APPENDIX I:

FOCUS SPECIES PROFILES

(LISTED ALPHABETICALLY BY COMMON NAME)

Alewife floater, *Anodonta implicata*

Nature Serve Global Rank: G5
Federal status: None
Species of Greatest Conservation Need: NY, PA, DE

Overview

The alewife floater is a freshwater unionid mussel that occurs from North Carolina to Nova Scotia. It is a medium to large mussel and inhabits streams, ponds and lakes. Its distribution appears to be controlled by the distribution of its host fish, the alewife, *Alosa pseudoharengus*. American shad, blueback herring and striped bass may also serve as host fish for the alewife floater (Kneeland and Rhymer 2008). Current distribution is probably significantly reduced due to the effect of dams and other barriers on movement of the host fish (Watters 1996). In Connecticut restoration of fish passage for alewives and other potential host fish allow for range expansion of 200km (Smith 1985).

Management Responsibility

Management responsibility lies with each state's environmental conservation agency usually through each state's respective Natural Heritage programs. The Partnership for the Delaware Estuary and The Academy of Natural Science in Philadelphia have been active in monitoring alewife floaters and other mussels in the middle and lower Delaware River and its tributaries. The USGS, The Nature Conservancy, and the National Park Service have been active in monitoring this, and other mussel species, in the Upper Delaware usually as part of dwarf wedgemussel research (Baldigo et al. 2008, Lellis 2001, 2002).

Current Status and Threats in the Delaware River Basin

The alewife floater is the second most common mussel in the Delaware River after the Eastern Elliptio. Recent mussel surveys discovered alewife floaters in the urban corridor between Trenton and Philadelphia (Kreeger et al. 2011). There is also a significant population in the Neversink River in NY.

Spatial Extent in the Delaware River Basin

New York: Mainstem Delaware River, Neversink River

Pennsylvania and New Jersey: Mainstem Delaware River: Delaware Water Gap and from Trenton and Philadelphia.

Delaware: Blackbird Creek, Drawyer Creek, Deep Creek, Little Creek.

Potential Conservation Actions

1. Remove and/or mitigate barriers that restrict movement of alewives and other potential anadromous host fish.
2. Maintain/restore forest buffers along streams with mussel occurrences.

American Black Duck, *Anas rubripes*

NatureServe Global Rank : G5
Federal Status: None
Species of Greatest Conservation Need: All Basin States

Overview

The American Black Duck is a large dabbling duck, similar in appearance to mallards. Its range is from the Mississippi Valley east to the Atlantic seaboard and north into the Canadian Maritimes. It was once the most abundant duck species in Eastern North America; however, the species went under a dramatic decline from the 1950's to the 1980's and has yet to recover. What caused the drastic decline is not clear, and what is limiting the current recovery is also not clear. Recently it appears that the population of Black Duck has stabilized and may actually be increasing in some areas.

Management Responsibility

Management responsibility for this game species is shared between the US Fish and Wildlife Service, the four states' relevant game management agencies and private non-profits, particularly Ducks Unlimited. Ducks Unlimited, New Jersey, Delaware and other states are part of a regional research effort to study migratory and breeding behavior of black ducks in order try to understand the reasons for the declines (Ducks Unlimited 2011). In addition, the Black Duck Joint Venture, an international partnership between the United States and Canada, was formed in 1989 to help determine population trends and identify factors affecting the duck population. In 2008, the Black Duck Joint Venture developed a 5-year strategic plan to guide Joint Venture conservation actions for the Black Duck (BDJV 2008).

Current Status and Threats in the Delaware River Basin

Delaware Bay supports the largest concentration of overwintering black ducks in the world. The Delaware River Basin lies in the heart of the permanent resident distribution area for the species. Delaware River Basin wetlands provide breeding, migration stopover, and wintering habitat for Black Duck. Loss and degradation of quality wintering habitat in the Atlantic Flyway is thought to be one of the causes for the decline; however, interbreeding with mallards is also a serious threat. Black ducks often lose habitat to mallards in areas that become deforested or otherwise developed for human use.

Spatial Extent in the Delaware River Basin

New York: The New York State portion of the Basin supports both breeding and stopover habitat within inland wetlands, particularly in standing freshwater bodies like the Bashakill and Mongaup watersheds.

New Jersey: In addition to inland wetlands, New Jersey also supports shallow water habitats all along the Delaware River and Bay. The Coastal Plain wetlands are particularly favorable habitat.

Pennsylvania: On the Pennsylvania side of the Upper Delaware there are larger areas of fresh water shallows in the lakes, reservoirs and streams of the Pocono Plateau and areas further north.

Delaware: Coastal Plain wetlands along the Delaware Bay.

Potential Conservation Actions

1. Protect large areas of unfragmented salt and brackish marsh.
2. Restore degraded salt marsh adjacent to large unfragmented quality salt marsh.
3. Restore wetlands and floodplain forests on marginally-productive agricultural fields.
4. Support research on the distribution, population growth trends, and demographic parameters of black ducks throughout their range.

American shad, *Alosa sapidissima*

NatureServe Global and State Rankings: G5
Federal Status: None.
Species of Greatest Conservation Need: NY

Overview

American shad, *Alosa sapidissima,* is an anadromous species distributed along the Atlantic coast from southern Labrador to northern Florida and is a member of the herring family, Clupeidae. American shad is the largest member of the herring family with adults commonly reaching four to eight pounds. The historical range of American shad extended from Sand Hill River, Labrador, Newfoundland, to Indian River, Florida, in the western Atlantic Ocean (Green et al. 2009). The present range extends from the St. Lawrence River in Canada to St. Johns River, Florida.

Management Responsibility

American shad are managed by the American States Marine Fisheries Commission (ASMFC) under Amendment III to the Shad and River Herring Fishery Management Plan (FMP) (ASMFC 2010a). In the Delaware River Basin shad are cooperatively managed by the Delaware River Basin Fish and Wildlife Management Cooperative. In 1999, the ASMFC approved Amendment I to the Shad FMP. Amendment I was developed in response to a severely depleted American shad stock and through Amendment I the ocean-intercept fisheries for shad was phased out between 2000 and 2005.

Current Status and Threats in the Delaware River Basin

The American shad stock in the Delaware River is considered stable but at historic low number (ASMFC 2010a). In response to still declining shad numbers range-wide, despite closure of ocean fishery, the ASMFC in February of 2010 approved Amendment III to the FMP. The Amendment establishes a coastwide commercial and recreational moratorium, with exceptions for sustainable systems. Sustainability will be determined through state specific management plans, and applies to systems that can demonstrate their commercial and/or recreational fishery will not diminish the potential future stock reproduction and recruitment. The Delaware River Fish and Wildlife Management Cooperative is currently developing an updated Shad Management Plan. The Amendment allows for any state or jurisdiction to keep their waters open to a catch and release recreational fishery. States or jurisdictions without an approved sustainability management plan in place by January 1, 2013 will be closed (with the exception of catch and release recreational fisheries) (ASMFC 2010a). Threats to the American shad include dams on major spawning tributaries, entrainment/impingement from water cooling facilities, bycatch and increased predation.

Important areas in the Delaware River Basin

New York: Delaware mainstem, East Branch of the Delaware River, and Neversink River.

New Jersey: Delaware mainstem, Rancocas, Crosswicks and Assiscunk Creeks, Copper River, Mantua and Big Timber Creeks, Maurice River, and Raccoon Creek.

Pennsylvania: Delaware mainstem, Schuylkill and Lehigh Rivers and Neshaminy Creek.

Potential Conservation Actions

1. Dam removal on the Lehigh River, Brandywine Creek, and other significant tributaries.
2. Establishment of a coordinated long-term monitoring effort to accurately document stock size.
3. Reduce impingement and entrainment at water intake facilities.
4. Support research into sources of mortality to spawning adult and juvenile shad.

Atlantic sturgeon, *Acipenser oxyrhynchus oxyrhynchus*

NatureServe Global Rank: G3
Federal Status: NOAA Species of Concern, Candidate Species: U.S. Endangered Species Act.
Species of Greatest Conservation: NJ, DE, PA

Overview

Atlantic sturgeon are an ancient fish, dating back at least 70 million years, and can be found along the entire Atlantic coast from Florida to Labrador, Canada. They are anadromous, migrating from the ocean into coastal estuaries and rivers to spawn. Atlantic sturgeon may live up to 70 years old, with females reaching sexual maturity between the ages of seven to 30, and males between the ages of five to 24. Historically Atlantic sturgeon spawned in 35 river systems. Today they can be found in 30 rivers, and spawning occurs in at least 20 in the United States.

Management Responsibility

Atlantic sturgeon are managed under a Fishery Management Plan implemented by the Atlantic States Marine Fisheries Commission (ASMFC). In 1998, the ASFMC instituted a coast-wide moratorium on the stock, which is to remain in effect until there are at least 20 protected age classes in each spawning stock (anticipated to take up to 40 or more years). NMFS followed the ASMFC moratorium with a similar moratorium for Federal waters. A petition to list the species was submitted in 1998. After a status review, it was determined that the species did not merit listing under the Endangered Species Act (ESA) at that time. In 2005 NMFS initiated a second status review of Atlantic sturgeon to reevaluate whether this species required protection under the ESA. The status review was completed in 2007. In 2009 NRDC petitioned to have the species listed. In January of 2010 NMFS determined that the petition was warranted. In October of 2010 the National Marine Fisheries Service's Northeast Region determined that listing endangered status is warranted for the New York Bight Distinct Population Segment (which comprises both the Hudson and Delaware Atlantic sturgeon stocks) (Federal Register 2010).

Current Status and Threats in the Delaware River Basin

Atlantic sturgeon were severely overfished in the 19th and 20th centuries. The Delaware River once supported one of the largest populations of sturgeons, but during the late 1800's American caviar rush, both shortnose and Atlantic sturgeon were nearly wiped out along the east coast of the United States. A final decision on listing the species under the ESA is due shortly. Until quite recently it was still unclear whether a spawning population in the Delaware River existed, as young were thought to be coming from the Hudson River population. In 2010 biologists from Delaware captured the first Young of the Year Atlantic sturgeon in the Delaware River; this was the first documented case of spawning Atlantic sturgeon in the Delaware River in over 50 years. Threats in the Delaware include contaminants, dredging in critical habitat, waterfront development, bycatch, water intake systems, water quality (juveniles), ship strikes, salt front encroachment into spawning areas, and poaching.

Spatial Extent in the Delaware River Basin

See map in Appendix II.

Potential Conservation Actions

1. Protect and regulate critical instream habitats.
2. Reduce boat speed in sturgeon concentration areas.
3. Upgrade water intake facilities

Bald Eagle, Haliaeetus leucocephalus

NatureServe Global Rank: G5

Federal Status: Bald and Golden Eagle Protection Act, Migratory Bird Treaty Act

Species of Greatest Conservation Need: All basin states.

Overview

Bald eagles are found throughout North America. It is the only eagle found exclusively in North America. Overhunting in the late 1800's and egg shell thinning due to DDT poisoning nearly drove the species to extinction by the 1960's. Since then it has made a remarkable recovery and was removed from the U.S. Endangered Species List in 2007. The Upper Delaware River and the Delaware Bay regions are both considered some of the most important habitat for Bald Eagles in the Eastern United States.

Management Responsibility

The United States Fish and Wildlife Service (USFWS) is coordinating the post-delisting monitoring of bald eagles. A Post-delisting Monitoring Plan will monitor the status of the Bald Eagle by recommending collection of data on occupied nests over a 20-year period with sampling events held once every 5 years starting in early 2009 (USFWS 2010b). USFWS has a Bald Eagle monitoring team and will work with the

States, Tribes and other partners to implement the monitoring plan. Although USFWS is coordinating the post-listing monitoring, each state's respective fish and wildlife management agency is responsible for management of Bald Eagles. Pennsylvania's Bureau of Wildlife Management recently developed a detailed Bald Eagle Management Plan (Gross and Brauning 2010). NJ Department of Environmental Protection has an active Bald Eagle program through its Endangered and Nongame Species Program. NY State has a Bald Eagle Program through the Department of Conservation and Delaware State through the Delaware Natural Resources and Environmental Control.

Current Status and Threats in the Delaware River Basin

The 120-mile stretch of the Delaware River from Hancock, NY to the Delaware Water Gap is one of the most important inland bald eagle wintering habitats in the Northeast. These eagles migrate from more northern areas in search of food and shelter. In addition, the Upper Delaware is home to resident breeding eagles that remain year round. Delaware Bay is another important concentration area for overwintering, breeding and stopover habitat. Although no longer federally listed, eagles are still listed as Threatened in New York and Endangered in New Jersey and Delaware. Continuing threats include disturbance from humans and habitat destruction/fragmentation especially along major rivers. An emerging threat for Bald Eagles is wind development. The USFWS has drafted an Eagle Conservation Plan intended to assist parties to avoid, minimize, and mitigate adverse effects on bald and golden eagles due to wind energy development (USFWS 2011).

Spatial Extent Bald Eagle in the Delaware Basin

New York: Orange, Sullivan and Delaware Counties. Port Jervis to Hancock along the mainstem Delaware River, Mongaup Valley Wildlife Management Area and the Basha Kill Wildlife Management Area.

New Jersey: Sussex and Warren Counties along the Delaware River. Salem, Cumberland and Cape May Counties in the southern part of the state. The Cohansey River Corridor supports one of the densest populations of both wintering and nesting bald eagles.

Pennsylvania: Pike and Wayne Counties. Mainstem Delaware from Bushkill, PA to Equinunk PA, Promised Land State Park, Confluence of Lackawaxen River with Delaware River.

Delaware: Sussex, New Castle and Kent Counties.

Potential Conservation Actions

1. Protect, through easement or acquisition, shoreline and ridge habitats along both sides of the Upper Delaware River from Port Jervis to Hancock, NY.
2. Support programs in Cohansey River watershed that restore wetlands, riparian buffers and upland forests.

Blue Crab, *Callinectes sapidus*

Nature Serve Global Rank: Not yet ranked.
Federal status: None.
Species of Greatest Conservation Need: DE

Overview

The range of the blue crab is from Nova Scotia along the western Atlantic coast, throughout the Gulf of Mexico and the Caribbean Sea and down the east coast of South America to northern Argentina. The blue crab's Latin name means "beautiful swimmer" and "savory". It is the largest and most valuable commercial fishery in Maryland, Virginia, Delaware, and North Carolina. The blue crab walks sideways on the seafloor, a trait unique among crabs. Blue crabs play an important ecological role as a major predator in estuaries and also as prey (Hines 2007, Millikin and Williams 1980).

Management Responsibility

Blue crabs and the fishery are managed in New Jersey by the NJ Division of Fish and Wildlife under the Department of Environmental Protection and in Delaware by the Division of Fish and Wildlife of the Department of Natural Resources and Environmental Control. In addition, NOAA plays an advisory role to the states.

Current Status and Threats in the Delaware River Basin

Blue crabs are one of the most important commercial and recreational species in Delaware Bay. Approximately 21 million crabs are taken in the bay each year from the commercial and recreational fishery. Blue crabs are benthic organisms and spend much of their adult life in or around tidal marshes and tidal creeks. Jivoff and Able's (2003) research on salt hay marsh restoration suggests that restored marshes lead to better growth of blue crabs. They play an important ecological role in the bay ecosystem; as the main predator on grazer snails, crabs keep snail populations in balance, important for reducing grazing on salt marsh vegetation by snails. Sea turtles come into the bay to feed on blue crabs, and American eels are also a major predator on blue crabs. Threats to blue crabs include overharvest, habitat loss, and water quality degradation.

Spatial Extent in the Delaware River Basin

Most abundant throughout the Delaware Bay but can occur upstream into the tidal estuary as well. In NJ, the Maurice River estuary is of particular importance.

Potential Conservation Actions

1. Restore degraded salt marshes.
2. Develop a regional blue crab fishery management plan.

Bog Turtle, *Glyptemys muhlenbergii*

Nature Serve Global Rank: G3
Federal Status: Threatened
Species of Greatest Conservation Need: NJ, PA and DE

Overview

The Bog Turtle is a small turtle occupying isolated seepage meadows and fen habitats in southeastern NY, much of NJ, PA and the Piedmont of eastern Maryland and Virginia. Range-wide the species is split into northern and southern populations with an approximate 400 km gap between MD populations in the north and VA populations in the south. The Northern population was Federally-listed as Threatened in 1997 under the Endangered Species Act (ESA) because of declines in local populations due to illegal collection, habitat loss, and excessive predation. A Bog Turtle recovery plan was published in 2001, and a draft update to the recovery plan was written in 2008 (USFWS 2001, 2009).

Management Responsibility

Due to its Federal ESA status, the US Fish and Wildlife Service (USFWS) is the lead management agency for this species, and the PA USFWS field office has lead management responsibilities. Each state's fish and wildlife management agency also bears responsibility. In addition to Federal and State entities, many other non-governmental agencies are involved with the management and restoration of this species, including The Nature Conservancy, Environmental Defense, and The National Fish and Wildlife Foundation (NFWF). NFWF has developed a 10-year plan to protect and restore bog turtle populations (NFWF 2009). Although the NFWF plan is focused on the two recovery units that buffer the Delaware basin, the recommendation and strategies could be applied to the Delaware River basin as well. Prescribed management activities to improve habitat include low density grazing, invasive and woody plant removal, and predator exclusion.

Current Status and Threats in the Delaware River Basin

Most bog turtle populations in the Delaware Basin occur in Pennsylvania and New Jersey. There are 165 relatively secure populations scattered throughout the five recovery units, and the Delaware Recovery unit has 80 populations in it. Five recovery units were delineated in the 2001 plan, including a Delaware Recovery Unit, the most ecologically diverse recovery unit, but also the one with the most pressure from development (USFWS 2001). A Bog Turtle Spotlight Species Action Plan (USFWS 2009) developed by the PA Field Office of USFWS further calls for the protection of core habitats and adjacent lands using the USDA NRCS Wetland Reserve Program (WRP) funds to attract matching conservation funds. The major threats in the Delaware Basin are habitat loss, invasive species, hydrologic alteration, illegal collection, predation and road mortality (USFWS 2009).

Spatial Extent in the Delaware River Basin

New Jersey: Paulinskill, Flatbrook and Pequest watersheds in Sussex County. Musconetcong and Pequest rivers and Pohatcong Creek in Warren Co. Salem River watershed in Salem Co. Crosswicks, Rancocoas and Assiscunk Creek watersheds in Burlington Co. Raccoon and Oldmans Creek watersheds in Gloucester Co (USFWS 2010a).

Pennsylvania: White Clay Creek watershed Chester Co., Cherry Valley, Monroe, Co. Cumberland Co., Delaware and Franklin Counties (CPFBC 2011).

Delaware: White Clay Creek watershed, Newcastle, Co (WWC 2011).

Potential Conservation Actions

1. Protect by conservation easement or purchase all bog turtle sites with viable populations. In particular, properties with willing landowners within the boundaries of the Cherry Valley National Wildlife Refuge in PA are of high importance due to the occurrence of a significant metapopulations in this area.
2. Protect and ensure compatible management of adjacent uplands and wetlands.
3. Identify site specific buffer zones and mitigate threats within those zones.
4. Reduce hydrologic alteration to priority bog turtle sites.
5. Support research into the genetics and migratory patterns of bog turtle.

Bridle Shiner, *Notropis bifrenatus*

Nature Serve Global Rank: G3;
Federal Status: None
Species of Greatest Conservation Need: PA, NJ, and DE

Overview

The Bridle Shiner is a small minnow up to about 5cm in length, silver with black ventral stripes. It is found in eastern North America from Eastern Lake Ontario to South Carolina. Bridle shiners are globally rare and critically imperiled, undergoing rangewide declines in abundance and distribution. It is listed as Near Threatened on the International Union for Conservation of Nature (IUCN) Red List. The species tends to occur in slower moving waters in streams, usually with abundant vegetation, behind beaver dams, but also can occur in lakes and ponds in protected locations.

Management Responsibility

Management responsibility falls with each individual state fish and wildlife agency; however, a majority of occurrences of bridle shiner are found within the Delaware River Water Gap National Recreation Area and the Upper Delaware Scenic and Wild River, both managed by the National Park Service (Horwitz et al. 2008). Due to its declining status, it is a priority for the National Park Service, which has funded fish surveys throughout both parks to document additional occurrences.

Current Status and Threats in the Delaware River Basin

Once common in many parts of the basin, the bridle shiner is now rare. Recent surveys within the basin have documented bridle shiners in small sluggish warm-water creeks, permanent backwaters within the floodplain and in beaver ponds. It is listed as endangered in Pennsylvania and a Species of Concern in NJ. Threats include siltation, nutrient enrichment, and flow alteration.

Spatial Extent in the Delaware River Basin

New York: Mainstem Delaware River, East and West Branches of the Delaware River (Horwitz et al. 2008).

New Jersey: Flatbrook watershed (Horwitz et al. 2008).

Pennsylvania: Marshalls Creek (Brodhead Watershed Association 2002).

Potential Conservation Actions

1. Fund additional bridle shiner surveys outside of National Park boundaries.
2. Develop management plan for documented populations.
3. Allow for natural beaver activity to occur where feasible.

Brook floater, Alasmidonta varicosa

NatureServe Global Rank: G3

Federal status: USFWS Species of Concern

Species of Greatest Conservation Need: All basin states.

Overview

The brook floater is a small, rare, freshwater unionid mussel. It is found in rivers and streams from South Carolina to Canada and as far west as West Virginia. The brook floater has undergone significant declines throughout its range. As do other freshwater mussel species, brook floater requires a host fish to complete its life cycle. Potential fish hosts for the brook floater include: blacknose dace, longnose dace, golden shiner, pumpkinseed, slimy sculpin, yellow perch, and margined madtom (Nedeau 2000).

Management Responsibility

Management responsibility lies with each state's environmental conservation agency usually through their Natural Heritage programs. Brook floaters are a USFW Species of Concern in Region 5. The USGS, The Nature Conservancy, and the National Park Service have been active in monitoring this species and other mussel species in the Upper Delaware, usually as part of dwarf wedgemussel research.

Current Status and Threats in the Delaware River Basin

It is listed as endangered in NJ, imperiled in PA and threatened in NY. Although the brook floater once occurred in Red Clay Creek, Delaware, it is now considered extirpated from the state. Threats include siltation, flow alteration, chemical pollution, and barriers to dispersal of host fish.

Spatial Extent in the Delaware River Basin

New York: Neversink River, Lower Beaverkill, mainstem Delaware River (Baldigo et al. 2008, Strayer and Jirka 1997).
New Jersey: Stony Brook, Musconetcong, Raritan, and Lamington rivers and the upper mainstem Delaware River (CWF 2011a).
Pennsylvania: Montgomery Co. (PANHP 2011).

Potential Conservation Actions

1. Restore/maintain adequate riparian buffers to protect water quality along streams harboring mussels.
2. Protection by easement or acquisition of riparian lands where this species occurs and upstream.
3. Remove barriers to host fish movement.
4. Support surveys to document additional occurrences

Brook Trout, Salvelinus fontinalis

NatureServe Global Rankings: G5
Federal Status: USFWS Species of Concern
Species of Greatest Conservation Need: PA, NY, NJ.

Overview

Brook trout are the only native trout in the Eastern United States. They are found from Georgia to Maine. It is an iconic species in the Upper Delaware and is prized by fly fisherman. Fly fishing was invented in the Upper Delaware on account of this species. Brook trout are found in cold, clear well-oxygenated waters. Brook trout are greatly reduced throughout their range--most significantly in the mid-Atlantic region, where they no longer occur in large rivers and are restricted primarily to headwater streams (EBTJV 2006).

Management Responsibility

Brook trout are managed by each state's representative fish and wildlife agency. In recognition of the need for a regional approach to conservation and restoration of brook trout, the Eastern Brook Trout Joint Venture was formed in 2004. It was the first partnership pilot project for the newly established National Fish and Habitat Partnership. The partnership is made up of state fish and wildlife agencies, Trout Unlimited, Federal agencies, local watershed groups and many others. The partnership published a range wide assessment of brook trout in 2006. It has taken the leadership role in the protection and restoration of brook trout throughout the east. In the Delaware River basin, the most critical need is the protection of the most intact watersheds and restoration of degraded but still viable watersheds.

Current Status and Threats in the Delaware River Basin

Other than in a few locations, Brook trout populations in the Delaware basin are significantly reduced in abundance or in some cases extirpated (EBTJV 2006). A few watersheds are still relatively intact, such as the Beaverkill-Willowemoc system in New York. In the basin a variety of threats impact brook trout populations, including increased water temperature, siltation, loss of connectivity, competition with non-native trout species, isolation, acid rain and acid pulses during critical spawning and rearing times, climate change, and acid mine drainage.

Spatial Extent in the Delaware River Basin

New York: Brook trout occur in all of the major Delaware drainages in New York State. Some examples include the Beaverkill Willowemoc system and the Neversink River.

New Jersey: In New Jersey, selected watersheds, primarily in northern New Jersey, support Brook Trout. Some examples include, Musconetcong and Flatbrook watersheds, as well as Pohatcong Creek.

Pennsylvania: Brook trout occur in all of the major Delaware drainages in Pennsylvania. Some examples include the Brodhead, Lackawaxen River, Upper Little Schuylkill, Martins Creek, Bushkill, and Upper Brandywine.

Potential Conservation Actions

1. Eliminate stocking and remove non-native trout in naturally reproducing brook trout streams and ponds.
2. Protect watersheds identified by the Eastern Joint Venture as "intact or reduced"
3. Provide funding for projects supported by Eastern Brook Trout Joint Venture.

Cerulean Warbler, *Dendroica cerulean*

NatureServe Global Rankings: G4
Federal Status: USFWS Species of Concern & Migratory Bird Treaty Act.
Species of Greatest Conservation Need: All basin states.

Overview

The Cerulean Warbler is a small Neotropical migrant songbird that overwinters in forests along the mid elevations of the Andean Cordillera Mountains in South America and returns to North America to breed, with stopover habitat in Central America. It is declining significantly throughout its range and was considered for listing under the U.S. Endangered Species Act in 2000 (USFWS 2007a). The Cerulean Warbler is among the highest priority landbirds for conservation in the United States. It ranks as an extremely high priority on the National Partners in Flight (PIF) Watchlist and is Yellow ranked on the Audubon Watchlist. The Cerulean Warbler is a US Fish and Wildlife Service Species of Concern.

Management Responsibility

The Cerulean Warbler is protected under the Migratory Bird Treaty Act. The US Fish and Wildlife Service is the lead agency for migratory birds, as well as each state's wildlife management agency. In the Upper Delaware most Cerulean Warblers occur on protected lands, although there is a lack of specific management guidelines for managing critical habitat for this species, and some of these habitats could be threatened by recreational development (Rosenburg et al. 2000).

Current Status and Threats in the Delaware River Basin

Cerulean warblers arrive in the Delaware Basin in April and stay throughout the summer before returning to South American in early fall. Delaware River riparian and bottomland habitat appears to be very important to Cerulean Warblers in this part of their range, although to a lesser extent they are also found along dry ridge tops. A common feature of Cerulean warbler habitat is stands of mature sycamore trees, as well as oaks, maples and tulip trees (Rosenburg et al. 2000).

The Cerulean Warbler faces the threat of major habitat loss on its overwintering, stopover and breeding habitat (its wintering habitat in mid-elevations of the Andean cordillera is critically threatened). Breeding areas in the Northeast are often in floodplains or other wet conditions and are often in areas with large, mature trees and closed or semi-open forest canopies (NatureServe 2010). Breeding is most successful in areas of unfragmented forest interior; conservation success can only be achieved with riparian habitat protection in the context of large, unbroken forest blocks.

Most critical threats in its breeding range include fragmentation of forest habitat, especially by commercial and residential development in stream valleys. In addition, loss of appropriate vegetation cover in mature forests is believed to reduce reproductive success (Rosenburg et al. 2000).

Spatial Extent in the Delaware River Basin

New York: Riparian areas along the Delaware mainstem near Port Jervis and the Bashakill Wildlife Management Area, north of Port Jervis (NYDEC 2008).

New Jersey: Riparian areas along Delaware mainstem from the Water Gap north to Port Jervis, NY. Big Flat Brook, Kittatinny Ridge near High Point State Park, Stokes State Forest. Bulls Island State Park.

Pennsylvania: Riparian areas along Delaware River from the Water Gap to Port Jervis. PA potion of White Clay Creek and in headwater forest blocks in the Hay Creek/French Creek drainages in Southeast PA (Rosenberg et al. 2000, Pennsylvania Audubon 2001).

Delaware: White Clay Creek in riparian areas and adjacent upland forest (Rosenberg et al. 2000).

Potential Conservation Actions

1. Protect and restore floodplain forests and wet bottomland along the mainstem Delaware and major tributaries from Delaware Gap north to Port Jervis vicinity.

2. Reduce fragmentation and degradation of mature deciduous forest especially between the Delaware Gap and Port Jervis.
3. Develop habitat management guidelines for Cerulean Warblers in the basin to improve forest management to allow more deciduous forest to reach maturity with appropriate structural complexity and manage for appropriate understory habitat.

Dwarf wedgemussel, *Alasmidonta heterodon*

NatureServe Global Rank: G1
Federal status: Endangered
Species of Greatest Conservation Need: All basin states

Overview

The dwarf wedgemussel is a very small freshwater unionid mussel distributed from New Hampshire to North Carolina. The dwarf wedge mussel was once found in more than 70 locations in Atlantic coast drainages. Its life cycle is typical of the freshwater mussels in that the larvae attach to a host fish for a certain period of time before detaching and settling on the streambed. The dwarf wedge mussel was federally listed as endangered under the Endangered Species Act in 1990. Tessellated darters are the host fish for the dwarf wedgemussel; however, recent research has identified other potential host fish, such as the shield darter and the slimy sculpin (White 2007).

