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.

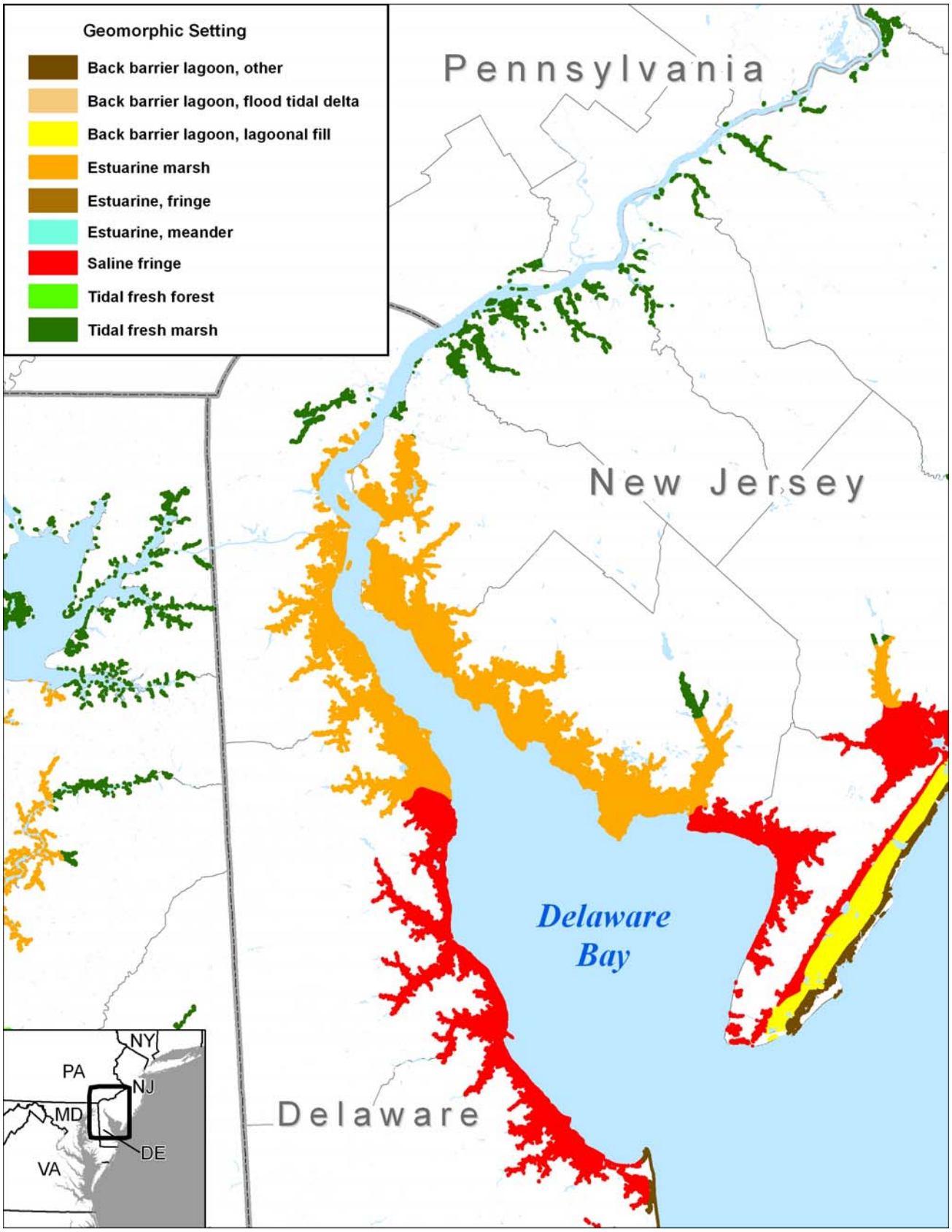
Historically, much of the bay's shoreline was diked to reclaim wetlands for farming. However, in recent decades, dikes have been removed to support wetland restoration.[410] At the same time, there has been an expansion of the common reed, *Phragmites australis*, at higher elevations and in many of the 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?

