, T., P.L. Wiberg, and T.G. Milligan, 2000, "Flow and sediment transport on a tidal salt marsh surface," *Estuarine, Coastal and Shelf Science* 50:315–331, p. 324.

[489]Reed et al., 2008, Section 2.1.

[490]Erwin et al., 2004, p. 891 (see note 16).

[491]Erwin et al., 2006 (see note 58).

Most wetlands are able to keep pace with rising sea level today, become marginal with an acceleration of 2 mm/year, and would be lost with a more substantial acceleration (see Reed et al., Section 2.1). Shore protection is unlikely along much of the mainland opposite the barrier islands and lagoonal marshes. In those unprotected areas, marshes are likely to migrate inland into low-lying areas. Kastler and Wiberg found that from 1938 to 1990 mainland salt marshes on the Eastern Shore increased in area by 8.2 percent, largely as a result of encroachment of salt marsh into upland areas.[493]

Sea level rise may also contribute to invasion by the common reed (*Phragmites*), which provides lower quality habitat. Higher sea levels cause groundwater discharge to migrate upslope with greater volume. Common reed can invade where this discharge flows over the marsh surface, providing lower salinity habitat.[494]

Impacts on fish and wildlife. Sea level rise is considered a major threat to bird species in this area, which is known as the Virginia Barrier Island/Lagoon Important Bird Area (IBA).[495] Biologists at the Patuxent Wildlife Research Center suggest that submergence of lagoonal marshes in Virginia would have a major negative effect on marsh-nesting birds such as black rails, seaside sparrows, saltmarsh sharp-tailed sparrows, clapper rails, and Forster's terns.[496] The USFWS considers black rail and both sparrow species "birds of conservation concern" because populations are already declining in much of their range.[497] A study of Virginia marshes found that the number of bird species was directly related to marsh size; the minimum marsh size found to support significant marsh bird communities was 4.1–6.7 ha (10–15 acres).[498]

A diversity of resident and estuarine and marine transient fish species move in and out of marshes with the tides to take advantage of the abundance of decomposing plants in the marsh and refuge from predators.[499] Marine transients include recreationally and commercially important species, including black drum, striped bass, bluefish, and Atlantic croaker. A study in Virginia showed that nekton abundance and diversity is greater in fringing marsh than along intertidal shorelines that are armored.[500]

Where sea level rise leads to increased flooding of the marsh, some fishes may benefit, at least in the short term, from an increase in tidal creeks and channels, providing greater access to the marsh. More water on the marsh surface may also provide some benefits. For example, in the salt marshes of the Eastern Shore, resident fishes such as common mummichog and spotfin killifish, and invertebrates such as grass shrimp, forage in shallow waters on the marsh surface to take advantage of an underutilized food source and to avoid predators.[501] However, where marshes drown, the loss of marsh primary production will impair the value of the habitat for fish and shellfish. Virginia's highly valued commercial and recreational fishing industry may be harmed if fish and shellfish production declines in these areas.

Sea Level Fen

A globally rare sea level fen community—one of only four in Virginia—is found in the Mutton Hunk Fen Natural Area Preserve fronting

[492]Erwin et al., 2004, p. 891 (see note 16).
[493]Kastler and Wiberg, 1996 (see note 486).
[494]Barry Truitt (see note 360).
[495]Watts, B.D., 2006, Synthesizing Information Resources for the Virginia Important Bird Area Program: Phase I, Delmarva Peninsula and Tidewater, Center for Conservation Biology Technical Report Series, CCBTR-06-05, College of William and Mary, Williamsburg, VA, p. 6.
[496]Erwin et al., 2004, p. 901 (see note 16).
[497]USFWS, 2002, Birds of Conservation Concern 2002, Division of Migratory Bird Management, Arlington, VA, Table 30. Available at: http://www.fws.gov/migratorybirds/reports/reports.html.
[498]Watts, 1993 (see note 61).
[499]See general discussions in Boesch and Turner, 1984 (see note 318); and Kneib, 1997 (see note 17).
[500]Carroll, R.A., 2002, Nekton utilization of intertidal fringing salt marsh and revetment hardened shorelines, M.S. Thesis, School of Marine Sciences, College of William and Mary, Williamsburg, VA.
[501]Yozzo, D.J., A. Mannino, and D.E. Smith. 1994. "Mid-summer abundance of resident sub-adult marsh nekton at the Virginia Coast Reserve," *Virginia Journal of Science* 45:21–30, as cited by Layman, C.A., 2000, "Fish assemblage structure of the shallow ocean surf zone on the Eastern Shore of Virginia Barrier Islands," *Estuarine, Coastal, and Shelf Science* 51:201.