Management Responsibility

As a Federally endangered species, management responsibility for the dwarf wedgemussel rests with the US Fish and Wildlife Service. The Recovery plan was written in 1993, and 5-year status review was published in 2007 (USFWS 2007b). Additional agencies and organizations involved in monitoring dwarf wedgemussel populations include the USGS, The Nature Conservancy, and the National Park Service (Baldigo et al. 2008, Lellis 2001, 2002).

Current Status and Threats in the Delaware River Basin

Although once only known to occur in the Neversink River in the Delaware River Basin, multiple other occurrences of dwarf wedgemussel have been found in the Upper Delaware--in particular, the Flatbrook drainage in NJ and multiple occurrences in the mainstem of the Upper Delaware between Hancock and Callicoon, NY (Lellis 2001). In 2005, extreme floods in the Upper Delaware significantly impacted the Neversink River population (Cole and White 2006). Other threats include flow alteration from dams, habitat loss and water quality impacts.

Spatial Extent in the Delaware River Basin (USFWS 2007)

New York: Neversink River, mainstem Upper Delaware.

New Jersey: Flatbrook, Paulinskill and Pequest Rivers.

Pennsylvania: Mainstem Upper Delaware River.

Potential Conservation Actions

1. Protect the Flatbrook River in NJ from impacts due to agricultural runoff and siltation.
2. Restore floodplain connectivity, side channel habitat, and riparian vegetation to reduce impacts of future flood events by creating refugia from high flows.
3. Resurvey Neversink and Delaware Rivers to determine new baseline population data after repeated flood events.
4. Increase understanding of flow and temperature needs of dwarf wedgemussel.

Green floater, *Lasmigona subviridis*

NatureServe Global Rank: G3
Federal status: USFWS Species of Concern
Species of Greatest Conservation Need: NY, NJ, PA

Overview

The green floater is a small very rare freshwater unionid mussel found from North Carolina to New York. Unlike most freshwater mussel species, the green floater is hermaphroditic. Host fish have not been determined for the green floater; however, it may be a freshwater mussel species that does not require a host fish for successful reproduction (Lellis and King 1998). It is listed as Near Threatened on the IUCN Red List Category of Threatened and Endangered Species and has been considered for listing under the Endangered Species Act.

Management Responsibility

USFWS Region 5 is the lead agency for this Federal Species of Concern. In addition, management responsibility also lies with each state's environmental conservation agency usually through their Natural Heritage programs.

Current Status and Threats in the Delaware River Basin

The green floater is endangered in New Jersey. The status of this mussel species in the Delaware River basin it not clear. It appears to be represented by one individual in the Stony Brook drainage in NJ; however, it is a small mussel and may be undercounted or missed in mussel surveys. The species was documented in the early 1800's from the Schuylkill River and other streams in Pennsylvania (Conrad 1835). Threats likely include dams, siltation, and flow alteration.

Spatial Extent in the Delaware River Basin

NJ: Pequest, Musconetcong watersheds
PA: Schuylkill watershed

Potential Conservation Actions

1. Conduct more freshwater surveys to determine status in the basin.

Horseshoe crab, *Limulus polyphemus*

NatureServe Global Rank G5
Federal Status: None
Species of Greatest Conservation Need: DE

Overview

The horseshoe crab is an arthropod that occurs along the east coast of North America from Nova Scotia to the Yucatan Peninsula in Mexico. Not actually a crab, horseshoe crabs are more closely related to spiders and scorpions. The horseshoe crab is a "living fossil" that has been around for over 300 million years and is a keystone species in the life cycle of migrating shorebirds in particular. It is listed as "Near Threatened" on the IUCN Red List.

Management Responsibility

Since 1998, the horseshoe crab fishery has been managed cooperatively by Atlantic coast states through the Atlantic States Marine Fisheries Commission under the 1998 Horseshoe Crab Fishery Management Plan (FMP) (ASMFC 1998). Management of the horse shoe crab has presented unique challenges. In addition to its importance as bait for eel and conch fisheries, horseshoe crab blood is used by the biomedical industry to produce Limulus Amoebocyte Lysate (LAL), an important tool in the detection of contaminants in patients, drugs and other medical supplies, and lipid rich horseshoe crab eggs are critical fuel for red knots and other migrating shorebirds.

Current Status and Threats in the Delaware River Basin

Since 1990, surveys have been conducted of horseshoe crabs spawning in Delaware Bay. The Delaware National Estuarine Research Reserve (DNERR) coordinates the survey on three Delaware Bay beaches each spring. Multiple addendums to the FMP have tightened harvest restrictions; in addition, via Addendum I the Board recommended to the federal government the creation of the Carl N. Schuster Jr. Horseshoe Crab Reserve, an area of nearly 1,500 square miles in federal waters off the mouth of Delaware Bay that is closed to horseshoe crab harvest. The reserve was established in 2000 (ASMFC 2009b). Harvest restrictions appear to be working, and the 2009 Horseshoe Crab Stock Assessment concluded that crab abundance in the Delaware Bay Regions has increased (ASMFC 2009). However, harvest of crabs may have moved to other states that have less strict restrictions. Threats include overharvesting, especially of females, and loss of suitable spawning beaches. Currently, mortality of horseshoe crabs by the biomedical industry is exceeding the cap set in the 1998 FMP.

Spatial Extent in the Delaware River Basin

Horseshoe crabs spawn in the lower portion of the Delaware Bay on sandy beaches. In Delaware, spawning areas range from Bombay Hook south to Cape Henlopen in Kent and Sussex counties. In New Jersey, spawning areas are found throughout the shorelines of Cumberland and Cape May counties.

Potential Conservation Actions

1. Address increase in mortality above cap set in 1998 of mortality from biomedical harvest.

2. Identify critical beach restoration projects to improve sand coarseness for good horseshoe crab egg-laying habitat and implement habitat restoration.

Longtailed salamander, *Eurycea longicauda longicauda*

NatureServe Global Rank: G5
Federal status: None
Species of Greatest Conservation Need: NJ, NY, DE

Overview

Long-tailed salamanders are a species of lungless salamanders that are found from southern New York down through Georgia and northern Florida, west to Alabama. The long-tailed salamander is found near springs, streams, swampy floodplains, limestone seepages, and caves. There are two subspecies. The subspecies found in the Delaware basin *E. L. longicauda* has black vertical bars on its long tail.

Management Responsibility

Management responsibility lies with each state's environmental conservation agency usually through their State Natural Heritage programs.

Current Status and Threats in the Delaware River Basin

The long-tailed salamander is listed as Threatened in New Jersey due to habitat loss. It is considered abundant in PA; it is rare in NY, however, southern NY is at the northern most extent of this salamander's range and likely explains the rarity. Habitat loss, groundwater contamination, runoff and hydrologic alteration are the primary threats to this species (CWF 2011c).

Spatial Extent in the Delaware River Basin

New York: Basher Kill watershed.

New Jersey: Delaware River Water Gap, Wickecheoke Creek; Flatbrook, Musconetcong and Paulins Kill watersheds.

Pennsylvania: Widespread, Delaware River Water Gap, in particular.

Delaware: Upper Christina River and Upper White Clay Creek.

Potential Conservation Actions

1. Identify, protect, maintain, and restore forested wetland habitats.
2. Protect groundwater from contamination.
3. Protect streams, seeps and ponds from hydrological alteration and runoff.

Louisiana Waterthrush, *Seiurus motacilla*

NatureServe Global Rank: G5;
Federal Status: U.S. Migratory Bird Treaty Act
Species of Greatest Conservation Need: All Basin States.

Overview

Louisiana Waterthrush is a small Neotropical migrant that winters primarily in Central Americana and the Caribbean and breeds in the United States and Canada. It is the only obligate riparian passerine species in the U.S (Master et al. 2005). It is believed to be declining and is a Partner's in Flight Species of Regional Concern.

Management Responsibility

As a migratory bird, the Louisiana Waterthrush is protected under the U.S. Migratory Bird Treaty Act. In addition to the US Fish and Wildlife Service, management responsibility rests mainly with each State's Fish and wildlife agencies. Private non-profit conservation organizations like the Audubon Society are also active in research and monitoring.

Current Status and Threats in the Delaware River Basin

Research in PA has shown headwaters with extensive forest canopy cover, lack of sedimentation, and abundant aquatic invertebrates appear to support the greatest numbers of Louisiana waterthrushes (O'Connell et al. 2003). Threats include forest fragmentation, any activity that degrades headwater stream water quality, loss of forested riparian areas, over-browse by white tailed deer and stream acidification (Mulvihill et al. 2008).

Spatial Extent in the Delaware River Basin

New York: Most of the Upper Delaware except in the West Branch of the Delaware River above the Cannonsville Reservoir (NYDEC 2008).

New Jersey: Along the Delaware River and also along the Delaware Bayshores in Cape May and Cumberland Counties.

Pennsylvania: Lehigh River, the western edge of Broad Mountain, and further south along the Delaware mainstem. It also occurs in wooded, high quality stream areas in northern and southern Chester County in the French and Brandywine Creek valleys.

Delaware: The Brandywine Valley occurrence of Louisiana Waterthrush continues into New Castle County.

Potential Conservation Actions

1. Protect forest cores >250 acres and minimize edges.
2. Manage forests to preserve dense understory of shrubs and saplings.

3. Protect and restore floodplain forests and wet bottomland along small and medium-sized streams of high quality, especially those with structurally-complex and diverse adjacent upland forest.
4. Reduce white tail deer over browse.
5. Reduce activities that impact water quality, including ATV use near streams.

North American Beaver, *Castor Canadensis*

NatureServe Global Rank: G5
Federal Status: None
Species of Greatest Conservation Need: No

Overview

The American Beaver is distributed throughout North America. It is the largest rodent in North America and is associated with slow moving water bodies and wetlands near forests. Beavers are often referred to as aquatic engineers because they fundamentally alter the aquatic systems in which they reside by creating their own habitat. Beavers are keystone species of aquatic systems, creating fish habitat, storing sediment and nutrients, moderating temperature, and alternating the riparian/wetland interface. Beaver ponds act as sponges, effectively storing water during wet periods and releasing it slowly during dry periods (Arner and Jones 2009). If there are enough beaver ponds within the headwaters of a catchment, beaver ponds can reduce streamflow downstream of dams during moderate flood events (Burns & McDonnell 1998).

Management Responsibilities and Needs

Beavers are generally managed by state fish and wildlife agencies. The PA Game Commission just released their 2010-2019 Beaver Management Plan that recognizes the importance of beaver to aquatic systems and strives to establish sustainable healthy beaver populations while minimizing human conflicts with the rodent (Hardisky 2011).

Current Status and Threats in the Delaware River Basin

American beaver were locally and regionally extirpated by the initial westward expansion of early Euro-American settlement, because beaver pelts were a highly prized fur for coats and hats. Beavers were extirpated in PA (and elsewhere) by 1902, and restoration in PA began in the early 1900's. Today beavers are found throughout most of the Delaware basin. PA, NJ and NY also have healthy populations in the Delaware River basin. Although beavers can be problematic in suburban areas, some municipalities have learned to adapt in light of the importance of this species to aquatic systems. In one instance in NJ, Knowlton Township, after years of trying to outwit the beaver, finally gave in and raised township roads that were repeatedly flooded by beaver activity. The town now celebrates the beaver with an annual Beaver Day with a parade (New York Times 2007). Today, the biggest threat to beavers comes when beavers are killed or moved due to conflicts with human beings or infrastructure.

Spatial Extent in the Delaware River Basin

Beavers are found throughout the Delaware River basin.

Potential Conservation Actions

1. Develop riparian land owner education programs to make owners aware of non-lethal control measures.
2. Where feasible, alter infrastructure to allow natural beaver activity to occur.

Northern Diamondback Terrapin, *Malaclemys terrapin terrapin*

NatureServe Global Rank: G4

Federal status: None.

Species of Greatest Conservation Need: NJ and DE

Overview

Northern diamondback terrapin, *Malaclemys terrapin terrapin*, is a subspecies of Diamondback turtle. The Northern diamondback terrapin is distributed from Cape Cod, MA to Cape Hatteras, NC. It is the only turtle in the world completely adapted to life in brackish-water coastal marshes; however, breeding females must leave the marshes to lay their eggs on sandy beaches. It was nearly hunted to extinction in the early 1900's.

Management Responsibility

Management for diamondbacks in New Jersey lies with the Division of Fish and Wildlife, Endangered and Nongame Species Program. In Delaware, the Bureau of Marine Fisheries and Delaware Natural Resources and Environmental Control is responsible for this species. In addition, The Wetlands Institute, in cooperation with the Richard Stockton College of New Jersey, and the NJ Conserve Wildlife Foundation are actively involved in terrapin research and conservation.

Current Status and Threats in the Delaware River Basin

Current population status is unclear. It is a species of Special Concern in NJ due to apparent declines in population (CWF 2011b). Threats include habitat loss from coastal development, shoreline stabilization, altered hydrology of tidal marshes from mosquito ditches, road mortality, predation, drowning in crab pots, and illegal collection.

Spatial Extent in Delaware River Basin

Diamondback terrapins are found along bay shoreline in areas with appropriate salt marsh and beach habitat in both New Jersey and Delaware.

Potential Conservation Actions

1. Support restoration/protection projects in areas that provide both sandy beach habitat and salt or fringe marsh habitats.
2. Identify key road-crossing areas of northern diamondback terrapin and work with appropriate government agencies to install turtle crossing signs and erect turtle barriers or provide safe passage, as appropriate, depending on the habitat and location.

3. Support research to determine current population and define viable population size for long-term sustainability of the population.

Red Knot, *Calidris canutus rufus*

Nature Serve Global Rank: G4
Federal Status: Candidate for listing under Endangered Species Act.
Species of Greatest Conservation Need: DE and NJ.

Overview

Calidris canutus rufus is one of six sub species of red knots found worldwide. This species profile exclusively refers to the *rufus* subspecies. The red knot overwinters in the southern tip of South America and undertakes one of the longest migrations on earth, flying nearly 10,000 miles to the Canadian Arctic to breed in the summer. In recent years, red knot numbers have plummeted, and it is a Candidate Species for listing under the Endangered Species Act. In addition, the red knot is listed as Highly Imperiled on the U.S. Shorebird Conservation Plan (USFWS 2004) and is a USFWS Spotlight Species.

Management Responsibility

The US Fish and Wildlife Service, specifically the USFWS's NJ Field Office, is the lead agency for managing red knots, in coordination with Federal and State agencies and other non-governmental organizations. The National Fish and Wildlife Foundation is developing a business plan for the red knot as part of its Keystone Initiative. This plan will develop goals and measures to assess progress towards conservation goals. Inconsistency among states in the ability to restrict activities harmful to red knots (and other shorebirds) as well horseshoe crabs was listed as a major impediment to effective conservation of this species in the USFWS status assessment published in 2007 (Niles et al. 2007).

Current Status and Threats in the Delaware River Basin

Along its spring migration north, a large majority of red knots stopover in Delaware Bay to gorge on horseshoe crab eggs to replenish their fat reserves before continuing on to the Arctic. Delaware Bay is the most important stopover site along the northern migration route. In 1998 there were 50,000 red knots counted in Delaware Bay, but counts from 2003-2010 have been around 15,000 each year (Dey et al. 2011). Threats include disturbance and insufficient quantities of horseshoe crab eggs.

Spatial Extent in the Delaware River Basin

New Jersey**:** Critical habitat along Delaware Bay for the spring migration is along the intertidal zone from the mouth of the Cohansey River to North Cape May.

Delaware: Occur on coarse sandy beaches particularly around Cape May Point State Park.

Potential Conservation Actions

1. Create High Tide Roost Sites within impoundments on State and Federal Wildlife Areas.
2. Adopt region-wide or nationwide restrictions to protect shorebirds and horseshoe crabs.
3. Contribute to studies of the health of critical wintering and breeding habitat in Chile, Argentina, Northern Canada and Alaska and use results to give insight into improving wintering and breeding habitat conditions.
4. Conduct beach restorations to improve coarseness and particle size heterogeneity to enhance the substrate for horseshoe crab egg laying.
5. Increase protected areas in the Sussex County (Slaughter Beach) area in Delaware.
6. Increase protected lands adjacent to existing Wildlife Management Areas in Cumberland and Cape May Counties in NJ.

River Herring:
Alewife, *Alosa pseudoharengus*
Blueback herring, *Alosa aestivalis*

NatureServe Global and State Rankings: G5
Federal Status: NOAA Species of Concern
Species of Greatest Conservation Need: None.

Introduction

Due to similar life history and difficulty distinguishing between these two anadromous species, alewife, *Alosa pseudoharengus* and blueback herring, *Alosa aestivalis are collectively referred to and managed as river herring where the species overlap.* The range of the alewife extends from Labrador to South Carolina, while the range of the blueback herring is from Nova Scotia to Florida. In coastal rivers where the distributions of the two species overlap, the fisheries are typically mixed. They are an important forage fish for a variety of species including American eel, striped bass, tuna, eagles, fur bearing aquatic mammals, kingfishers, cod, pollack, bluefish and others (ASMFC 2009a).

Management Responsibility

River herring are managed by the Atlantic States Marine Fisheries Commission (ASMFC) under Amendment II to the Fishery Management Plan (FMP) for Shad and River Herring. Due to serious concerns regarding the status of river herring in 2007, the ASMFC proposed Amendment II to the FMP, and it was approved in 2009. A benchmark assessment of river herring populations is scheduled to be completed in 2011. Amendment II requires that state and jurisdictions develop sustainable fishery plans in order to maintain a commercial and/or recreational river herring fishery. Fisheries without such plans will be required to close by January 1, 2012 (ASMFC 2009a).

Current Status and Threats in the Delaware River Basin

Like in other rivers along the Atlantic coast, river herring runs in the Delaware Basin appear to have decreased significantly. How far upstream river herring occur in the Delaware River may be dependent on the abundance of spawning adults in the river (Horwitz et al. 2008). Many New England states have had moratoriums for a significant amount of time without sign of recovery. In the Delaware River basin, river herring are cooperatively managed by the Delaware River Basin Fish and Wildlife Management Cooperative. At this time, no sustainability targets have been defined for river herring of the Delaware River Basin management unit. The Draft Management Plan for the Delaware River calls for the complete closure of commercial and recreational fisheries of Delaware, New Jersey, New York, and Pennsylvania in the Delaware River as required under Amendment II (DRBFWMC 2009). Threats include ocean bycatch, dams, water intake facilities predator-prey imbalance, and overfishing.

Spatial Extent in the Delaware River Basin

New York: Neversink River. Mainstem Delaware to Hancock, NY.

New Jersey: Mainstem Delaware River, most suitable tributaries.

Pennsylvania: Mainstem Delaware River, most suitable tributaries

Delaware: Most suitable tributaries.

Potential Conservation Actions

1. Reduce ocean bycatch, especially in the Atlantic herring fishery.
2. Reduce impingement and entrainment at water intake facilities.
3. Remove/mitigate barriers on important spawning tributaries.

Saltmarsh Sparrow, *Ammodramus caudacutus*

NatureServe Global Rank: G4
Federal Status: USFWS Bird of Conservation Concern. Migratory Bird Protection Act.
Species of Greatest Conservation Need: NJ, DE

Overview

The saltmarsh sparrow is a small sparrow that breeds in salt marshes along the Atlantic Ocean coast from southern Maine to northern North Carolina. The saltmarsh sparrow and Nelson's sharp-tailed sparrows were considered a single species until 1995. The saltmarsh sparrow is a salt marsh obligate species, spending its entire lifecycle in salt marshes. The species is migratory and winters in salt marshes from southern New Jersey to northern Florida along the Atlantic Ocean coast of the U.S. It also winters in salt marshes along the Gulf Coast in northern Florida. The saltmarsh sparrow is a Partners in Flight Species of Continental Importance for the U.S. & Canada (Rich et al. 2004). Saltmarsh sparrow populations are declining, and the species is ranked as "Vulnerable" on the IUCN Red List of Threatened species.

Management Responsibility

As a migratory bird, the saltmarsh sparrow is protected under the 1908 Migratory Bird Protection Act. It is a USFWS Bird of Conservation Concern (USFWS 2008). The USFWS along with state agencies and non-profits such as the Audubon Society coordinate management and research on this species.

Current Status and Threats in the Delaware River Basin

The Delaware Bay coastline supports high quality salt marsh habitats that are significant breeding and wintering habitat for the saltmarsh sparrow. Threats include salt marsh drainage, ditching, fragmentation, invasion by *Phragmites australis* or predation in lower quality habitat (Paxton 2007). Saltmarsh sparrows breed best in habitats greater than 50 acres in size (Greenlaw and Rising 1994).

Spatial Extent in the Delaware Basin

High quality salt marsh in Delaware Bay in New Jersey and Delaware.

Potential Conservation Actions

1. Protect high quality salt marsh habitats, especially those larger than 50 acres.
2. Restore natural hydrology to significant marshes by plugging ditches.
3. Control nest predators such as raccoons in significant salt marsh habitats.
4. Suppress *Phragmites* invasion into high marsh areas.

Shortnose sturgeon, *Acipenser brevirostrum*

NatureServe Global Rank: G3

Federal Status: Endangered

Species of Greatest Conservation: NJ, DE, PA

Overview

Shortnose sturgeon is an anadromous and/or amphidromous fish (a fish that moves between fresh and salt water during some part of life cycle, but not for breeding) depending on river basin and possibly abundance. It is the smallest of the seven sturgeon species in North America, reaching a maximum size of 3.5 feet and 14 pounds (Dadswell et al. 1984). The geographic range of shortnose sturgeon is from the St. John River in New Brunswick Canada to the St. Johns River in Florida. Shortnose sturgeon do not make long off-shore ocean migrations like Atlantic sturgeon but mainly remain in fresh water with some movement into brackish waters. Shortnose sturgeon was listed as endangered throughout its range on March 11, 1967 under the Endangered Species Preservation Act of 1966 (a predecessor to the Endangered Species Act of 1973).

Management Responsibility

NOAA's National Marine Fisheries Service (NMFS) assumed jurisdiction for shortnose sturgeon in 1974. A shortnose sturgeon status review was drafted in 1987. Although it was originally listed as endangered throughout its range, NMFS designated 19 Distinct Population Segments for shortnose sturgeon. The Final Recovery Plan for shortnose was published in 1998 (National Marine Fisheries Service 1998). NMFS is presently conducting an updated status review for shortnose sturgeon.

Current Status and Threats in the Delaware River Basin

Historical abundance data for shortnose are not available. Catch records during the height of the commercial fishery for sturgeon did not differentiate between shortnose and Atlantic sturgeon (NMFS 1998). In 2004 the most recent population estimate in the Delaware River was 8445 (Bain et al. 2007). Threats in the Delaware include containments (especially endocrine disrupting chemicals), dredging in critical habitat, waterfront development, bycatch, water intake systems, water quality degradation (juveniles), ship strikes, and poaching.

Spatial Extent in the Delaware River Basin

See map in Appendix II.

Potential Conservation Actions

1. Critical habitat designation of important habitats for sturgeon within Delaware River.
2. Reduce boat speeds in concentration areas.
3. Improve water quality (dissolved oxygen) in juvenile concentration areas.
4. Retrofit water intake facilities with best technology available to reduce impingement and entrainment.
5. Support research into long-term population size monitoring.

Tidewater mucket, *Leptodea ochracea*

NatureServe Global Rank: G3
Federal status: None
Species of Greatest Conservation Need: NJ, DE

Overview

The tidewater mucket is a medium-sized freshwater unionid mussel that is found from Georgia north into Nova Scotia. It is often confused with the yellow lampmussel. Wick (2003) found that white perch are a suitable host fish. Another potential host is the killifish (Kneeland and Rhymer 2008). Alewife and striped bass are also thought to be potential host fish for the tidewater mucket, but more research is needed.

Management Responsibility

Management responsibility lies with each state's environmental conservation agency usually through each state's respective Natural Heritage programs. The Partnership for the Delaware Estuary and the Academy of Natural Science in Philadelphia have been active in monitoring this species as well as other freshwater mussels.

Current Status and Threats in the Delaware River Basin

The tidewater mucket is state threatened in New Jersey and endangered in Delaware. Mussel surveys recently discovered tidewater muckets in the mainstem Delaware River in the urban corridor between Trenton and Philadelphia (Kreeger et al. 2011). This find provides optimism that additional mussel occurrences will be found in this stretch of the river and that this find also indicates that water quality has improved in the mainstem. Threats include siltation, flow alteration, dams and loss of host fish.

Spatial Extent in the Delaware River Basin

New Jersey: Menantico, Rancocas and Alloway Creeks, Delaware River mainstem (CWF 2011d).

Pennsylvania: Mainstem Delaware River between Trenton and Philadelphia (Kreeger et al. 2011).

Potential Conservation Actions

1. Support further mussel surveys to document distribution and abundance throughout the basin.
2. Support further research to document host fish for tidewater mucket in Delaware River.

Yellow lampmussel, *Lampsilis cariosa*

NatureServe Global Rank: G3
Federal status: USFWS Species of Concern
Species of Greatest Conservation Need: All basin states

Overview

The yellow lampmussel is a large, bright yellow freshwater unionid mussel. It is found in Atlantic Coast drainages from Nova Scotia to Georgia and the in St. Lawrence River System. It is listed as Endangered on the IUCN Red List of Threatened and Endangered Species. It also is a former candidate for federal listing under the Endangered Species Act. Its known host fish include yellow and white perch. Striped bass has emerged as a potential host fish as well (Kneeland and Rhymer 2008).

Management Responsibility

The yellow lampmussel is a USFW Species of Concern. Management responsibility lies with each state's environmental conservation agency usually through their Natural Heritage programs. The Partnership for the Delaware Estuary (PDE) and the Philadelphia Academy of Science have been active in conducting surveys for the mussel in the lower part of the basin. In 2007 PDE launched a Freshwater Mussel Recovery Program to restore the resiliency of freshwater mussels in the basin (PDE 2011).

Current Status and Threats in the Delaware River Basin

The yellow lampmussel is found in the mainstem Delaware. It is threatened in New Jersey and a Species of Concern in Pennsylvania. Recent surveys between Trenton and Philadelphia have documented the occurrence of this species in this urbanized stretch of the river. Threats are not well understood for this species, though like other mussels species it is likely impacted by siltation, flow alteration and loss of host fish.

Spatial Extent in the Delaware River Basin

This mussel is found in the mainstem Delaware River in NY, PA and NJ from Callicoon, NY south to Philadelphia.

Potential Conservation Actions

1. Support additional mussel surveys in the Delaware to more accurately document the status of this mussel in the basin.
2. Support additional research into life history requirements for this species.

Species Profile References

Arner, D.H. and J.C. Jones. 2009. Wildlife habitat management for special use areas. Mississippi State University, Mississippi, USA.

Atlantic States Marine Fisheries Commission. ASMFC. 1998. Interstate fishery management plan for horseshoe crab. Atlantic States Marine Fisheries Commission, Fishery Management Report No. 32. Washington, DC.

Atlantic States Marine Fisheries Commission. ASMFC. 2009a. Amendment 2 to the Interstate fishery management plan for shad and river herring (River Herring Management). Washington, DC.

Atlantic States Marine Fisheries Commission. ASMFC. 2009b. Stock assessment report No. 09-02 (Supplement A) of the Atlantic States Marine Fisheries Commission. Horseshoe crab stock assessment for peer review. Washington, DC. http://www.asmfc.org/speciesDocuments/horseshoeCrab/annualreports/stockassmtreports/2009HorseshoeCrabStockAssessmentReport.pdf. Accessed 30 May 2011.

Atlantic States Marine Fisheries Commission. ASMFC. 2010a. Amendment III to the interstate fishery management plan for shad and river herring (American Shad Management). Washington, DC.

Atlantic States Marine Fisheries Commission. ASMFC. 2010b. Addendum VI to the interstate fishery management plan for horseshoe crab Delaware Bay Region Management Program. Atlantic States Marine Fishery Commission. http://www.asmfc.org/speciesDocuments/horseshoeCrab/fmps/hscAddendumVI.pdf. Accessed 30 May 2011.

Audubon Pennsylvania. 2011. http://iba.audubon.org/iba/viewSiteProfile.do?siteID=9148navSite=state. Accessed 27 Jan 2011.

Bain, M.B., N. Haley, D.L. Peterson, K.K. Arend, and K.E. Mills. 2007. Recovery of a US endangered fish. PLoS ONE 2(1): e168. doi:10.1371/ journal.pone.0000168.

Baldigo, B.P., A.G. Ernst, G.E. Schuler, and C.D. Apse. 2008. Relations of environmental factors with mussel-species richness in the Neversink River, New York. U.S. Geological Survey Open-File Report 2007-1283. http://pubs.usgs.gov/of/2007/1283/.

Black Duck Joint Venture Management Board. 2008. Black duck joint venture strategic plan 2008—2013. U.S. Fish and Wildlife Service, Laurel, Maryland; Canadian Wildlife Service, Ottawa, Ontario. http://www.blackduckjv.org/docs/BDJV%20Strategic%20Plan%202008_2013.pdf. Accessed 13 May 2011.