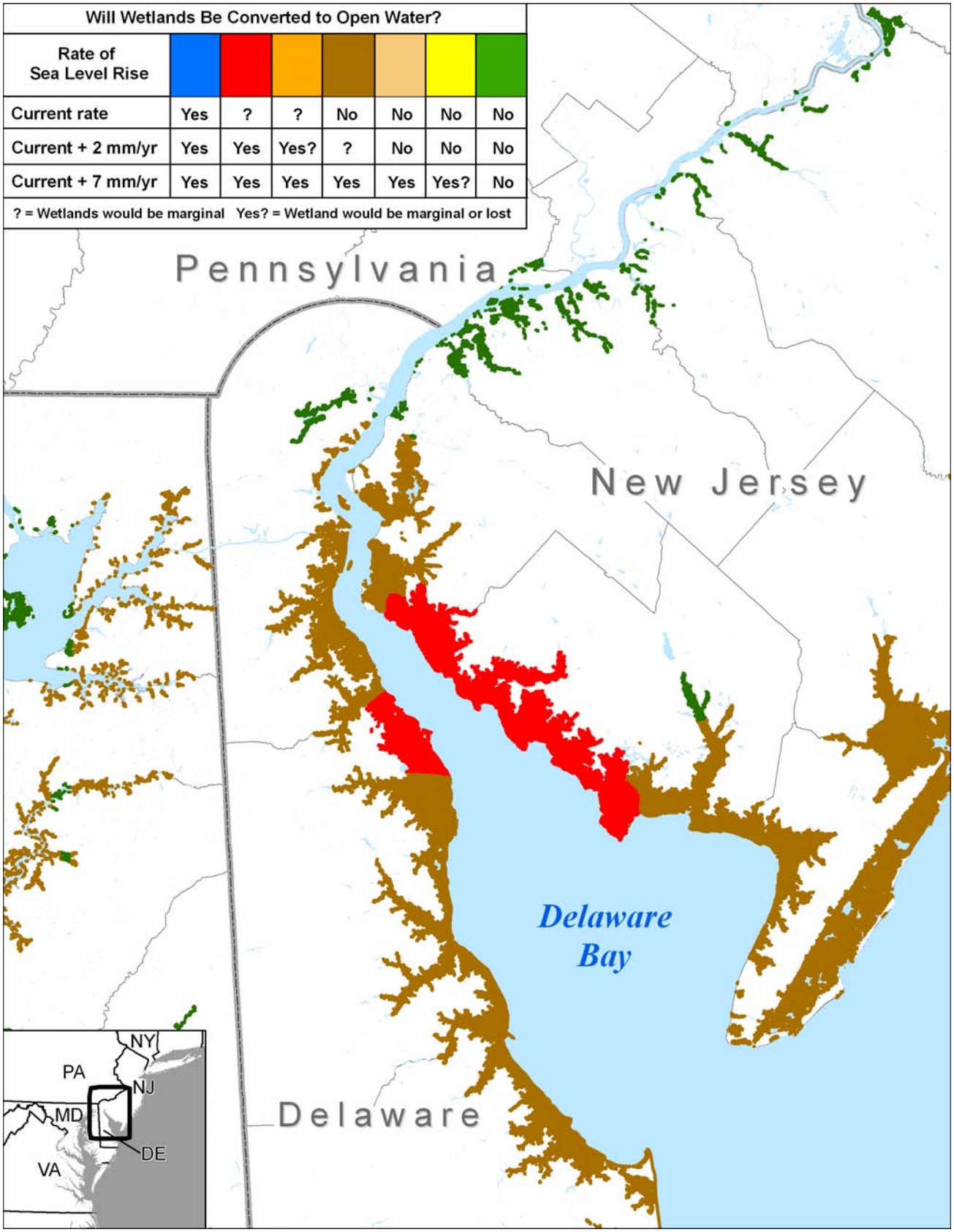
As a general rule, where the bay's shoreline is armored, the landward migration of the marsh will be impeded. Along Delaware Bay, most of the shore is undeveloped and unlikely to be armored. Each acre of land submerged, however, would not necessarily correspond to an acre of increased wetland habitat: 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

---

[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)

.