Gargathy Bay in eastern Accomack County.[502] This extremely rare type of coastal wetland grows only under the unusual circumstances where there is a natural seep from a nearby slope providing nutrient-poor groundwater to support its unique vegetation, and where there is protection from nutrient-rich tidal flow (see Section 3.1 for more description of sea level fens). The Division of Natural Heritage within the Virginia Department of Conservation and Recreation believes that chronic sea level rise with intrusions of tidal flooding and salinity poses "a serious threat to the long-term viability" of sea level fens.[503] If rising seas reach the Mutton Hunk Fen Natural Area, the influx of nutrient-rich waters may destroy the populations of the rare plant species at this site, including the carnivorous sundew, and bladderwort.[504] On the other hand, sea level rise could cause groundwater discharge to increase in volume at some locations, which would benefit fens.[505]

Back-Barrier Beaches

The beaches on the mainland behind the barrier island complex of the Eastern Shore are small strips of beach that are relatively stable because they are protected from high energy wave action. Where beaches erode in front of shoreline protection structures and are not replenished, the many invertebrates that burrow in the sand and species that spawn on beaches will lose critical habitat. Rare species that have sometimes been observed on these beaches include the northern diamondback terrapin and the northeastern tiger beetle.[506]

Tidal Flats

CCSP submissions by the USGS will address the likelihood that sea level rise will reduce the area of tidal flats in areas with naturally low sediment supplies like the Eastern Shore. Loss of tidal flats would eliminate a rich invertebrate food source for migrating birds such as whimbrels, dowitchers, dunlins, black-bellied plovers, and semipalmated sandpipers.[507]

Shallow Waters and Submerged Aquatic Vegetation (SAV)

Natural eelgrass beds occur in a number of areas along the sea side of the Eastern Shore, and are most abundant in Chincoteague Bay. There are also some successful eelgrass restoration projects in South Bay, Cobb Bay, Hog Island Bay, and Spider Crab Bay.[508] The potential effects of sea level rise on eelgrass beds have not been studied directly. However, Short and Neckles estimate that, in general, a 50 cm increase in water depth as a result of sea level rise could reduce the available light in coastal areas by 50 percent, resulting in a 30–40 percent reduction in SAV growth. [509] Where this may occur in the nearshore waters of eastern Northampton and Accomack counties would depend on current local conditions such as water depth, the maximum depth of eelgrass growth, and water clarity. A local expert with The Nature Conservancy suggests that because eelgrass is at the southern limit of its range in the Coastal

[502]Fact sheet by Virginia Department of Conservation and Preservation on the Mutton Hunk Fen Natural Area Preserve. Accessed December 5, 2007 at: http://www.dcr.virginia.gov/natural_heritage/natural_area_preserves/muttonhunk.shtml.

[503]Virginia Department of Conservation and Recreation, 2001, The Natural Communities of Virginia, Ecological Classification of Ecological Community Groups, First Approximation, Division of Natural Heritage Natural Heritage Technical Report 01-1, p. 48.

[504]Mutton Hunk Fen Natural Area Preserve Fact Sheet (see note 502).

[505]The authors would like to thank reviewer Barry Truitt for pointing this out (see note 360).

[506]See information on these species and their status in Virginia, provided in Chapter 3: Refuge and Resource Descriptions (specifically pages 3-20 and 3-32) of USFWS, 2004, Eastern Shore of Virginia and Fisherman Island Nation Wildlife Refuges Comprehensive Conservation Plan, Northeast Regional Office, Hadley, MA, available at: http://library.fws.gov/CCPs/eastshoreVA_index.htm.