Brodhead Watershed Association. 2002. Brodhead watershed conservation plan. Final Report. http://www.brodheadwatershed.org/pdf/brodheadconservationplan/fullreport.pdf. Accessed 30 May 2011.

Burns, D.A. and J.J. McDonnell. 1998. Effects of a beaver pond on runoff processes: comparison of two headwater catchments. Journal of Hydrology. 205: 248–264.

Cole, J. and B.S. White. 2006. An assessment of freshwater mussels in the Neversink River following removal of the dam at Cuddebackville, NY and a severe spring flood event. Cuddebackville, New York: The Nature Conservancy.

Commonwealth of Pennsylvania, Fish and Boat Commission. CPFBC. 2011. Endangered and threatened species of Pennsylvania. http://www.fish.state.pa.us/etspecis.htm. Accessed 14 April 2011.

Conrad, T.A. 1835. Additions to, and corrections of, the catalogue of species of American Naiades, with descriptions of new species and varieties of fresh water shells. . Appendix to synoptical table to new freshwater shells of the United States, with coloured illustrations; a monograph of the genus Anculotus of Say; a synopsis of the American Naiades. 1–8, 9. Philadelphia, Pennsylvania: J. Dobson.

Conserve Wildlife Foundation (CWF). 2011a. New Jersey endangered and threatened species field guide: brook floater. http://www.conservewildlifenj.org/species/fieldguide/view/Alasmidonta%20varicosa/. Accessed 9 May 2011.

Conserve Wildlife Foundation (CWF). 2011b. New Jersey endangered and threatened species field guide: diamondback terrapin. http://www.conservewildlifenj.org/species/fieldguide/view/Malaclemys%20terrapin%20terrapin/. Accessed 10 May 2011.

Conserve Wildlife Foundation (CWF). 2011c. New Jersey endangered and threatened species field guide: long-tailed salamander. http://www.conservewildlifenj.org/species/fieldguide/view/Eurycea%20longicauda%20longicauda/. Accessed 30 May 2011.

Conserve Wildlife Foundation (CWF). 2011d. New Jersey endangered and threatened species field guide: tidewater mucket. http://www.conservewildlifenj.org/species/fieldguide/view/Leptodea%20ochracea/. Accessed 30 May 2011.

Dadswell, M.J., B.D. Taubert, T.S. Squiers, D. Marchette and J. Buckley. 1984. Synopsis of biological data on shortnose sturgeon (*Acipenser brevirostrum*, LeSueur 1818). NOAA Technical Report. NMFS 14.

Delaware River Basin Fish and Wildlife Management Cooperative. DRBFWMC. 2009. Draft fishery management plan for river herring of the Delaware River: a comprehensive plan for the states of: Delaware, New Jersey, New York, and Pennsylvania. Delaware River Basin Fish & Wildlife Management Cooperative.

Dey, A.D., N.J. Niles, P.H.P. Sitters, K. Kalasz, and R.I.G. Morrison. 2011. Update to the status of the Red Knot Calidris canutus in the Western Hemisphere. April 2011. http://www.manomet.org/sites/manomet.org/files/scidocs-pdfs/Red%20Knot%20status%20update%202011%20Dey%20et%20al%20%2011%2005-22.pdf. Accessed 6 June 2011.

Ducks Unlimited. 2011. Black Duck study. http://www.ducks.org/conservation/black-duck-study/black-duck-study. Accessed 13 May 2011.

Eastern Brook Trout Joint Venture. 2006. About the eastern brook trout venture. www.easternbrooktrout.org. Accessed 13 April 2011.

Federal Register. Proposed listing determinations for three distinct population segments of Atlantic sturgeon in the northeast region. Federal Register Vol. 75, No. 193. Wednesday, October 6, 2010. Accessed 17 May 2011. http://www.nmfs.noaa.gov/pr/pdfs/fr/fr75-61872.pdf.

Green, K. E., J.L. Zimmerman, R.W. Laney, and J.C. Thomas-Blate. 2009. Atlantic coast diadromous fish habitat: a review of utilization, threats, recommendations for conservation, and research needs. Atlantic States Marine Fisheries Commission Habitat Management Series No. 9. Washington, D.C.

Greenlaw, J.S. and J.D. Rising. 1994. Saltmarsh Sharp-tailed Sparrow (*Ammodramus caudacutus*). In The Birds of North America Online, ed. A. Poole, Cornell Lab of Ornithology. Ithaca, New York. http://bna.birds.cornell.edu/bna/species/112doi:10.2173/bna.112. Accessed 4 April 2011.

Gross, D.A. and D.W. Brauning. 2010. Bald Eagle management plan: 2010-2019. Bureau of Wildlife Management Pennsylvania Game Commission. Harrisburg, Pennsylvania. http://academic.keystone.edu/jskinner/WildlifeFisheries/Bald%20Eagle%20Management%20Plan%2020101.pdf. Accessed 13 May 2011.

Hardisky. 2011. Beaver management in Pennsylvania (2010-2019). Pennsylvania Game Commission. http://www.portal.state.pa.us/portal/server.pt/gateway/PTARGS_0_2_1059357_0_0_18/Beaver%20Management%20in%20Pennsylvania%202010-2019.pdf. Accessed 16 May 2011.

Hines, A.H. 2007. Ecology of juvenile and adult blue crabs. In The Blue Crab *Callinectes sapidus*. eds. V.S. Kennedy & L.E. Cronin, 565-654. College Park, Maryland: Maryland Sea Grant.

Horwitz, R., P. Overbeck, D. Keller, and S. Moser. 2008. Fish inventories of Delaware Water Gap National Recreation Area and Upper Delaware Scenic and Recreational River. Philadelphia, Pennsylvania: Academy of Natural Sciences Report No. 08-06. U.S. Department of the Interior, National Park Service, Northeast Region.

Jivoff, P. and K.W. Able. 2003. Evaluating salt marsh restoration in Delaware Bay: the response of blue crabs, Callinectes sapidus, at former salt hay farms. Estuaries 26: 709-719.

Kneeland, S.K., and J.M. Rhymer. 2008. Determination of fish host use by wild populations of rare freshwater mussels using a molecular identification key to identify Glochidia. Journal of the North American Benthological Society 27(1): 150-160.

Kreeger, D., R.T. Thomas, S. Klein, A. Padeletti and W. Lellis. 2011. Recent discoveries of rare freshwater mussels (Unionidae) in the urban corridor of the Delaware Estuary. Poster:. Delaware Estuary Science & Environmental Summit. Cape May, New Jersey.

Lellis, W.A. 2001. Freshwater mussel survey of the Delaware scenic and recreational river, qualitative survey 2000. Report to the National Park Service, February 20, 2001.

Lellis, W.A. 2002. Freshwater mussel survey of the Delaware Water Gap National Recreation Area, qualitative survey 2001. Report to the National Park Service, March 8, 2002.

Lellis, W.A. and T.L. King. 1998. Release of metamorphosed juveniles by the green floater, Lasmigona subviridis. Triannual Unionid Report 16:22.

Master, T.L., R.S. Mulvihill, R.C. Leberman, J. Sanchez and E. Carmen. 2005. A preliminary study of riparian songbirds in Costa Rica, with emphasis on wintering Louisiana Waterthrushes. In Bird Conservation Implementation and Integration in the Americas: Proceedings of the Third International Partners in Flight Conference, eds. C. John Ralph and Terrell D. Rich, 528-532. 20-24 March 2002. Volume 1 General Technical Report. PSW-GTR-191, Asilomar, California. Albany, California: U.S. Dept. of Agriculture, Forest Service, Pacific Southwest Research Station.

Millikin, M.R. and A. B. Williams. 1980. Synopsis of biological data on the blue crab, *Callinectes sapidus* rathbun. National Oceanic and Atmospheric Association Technical Report N.M.F.S. 1. FAO Fisheries Synopsis 138. Washington, D.C.: National Oceanic and Atmospheric Administration.

Mulvihill, R.S., F.L. Newell, and S.C. Latta. 2008. Effects of acidification on the breeding ecology of a stream-dependent songbird, the Louisiana Waterthrush (*Seiurus motacilla*). Freshwater Biology 53: 2158-2169.

National Fish and Wildlife Foundation. 2009. Draft business plan for the bog turtle. http://www.nfwf.org/Content/ContentFolders/NationalFishandWildlifeFoundation/GrantPrograms/Keystones/WildlifeandHabitat/Bog_Turtle_Biz_Plan.pdf. Accessed 14 April 2011.

National Marine Fisheries Service. 1998. Recovery plan for the shortnose sturgeon (*Acipenser brevirostrum*). Silver Spring, Maryland: The Shortnose Sturgeon Recovery Team for the National Marine Fisheries Service.http://www.nmfs.noaa.gov/pr/pdfs/recovery/sturgeon_shortnose.pdf. Accessed 31 May 2011.

NatureServe. 2010. NatureServe Explorer: An online encyclopedia of life. Version 7.1. Arlington, Virginia: NatureServe. http://www.natureserve.org/explorer. Accessed 20 May, 2011 .

Nedeau, E.J, M.A. McCollough, and B.I. Swartz. 2000. The freshwater mussels of Maine. Augusta, Maine: Maine Department of Inland Fisheries andWildlife.

New York Department of Environmental Conservation. (NYDEC). 2008. NY State breeding bird atlas dataset 2002-2005. http://www.dec.ny.gov/pubs/42978.html. Accessed 27 January 2011.

New York Times. 2007. Beaver population poses some problems. http://www.nytimes.com/2007/10/07/nyregion/nyregionspecial2/07topicnj.html. Accessed 16 May 2011.

Niles, L.J., H.P. Sitters, A.D. Dey, P.W. Atkinson, A.J. Baker, K.A. Bennett, K.E. Clark, N.A. Clark, C. Espoz, P.M. Gonzalez, B.A. Harrington, D.E. Hernandez, K.S. Kalasz, R. Matus, C.D. T. Minton, R.I.G. Morrison, M.K. Peck, and I.L. Serrano. 2007. Status of the Red Knot (*Calidris canutus rufa*) in the Western Hemisphere. Pleasantville, New Jersey: US Fish and Wildlife Service, Ecological Services. 08232. http://www.fws.gov/northeast/PDF/RedKnotAssessmentMay2007.pdf. Accessed 21 April 2011.

O'Connell, T.J., R.P. Brooks, R.S. Mulvihill, T.L. Master, and S.E. Laubscher. 2003. Using bioindicators to develop a calibrated index of regional ecological integrity for forested headwater ecosystems. Final Report to U.S. Environmental Protection Agency, STAR Grants Program. Report No. 2003-01. University Park, Pennsylvania: Penn State Cooperative Wetlands Center, Pennsylvania State University.

Partnership for the Delaware Estuary. 2011. Freshwater mussel program. http://www.delawareestuary.org/science_projects_mussel_restoration.asp. Accessed 20 May 2011.

Paxton, B.J. 2007. Potential impact of common reed expansion on threatened highmarsh bird communities on the seaside: breeding bird surveys of selected high-marsh patches. Center for Conservation Biology Technical Report Series, CCBTR-07-03. Williamsburg, Virginia: College of William and Mary. http://www.ccb-wm.org/news/paper/CCBTR07003_highmarsh_breeding.pdf. Accessed 18 May 2011.

Pennsylvania Audubon. 2001. Pennsylvania important bird areas. Site 75. http://pa.audubon.org/Sites/Site75.pdf. Accessed 27 Jan 2011.

Pennsylvania Natural Heritage Program (PANHP). 2011. Fact sheet: brook floater: *Alasmidonta varicosa.* http://www.naturalheritage.state.pa.us/factsheets/12195.pdf. Accessed 9 May 2011.

Rich, T.D., C.J. Beardmore, H. Berlanga, P.J. Blancher, M.S. W. Bradstreet, G.S. Butcher, D.W. Demarest, E.H. Dunn, W.C. Hunter, E.E. Iñigo-Elias, J.A. Kennedy, A.M. Martell, A.O. Panjabi, D.N. Pashley, K.V. Rosenberg, C.M. Rustay, J.S. Wendt, T.C. Will. 2004. Partners in flight: North American landbird conservation plan. Ithaca, New York: Cornell Lab of Ornithology. http://www.pwrc.usgs.gov/pif/cont_plan/PIF2_Part1WEB.pdf. Accessed: 18 May 2011.

Rosenberg, K.V., S.E. Barker, and R.W. Rohrbaugh. 2000. An atlas of Cerulean Warbler populations: final report to USFWS: 1997-2000 Breeding Seasons. Ithaca, New York: Cornell Lab of Ornithology.

Smith, D.G. 1985. Recent range expansion of the freshwater mussel *Anodonta implicata* and its relationship to clupeid fish restoration in the Connecticut River system. Freshwater Invertebrate Biology 4:105–108.

Strayer, D.L. and K.J. Jirka. 1997. The pearly mussels of New York State. Albany, New York: The New York State Education Department.

U.S. Fish and Wildlife Service (USFWS) 2001. Bog turtle (C*lemmys muhlenbergii)*, northern population recovery plan. Hadley, Massachusetts. http://www.fws.gov/northeast/nyfo/es/bogturtle.pdf. Accessed 14 April 2011.

U.S. Fish and Wildlife Service (USFWS). 2004. U.S. shorebird conservation plan, 2004. High Priority Shorebirds Unpublished Report. Arlington, Virginia: U. S. Fish and Wildlife Service. http://www.fws.gov/shorebirdplan/downloads/ShorebirdPriorityPopulationsAug04.pdf. Accessed 21 April 2011.

U.S. Fish and Wildlife Service (USFWS). 2007a. A conservation action plan for the Cerulean Warbler (*Dendroica cerulea*). USFWS Division of Migratory Bird Management Focal Species Program. http://www.fws.gov/migratorybirds/CurrentBirdIssues/Management/FocalSpecies/Plans/CeruleanWarbler.pdf

U.S. Fish and Wildlife Service (USFWS). 2007b. Dwarf wedgemussel *Alasmidonta heterodon*. 5-Year review: Summary and evaluation. Concord, New Hampshire: U.S. Fish and Wildlife Service New England Field Office. http://www.fws.gov/newengland/pdfs/DwarfWedgemussel_5yrreveiw.pdf . Accessed 9 April 2011.

U.S. Fish and Wildlife Service. 2008. Birds of conservation concern 2008. Arlington, Virginia: United States Department of Interior, Fish and Wildlife Service, Division of Migratory Bird Management. http://www.fws.gov/migratorybirds/NewReportsPublications/SpecialTopics/BCC2008/BCC2008.pdf. Accessed 18 May 2011.

U.S. Fish and Wildlife Service (USFWS). 2009. Bog turtle spotlight species action plan. http://www.fws.gov/northeast/endangered/pdf/Bog%20turtle%20SSAP.pdf. Accessed 14 April 2011.

U.S. Fish and Wildlife Service (USFWS). 2010. Endangered species: bog turtle. Federally Listed and Candidate Species Occurrences in New Jersey by County and Municipality. New Jersey Field Office. http://www.fws.gov/northeast/njfieldoffice/pdf/munlist.pdf. Accessed 14 April 2011.

U.S. Fish and Wildlife Service (USFWS). 2010b. Post-delisting monitoring plan for the Bald Eagle (*Haliaeetus leucocephalus*) in the contiguous 48 states. Twin Cities, Minnesota: U.S. Fish and Wildlife Service, Divisions of Endangered Species and Migratory Birds and State Programs, Midwest Regional Office. http://www.fws.gov/midwest/eagle/protect/FINAL_BEPDM11May2010.pdf. Accessed 13 May 2011.

U.S. Fish and Wildlife Service (USFWS). 2011. Draft Eagle conservation plan guidance. http://www.fws.gov/windenergy/docs/ECP_draft_guidance_2_10_final_clean_omb.pdf. Accessed 13 May 2011.

Watters, G.T. 1996. Small dams as barriers to freshwatermussels (Bivalvia unionoida) and their hosts. Biological Conservation 75:79–85.

White, B. S-J. 2007. Evaluation of host fish suitability for the endangered dwarf wedgemussel, *Alasmidonta heterodon.* Master of Sciences Thesis. College Park, Pennsylvania: Pennsylvania State University, Graduate School College of Agricultural Sciences.

White Clay Creek Watershed Organization. 2011. List of amphibians and reptiles. http://new.whiteclay.org/mgmtplan/appendices/amphibians. Accessed 14 April 2011.

Wick, P.C. 2003. Fish hosts and demographics of *Lampsilis cariosa* and *Leptodea ochracea*, two threatened freshwater mussels in Maine. Master of Sciences Thesis. Orono, Maine: University of Maine.

APPENDIX II:

DIADROMOUS FISH HABITAT MAPS

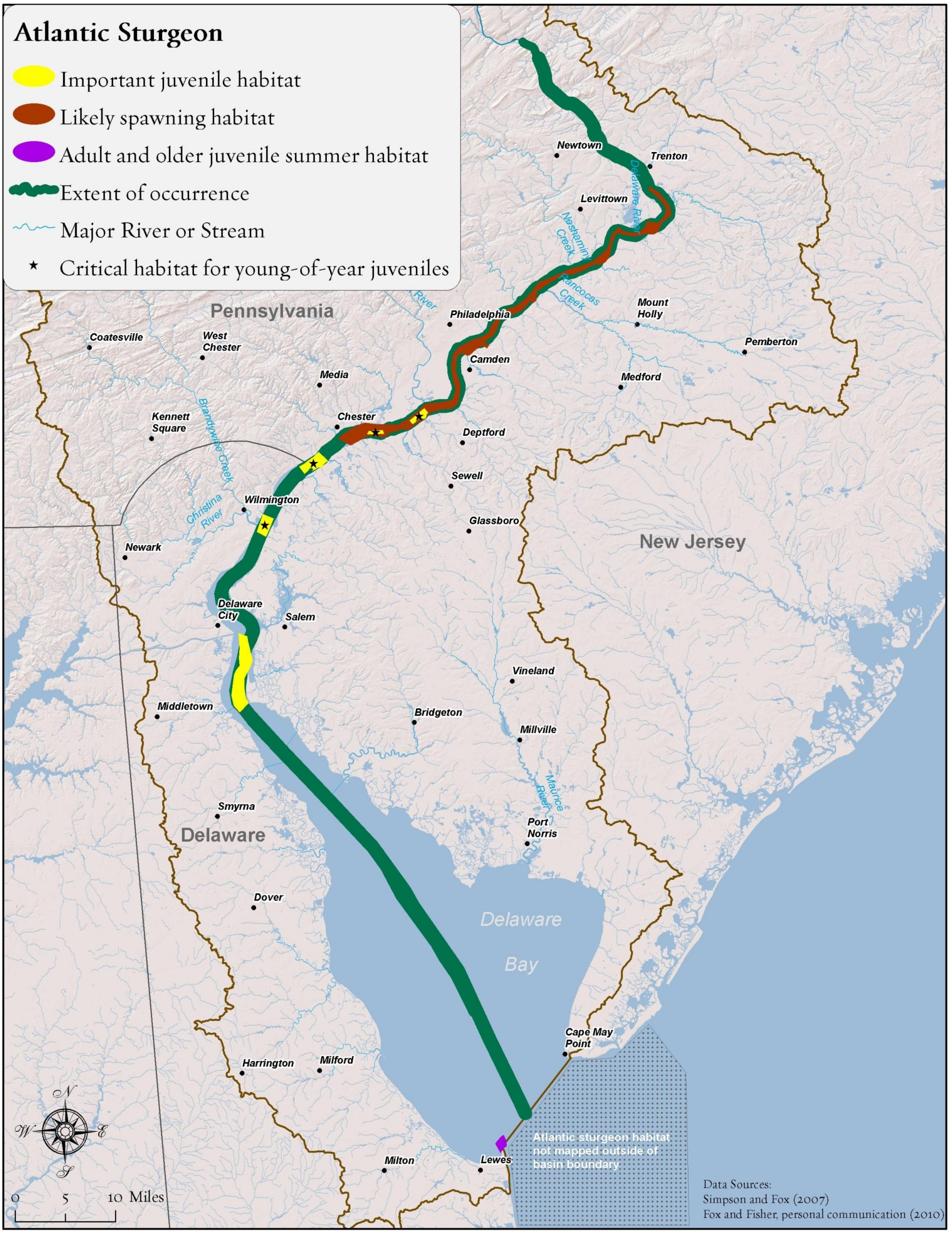


Figure 1: Atlantic sturgeon critical habitat locations and extent of occurrence in the Delaware River Basin.

Fox, D.A. and M. Fisher. 2010. Personal communication.

Simpson P.C. and D.A. Fox. 2007. Atlantic sturgeon in the Delaware River: contemporary population status and identification spawning areas completion report: Award NA05NMF4051093. http://www.nero.noaa.gov/StateFedOff/grantfactsheets/DE/FINAL%20REPORTS/FINAL%20NA05NMF4051093.pdf. Accessed 18 May 2011.

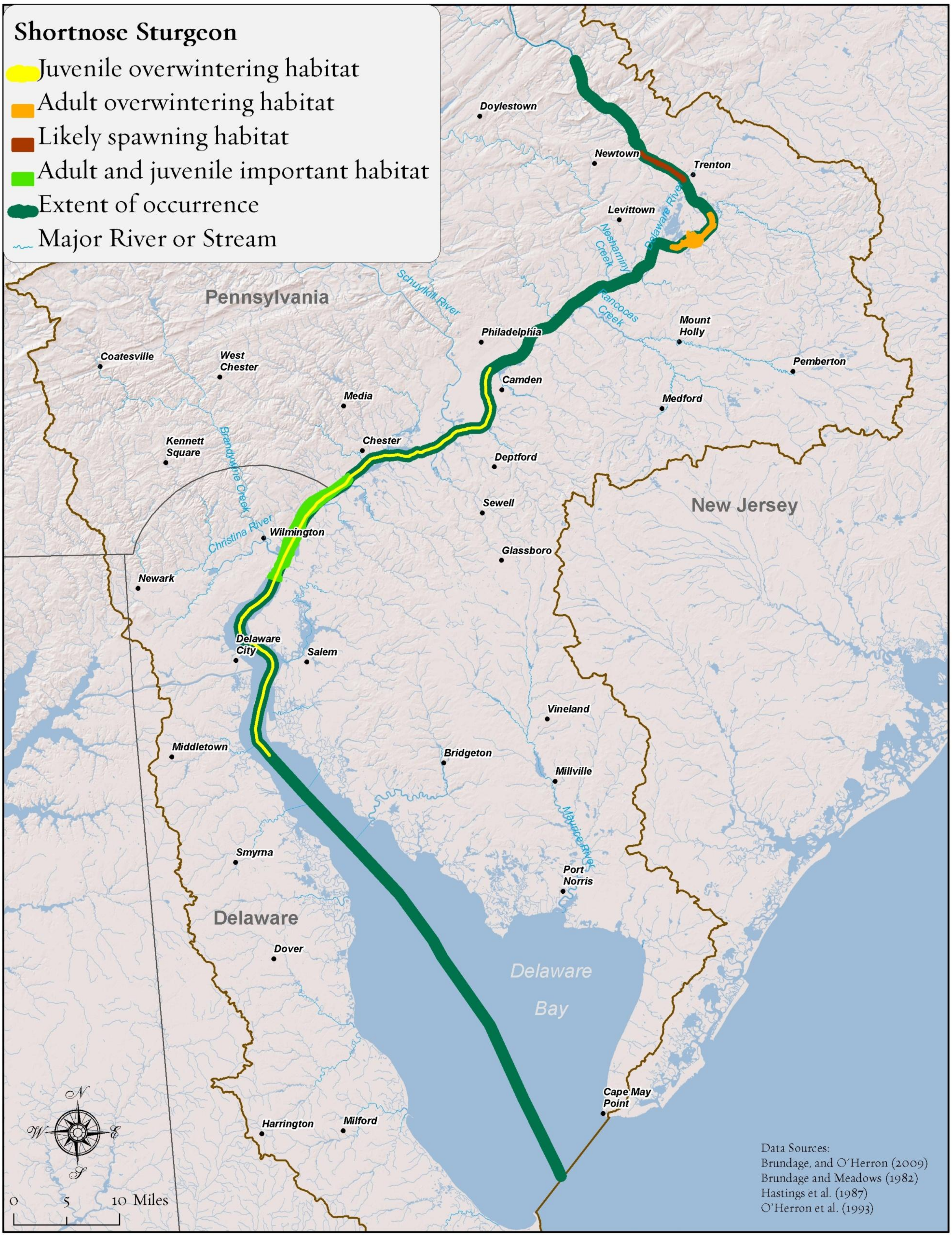


Figure 2. Shortnose sturgeon critical habitat areas and extent of occurrence in the Delaware River Basin.

Brundage, H. M., and R.E. Meadows. 1982. Occurrence of the endangered shortnose surgeon, *Acipenser brevirostrum*, in the Delaware River. Estuaries 5:203-208.

Brundage, H.M., and J.C. O'Herron. 2009. Investigations of juvenile shortnose and Atlantic sturgeons in the lower tidal Delaware River. Bulletin of the New Jersey Academy of Science 54(2): 1-8.

Hastings, R.W., J.C. O'Herron., K. Schick, and M. Lazzari. 1987. Occurrence and distribution of shortnose sturgeon, *Acipenser brevirostrum*, in the upper tidal Delaware River. Estuaries 10:337-341.

O'Herron, J.C., K.W. Able, and R.W. Hastings. 1993. Movements of shortnose sturgeon (*Acipenser brevirostrum*) in the Delaware River. Estuaries 16:235-240.

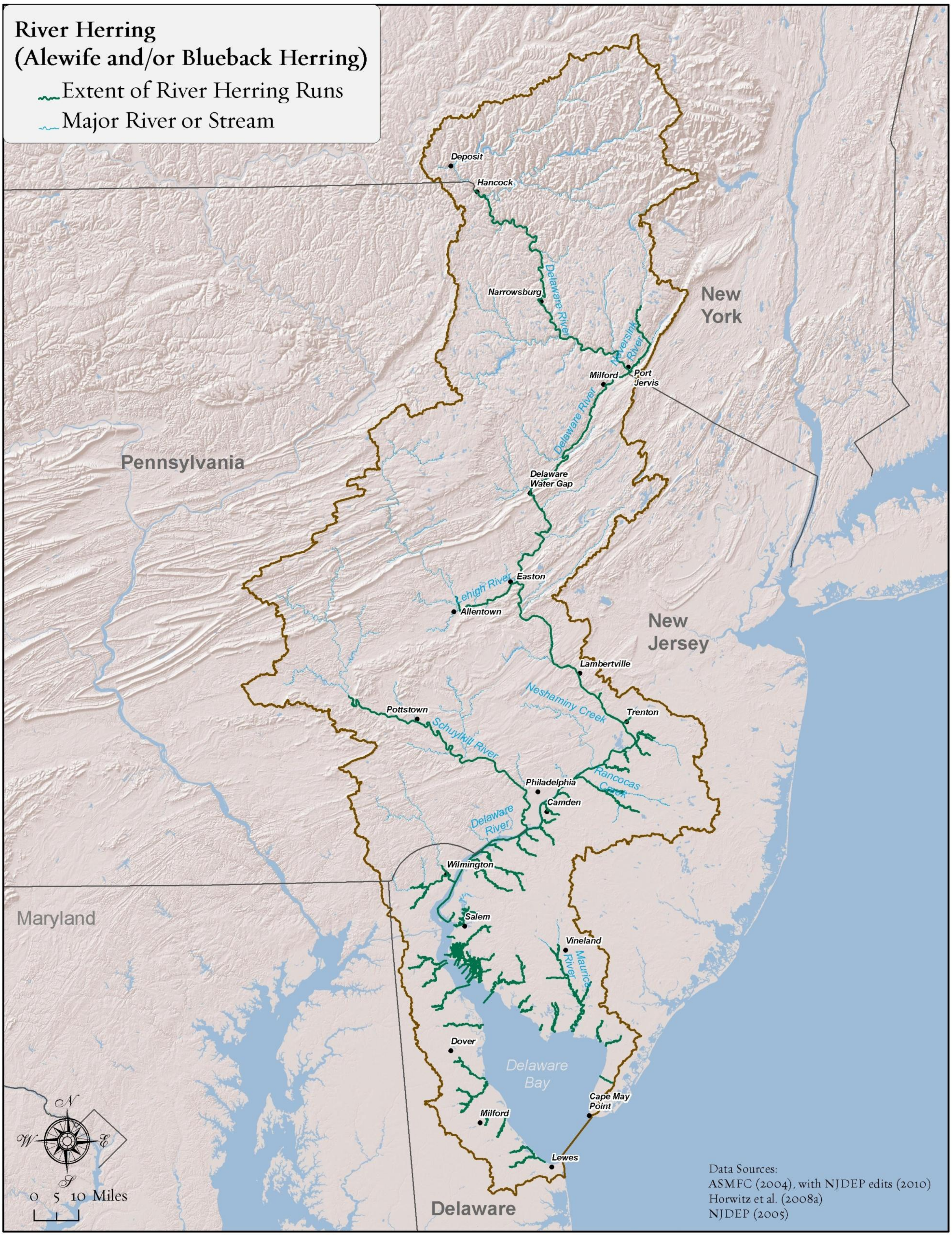


Figure 3. Extent of river herring spawning runs in Delaware River Basin.

Atlantic States Marine Fisheries Commission (ASMFC). 2004. Alexa McKerrow, Project Manager, Biodiversity and Spatial Information Center (BaSIC) at North Carolina State University (NCSU). Alexa_Mckerrow@ncsu.edu. New Jersey Department of Environmental Protection 2010 edits.