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

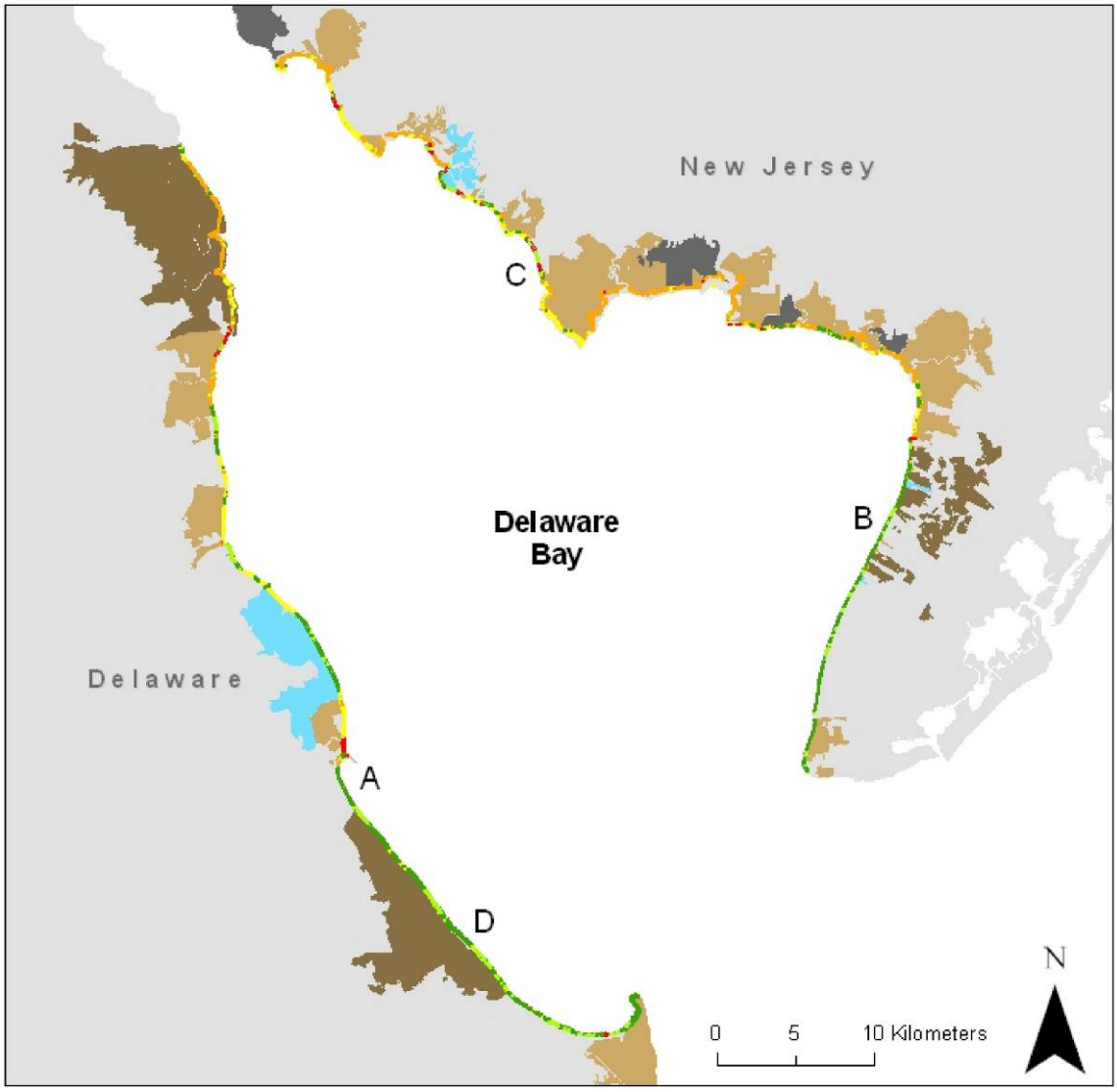
Shoreline Length	Delaware		New Jersey		NJ+DE
…by Habitat Type (percentage of bay shoreline)[a]	km	%	km	%	%
Beach	68	74	62	42	54
Armored Shore	3.7	4	8.3	6	5
Organic	20	22	78	53	41
Total Shoreline	91	100	148	100	100
…by Indicators of Future Shore Protection					
Protection Structures set back from shore[a]	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.