[507]The Nature Conservancy project profile for the Virginia Coast Reserve, 2006, available by searching on "field guides" at http://www.nature.org/wherewework. See also Watts, B.D., and B.R. Truitt, 2000, "Abundance of shorebirds along the Virginia barrier islands during spring migration," *Raven* 71:33–39.

[508]Information provided in July 12, 2006, email to E. Strange of Stratus Consulting from Scott Lerberg of the Virginia Seaside Heritage Program. Orth, R. J., M. L. Luckenbach, S. R. Marion, K. A. Moore. and D. J. Wilcox, in press, "Recovery of the seagrass *Zostera marina* (eelgrass) in the Delmarva Coastal Bays, USA," *Aquatic Botany*.

[509]Short and Neckles, 1999 (see note 91).

Bays, global warming may be a greater factor in its persistence than light reduction.[510]

Loss of eelgrass beds could harm local populations of birds, fish, and shellfish. Various waterbirds feed on eelgrass beds, including brant, canvas back, and American black duck.[511] Virginia's commercial and recreational fisheries include many estuarine and marine species that rely on eelgrass for nursery habitat.[512] A number of highly valued shellfish species are also found here, including bay scallop, hard clam, and blue crab.

Marsh and Bay Islands

Several bird species of concern in Virginia and elsewhere along the Atlantic Coast, including gull-billed terns, common terns, black skimmers, and American oystercatchers, nest on shellpiles on marsh islands.[513] The advantage of this is that the shellpiles are generally free of mammalian predators. However, marsh islands are also subject to tidal flooding, which is known to reduce the reproductive success of island-nesting birds.[514] Therefore, as islands experience more erosion and flooding as a result of sea level rise, local populations of island-nesting birds may decline.

Island shrinking is already apparent along the Eastern Shore. From 1949 to 1990, Chimney Pole marsh showed a 10 percent loss to open water.[515] Chimney Pole marsh is directly inside Quinby Inlet and subjected to high energy wave action during storms. As early as the mid-1990s, gull-billed tern nests on Chimney Pole Island were only a foot above the June high water mark, indicating its vulnerability to even relatively low increases in rates of sea level rise.[516]

Coastal Habitat for Migrating Neotropical Songbirds

Because of their importance for migrating neotropical songbirds such as indigo buntings and ruby-throated hummingbirds, the coastal areas of southern Northampton County are a designated Important Bird Area (IBA).[517] Not only are these birds valued for their beauty but they also serve important functions of dispersing seeds and controlling insect pests. It is estimated that a pair of warblers can consume thousands of insects as they raise a brood.[518]

Chesapeake Bay is a significant physical barrier that acts as a bottleneck for migrating birds, funneling southbound migrants to lower Northampton County, where they concentrate within the tree canopy and thick understory vegetation found within the lower 9.66 km (6 miles) of the peninsula within 188.82 m (200 yards) of the shoreline. Loss of this understory vegetation as a result of rising seas would eliminate this critical stopover area for neotropical migrants, many of which have shown consistent population declines since the early 1970s.[519]

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[510]Barry Truitt (see note 360).
[511] Perry and Deller, 1996 (see note 100).
[512]Wyda et al., 2002 (see note 95).
[513]Rounds et al., 2004 (see note 78).
[514]Eyler et al., 1999 (see note 78).
[515]Kastler and Wiberg, 1996 (see note 486).
[516]Erwin, R.M., J.G. Haig, D.B. Stotts, B. Truitt, and C.R. Carlson, 1995, Will the tide tern? Rising sea levels, invasive species, agricultural pesticides, and nesting gull-billed terns. Available at: http://www.vcrlter.virginia.edu/davedocs/VCRASC95/erwin.html .

[517]Watts, 2006, p. 5 (see note 495).
[518]Mabey, S., B. Watts, and L. McKay, n.d., Migratory Birds of the Lower Delmarva: A Habitat Management Guide for Landowners, The Center for Conservation Biology, College of William and Mary, Willamsburg, VA, p. 7.
[519]Mabey et al., p. 10 (see note 518).