Horwitz, R., P. Overbeck, D. Keller, and S. Moser. 2008a. Fish inventories of Delaware Water Gap National Recreation Area and Upper Delaware Scenic and Recreational River. Academy of Natural Sciences Report No. 08-06. Philadelphia, Pennsylvania: U.S. Department of the Interior, National Park Service, Northeast Region.

New Jersey Department of Environmental Protection (NJDEP). 2005. Locations of anadromous American shad and river herring during their spawning period in New Jersey's freshwaters including known migratory impediments and fish ladders. Sicklerville, New Jersey: Division of Fish and Wildlife Bureau of Freshwater Fisheries Southern Regional Office.

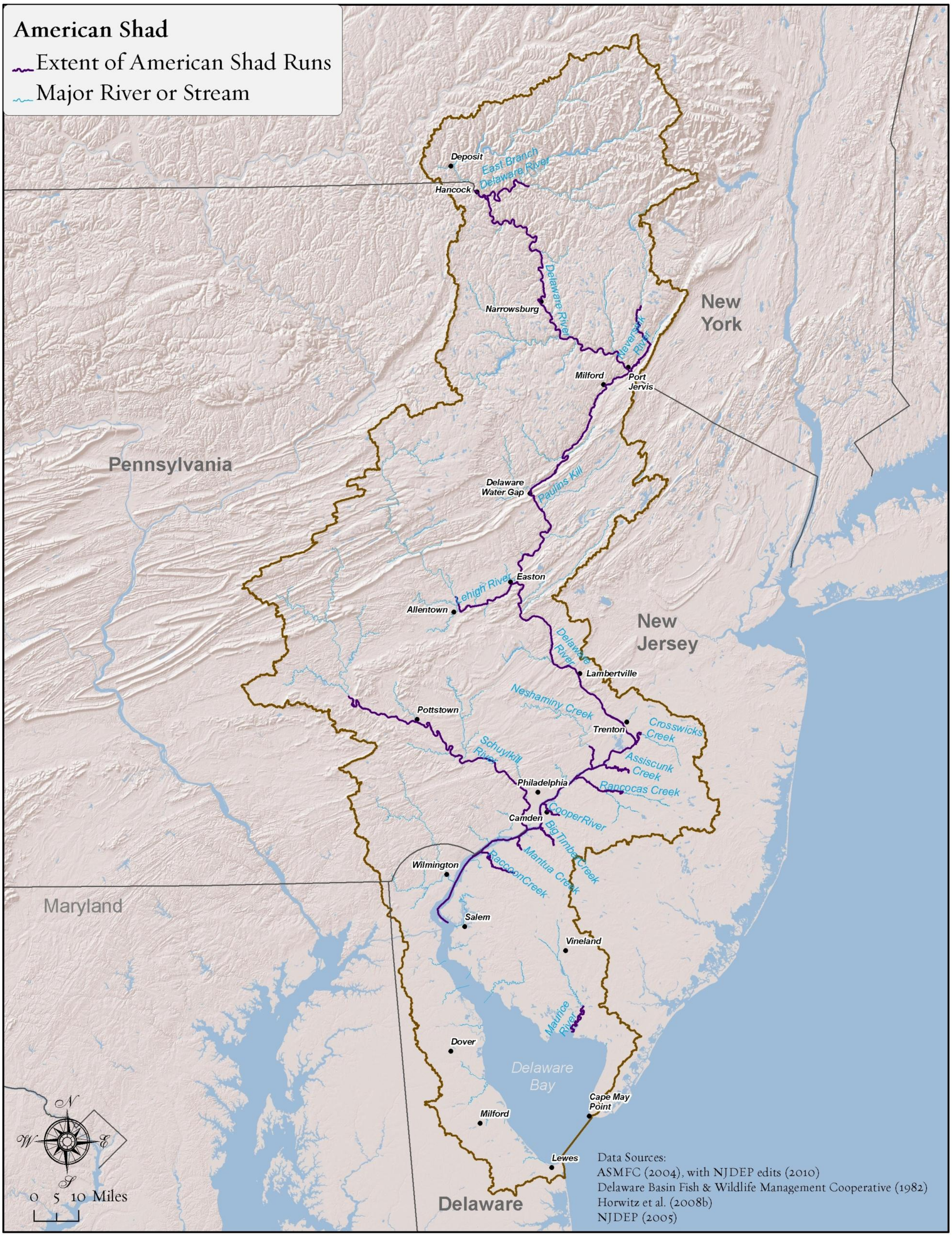


Figure 4. Extent of American shad spawning runs in Delaware River Basin.

Atlantic States Marine Fisheries Commission (ASMFC). 2004. Alexa McKerrow, Project Manager, Biodiversity and Spatial Information Center (BaSIC) at North Carolina State University (NCSU). Alexa_Mckerrow@ncsu.edu; with NJDEP 2010 edits.

Delaware River Basin Fish and Wildlife Management cooperative. DRBFWMC. 2009. Draft fishery management plan for river herring of the Delaware River: a comprehensive plan for the states of Delaware, New Jersey, New York, and Pennsylvania. Delaware River Basin Fish & Wildlife Management Cooperative.

Horwitz, R., D. Keller, S. Moser and P. Overbeck. 2008b. Neversink shad study: final report. Submitted to The Nature Conservancy, Patrick Center for Environmental Sciences. The Academy of Natural Sciences.

New Jersey Department of Environmental Protection (NJDEP). 2005. Locations of anadromous American shad and river herring during their spawning period in New Jersey's freshwaters including known migratory impediments and fish ladders. Sicklerville, New Jersey: Division of Fish and Wildlife Bureau of Freshwater Fisheries Southern Regional Office.

APPENDIX III:

MEASURES USED TO CONDUCT CONDITION ASSESSMENTS OF FRESHWATER ECOSYSTEMS

Appendix III: Measures Used to Conduct Condition Assessments of Freshwater Ecosystems

MEASURES USED TO CONDUCT CONDITION ASSESSMENTS OF FRESHWATER ECOSYSTEMS

This section provides an overview of the measures used to evaluate the condition of our freshwater ecosystems. Following is a brief description of each measure analyzed, including the rationale for selecting each measure, detailed methods for the spatial analysis, and the data sources used in the analysis. Supplementary tables, organized by freshwater ecosystem, are provided at the end of the document and include the thresholds used for each measure.

To evaluate the condition of our three freshwater ecosystems – floodplains, headwaters, and wetlands - we first determined each system's key ecological attributes (KEAs). KEAs are the aspects of an ecosystem's biology or ecology that, if present, defines a healthy system and if missing or altered, would lead to the outright loss or extreme degradation of that ecosystem over time. Although differences exist between each ecosystem's KEAs, we found we could group the KEAs into five categories within which individual measures were developed to specifically address the ecological needs and sensitivity of each ecosystem. The five categories include: Aquatic Connectivity, Flow Regime, Landscape Condition, Size, and Resiliency.

Aquatic Connectivity

Rationale: The upstream/downstream connectivity of freshwater rivers is important, as in-stream barriers can prevent the longitudinal movement of water, sediment, nutrients, organic matter, and aquatic organisms (Ciruna and Braun 2005). Dams can prevent migratory fish from reaching critical habitat. Connected streams are critical for the movement and dispersal of host fish for mussels, for local migratory species, and for diadromous fish species.

Spatial Analysis: Using TNC's Barrier Analysis Tool (BAT) Version 1.0, we identified which aquatic systems were more longitudinally connected upstream through their headwaters and downstream to the mainstem and ultimately to the Delaware Bay. This tool calculates the available upstream, downstream, or cumulative stream network size that is not blocked by barriers. By adding the length of all tributaries until it reaches either a barrier or a river source, it defines the **SIZE OF A FUNCTIONAL OR CONNECTED NETWORK**. We further evaluated the percentage of each floodplain complex and headwater stream network (HSN) included in a functionally connected network. [1]

In addition, we evaluated the lateral connectivity of floodplains and riverine wetlands by determining the amount of each complex that is within the 100-year floodplain. This analysis identifies those floodplains that are still hydrologically connected to the river and it further identifies areas of potential flood storage.

[1] The results of our functional connected networks analysis are preliminary due to limitations in available datasets. Access to more complete dam data and review of dam location precision is needed to improve the accuracy of these results.

Data Sources: Geographic Names Information System database, NY, NJ, PA, DE State Dam Inventories 2010, Army Corps National Inventory of Dams (NID) 1998, Federal Emergency Management Agency 100- and 500-year floodplains FEMA Map Service Center - Digital Q3 Available for region as of 2007, NHDPlus 1:100,000 streamlines 206, The Nature Conservancy, Barrier Analysis Tool (Version 1.0) [Software], 2010.

Flow Regime

Rationale: Freshwater and riparian ecosystems are highly dynamic and require natural variations in water flow to support the processes that sustain their biodiversity over time (Smith et al. 2008). An ecologically functional floodplain requires interaction with a river that retains a flow regime with sufficient variability to encompass the flow levels and events that support important floodplain processes (Opperman 2010). Human-induced alterations to the flow magnitude, timing, duration, and rate of change of flow can cause various negative impacts throughout an affected watershed. (Poff et al. 1997). Several studies have demonstrated increased hydrologic alteration as the ratio between upstream dam storage and streamflow increases (Zimmerman and Lester 2006, Vogel et al. 2007, Fitzhugh and Vogel 2010).

Spatial Analysis: Dams for flood control, hydropower, and water supply not only act as barriers to movement, but they also alter the natural variations in flow. The volume of water stored in reservoirs as a proportion of mean annual streamflow, referred to as a **DAM STORAGE RATIO**, provides another indicator of the degree of impact dams may have on the system. We calculated the dam storage ratio using the sum of upstream reservoir storage as a proportion of mean annual stream flow attributed to each NHDPlus streamline. Cumulative upstream storage values were calculated using the Barrier Analysis Tool (2010).

We analyzed dam storage ratios to estimate the risk of hydrologic alteration. We consider reaches with a storage ratio >0.5 (or 50 %) at high risk of hydrologic alteration, consistent with published thresholds (Zimmerman and Lester 2006, Fitzhugh and Vogel 2010). This analysis was conducted for floodplain complexes and headwater stream networks.

This ratio does not incorporate potential hydrologic alterations due to dam operations, which may be as or more important than the volume of water stored. Assessing hydrologic changes due to dam operations can be done when more detailed streamflow and/or operations data is available (e.g., Moberg et al. 2010).

Data Sources: Geographic Names Information System database, NY, NJ, PA, DE State Dam Inventories 2010, Army Corps National Inventory of Dams (NID) 1998, NHDPlus 1:100,000 streamlines 2006, The Nature Conservancy, Barrier Analysis Tool (Version 1.0) [Software], 2010.

Appendix III: Measures Used to Conduct Condition Assessments of Freshwater Ecosystems

Landscape Condition

Rationale: The amount and configuration of land cover types within floodplains, headwaters, and the watersheds surrounding a freshwater system can strongly influence ecological integrity. Land cover changes affect hydrologic regime, chemical regime, and connectivity between a river and surrounding lands. For example, even low levels of impervious cover (between 1% and 3%) have been shown to have significant impacts on aquatic species (King and Baker 2010, Cuffney et al. 2010). A study of northeastern brook trout populations found that those in watersheds with less than 82% natural cover were likely to be extirpated, whereas in watersheds with greater than 90% natural cover, populations were likely to be intact (Hudy et al. 2005). Natural land cover can help slow down or retain flood waters, sustain natural flow regimes (DVWK 1999a in Sartor 2005), and buffer streams from pollutants and sediments (Fisher and Fischenich 2000).

Spatial Analysis: This analysis focused on the analysis of **IMPERVIOUS AND NATURAL COVER**. We analyzed the acreage and percent of natural cover for floodplains. We also analyzed the percent of natural cover and impervious cover for headwater stream networks (HSN) and for those HSN lands surrounding wetland systems. Within the HSN footprint, the total acreage and percent of natural land cover classes were calculated.

Data Sources: Multi-Resolution Land Characteristics Consortium (MRLC) National Land Cover Dataset (NLCD) Impervious Surface 2001, Multi-Resolution Land Characteristics Consortium (MRLC) NLCD 30m Land Cover 2001. The Nature Conservancy The Active River Area (Smith et al. 2008) Spatial Model, 2008.

Size and Abundance

Rationale: The size of conservation areas need to be large enough for species and ecosystems to be able to recover from natural and anthropogenic disturbances (Groves 2003). This notion of "being large enough" was one of the driving forces behind the development and identification of floodplain complexes, which need to be large enough for species to recover from disturbances such as flooding and ice scour.

Size was also a significant factor in the identification of wetland priorities. Large wetlands are critical for maintaining suitable habitat for Comprehensive Wildlife Conservation Strategy priority species that require large wetland sites. Preservation of these sites will also support the conservation of most other priority species in this habitat suite (Pennsylvania State Wildlife Action Plan 2005).

In addition to size, we also evaluated the acreage and density or concentration of embedded systems such as wetlands, with the landscape areas. Evaluating acreage and density provides insights into the relative abundance of freshwater ecosystems within specific units of analysis.

Spatial Analysis: We analyzed the **SIZE OF WETLANDS** by reclassifying the NLCD 2001 wetland cover types into contiguous wetlands, defined as wetlands which share a side or corner. Through this process, individual wetlands, of varying types, that shared a side or corner were joined, enabling us to identify wetlands complexes consisting of various wetland types and diversity.

We analyzed the density of riverine and headwater wetlands within floodplain and headwater stream networks, respectively.

Data Sources: Multi-Resolution Land Characteristics Consortium (MRLC) NLCD 30m Land Cover 2001.

Resiliency

Rationale: Baseflow is the component of stream flow that can be attributed to groundwater (Wolock 2003). It is essential to maintain temperature regimes that are healthy for aquatic organisms, to enable the chemical transfer of nutrients and minerals between surface and groundwater systems, to maintain perennial flow in many smaller headwater stream systems, and to augment surface water flows in larger streams (Winter et al. 1998, Fanok 2000, Ciruna and Braun 2005).

Spatial Analysis: Using groundwater availability data obtained from the United States Geological Survey (Sloto and Buxton 2007), we assessed the **VOLUME OF GROUNDWATER AVAILABLE AND THE PERCENT OF GROUNDWATER USED** in each headwater network. Headwaters with high baseflow contributions and low groundwater use are areas that may provide refugia to aquatic flora and fauna during times of temperature and flow-related stress.

We also evaluated the **SIZE (LENGTH) OF CONNECTED AQUATIC SYSTEMS** using the BAT and further evaluated the percentage of each floodplain complex and headwater stream network included in a functional network. While a measure of size, long connected freshwater systems provide places for species to move during times of environmental stress, enhancing their resilience.

As global climate change, increased fragmentation of the landscape and other threats continue to escalate, providing for and identifying where there is resiliency in freshwater networks, through groundwater refugia or network connectivity, is critical.

Data Sources: TNC's Barrier Analysis Tool 2010. U.S. Army Corps National Inventory of Dams (NID) 1998. NY, NJ, PA State Dam Inventories 2010, NHD Plus Waterfalls 2006, ESRI GDT 1:100,000K Roads 2003, USGS Pennsylvania Water Science Center, USGS Groundwater Availability Data, Sloto and Buxton 2007.

Appendix III: Measures Used to Conduct Condition Assessments of Freshwater Ecosystems

Floodplain Complex and Floodplain (Riverine) Wetland Complex Condition Analysis

Floodplain Complexes: Summary of measures and thresholds per floodplain complex river size applied to the condition analysis of Floodplain Complexes.

Key Ecological Attribute	Measure	Mainstem Floodplain Complexes Thresholds	Major River Floodplain Complexes Thresholds	Small River Floodplain Complexes Thresholds
Aquatic Connectivity	Percent of Complex occurring within a specified size ***Functional Connectivity Network***	100% of complex is completely connected to the Bay	>50% of complex in Functional Connectivity Network > 100 miles long	>50% of complex in Functional Connectivity Network > 100 miles long
Flow Regime	Percent of Complex occurring along a river with a specified ***Dam Storage Ratio***	> 50% of complex has dam storage ratio between 5-25% *(low risk of hydrologic alteration)*	> 50% of complex has dam storage ratio < 5% *(very low risk of hydrologic alteration)*	> 50% of complex has dam storage ratio < 5% *(very low risk of hydrologic alteration)*
Ecosystem Condition	Complex ***Acreage and Percent Natural Cover*** are both above the median for all complexes on similar-sized rivers	Floodplain Complex > 3000 acres & > 60% Natural Cover	Floodplain Complex > 3000 acres & > 73% Natural Cover	Floodplain Complex > 1000 acres & > 66% Natural Cover

Riverine Wetland Complexes: Summary of measures and thresholds per floodplain complex river size applied to the condition analysis of Riverine Wetland Complexes.

Key Ecological Attribute	Measure	Mainstem Floodplain Complexes Thresholds	Major River Floodplain Complexes Thresholds	Small River Floodplain Complexes Thresholds
Wetland Abundance *(Acreage & Density)*	***Total Acreage and Percent*** of *active river area* that is ***Wetland*** are both above the median	Complex > 571 acres & > 20% Wetland	Complex > 143 acres & > 21% Wetland	Complex > 316 acres & > 20% Wetland
Aquatic Connectivity *(Lateral Connectivity)*	Total Acreage and Percent of Wetland Complex within the ***FEMA 100-Year Floodplain*** are both above the median	Complex > 381 acres & > 17% in 100-Year Floodplain	Complex > 153 acres & 31% in 100-Year Floodplain	Complex > 151 acres & > 28% In 100-year Floodplain
Surrounding Landscape Condition	***Total Acreage and Percent Natural Cover*** in *active river area* surrounding Wetland Complex are both above the median	Surrounding ARA > 1571 acres & > 57% Natural Cover	Surrounding ARA > 407 acres & > 57% Natural Cover	Surrounding ARA > 641 acres & > 62% Natural Cover

Appendix III: Measures Used to Conduct Condition Assessments of Freshwater Ecosystems

Headwater Stream Network and Headwater Wetland Condition Analysis

Headwater Stream Networks: Summary of measures and thresholds applied to the condition analysis of Headwater Stream Networks.

Key Ecological Attributes	Measure	Measure Thresholds
Aquatic Connectivity	Percent of Headwater Stream Network occurring within a specified size **Functional Connectivity Network** is above the basin mean	> 50% of Headwater Stream Network is in a Functional Connectivity Network > 100 miles long or is connected to the Bay
Flow Regime	Percent of Headwater Stream Network occurring along a river with a specified **Dam Storage Ratio** is above the basin mean	> 82% of the Headwater Stream Network length has a Dam Storage Ratio < 50% *(very low to moderate risk of hydrologic alteration)*
Baseflow	Headwater Stream Network **Baseflow** availability is above the basin mean and Percent Used is below the basin mean	Baseflow availability > 0.39 mgd/sq mile Percent used is < 3.9%

Headwater Wetlands: Summary of measures and thresholds applied to the condition analysis of Headwater Wetlands.

Key Ecological Attribute	Measure	Measure Thresholds
Size	**Number of wetlands > 25 acres** is above the basin mean or **at least one wetland > 250 acres**	7 or more wetlands greater than 25 acres or one wetland > 250 acres
Surrounding Landscape Condition	**Percent of Natural Cover and Percent with < 3% Impervious Cover surrounding** Wetlands in Headwater Stream Network are both above the basin mean	> 61% of the headwater stream network is in natural cover and more than 91% of the headwater stream network has <3% impervious cover

LITERATURE CITED

Barrier Analysis Tool (Version 1.0) [Software]. 2010. The Nature Conservancy and the Northeast Association of Fish and Wildlife Agencies. Software Developer: Duncan Hornby.

Ciruna, K. and D. Braun. 2005. Freshwater fundamentals: watersheds, freshwater ecosystems, and freshwater biodiversity. In A practitioner's guide to freshwater biodiversity conservation , eds. N. Silk and K. Ciruna, 11-36. Washington, DC: Island Press.

Cuffney, T.F., R.A. Brightbill, J.T. May, and I.R. Waite. 2010. Responses of benthic macroinvertebrates to environmental changes associated with urbanization in nine metropolitan areas. Ecological Applications 20(5): 1384–1401.

Fanok, S. 2000. A groundwater chemistry and flow system assessment for the Mt. Bethel Fens. Harrisburg, Pennsylvania: The Nature Conservancy.

Fischer, R. A., and J.C. Fischenich. 2000. Design recommendations for riparian corridors and vegetated buffer strips. EMRRP Technical Notes Collection (ERDC TN-EMRRP-SR-24). Vicksburg, Mississippi: U.S. Army Engineer Research and Development Center. www.wes.army.mil/el/emrrp.

Fitzhugh, T.W. and R.M. Vogel. 2010. The impact of dams on flood flows in the United States. 2010. River Research Applications *www.interscience.wiley.com* *DOI: 10.1002/rra.1417.*

Groves, C.R. 2003. Drafting a conservation blueprint: a practitioner's guide to planning for biodiversity. Washington, DC: Island Press.

Hudy, M., T. Thieling, N. Gillespie, and E.P. Smith. 2005. Distribution, status, and perturbations of brook trout within the eastern United States. Final Report Eastern Brook Trout Joint Venture.

King, R.S., and M.E. Baker. 2010. Considerations for analyzing ecological community thresholds in response to anthropogenic environmental gradients. Journal of the North American Benthological Society 29(3): 998–1008.

Moberg, T., C. Apse, and M. DePhilip. 2010. Flow alteration in the Upper Delaware River basin: a historical analysis of water supply reservoir management impacts (1954-2009). Harrisburg, Pennsylvania: The Nature Conservancy.

Opperman, J.J., R. Luster, B.A. McKenny, M. Roberts, and A.W. Meadows. 2010. Ecologically functional floodplains: connectivity, flow regime, and scale. Journal of the American Water Resources Association 46(2): 211-226.

Pennsylvania Game Commission and Pennsylvania Fish and Boat Commission, 2005. Pennsylvania Comprehensive Wildlife Conservation Strategy, Version 1.0.

Poff, N.L., J.D. Allan, M.B. Bain, J.R. Karr, K.L. Prestegaard, B. Richter, R. Sparks, and J. Stromberg. 1997. The natural flow regime: a new paradigm for riverine conservation and restoration. BioScience 47:769-784.

Sartor, J.F. 2005. Flood water retention by riverine and terrestrial forests. American Society of Civil Engineers Conference Proceedings 178: 81. http://www.fh-trier.de/fileadmin/groups/11/bauingenieurwesen/Personen/sartor/Forschung/sartor-asce-williamsburg-2005.pdf.

Sloto, R. and D. Buxton. 2007. Estimated ground-water availability in the Delaware River Basin, 1997-2000. Scientific Investigations Report 2006-5125-Version 1.1. Reston, Virginia: U.S. Geological Survey.

Smith, M.P., R. Schiff, A. Olivero, and J.G. MacBroom. 2008. The active river area: a conservation framework for protecting rivers and streams. Boston, Massachusetts: The Nature Conservancy.

Vogel, R.M., J. Sieber, S.A. Archfield, M.P. Smith, C.D. Apse, and A. Huber-Lee. 2007. Relations among storage, yield, and instream flow. Water Resources Research Vol. 43, W05403.

Winter, T.C., J.W. Harvey, O.L. Franke, and W.M. Alley. 1998. Ground Water and surface water-a single resource. U.S. Geological Survey Circular 1139.

Wolock, D.M. 2003. Base-flow index grid for the conterminous United States. U.S. Geological Survey Open-File Report 03-263. Reston, Virginia: U.S. Geological Survey. http://water.usgs.gov/lookup/getspatial?bfi48grd. Accessed August 2010.

Zimmerman J. and A. Lester. 2006. Spatial distribution of hydrologic alteration and fragmentation among tributaries of the Connecticut River. Northampton, Massachusetts: The Nature Conservancy, Connecticut River Program.

APPENDIX IV:

MEASURES USED TO CONDUCT CONDITION ASSESSMENTS OF TIDAL MARSH ECOSYSTEMS AND SUMMARY MAPS

Appendix IV: Measures Used to Conduct Condition Assessments of Tidal Marsh Ecosystems and Summary Maps

MEASURES USED TO CONDUCT CONDITION ASSESSMENTS OF TIDAL MARSH ECOSYSTEMS

Tidal Marsh Ecosystems

Our analysis area included all HUC12 watersheds that drain directly into Delaware Bay marshes, upstream to the Delaware Memorial Bridge. This is the upstream terminus of bay-fringing wetlands. Further upstream, tidal wetlands are predominately tributary-associated freshwater tidal wetlands that occur in discrete patches.

"In-Marsh" Analysis

Measure	Rationale	Data	Spatial Analysis
High salt marsh	This habitat is a primary breeding habitat for several species of conservation concern (e.g. salt marsh sparrow and black rail, Rosenberg and Wells 2005) and has a greater vulnerability to sea level rise than other salt marsh habitats (Donnelly and Bertness 2001).	Delaware Natural Heritage Program habitat mapping	For New Jersey, there is no high-resolution map of high salt marsh (*Spartina patens* and *Distichlish spicata*-dominated). We mapped this habitat using 2006 National Agriculture imagery Program data for New Jersey. In this true-color, growing season imagery, high marsh is easily distinguished from surrounding *Spartina alterniflora* and *Phragmites australis*-dominated marsh. To automate high marsh mapping, we used Feature Analyst software (version 5.0, Overwatch Geospatial 2010). This process involves hand-digitizing polygons as a training data set which Feature Analyst uses to create an initial map. This initial map is then refined with further training inputs, where errors of omission and commission are identified. This refinement process continues until the visual inspection of results reveals no obvious errors. We supplemented this visual inspection with ground-truthing in areas where the vegetation composition was not clear from aerial photos.
Habitat complexity	Areas of higher native habitat diversity can support higher levels of biological diversity (McKinney et al. 2009, Tews et al. 2004) and the presence of the full suite of salt marsh habitats in an area can in	National Hydrology Dataset. High Resolution data for waterbody data to identify large creeks and salt marsh ponds and flowlines to identify smaller creeks, high marsh habitat map described above, Phragmites	Using the datasets, we created a habitat mosaic (30m resolution raster layer), representing low marsh, high marsh, phragmites, large creeks, small creeks, and ponds for the marshes of our study area. We then calculated habitat diversity in a 1000m circular moving window across this mosaic using Fragstats software. For this diversity metric, we excluded *Phragmites*, so that areas with only *Phragmites* would receive the lowest habitat diversity score.

Appendix IV: Measures Used to Conduct Condition Assessments of Tidal Marsh Ecosystems and Summary Maps

Measure	Rationale	Data	Spatial Analysis
	some cases indicate a lack of past disturbance.	maps from Delaware Natural Heritage and Rutgers CRSSA 1995 Landcover classification, and marsh area boundaries based on NWI-classified estuarine and marine wetlands.	
Marsh elevation	Past land use practices have altered salt marshes through compaction, biomass removal, and decreased accretion rates (Weishar et al. 2005). These alterations sometimes result in marsh areas with unnaturally low elevations that are vulnerable to sea level rise in the immediate future.	LIDAR-derived digital elevation models for Delaware Bay marshes.	LIDAR has important limitations in marsh habitats that prevent detailed analyses of marsh elevation. Nonetheless, it can be useful for identifying areas of particularly low elevation that are vulnerable to sea level rise. We clipped LIDAR data to marsh area and classified it by standard deviations around the mean. We then smoothed the data using the Focal Statistics function in ArcMap to calculated a mean across an 8-cell moving window. Areas that were 1 standard deviation below the mean marsh elevation were identified as low elevation marsh.
Marsh ditching	Ditching marshes alters natural marsh hydrology, reduces the availability of certain habitats (e.g. ponds), and fragments interior marshes (Lathrop et al. 2000).	National Hydrology Dataset (NHD) High Resolution flowlines	We used NHD flowlines tagged as ditches and hand digitized additional areas to supplement this dataset. We calculated the relative density of ditches across the marsh area by rasterizing this line data (30m resolution) and calculating the Fragstats Edge Density metric in a 1000m circular moving window.
Marsh size	The fringing marsh surrounding the Delaware Bay varies in width. Size of wetlands and their distance from agricultural and urban landuses can affect biotic composition (Deluca et al. 2004). This measure highlights the widest areas of salt marsh that are the most isolated from upland areas.	National Wetlands Inventory data	We calculated a raster surface (30m resolution) that measured the distance from the marsh- upland interface. We then summarized by HUC12 watershed units to compute the average distance from upland edge for each watershed unit.

Appendix IV: Measures Used to Conduct Condition Assessments of Tidal Marsh Ecosystems and Summary Maps

Measure	Rationale	Data	Spatial Analysis
Shoreline development	Shoreline development interferes with the natural response of shorelines to changing conditions such as rising sea levels and storms (Fitzgerald et al. 2008) and reduces habitat availability for species dependent upon Delaware Bay beaches.	We used Rutgers CRSSA shoreline data created to develop a horseshoe crab habitat suitability index for the Bayshore. We supplemented these data by hand digitizing shoreline development in the upper reaches of the bay which were not mapped by Rutgers. We considered any beaches with houses along the shore to be developed, along with shoreline hardening features such as rip rap, roads, and jettys. We also considered dykes that run parallel to beaches to be a form of development since they prevent inland beach transgression.	We summarized these data by HUC12 watershed units and calculated percent shoreline development for each unit.

Coastal Watershed Analysis

Measure	Rationale	Data Used	Spatial Analysis
Undeveloped adjacent uplands	Undeveloped uplands adjacent to salt marsh allow for the inevitable process of coastal transgression, where beaches and marshes move inland as local sea levels rise. Allowing space for marsh migration is a key strategy for sea level rise adaptation (CCSP 2009).	We used NOAA Landover data along with bridge, culvert, and dam data that we mapped using aerial photos and LIDAR digital elevation models.	We evaluated connectivity between terrestrial and wetland habitats. To do this we first created an upland buffer of irregular width adjacent to coastal wetlands. The buffer extended from the upland/wetland interface to an elevation of six meters. Within this buffer we assessed connectivity between the upland/marsh edge to the far-upland side of the buffer area. Features that interrupted connectivity were development, roads, and dams. We considered traversable areas to be those with natural or agricultural landcover, stream corridors, bridges, and culverts. We used Circuitscape connectivity analysis software to examine connectivity between the wetland and upland edge of the buffer. Beyond interruptions from development, roads, and dams, we also incorporated slope data from LIDAR DEMs to account for the increased resistance to marsh

Appendix IV: Measures Used to Conduct Condition Assessments of Tidal Marsh Ecosystems and Summary Maps

Measure	Rationale	Data Used	Spatial Analysis
			migration that steeper-sloped areas would have. We simplified the resulting raster into discrete polygons that represented corridors between the wetland and upland side of the buffer.
Natural landcover in watershed	Non-point source run-off from agricultural and developed landscapes can be a significant stressor on estuarine habitats (Rodriguez et al. 2006, Basnyat et al.1999). Nutrient runoff in particular can cause eutrophication of the estuary and shifts in food webs (Valiela, Bowen 2002).	NLCD 2001 landcover and NHDPlus catchments.	We linked results from the NLCD 2001 NHDPlus Catchment Allocation and Upstream Accumulation Attributes tool to NHDPlus catchments in our analysis area. This yielded an accumulated upstream percent natural landcover for each catchment in our analysis area.
Freshwater connectivity	*Rationale:* Estuaries are, by definition, a product of the interaction between freshwater and marine ecosystems. Free-flowing river systems are essential for this interaction because they allow freshwater to flow into estuaries, provide marine organisms access to freshwater habitats, and create gradients of salinity that result in a broad range of vegetation communities (Gillanders, Kingsford 2002).	Data: Dam data from US Army Corps' National inventory of Dams, Geographic Names Information System Database, PA Fish and Boat Commission, PA Division of Dam Safety, DE Department of Natural Resources and Environmental Control, NJ Department of Environmental Protection. We also did fine-scale mapping of bridge, culvert, and dam data using aerial photos and LIDAR digital elevation models. NHDPlus catchments.	(1) Length of freshwater network connected to bay Using the Nature Conservancy's Barrier Assessment Tool, we identified the length between the Delaware Bay and the first upstream barrier for each stream network. (2) Percent of watershed connected to bay For % of watershed connected to bay, we divided the length of the freshwater network connected to the bay by the TOTAL number of miles of all streams and tributaries in each network. All values calculated above were joined back to the corresponding NHDPlus catchments.

Appendix IV: Measures Used to Conduct Condition Assessments of Tidal Marsh Ecosystems and Summary Maps

Metric weighting scheme

The Nature Conservancy proposes a weighting scheme below for evaluating the ecological integrity of tidal marshes based on the metrics described above. Our assessment of metric importance is based on the weight of evidence provided by the scientific literature associated with that metric. These weights are open to revision and adjustment as we calibrate our results with on-the-ground assessments of marsh condition and as we incorporate expert opinion provided by individuals from other organizations working around the bay.

Metric	high importance	med importance	low importance
High salt marsh	●		
Habitat complexity		●	
Marsh elevation	●		
Marsh ditching			●
Marsh size			●
Shoreline development	●		
Undeveloped adjacent uplands	●		
Natural landcover in watershed		●	
Freshwater connectivity	●		

Literature Cited

Basnyat, P., L.D. Teeter, K.M. Flynn, B.G. Lockaby. 1999. Relationships between landscape characteristics and nonpoint source pollution inputs to coastal estuaries. Environmental Management 23: 539–549.

Climate Change Science Program (CCSP). Titus, James G., K. Eric Anderson, Donald R. Cahoon, Dean B. Gesch, Stephen K. Gill, Benjamin T. Gutierrez, E. Robert Thieler, and S. Jeffress Williams. 2009. Coastal sensitivity to sea-level rise: a focus on the Mid-Atlantic region. U.S. Climate Change Science Program and the Subcommittee on Global Change Research. Washington DC: USA U.S. Environmental Protection Agency.

Deluca, W.V., C.E. Studds, L.L. Rockwood, P.P. Marra. 2004. Influence of land use on the integrity of marsh bird communities of the Chesapeake Bay, USA. Wetlands 24: 837-847.

Donnelly, J. P., M.D. Bertness. 2001. Rapid shoreward encroachment of salt marsh cordgrass in response to accelerated sea-level rise. Proceedings of the National Academy of Sciences of the United States of America 98: 14218-14223.

Fitzgerald, D.M., M.S. Fenster, B.A. Argow, I.V. Buynevich. 2008. Coastal impacts due to sea level rise. Annual Review of Earth and Planetary Sciences 36: 601-647.

Gillanders, B.M., M.J. Kingsford. 2002. Impact of changes in flow of freshwater on estuarine and open coastal habitats and the associated organisms. Oceanography and Marine Biology 40: 233–309.

Lathrop, R., M. Cole, R. Showalter. 2000. Quantifying the habitat structure and spatial pattern of New Jersey (U.S.A.) salt marshes under different management regimes. Wetlands Ecology and Management 8: 163-172.

McKinney, R., M. Charpentier, C. Wigand. 2009. Assessing the wildlife habitat value of New England salt marshes: I. Model and application. Environmental Monitoring and Assessment 154: 29-40.

Rodriguez, W., P.V. August, Y. Wang, J.F. Paul, A. Gold, N. Rubinstein. 2006. Empirical relationships between land use/cover and estuarine condition in the Northeastern United States. Landscape Ecology 22: 403-417.

Rosenberg, K. V. and J.V. Wells. 2005. Conservation priorities for terrestrial birds in the northeastern United States. In Bird conservation implementation and integration in the Americas: proceedings of the Third International Partners in Flight Conference 2002 March 20-24, Asilomar, California, eds. C. John Ralph and Terrell D. Rich, Volume 1 Gen. Tech. Rep. PSW-GTR-191. Albany, California: U.S. Dept. of Agriculture, Forest Service, Pacific Southwest Research Station.

Tews, J., U. Brose, V. Grimm, K. Tielbörger, M.C. Wichmann, M. Schwager, F. Jeltsch. 2004. Animal species diversity driven by habitat heterogeneity/diversity: the importance of keystone structures. Journal of Biogeography 31: 79–92.

Valiela, I., J.L. Bowen. 2002. Nitrogen sources to watersheds and estuaries: role of land cover mosaics and losses within watersheds. Environmental Pollution 118: 239-248.

Weishar, L., J. Teal, R. Hinkle. 2005. Designing large-scale wetland restoration for Delaware Bay. Ecological Engineering 25: 231-239.

Appendix IV: Measures Used to Conduct Condition Assessments of Tidal Marsh Ecosystems and Summary Maps

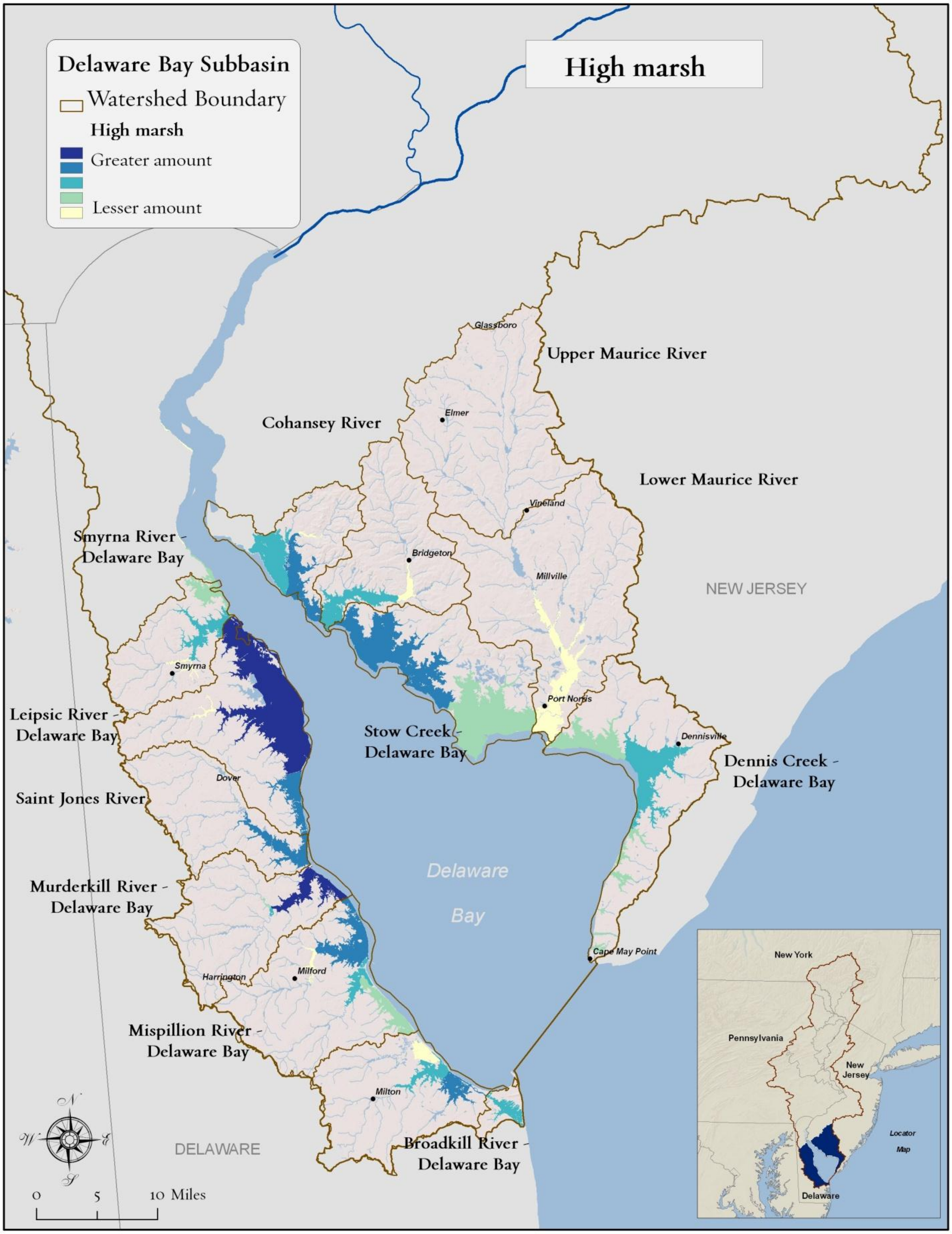


FIGURE 1. The relative distribution of high marsh in Delaware Bay salt marshes. Results are summarized by HUC-12 sub-watersheds.

Appendix IV: Measures Used to Conduct Condition Assessments of Tidal Marsh Ecosystems and Summary Maps

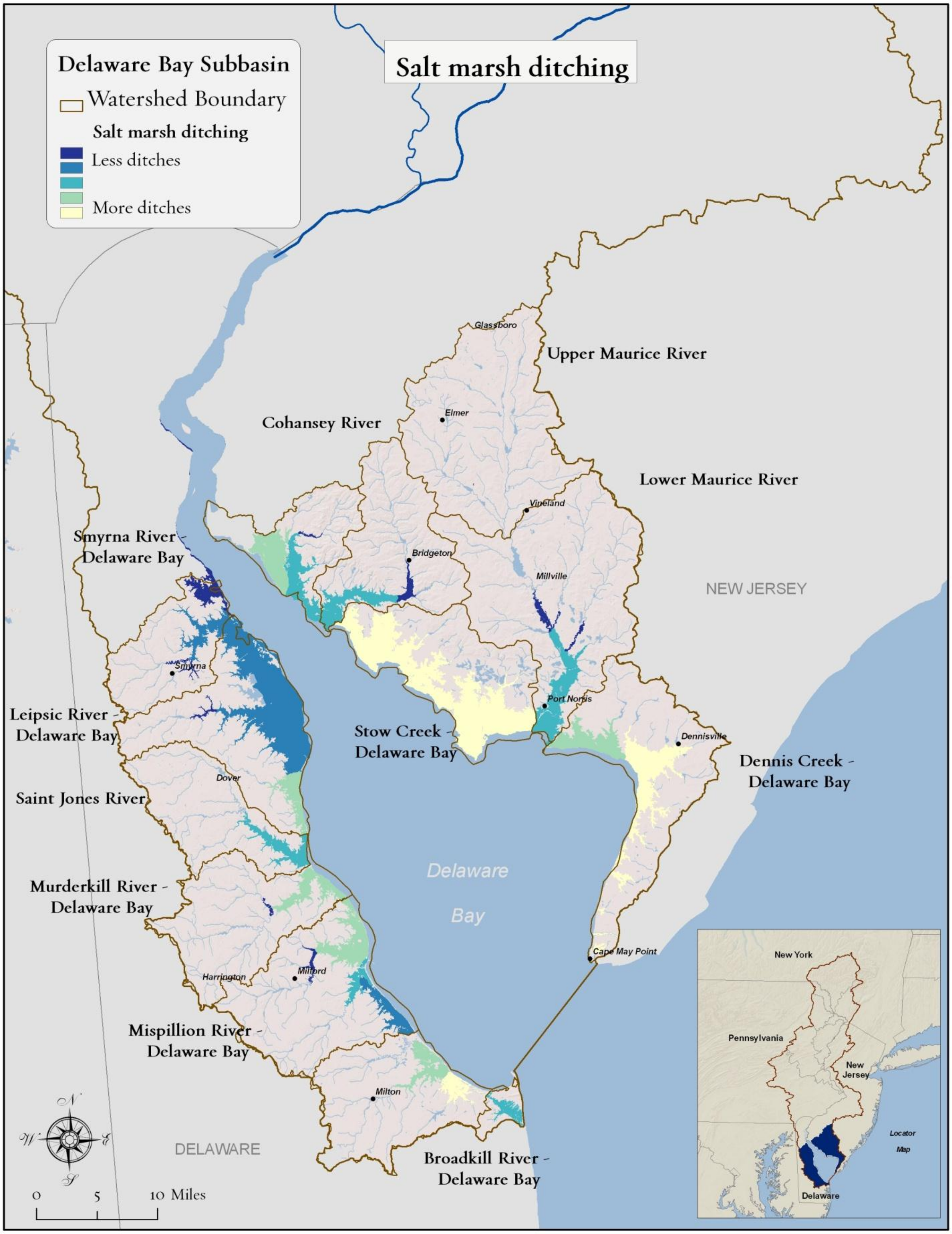


Figure 2. The relative density of ditches in Delaware Bay salt marshes. Results are summarized by HUC-12 sub-watersheds.

Appendix IV: Measures Used to Conduct Condition Assessments of Tidal Marsh Ecosystems and Summary Maps

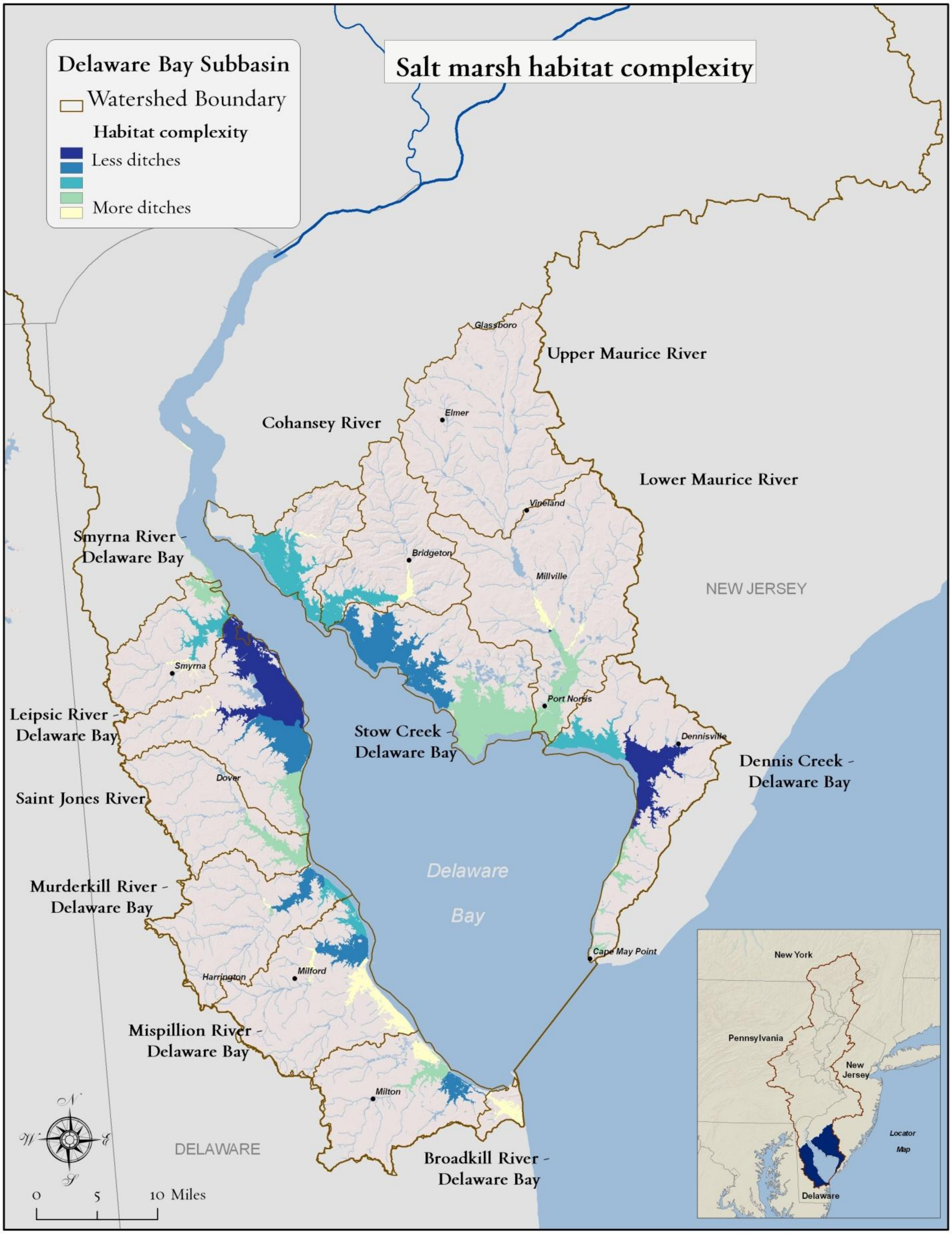


Figure 3. The relative habitat complexity of salt marshes in the Delaware Bay. Results are summarized by HUC-12 sub-watersheds.

Appendix IV: Measures Used to Conduct Condition Assessments of Tidal Marsh Ecosystems and Summary Maps

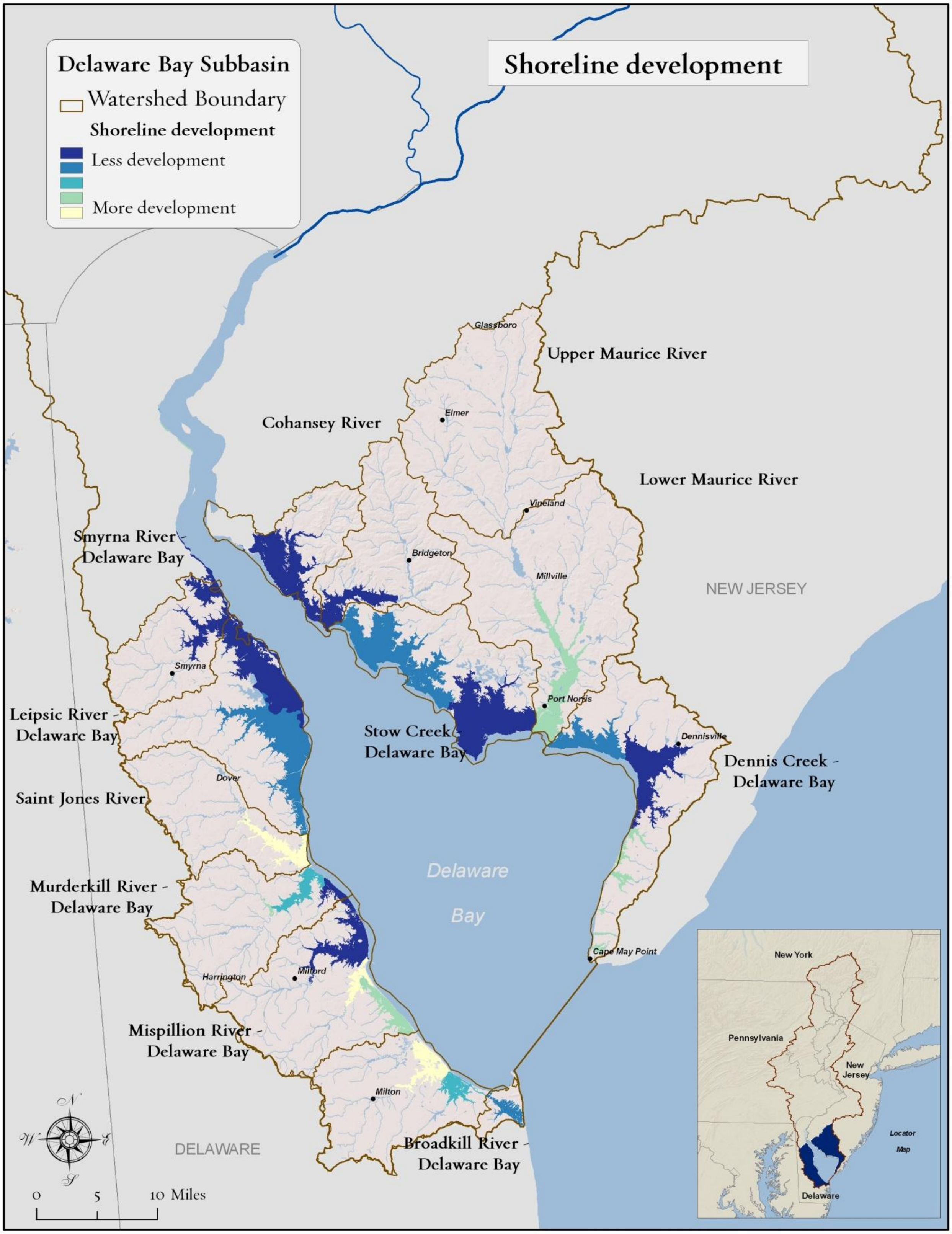


Figure 4. The distribution of development along Delaware Bay shorelines. Results are summarized by HUC-12 sub-watersheds.

Appendix IV: Measures Used to Conduct Condition Assessments of Tidal Marsh Ecosystems and Summary Maps

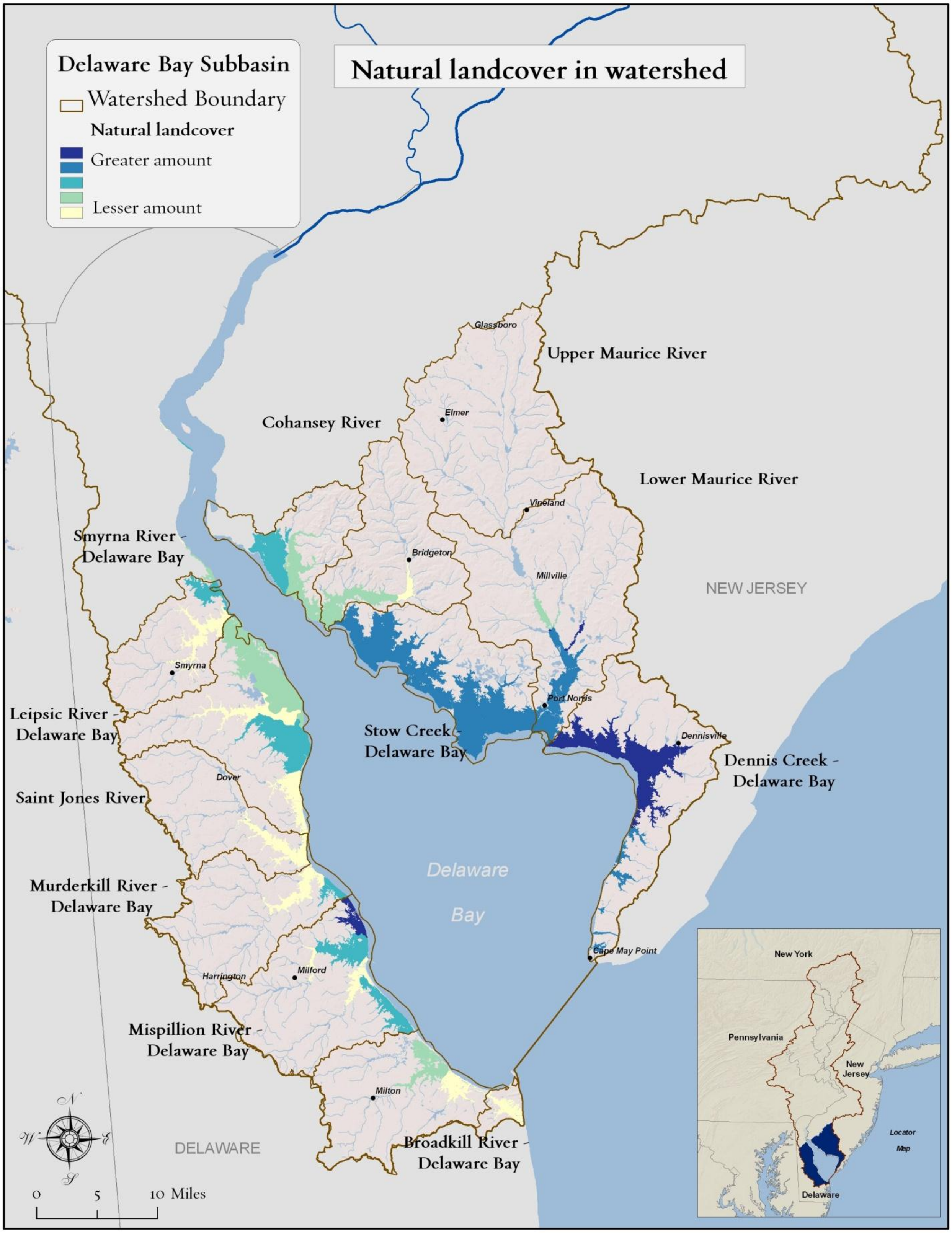


Figure 5. The relative amount of undeveloped uplands adjacent to salt marsh in the Delaware Bay. Results are summarized by HUC-12 sub-watersheds.

Appendix IV: Measures Used to Conduct Condition Assessments of Tidal Marsh Ecosystems and Summary Maps

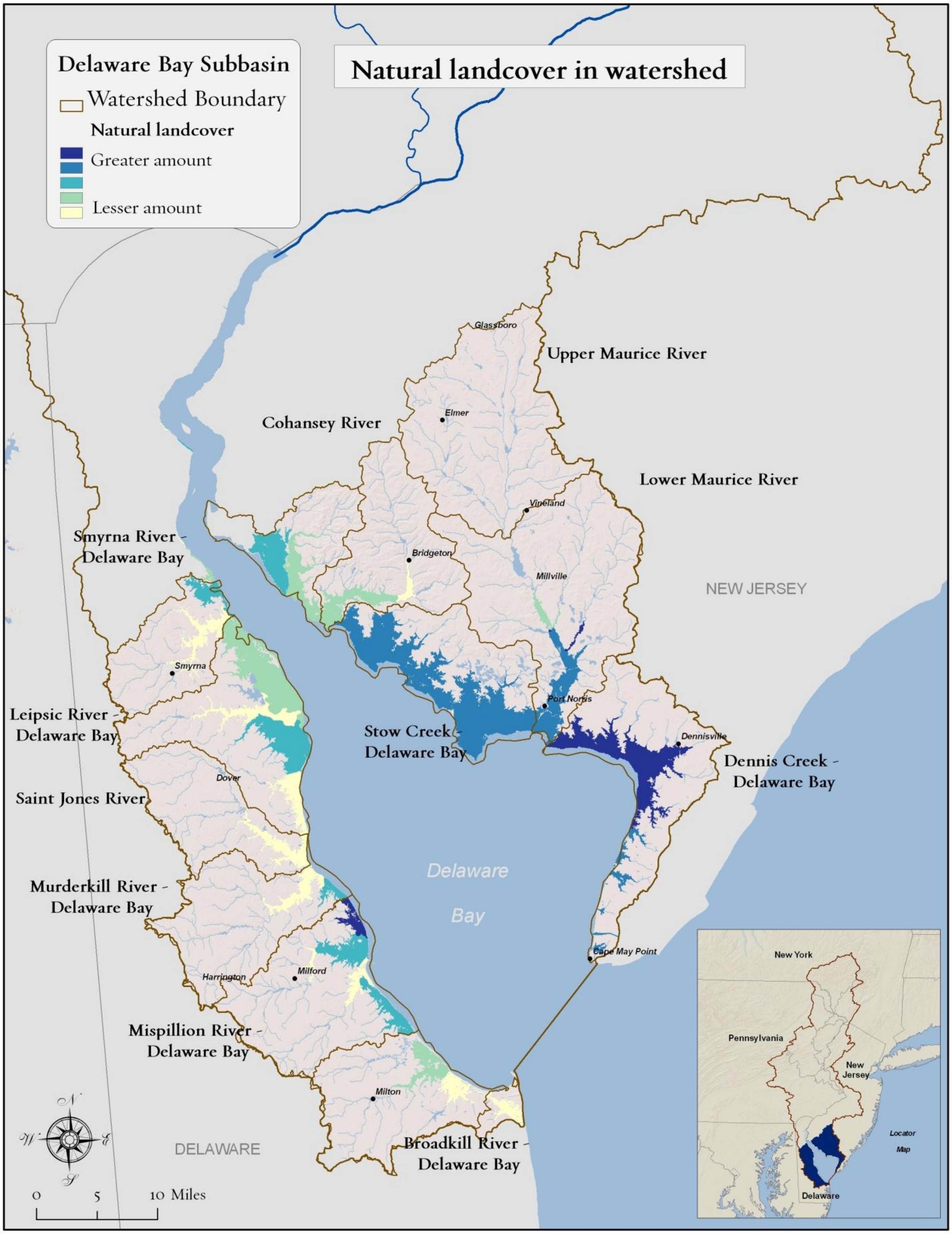


Figure 6. The relative amount of natural land cover in coastal watersheds upstream of Delaware Bay salt marshes. Results are summarized by HUC-12 sub-watersheds.

Appendix IV: Measures Used to Conduct Condition Assessments of Tidal Marsh Ecosystems and Summary Maps

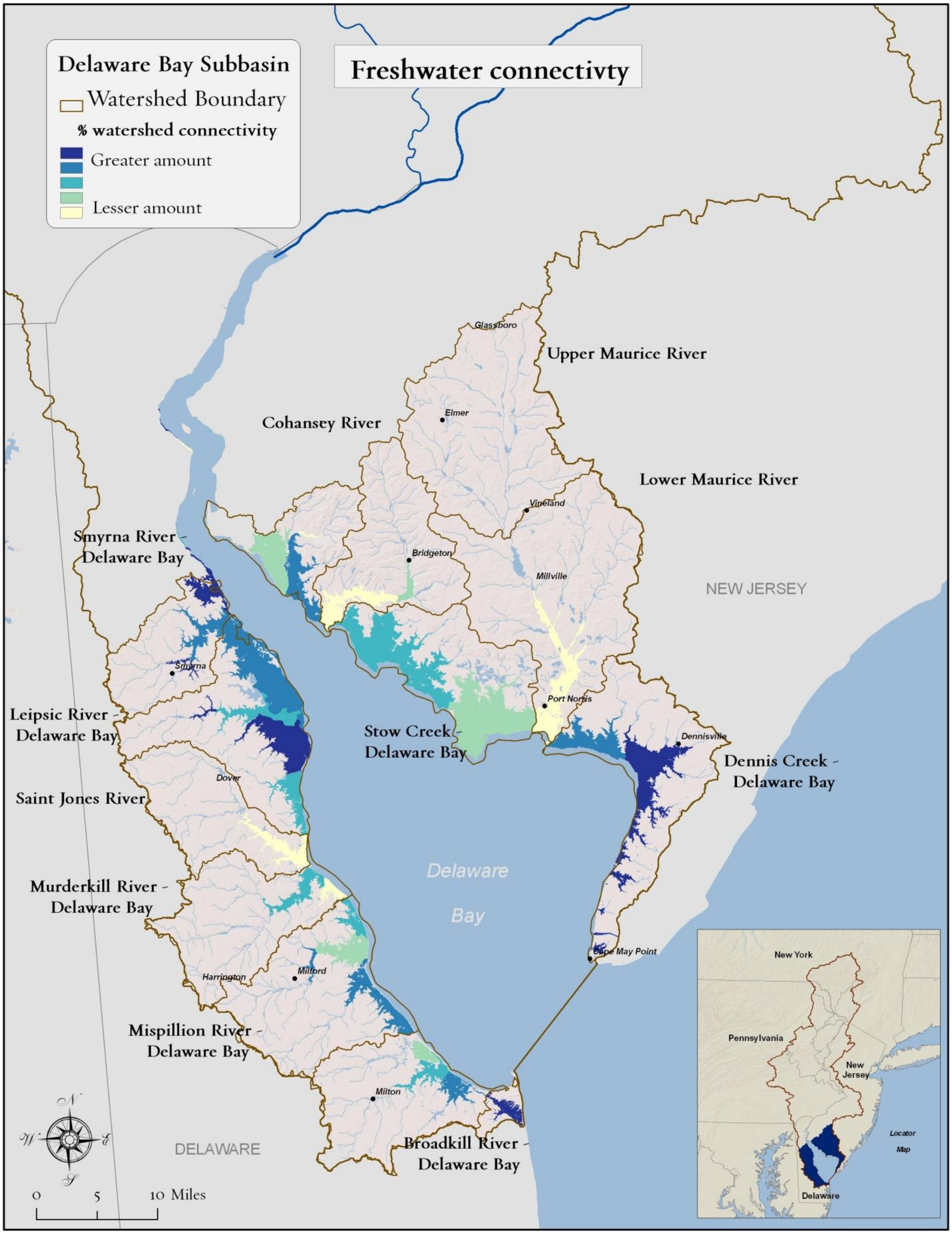


Figure 7. The relative connectivity of coastal watersheds that drain into Delaware Bay salt marshes. Results are summarized by HUC-12 sub-watersheds.

Appendix IV: Measures Used to Conduct Condition Assessments of Tidal Marsh Ecosystems and Summary Maps

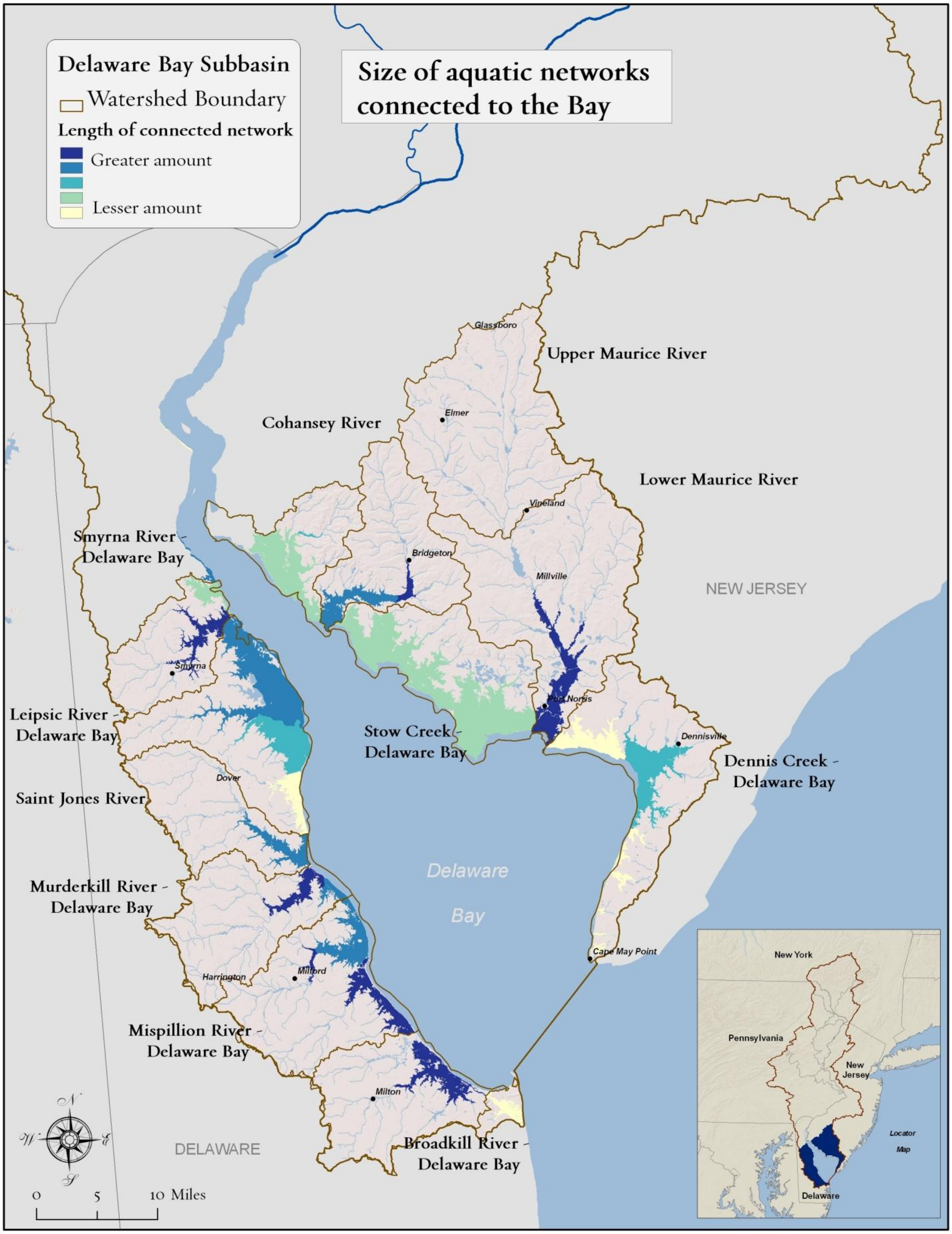


Figure 8. The relative size of connected coastal watersheds that drain into Delaware Bay salt marshes. Results are summarized by HUC-12 sub-watersheds.

APPENDIX V:

BENTHIC HABITATS OF THE DELAWARE BAY

Benthic Habitats of Delaware Bay

Mark G. Anderson, Joseph A.M. Smith, and Bartholomew D. Wilson

INTRODUCTION

This section describes and maps the major physical habitats of the Delaware Bay seafloor. We used information on benthic organisms, their distribution and their relationships to physical features, to delimit a distinct set of environments representing the variety of benthic habitats in the Bay. As individual species are adapted to variations in depth, sediment size, seabed topography and salinity, we examined these factors in relationship to the organism composition and classified them into basic types to illustrate the diversity of conditions existing on the seafloor. We hope that this benthic habitat map of the Delaware Bay, based on previously collected data, will provide a better understanding of the abundance and distribution of seafloor habitat types.

Benthic organisms are those that inhabit the sea floor; from the Greek word benthos, meaning "depths of the sea." Based on a just a small sample (246 samples), the seafloor habitats of the Delaware Bay contain over 300 species in 8 phyla including:

- 106 species of arthropods (crabs, lobsters, shrimp, barnacles)
- 75 species of mollusks (clams, scallops, squid, limpets, sea slugs, snails)
- 130 species of annelids (sea worms)
- 8 species of echinoderms (sea stars, sea urchins, sea cucumbers, sand dollars)
- 5 species of cnidarians (corals, anemones, jellyfish)
- 4 species of chordates (sea squirts)
- 1 species of poriferans (sponges)
- 6 species of nemerteans (ribbon worms)

The distributions and life histories of benthic organisms are tied to their physical environment. Filter feeders tend to dominate on shallow sandy bottoms while deposit feeders, may dominate in fine-grained mud. It is these distinct physical habitats that we identified, characterized, and mapped.

This chapter represents an initial effort to define and map marine benthic habitats using information on organism distributions combined with interpolated data on bathymetry, sediment grain size, and seafloor topography. The goal was to produce a bay-wide map of broadly-defined, but distinct with respect to the organism groups found within them.

This work is builds on the methods developed in the Nature Conservancy's Northwest Atlantic Marine assessment, (Green et al. 2010) particularly those described in chapter 3 - Benthic Habitats.

Please note that critical steps of accuracy assessment, cross-validation using independent datasets, comparisons with demersal fish habitat, and final expert peer review are ongoing

Definition of Target Habitats

The goal of this work was to identify and map the major benthic habitat types in the Delaware Bay. We defined a benthic habitat as a group of organisms repeatedly found together within a specific environmental setting. For example, silt flats in deep water typified by a specific suite of amphipods, clams, whelks and snails might be one habitat, while sand flats in shallow water might be another, providing it supports a different set of organisms. Conservation of these habitats is necessary to protect the full diversity of species that inhabit the seafloor, and to maintain the ecosystem functions of benthic communities.

Methods

To design a conservation plan for benthic diversity in the Delaware Bay it is essential to have some understanding of the extent and location of various benthic habitats (e.g. a map). Fortunately, the challenge of mapping seafloor habitats has produced an extensive body of research (see Kostylev et al. 2001; Green et al. 2005; Auster2006; World Wildlife Fund 2006; Todd and Greene 2008). In addition, comprehensive seafloor classification schemes have been proposed by many authors (see Dethier 1992; Brown 1993, European Environmental Agency1999; Greene et al. 1999; Allee et al. 2000; Brown 2002; Conner et al 2004; Davies et al. 2004; Greene et al.2005; Madden et al. 2009; Valentine et al. 2005; Kutcher 2006; and see reviews in National Estuarine Research Reserve System 2000 and Lund and Wilbur 2007). During development of the benthic map for the Nature Conservancy's Northwest Atlantic Marine Assessment (Anderson et al. 2010 in Greene et al. 2010),we reviewed the literature on seafloor classification, and examined the variety of approaches already utilized in order to develop the methodology used here.

Many of the existing schemes base their classifications on physical factors such as bathymetry, sediment grain size, sediment texture, salinity, bottom temperature, and topographic features. This is logical as there is ample evidence that benthic distribution patterns are associated with many of these variables. For example, temperature is correlated with the community composition of benthic macroinvertebrates (Theroux and Wigley 1998); substrate type is correlated with community composition and abundance of both the invertebrates and demersal fish (Auster et al. 2001; Stevenson et al. 2004); habitat complexity is correlated with species composition, diversity, and richness (Etter and Grassle 1992; Kostylev et al. 2001; Serrano and Preciado 2007, reviews in Levin et al. 2001); and depth is correlated with abundance, richness, and community composition (Stevenson et al. 2004).

The approach used here builds on existing schemes both explicitly and implicitly, and results can be readily compared to them. However, the goal of this assessment was to produce a map of broadly-defined benthic habitats in Bay using readily available information, and we are not proposing a new classification system.

Biological Factors: Benthic Organisms

The map of benthic habitats presented here is based directly on the distribution and abundance of benthic organisms in Delaware Bay, and the knowledge of these species and their distributions comes largely from seafloor samples described below. In the analysis of this data, groups of species with shared distribution patterns were identified, then thresholds in the physical factors were identified that correlated with those patterns. Specifically, three basic steps were followed: 1) quantitative analysis of the grab samples to identify distinct and reoccurring assemblages of benthic organisms, 2) recursive partitioning to relate the species assemblages to physical factors (bathymetry, sediment types, and seabed topographic forms), and 3) mapping the habitats based on the statistical relationships between the organism groups and the distribution of the physical factors. Although organism distributions were used to identify meaningful thresholds and cutoffs in the physical variables, the final habitat maps are composed solely of combinations of enduring physical factors and are thus closely related to the maps and classification schemes proposed by others.

This study was made possible by access to 234 samples of abundance and biomass data collected by the Delaware Estuary Benthic Inventory, Partnership for the Delaware Estuary and EPA Region 2 and Region 3. Data Sampling occurred during Summer 2008 (for sampling protocol see EPA's NCA or PDE's DEBI QAPP). The DEBI effort was multidisciplinary and many federal, state and regional partners contributed with design, sampling, sample analysis and data analysis products. The Partnership for the Delaware Estuary (PDE), a National Estuary Program, was the coordinating entity and grantee, working closely with EPA Region 3 and the EPA Atlantic Ecology Division. As reports and additional data analysis products are at: http://www.delawareestuary.org/science_projects_baybottom.asp.

Twelve more samples were provided by the National Marine Fisheries Service's (NMFS) Northeast Fisheries Science Center (NEFSC). The NEFSC conducted a quantitative survey of macrobenthic invertebrate fauna from the mid 1950s to the early 1990s and a few of these samples included Delaware Bay. Organisms collected in each sample were identified to species, genus, or family. A thorough discussion of the NEFSC sampling methodology, gear types, history, and an analysis of the benthic dataset, including the distribution and ecology of the organisms, can be found in the publications of Wigley and Theroux (1981 and 1998).

Classification Methods

Classification analysis began with the entire 234 sea-floor samples obtained from the DEBIP and the 12 samples from NEFSC. These were combined into a sample-by-species table indicating the abundance (by count) of each species within each sample. Where possible the analysis was done at the species level but in some cases, when an organism was abundant in many samples but only identified to genus, the genus was treated as a species. Species that only occurred in one sample were removed from the data set before analyzing the data as was information on plants, egg masses, and organic debris.

Samples with similar species composition and abundance were grouped together using hierarchical cluster analysis (PCORD, McCune and Grace 2002). This technique starts with pairwise contrasts of every sample combination then aggregates the pairs most similar in species composition into a cluster. Next, it repeats the pairwise contrasts, treating the clusters as if they were single samples, and joins the next most similar sample to the existing clusters. The process is repeated until all samples are assigned to one of the many clusters. For our analysis, the Sorenson similarity index and the flexible beta linkage technique with Beta set at 25 was used as the basis for measuring similarity (McCune and Grace 2002).

After grouping the samples, indicator species analysis was used to identify those species that were faithful and exclusive to each organism group (Dufrene and Legrande 1997). Lastly, Monte Carlo tests of significance were run for each species relative to the organism groups to identify diagnostic species for each group using the criterion of a p-value less than or equal to 0.10 (90% probability). The number of sets of clusters (testing 10 to 40) was determined by seeing which amount gave the lowest average p-value.

Physical Factors: Bathymetry, Substrate and Seabed Forms

To understand how the benthic invertebrate community distributions related to the distribution of physical factors, a spatially comprehensive data layer for each factor of interest was developed. Four aspects of seafloor structure were used: bathymetry, sediment grain size, topographic forms, and salinity. These factors were chosen because they are correlated with the distribution and abundance of benthic organisms. Data on each physical factor were compiled from separate sources and the techniques used to create a comprehensive map are discussed below.

Bathymetry

We based our bathymetry dataset on a publicly available digital elevation model for the Delaware Bay (estuarinebathymetry.noaa.gov). In order to use all of the biological samples in our analyses, we extended the bathymetry coverage upriver approximately 20 kilometers (Figure 1). To do this, we used depth-sounding points collected during the Delaware Bay and River Benthic Habitat Mapping Project (project website). We interpolated these data following the methods used for NOAA bathymetry, using linear interpolation to create a 30m DEM. We attributed each of the 246 organism samples with an estimate of the bathymetry at that point.

Geographic position: a proxy for salinity

In estuaries, salinity is an important driver of the composition of biological communities. This attribute is difficult to estimate over space because it is both annually and seasonally dynamic. Since we did not have access to an accurate map of the salinity gradient in the bay, we used a measure of Euclidean distance from the upper reach of our study area as a proxy for salinity to ensure that this environmental aspect was accounted for. Figure 2 shows a categorical map of salinity for the bay published by NOAA along with biological thresholds for our salinity proxy measure where we observed shifts in benthic species communities.

Seafloor Substrates: Soft Sediments and Hard Bottoms

Soft Sediments and Hard Bottoms Substrate data for the entire Bay was obtained from two sources. The primary source was the Delaware Coastal Programs of Delaware Department of Natural Resources and Environmental Control (DNREC) which has initiated a benthic habitat and sub-bottom sediment mapping project using remote acoustics (i.e., Roxann Seabed Classification, Chirp Sub-Bottom Profiler, and multi-bean surface imaging system). This work will ultimately be completed on both the Delaware and New Jersey sides of the Estuary and is being supported by multiple Federal and State agencies, non-profits, and academic institutions. This highly detailed bottom substrate map is furnishing important new information about the geospatial character of physical conditions across the estuary. For the purposes of this study we obtained the sample points and their attributes. For interpolation purposes, we converted the information on sediment fractions to an average grain size estimate for each sample.

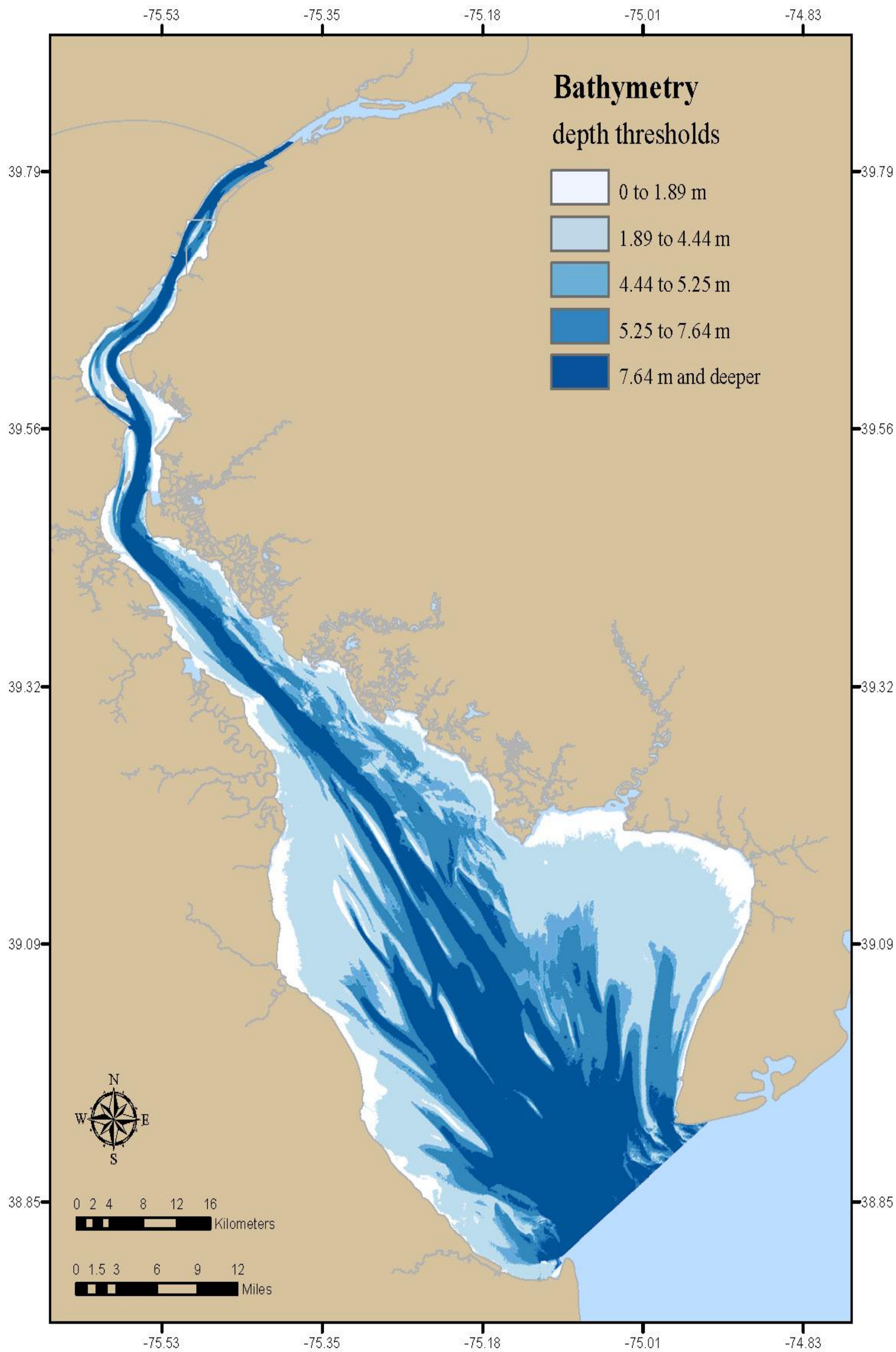


Figure 1. Bathymetry map of Delaware Bay.

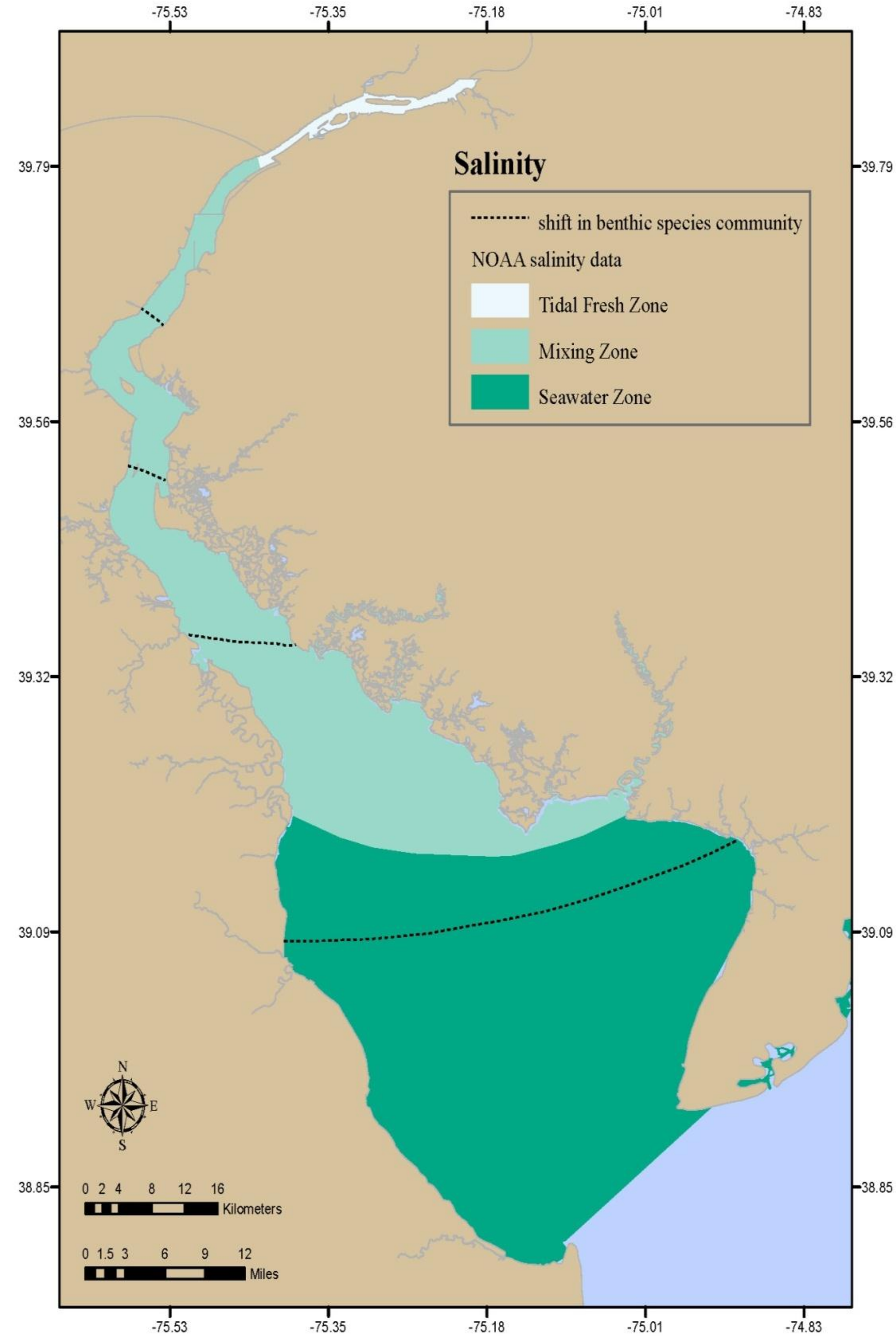


Figure 2. Salinity of the Delaware Bay: NOAA categorical delineation and ecological thresholds derived from analyses of species compostion.

In addition to the DNREC samples, we obtained sediment samples from usSEABED, a regional system that brings assorted numeric and descriptive sediment data together in a unified database (Reid et al. 2005). The information includes textural, geophysical, and compositional characteristic of points collected from the seafloor, and is spatially explicit. In total we had 3,706,489 sediment samples (Figure 3).

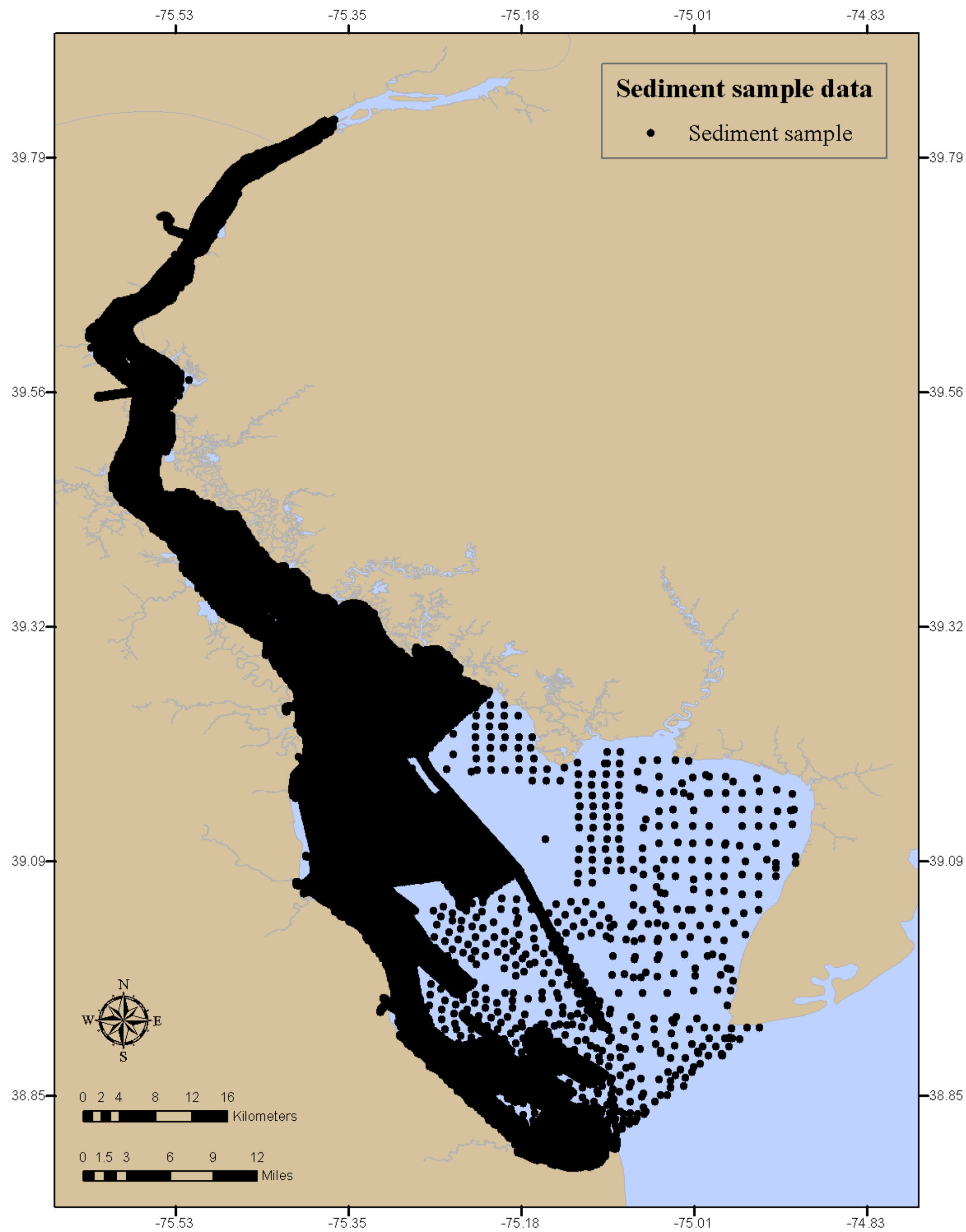


Figure 3. Distribution of the Sediment Samples. The dark areas are areas with high sampling density provided by the DNREC. The sparse areas were not sampled by the DNREC, but filled in with samples from usSEABED.

Interpolation of the Sediment Dataset

We interpolated the sediment data set in GIS using Inverse Distance Weighting with a squared exponent of distance and a variable search radius based on the nearest 12 points . The resulting 30m resolution interpolated map was used to attribute each of the 246 organism sample points with an estimate of the average sediment grain size at that point. For map display we used a Kriging interpolation that creates a smoother version of the sediment variation (Figure 4). A separate dataset of hard bottom locations was created from the points coded as rock or shell in the DNREC data set or "solid" in the usSeabed dataset. We overlaid these areas on the soft sediment interpolation to create the final sediment map (Figure 5). These data are a conservative representation of hard bottom areas of the bay and, particularly for shell, do not represent their entire distribution in the bay.

Seabed Topographic Forms

The Delaware Bay is characterized by a moderately complex central trench surrounded by simple sand. With this in mind, the seabed form data layer was developed to characterize seafloor topography in a systematic and categorical way, relevant to the scale of benthic habitats. The units that emerge from this analysis, from high flats to depressions, represent depositional and erosional environments that typically differ in fluvial processes, sediments, and organism composition (Wigley and Theroux 1981).

Seabed topographic forms were created from relative seabed position and degree of slope of each seafloor cell. Seabed position (or topographic position) describes the topography of the area surrounding a particular 30 m cell. Calculations were based on the methods of Fels and Zobel (1995) that evaluate the elevation differences between any cell and the surrounding cells within a specified distance. For example, if the model cell is, on average, higher than the surrounding cells, then it is considered to be closer to the ridge top (a more positive seabed position value). Conversely, if the model cell is, on average, lower than the surrounding cells then it is considered closer to the slope bottom (a more negative seabed position value).

The relative position value is the mean of the distance-weighted elevation differences between a given point and all other model points within a specified search radius. The search radius was set at 100 cells after examining the effects of various radii. Position was grouped into six classes that were later simplified to three classes: The second element of the seabed forms, degree of slope, was used to differentiate between steep slopes and flat depressions. Slope was calculated as the difference in elevation between two neighboring raster cells, expressed in degrees. After examining the distribution of slopes across the region, slopes were grouped according to the thresholds outlined in Table 1.

Slope and relative position were combined to create 18 possible seabed forms ranging from high flat banks to low level bottoms. Initially, all 18 types were used in the analysis of organism relationships (Figure 6), but results suggested that they could be simplified while maintaining, or improving, their explanatory power. Therefore, the analysis was simplified into the following four categories: High flat low flat, high slope and low slope (Figure 7).

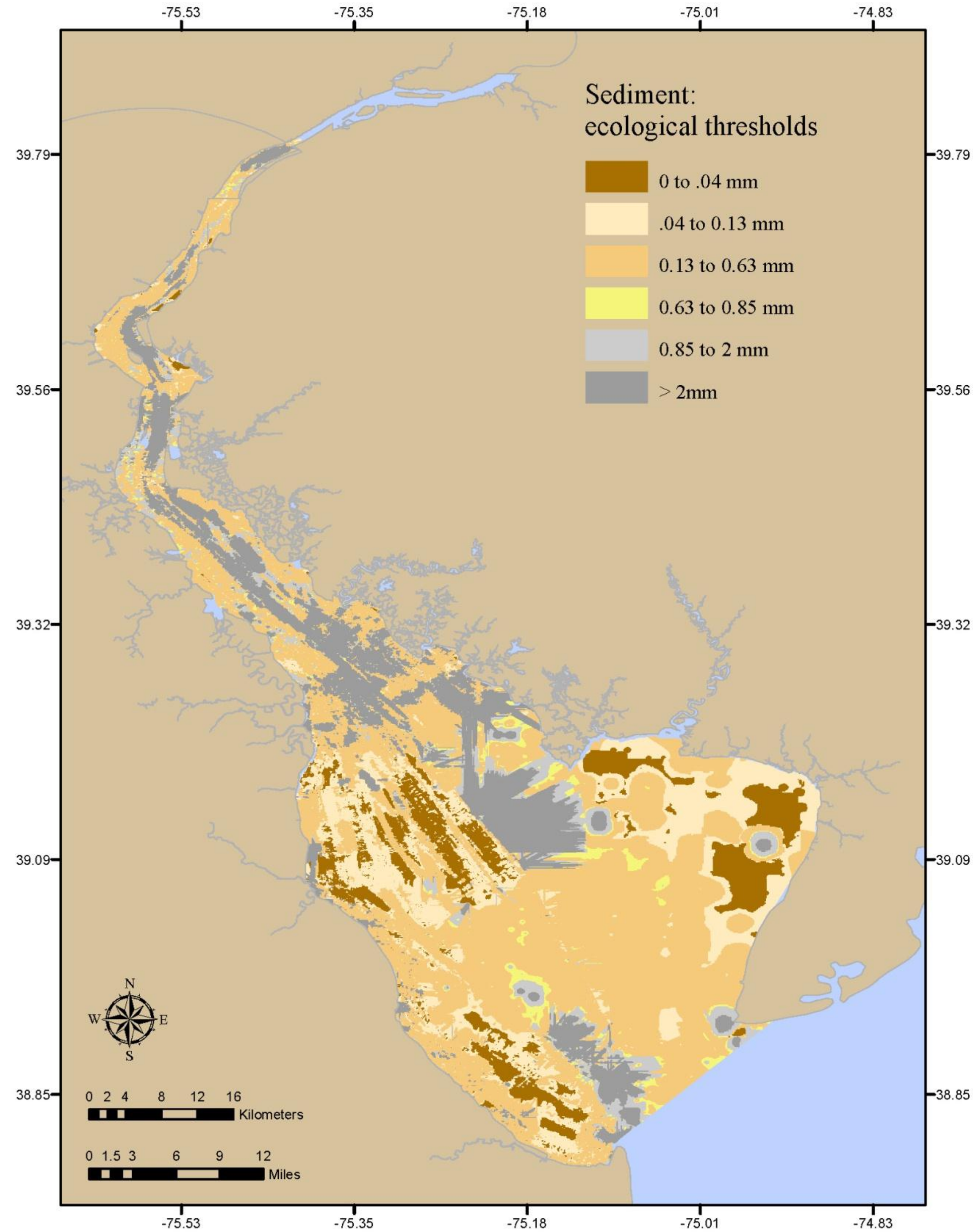


Figure 4. Interpolated map of soft sediments in Delaware Bay.

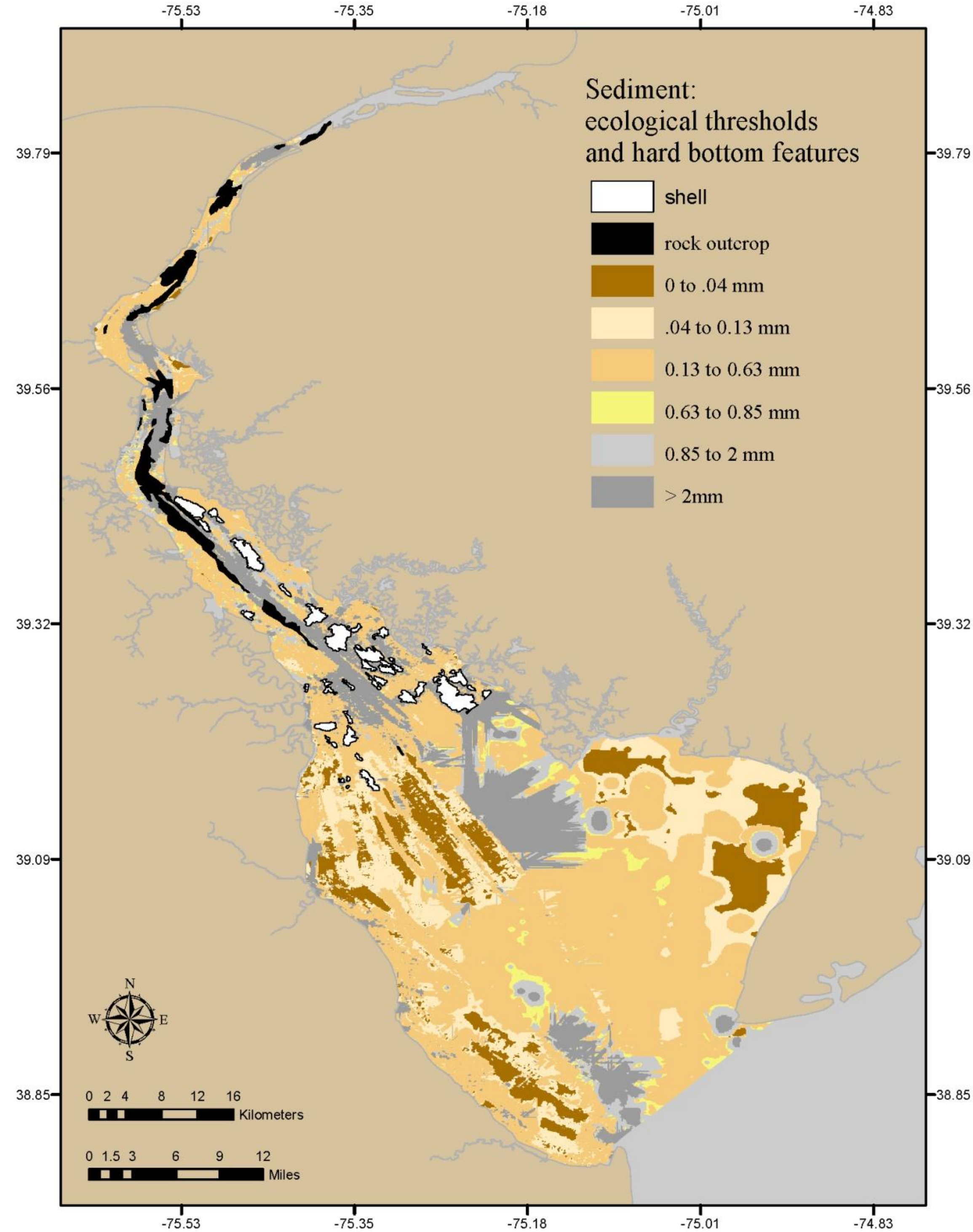


Figure 5. Soft sediment interpolation overlaid with hard bottom and shell areas. Hard bottom areas are cretaceous outcrops composed of highly compacted sand and silt. These data are a conservative representation of hard bottom areas of the bay and, particularly for shell, do not represent their entire distribution in the bay.

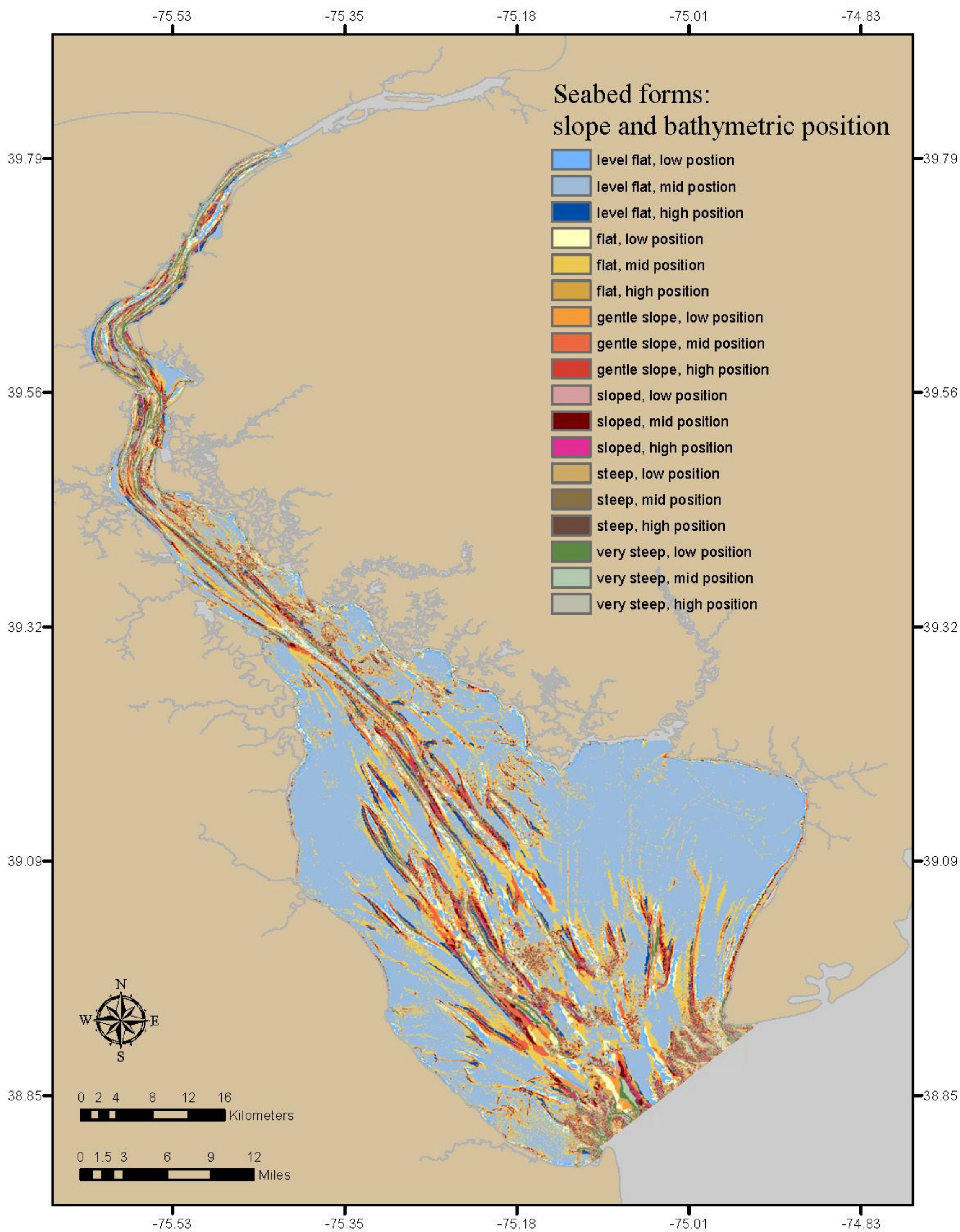


Figure 6. The eighteen-part seabed form model based on slope and position.

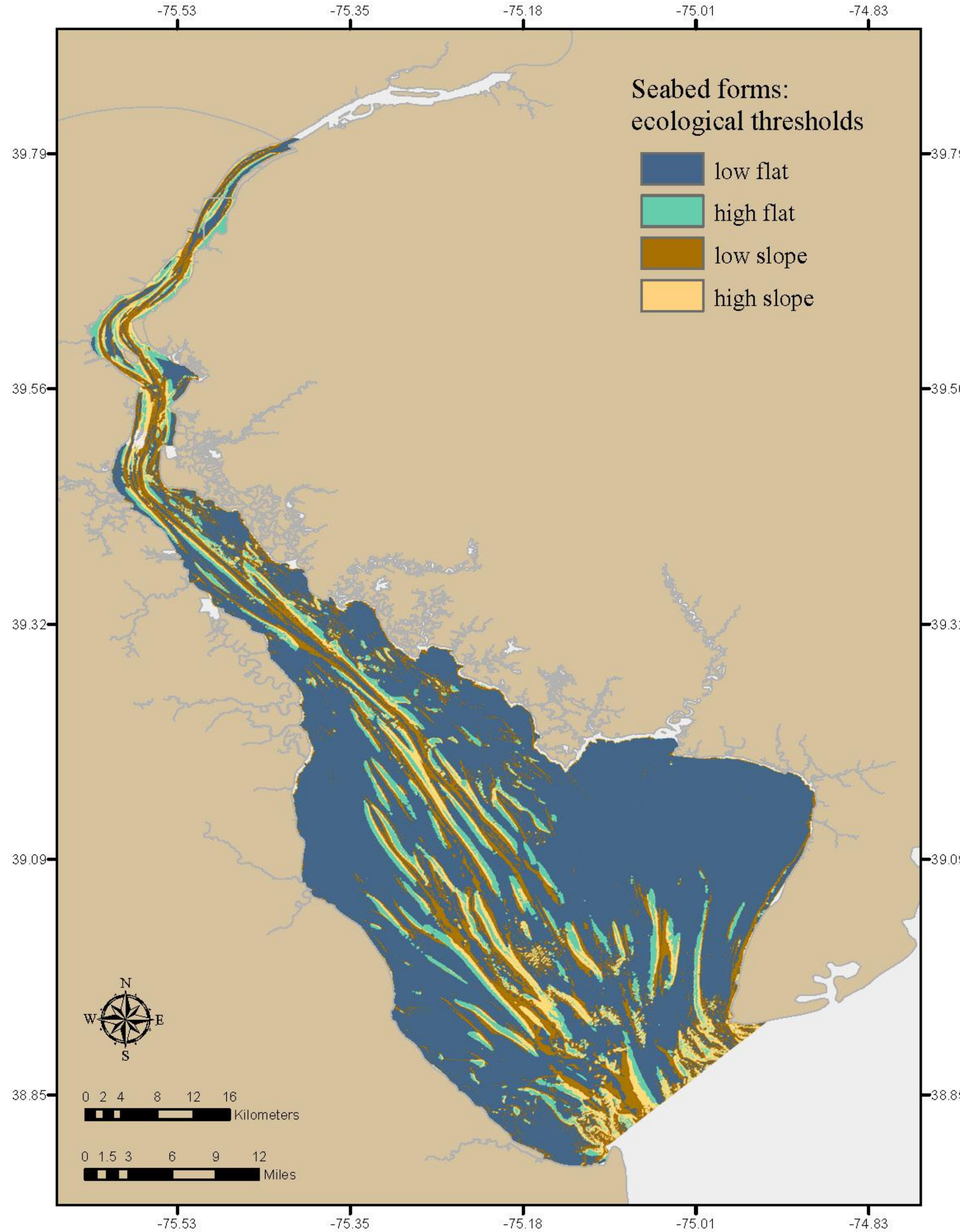


Figure 7. The simplified four-part seabed form model.

Table 1. Thresholds and simplification used in the seabed form model.

	Relative Position		
Slope	**High (positive)**	**Mid (0)**	**Low (negative)**
0 – 0.30 level flat	High flat	High flat	Low flat
0.30 – 1.15 flat	High flat	High flat	Low flat
1.15 – 2.30 gentle slope	High slope	High slope	Low slope
2.30 – 4.20 slope	High slope	High slope	Low slope
4.20 – 8.0 moderate slope	High slope	High slope	Low slope
8.0 + steep slope	High slope	High slope	Low slope

Linking the Organisms to Physical Factors

Recursive partitioning (JMP software package) was used to uncover relationships between benthic communities and the physical environment. Recursive partitioning is a statistical method that creates decision trees to classify members of a common population (the classification types) based on a set of dependent variables (the physical variables).

The analysis required each benthic grab sample to be attributed with the benthic community type that it belonged to, overlaid on the standardized base maps, and attributed with the information on depth, sediment grain size and seabed form appropriate to the point. Additionally, we attributed each point with the distance of the sample from the upper freshwater reach of the Bay as a proxy for salinity, as we had no direct measure of salinity. Regression trees were first built using all variables collectively to identify the variables driving organism differences. After examining the variable contributions collectively, individual regression trees were built for depth, grain size, and seabed forms to identify critical thresholds that separated sets of organism groups from each other. In recursive partitioning, these cuts are identified by exhaustively searching all possible cuts and choosing the one that best separates the dataset into non-overlapping subsets. For example, the first run of the organism groups on the bathymetry data separated the deep water samples from the shallow water samples while identifying the exact depth that most cleanly separated the two sets.

RESULTS

Based on the bathymetry dataset, the region varied in depth from 0 m at the coast to 47 m along the central trench. Critical depth thresholds (Figure 1) for benthic organisms are discussed under the organism classification. The sediment maps show a seafloor dominated by fine sand, along with large regions of finer silt. Hard bottom areas are concentrated in the upper estuary shell areas predominate in the mid and lower estuary (Figures 4 and 5).

Organism Classification

We classified the 246 data samples into 20 organism groups based species composition and abundance. A summary of the characteristic species and their indicator values for each is given in Appendix 1. This appendix includes a species-by-group table that gives diagnostic species for each organism group and shows its distribution across all the organisms groups. The mean indicator value and the probability of this distribution being random chance were calculated for each species in the group that it is most closely associated with. Most species don't have a common name, so only scientific names are listed. Local names can be found in Gosner (1979), Weiss (1995) and Pollock (1998) but they are often only for the family or genus, not the species.

Relationship of the organism groups to the physical factors

Salinity, or at least a proxy of distance from the upper reach, appeared to be the driving explanatory variable. This was most apparent in the initial clustering of the samples into four broad organism groups. These groups corresponded spatially to several published maps of salinity thresholds in the Bay (Figure 8 and 9, Table 2 a and b)

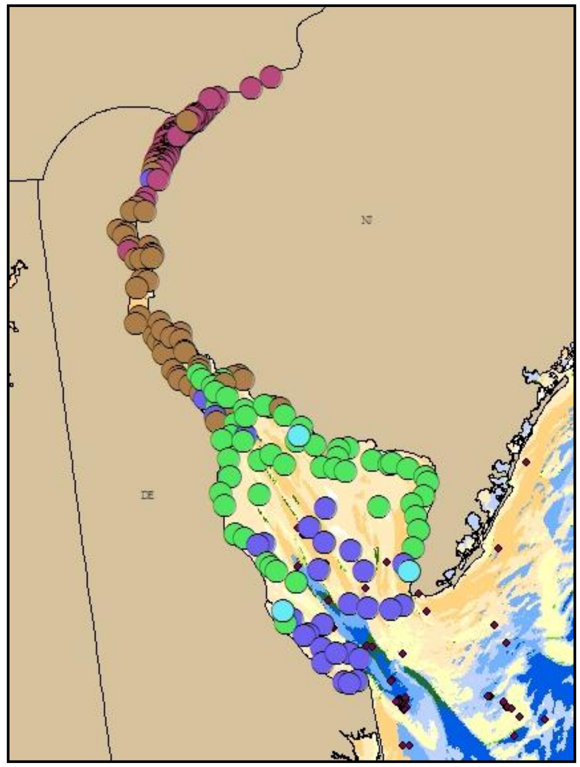
Table 2a. Organisms associated with group 1 (upper bay) and group 22 (mid bay). These patterns correspond spatially with fresh/brackish and brackish areas in the bay, although we did not test salinity.

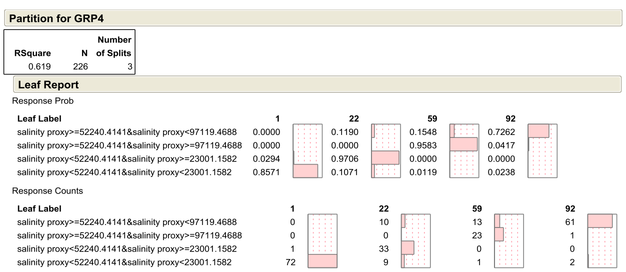
Group 1 Fresh/Brackish (0-23,001 m)	Importance value	P*	Group 22 Brackish (23,001 -52,240 m)	Importance value	P*
Annelida : Oligochaeta			**Annelida : Oligochaeta**		
Limnodrilus hoffmeisteri	44.9	0.0002	Tubificoides spp.	32.6	0.0002
Limnodrilus maumeensis	10	0.0026	**Annelida : Polychaeta**		
Limnodrilus udekemianus	13	0.0004	Boccardiella ligerica	26.9	0.0002
Tubificidae imm.	51.7	0.0002	Neanthes succinea	21.9	0.0002
Annelida : Polychaeta			**Arthropoda : Amphipoda**		
Marenzelleria viridis	31	0.0002	Leptocheirus plumulosus	7	0.0952
Arthropoda : Amphipoda			**Arthropoda : Isopoda**		
Apocorophium lacustre	26.8	0.0002	Cyathura polita	45.7	0.0002
Gammarus daiberi	55.5	0.0002	**Mollusca : Bivalvia**		
Arthropoda : Chironomidae			Macoma balthica	19.9	0.0002
Cryptochironomus sp.	7.8	0.0168	Macoma mitchelli	7.2	0.0336
Polypedilum halterale-grp.	28	0.0002	Mulinia lateralis	14.4	0.0126
Procladius sp.	6.5	0.0158	Rangia cuneata	19.7	0.0002
Arthropoda : Isopoda			**Nemertina**		
Cassidinidea ovalis	7.8	0.0092	Carinoma tremaphoros	22.1	0.0002
Chiridotea almyra	43.2	0.0002			
Mollusca : Bivalvia					
Corbicula fluminea	37.7	0.0002			
Sphaeriidae	5.2	0.0356			

Table 2b. Organisms associated with group 92 (lower bay) and group 59 (lowest). These patterns correspond spatially with saline and marine areas in the bay, although we did not test salinity.

Group 92 Saline 1 (52,240 -97,119 m)	Importance value	P*	Group 59 Saline 2 (>97,119 m)	Importance value	P*
Annelida : Polychaeta			**Annelida : Oligochaeta**		
Ampharetidae	19	0.0002	Oligochaeta	36.8	0.0002
Diopatra cuprea	6.2	0.0222	**Annelida : Polychaeta**		
Eteone heteropoda	25.3	0.0002	Amastigos caperatus	35.1	0.0002
Exogone dispar	7.8	0.0052	Aricidea catherinae	24.3	0.0002
Glycera dibranchiata	6.7	0.0414	Asabellides oculata	19	0.0004
Glycinde solitaria	58.7	0.0002	Brania wellfleetensis	6.9	0.0208
Heteromastus filiformis	19.4	0.0036	Caulleriella venefica	8.1	0.0028
Leitoscoloplos robustus	18.5	0.0002	Dipolydora socialis	4.2	0.0820
Mediomastus ambiseta	54.5	0.0002	Drilonereis longa	12.1	0.0002
Onuphidae	4.7	0.0340	Glycera americana	10.8	0.0004
Paraprionospio pinnata	25.1	0.0002	Glyceridae	4.2	0.0780
Pectinaria gouldii	38.4	0.0002	Leitoscoloplos spp.	20.8	0.0004
Podarkeopsis levifuscina	4.7	0.0384	Nephtyidae	21.6	0.0002
Polycirrus eximius	4.4	0.0648	Nephtys bucera	10.8	0.0016
Polydora cornuta	15.2	0.0014	Nephtys picta	24.3	0.0002
Sabellaria vulgaris	20.8	0.0002	Nereididae	8.1	0.0026
Spiochaetopterus costarum	36.1	0.0002	Paraonis fulgens	6.6	0.0180
Streblospio benedicti	32.4	0.0002	Parapionosyllis longicirrata	18.9	0.0002
Arthropoda : Amphipoda			Phyllodoce arenae	16.5	0.0004
Ampelisca abdita	48.2	0.0002	Polynoidae	5.4	0.0246
Ampelisca spp.	5.7	0.0660	Scoloplos spp. Or Scolelepis spp	12.1	0.0002
Ampelisca vadorum	17.4	0.0002	Sphaerosyllis erinaceus	5.4	0.0222
Batea catharinensis	5.8	0.0176	Spiophanes bombyx	16.2	0.0002
Cerapus tubularis	17.2	0.0008	Tharyx sp. A	38.8	0.0002
Elasmopus laevis	4.7	0.0328	**Arthropoda : Amphipoda**		
Gammarus palustris	10.9	0.0012	Acanthohaustorius intermedius	5.4	0.0264
Incisocalliope aestuarius	4.4	0.0674	Acanthohaustorius millsi	5.4	0.0228
Paracaprella tenuis	11.3	0.0042	Americhelidium americanum	9.4	0.0030
Arthropoda : Cumacea			Ampelisca verrilli	23.4	0.0002
Cyclaspis varians	28	0.0002	Ericthonius brasiliensis	10.9	0.0026
Leucon americanus	35.1	0.0002	Haustorius canadensis	8.1	0.0042
Arthropoda : Decapoda			Listriella barnardi	5.4	0.0268
Eurypanopeus depressus	7.8	0.0056	Microprotopus raneyi	15.9	0.0006
Arthropoda : Isopoda			Monocorophium tuberculatum	22.6	0.0002
Edotea triloba	37.9	0.0002	Parametopella cypris	5.4	0.0274
Synidotea laticauda	14	0.0012	Protohaustorius cf. deichmannae	18.9	0.0002
Chordata : Ascidiacea			Rhepoxynius hudsoni	20.2	0.0002
Molgula manhattensis	18.7	0.0002	Unciola serrata	17.5	0.0004
Cnidaria : Anthozoa			**Arthropoda : Cumacea**		
Diadumene leucolena	8	0.0174	Oxyurostylis smithi	23.3	0.0002
Edwardsia elegans	6.2	0.0210	**Arthropoda : Decapoda**		
Mollusca : Gastropoda			Brachyura	6.8	0.0130
Acteocina canaliculata	57.4	0.0002	Pagurus spp.	14.2	0.0002
Astyris lunata	10.6	0.0058	Pinnixa retinens	5.4	0.0266
Boonea seminuda	6.3	0.0152	Pinnixa spp.	5.9	0.0320
Crepidula fornicata	6.2	0.0222	**Arthropoda : Isopoda**		
Eupleura caudata	6.2	0.0186	Chiridotea caeca	8.1	0.0058
Ilyanassa obsoleta	14.1	0.0002	**Arthropoda : Tanaidacea**		
Odostomia engonia	32.3	0.0002	Tanaissus psammophilus	8.1	0.0042
Rictaxis punctostriatus	68.3	0.0002	**Chordata : Ascidiacea**		
Nemertina			Ascidiacea	9.1	0.0046
Amphiporus bioculatus	21.9	0.0002	**Chordata : Cephalochordata**	5.4	0.0280
Carinomella lactea	13	0.0022	Branchiostoma caribaeum	5.4	0.0280
Micrura leidyi	17.9	0.0004	**Mollusca : Bivalvia**		
Platyhelminthes : Turbellaria			Cyclocardia borealis	5.4	0.0244
Stylochus ellipticus	25	0.0002	Ensis directus	32.3	0.0002
			Gemma gemma	9.4	0.0926
			Nucula proxima	18.8	0.0002
			Spisula solidissima	13.5	0.0002
			Tellina agilis	65.3	0.0002
			Yoldia limatula	8.1	0.0040
			Mollusca : Gastropoda		
			Crepidula plana	7.5	0.0118
			Crepidula spp.	26.9	0.0002
			Kurtziella atrostyla	5.9	0.0322
			Nassarius trivittatus	14.4	0.0006
			Nudibranchia	6.3	0.0370
			Polinices duplicatus	5.9	0.0282
			Nemertina		
			Cerebratulus lacteus	5.1	0.0638
			Nemertina	12.3	0.0090

Figure 8. The distribution of the four broad organism groups across the bay. Data samples are color coded to groups where purple corresponds to group 1 (distance 0-23,001 m, "fresh/brackish"); brown corresponds to group 22 (distance 23,001 to 54,000, "brackish"); green corresponds to group 91 (distance 54,000 to 97,119 m, "saline"), and blue corresponds to group 59 (distance > 97,119 m "saline"). A list of the organisms found in each group is given in table 2 These groups are strongly separated by position in the bay which likely corresponds with salinity (R^2 0.619). Details shown in chart below where the bars show the proportion of samples that fall within the each criterion.





Partition for GRP4

RSquare	N	Number of Splits
0.619	226	3

Leaf Report

Response Prob

Leaf Label	1	22	59	92
salinity proxy>=52240.4141&salinity proxy<97119.4688	0.0000	0.1190	0.1548	0.7262
salinity proxy>=52240.4141&salinity proxy>=97119.4688	0.0000	0.0000	0.9583	0.0417
salinity proxy<52240.4141&salinity proxy>=23001.1582	0.0294	0.9706	0.0000	0.0000
salinity proxy<52240.4141&salinity proxy<23001.1582	0.8571	0.1071	0.0119	0.0238

Response Counts

Leaf Label	1	22	59	92
salinity proxy>=52240.4141&salinity proxy<97119.4688	0	10	13	61
salinity proxy>=52240.4141&salinity proxy>=97119.4688	0	0	23	1
salinity proxy<52240.4141&salinity proxy>=23001.1582	1	33	0	0
salinity proxy<52240.4141&salinity proxy<23001.1582	72	9	1	2

Distance from the freshwater upper bay was the single best explanatory variable ($R^2 = 0.61$), followed by bathymetry, grain size and seabed form. To determine what thresholds were important for each variable we ran the recursive partitioning analysis separately for each variable alone to see what cutoffs best separated the 19 organism groups from each other. We also ran tested these individually within the samples from the four position groups shown in figure 7. From this we extracted thresholds that were consistent both for the whole data set and within the four groups (Table 3)

Table 3. Thresholds for distance, depth, grain size and seabed forms derived from the organism data.

Distance from Fresh (m)	**Depth Zones (m)**	**Ave Grain Size (mm)**	**Seabed Forms**
0	0	0	Low flat (slope 1-2, position 1)
23,001	-1.89*	0.04	High flat (slope 1-2, position 2)
52,240	-4.44	0.13	Low slope (slope 3-6, position 1)
97,119	-5.25***	0.63***	High slope (slope 3-6, position 2)
	-7.64	0.85	
		2	

Benthic Habitat Types and Ecological Marine Units

The benthic habitat types we identified are presented in the following section of this document. Because the final results are a product of several steps, e.g. the macrofauna classification; the identification of relationships between the organism groups and the factors of depth, grain size and topography; and the mapping of benthic environments, the results and details on each step are provided separately in the appendices.

Two separate, but closely related final maps were created. The Ecological Marine Units (EMU) represent all four-way combinations of depth, sediment grain size, salinity, and seabed forms based on the ecological thresholds revealed by the benthic-organism relationships (Table 3). Benthic Habitats are EMUs clustered into groups that contain the same species assemblage. The two terms are not synonymous, but they are based on the same information, and thus, represent two perspectives on the seafloor. Essentially, the EMU maps show the full diversity of physical factor combinations, regardless of whether a specific habitat type was identified for the combination. The benthic habitat map shows only the combinations of factors, or groups of combinations, for which a benthic organism group was identified. It should be noted that the numbers of the EMUs and benthic habitats were derived from the statistical relationships and is completely arbitrary.

The Ecological Marine Unit map is based on a slightly simpler version of a Table 3, to emphasize the thresholds that were the most consistent across the whole bay and across the individual groups (Table 4, Figure 8).

Table 4. Thresholds used to create the Ecological Marine Units (Figure 8).

Distance from Fresh (m)	Depth Zones (m)	Ave Grain Size (mm)	Seabed Forms
0	0	0	Low flat (slope 1-2, position 1)
23,001	-1.89	0.04	High flat (slope 1-2, position 2)
52,240	-5.25	0.63	Low slope (slope 3-6, position 1)
97,119	< -5.25	2	High slope (slope 3-6, position 2)

The threshold and models used to map the benthic habitats were simpler and the maps should be considered schematic (Figure 9). To create the habitat map a separate model was developed within in “salinity” group (e.g. groups shown in figure 7 based on distance from the upper bay) because the analysis suggested that there were relatively different ecological correlates driving the patterns within each area (Table 5). Creating a more naturalistic map will require better information on salinity.

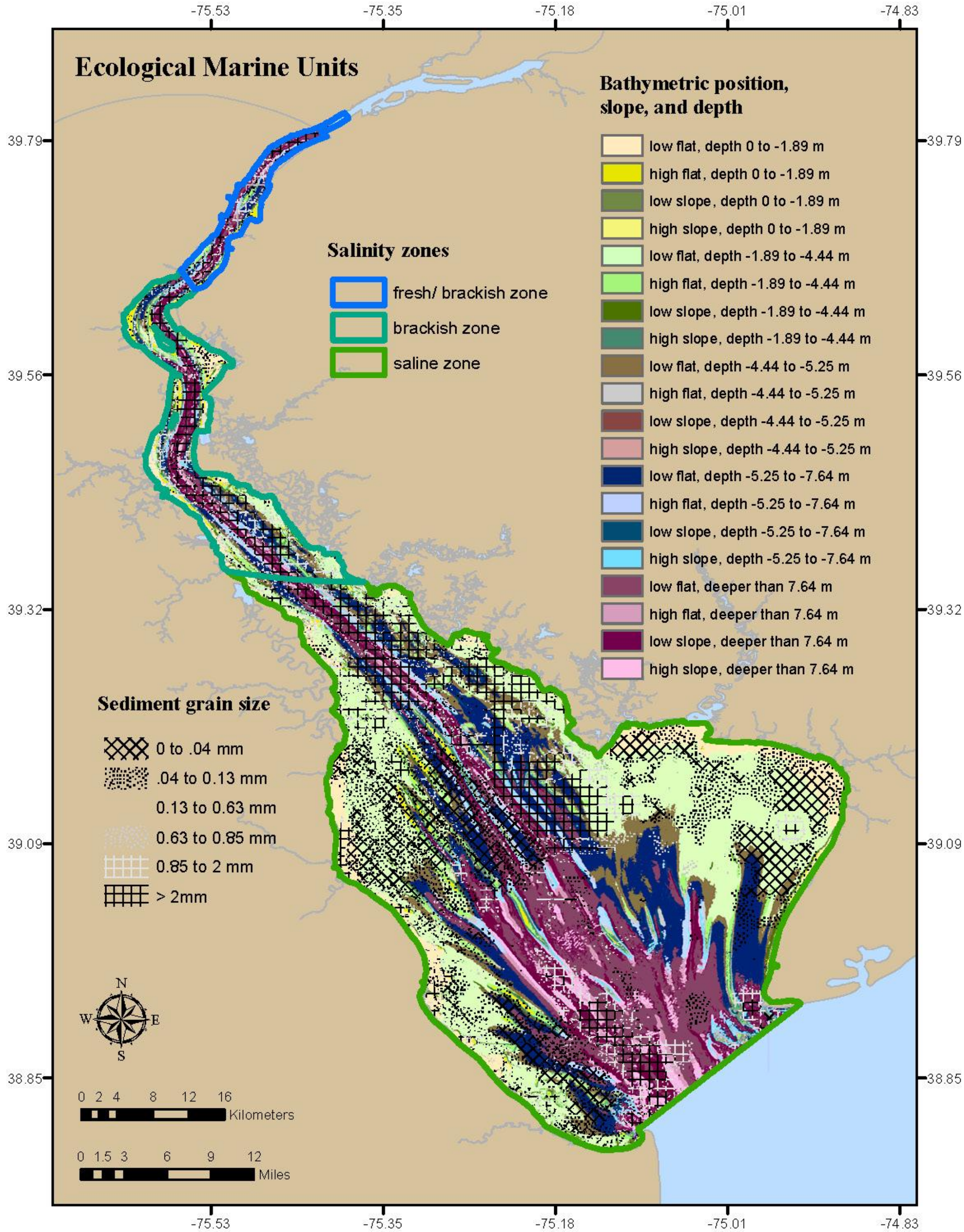


Figure 9. Ecological Marine Units of Delaware Bay

Appendix V: Benthic Habitats of the Delaware Bay

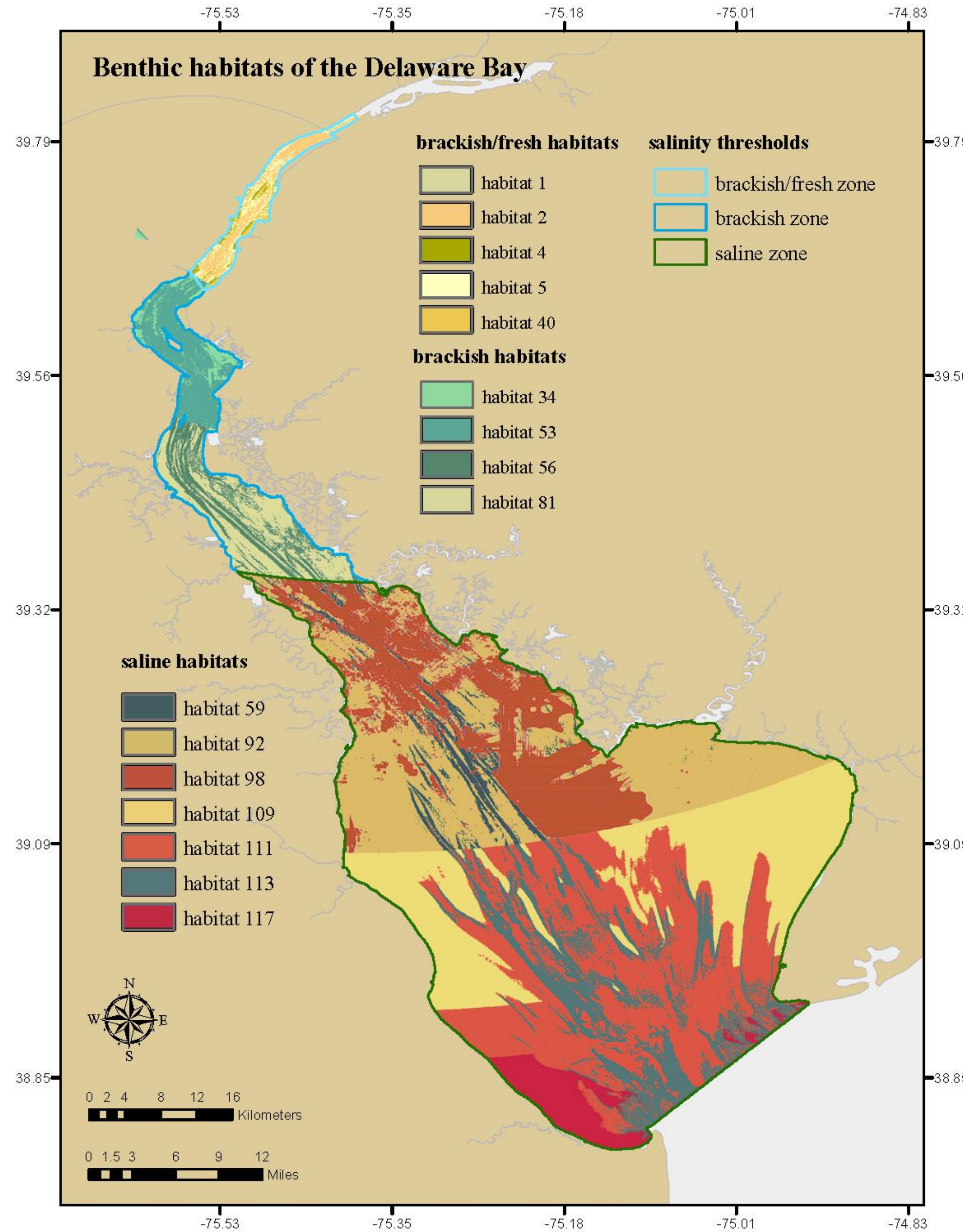


Figure 10. Benthic habitats of the Delaware Bay.

Table 5. Thresholds used in creating the benthic habitat map. The separation criteria are shown in the first column with distance and depth in meters, and sediment grain size in mm. How well the combination of criteria separates each group from the other groups can be seen in the table. For example, 14 of the 18 samples of group 98 were at a distance between 52,240 m and 82,640 m and on sediment grain size over 0.63 mm.

"SALINE" GROUP (Distance from fresh > 52,240)		**Groups**								
Rsquare = 0.533, N= 100 , Splits = 9	Most likely	**59**	**91**	**92**	**98**	**109**	**111**	**113**	**117**	**133**
Distance>=82,640 & depth<-5.25 m & Slope< 3	Group 111					1	6	5	3	
Distance>=82,640 & depth<-5.25 & Slope>=3	Group 113							5		
Distance>=82,640 & depth>=-5.25 & Distance<100,567	Group 109		1	9		8			1	
Distance>=82,640 & depth>=-5.25 & Distance>=100,567 & Distance<106,235	Group 111					1	4			
Distance>=82,640 & depth>=-5.25 & Distance>=100567.609 & Distance>=106,235	Group 117/133						1		3	3
Distance<82,640 & avg grainsize>=0.63	Group 98			3	14	1				
Distance<82,640 & avg grainsize<0.63 & Slope<3	Group 92		2	19	1	5				
Distance<82,640 & avg grainsize<0.63 & Slope>=3	Group 59/91	1	2	1	1					
"BRACKISH" GROUP (Distance from fresh > 23,001-52,240)		**Groups**								
Rsquare = 0.533, N= 100 , Splits = 9	Most likely	**22**	**34**	**53**	**56**	**81**				
Distance>=37,367 & Slope<3	Group 81			1	1	19				
Distance>=37,367 & Slope>=3	Group 56			1	3	3				
Distance<37,367 & Distance>=13,254 & avg grainsize<0.198	Group 34		9	1						
Distance<37,367 & Distance>=13,254 & avg grainsize>=0.198	Group 53	1	2	5	1					
"FRESH/BRACKISH" GROUP (Distance from fresh < 23,001)		**Groups**								
Rsquare = 0.361, N= 73	Most likely	**1**	**2**	**4**	**5**	**16**	**40**			
avg grainsize<0.64 & avg grainsize>=0.26	Group 5	2		5	8	4				
avg grainsize<0.64 & avg grainsize<0.26 & Distance>=10,227 & Position<3	Group 40		1	1	2	1	1			
avg grainsize<0.64 & avg grainsize<0.26 & Distance>=10,227 & Position>=3	Group 4	1	1	4						
avg grainsize<0.64 & avg grainsize<0.26 & Distance<10,227	Group 1	11	4			3				
avg grainsize>=0.64 & Position<9	Group 2 or 4	3	6	9						
avg grainsize>=0.64 & Position>=9	Group 1	6								

LIST OF FIGURES

LITERATURE CITED

Allee, R.J., M. Detheir, D. Brown, L. Deegan, R.G. Ford, T.F. Hourigan, J. Maragos, C. Schoch, K. Sealey, R. Twilley, M.P. Weinstein and M. Yoklavich. 2000. Marine and estuarine ecosystem and habitat classification. NOAA Technical Memorandum NMFS-F/SPO-43.

Anderson, T.J. and M.M. Yoklavich. 2007. Multiscale habitat associations of deepwater demersal fishes off central California. Fishery Bulletin 105:168-179.

Auster, P.J. 2006. Linking seafloor habitat mapping protocols to management and policy needs. Funding application to US Environmental Protection Agency.

Auster, P.J., K. Joy and P.C. Valentine. 2001. Fish species and community distributions as proxies for seafloor habitat distributions: the Stellwagen Bank National Marine Sanctuary example (Northwest Atlantic, Gulf of Maine). Environmental Biology of Fishes 60:331-346.

Brown, B. 1993. A classification system of marine and estuarine habitats in Maine: an ecosystem approach to habitats. Augusta, Maine: Maine Natural Areas Program, Department of Economic and Community Development.

Brown, S.K. 2002. Our living oceans benthic habitat classification system. NOAA NMFS Office of Science and Technology.

Charton, J.A. and A. Perez Ruzafa. 1998. Correlation between habitat structure and a rocky reef fish assemblage in the southwest Mediterranean. Marine Ecology 19:111-128.

Connor, D.W., J. Allen, N. Golding, K. Howell, L. Lieberknecht, K. Northen, and J. Reker. 2004. The national marine habitat classification for Britain and Ireland, version 04.05. Joint Nature Conservation Committee. http://www.jncc.gov.uk/pdf/04_05_introduction.pdf.

Danovaro, R., C. Gambi, A. Dell'Anno, C. Corinaldesi, S. Fraschetti, A. Vanreusel, M. Vincx, and A.J. Gooday. 2008. Exponetial decline of deep-sea ecosystem functioning linked to benthic biodiversity loss. Current Biology 18(1): 1-8.

Davies, C., D. Moss, and M.O. Hill. 2004. EUNIS Habitat Classification. European Environment Agency.

DeLong, A.K. and J.S. Collie. 2004. Defining essential fish habitat: a model-based approach. Narragansett, Rhode Island: Rhode Island Sea Grant.

Dethier, M.N. 1992. Classifying marine and estuarine natural communities: an alternative to the Cowardin system. Natural Areas Journal 12(2): 90-100.

Divins, D.L., and D. Metzger. NGDC Coastal Relief Model. http://www.ngdc.noaa.gov/mgg/coastal/coastal.html. Accessed 2008.

Dufrene, M. and P. Legendre. 1997. Species assemblages and indicator species: the need for a flexible asymmetrical approach. Ecological Monographs 67(3): 345-366.

Etter, R.J., and J.F. Grassle. 1992. Patterns of species diversity in the deep sea as a function of sediment particle size diversity. Nature 360: 576-578.

European Environment Agency. 1999. European Topic Centre on Nature Conservation. Work Programme: Task 4.3 EUNIS Habitat Classification, Draft Final Report. http://www.searchmesh.net/.

Fels, J. and R. Zobel. 1995. Landscape position and classifying landtype mapping for statewide DRASTIC mapping project. North Carolina State University. Technical Report. VEL.95.1 to North Carolina Department of Environment, Health and Natural Resources, Division of Environmental Management.

Fogarty, M.J. and C. Keith. 2007. Delineation of regional ecosystem units on the U.S. Northeast Continental Shelf. Woods Hole, Massachusetts: Northeast Fisheries Science Center, National Marine Fisheries Service.

Folk, R.L. 1954. The distinction between grain size and mineral composition in sedimentary rock nomenclature. Journal of Geology 62 (4): 344-359.

Gaspar, M.B., S. Carvalho, R. Constantino, J. Tata-Regala, J. Cúrdia, and C.C. Monteiro. 2009. Can we infer dredgefishing effort from macrobenthic community structure? ICES Journal of Marine Science 66: 2121–2132.

Gosner, K.L. 1979. A field guide to the Atlantic seashore. Boston, Massachusetts: Houghton Mifflin.

Greene, J.K., M.G. Anderson, J. Odell, and N. Steinberg, eds. 2010. The Northwest Atlantic Marine ecoregional assessment: species, habitats and ecosystems: phase one. Boston, Massachusetts: The Nature Conservancy, Eastern U.S. Division.

Greene, H.G., J.J. Bizzarro, J.E. Tilden, H.L. Lopez, and M.D. Erdey. 2005. The benefits and pitfalls of geographic information systems in marine benthic habitat mapping. In Place Matters, eds. Wright, D.J. and Scholz, A. J. Portland, Oregon: Oregon State University Press.

Greene, H.G., M M. Yoklavich, R M. Starr, V M. O'Connell, W W. Wakefield, D E. Sullivan, J.E. McRea Jr., and G.M. Caillet. 1999. A classification scheme for deep seafloor habitats. Oceanologica Acta 22: 663-678.

Gulf of Maine Council on the Environment. 2005. Workshop proceedings: marine habitats in the Gulf of Maine. http://www.gulfofmaine.org/council/publications/marine-habitat-workshop-proceedings.pdf.

Kostylev, V.E, B.J. Todd, G.B. Fader, R.C. Courtney, G.D. M. Cameron, and R.A. Pickrill. 2001. Benthic habitat mapping on the Scotian Shelf based on multibeam bathymetry, surficial geology and sea floor photographs. Marine Ecology Progress Series 219: 121-137.

Kutcher, T.E. 2006. A comparison of functionality between two coastal classification schemes developed within the National Oceanic and Atmospheric Administration. Silver Spring, Maryland: Report to NOAA/NOS/OCRM.

Levin, L.A., R.J. Etter, M.A. Rex, A.J. Gooday, C.R. Smith, J. Pineda, C.T. Stuart, R.R. Hessler, and D. Pawson. 2001. Environmental influences on regional deep-sea species diversity. Annual Review of Ecology, Evolution, and Systematics 32: 51-93.

Lindholm, J.B., P.J. Auster, and L S. Kaufman. 1999. Habitat-mediated survivorship of juvenile (0-year) Atlantic cod *Gadus morhua*. Marine Ecology Progress Series 180: 247-255.

Lough, R.G., P.C. Valentine, D.C. Potter, P. . Auditore, G.R. Bolz, J.D. Neilson, and R.I. Perry. 1989. Ecology and distribution of juvenile cod and haddock in relation to sediment type and bottom currents on eastern Georges Bank. Marine Ecology Progress Series 56: 1-12.

Lund, K. and A.R. Wilbur. 2007. Habitat feasibility study of coastal and marine environments In Massachusetts. Massachusetts Office of Coastal Zone Management. Boston, MA. 31 pp.

Madden, C.J., K. Goodin, R.J. Allee, G. Cicchetti, C. Moses, M. Finkbeiner, and D. Bamford. 2009. Coastland Marine Ecological Classification Standard. NOAA and NatureServe.

Mahon, R., S.K. Brown, K.C. T. Zwanenburg, D. B. Atkinson, K. . Buja, L. Clafin, G.D. Howell, M.E.onaco, R. N. O'Boyle, and M. Sinclair. 1998. Assemblages and biogeography of demersal fishes of the eastcoast of North America. Canadian Journal of Fisheries and Aquatic Sciences 55: 1704-1738.

McCune, B. and J.B Grace. 2002. Analysis of Ecological Communities. MjM software design. Oregon, USA. www.pcord.com.

NERRS (National Estuarine Research Reserve System). 2000. Evaluations of marine and estuarine ecosystem and habitat classification. NOAA Technical Memorandum NMFS-F/SPO-43. National Ocean Service, Office of Coast Survey, US Bathymetric & Fishing Maps. http://www.ngdc.noaa.gov/mgg/bathymetry/. Accessed 2008.

Norse, E.A. 1993. Global marine biological diversity. Center for Marine Conservation. Washington, DC: Island Press.

Pollock, L.W. 1998. A practical guide to the marine animals of Northeast North America. New Brunswick, New Jersey: Rutgers University Press.

Reid, J.M., J.A. Reid, C.J. Jenkins, M.E. Hastings, S.J. Williams, and L.J. Poppe. 2005. usSEABED: Atlantic coast offshore surficial sediment data release. U.S. Geological Survey Data Series 118, version 1.0. http://pubs.usgs.gov/ds/2005/118/.

Roworth, E. and R. Signell. 1998. Construction of a digital bathymetry for the Gulf of Maine. U.S. Geological Survey Publications 98-901. http://pubs.usgs.gov/of/1998/of98-801/bathy/.

Schratzberger, M., and S. Jennings. 2002. Impacts of chronic trawling disturbance on meiofaunal communities. Marine Biology 141: 991-1000.

Serrano, A., and I. Preciado. 2007. Environmental factors structuring polychaete communities in shallow rocky habitats: role of physical stress versus habitat complexity. Helgoland Marine Research 61: 17-29.

Shepard, F.P. 1954. Nomenclature based on sand-silt-clay ratios. Journal of Sedimentary Petrology 24: 151-158.

Stevenson D., L. Chiarella, D. Stephan, R. Reid, K. Wilhelm, J. McCarthy and M. Pentony. 2004. Characterization of the fishing practices and marine benthic ecosystems of the northeast US shelf and an evaluation of the potential effects of fishing on essential habitat. NOAA Technical Memorandum NMFS NE 181.

Theroux, R.B. and R.L. Wigley. 1998. Quantitative composition and distribution of the macrobenthic invertebrate fauna of the continental shelf ecosystems of the northeastern United States. NOAA Technical Report NMFS 140.

Thrush, S.F., J.E. Hewitt, V.J. Cummings, P.K. Dayton, M. Cryer, S.J. Turner, G.A. Funnell, R.G. Budd, C.J. Milburn, and M.R. Wilkinson. 1998. Disturbance of the marine benthic habitat by commercial fishing: Impacts at the scale of the fishery. Ecological Applications (8): 866-879.

Todd, B.J. and H.G. Greene. 2008. Mapping the Seafloor for Habitat Characterization. Geological Association of Canada.

Valentine, P.C., B.J. Todd, and V.E. Kostylev. 2005. Classification of marine sublittoral habitats, with application to the northeastern North America region. American Fisheries Society Symposium 41:183-200. http://woodshole.er.usgs.gov/project-pages/stellwagen/index.html.

Weiss, H.M. 1995. Marine animals of Southern New England and New York. State geological and natural history survey of Connecticut. Connecticut Department of Environmental Protection Bulletin 115.

Wentworth, C.K. 1922. A scale of grade and class terms for clastic sediments. Journal of Geology 30: 377–392.

Wigley, R.L. and R.B. Theroux. 1981. Atlantic continental shelf and slope of the United States-macrobenthic invertebrate fauna of the Middle Atlantic Bight region-faunal composition and quantitative distribution. Department of Interior, Geological Survey. Professional Paper 529-N.

World Wildlife Fund and Conservation Law Foundation. 2006. Marine ecosystem conservation for New England and Maritime Canada: a science-based approach to identifying priority areas for conservation. Boston, Massachusetts: Conservation Law Foundation and Halifax: Nova Scotia, Canada: World Wildlife Fund.

APPENDIX: Descriptions of the Benthic Habitats.

Table 1a. Organisms associated with groups (clusters) 1 through 53. The last two columns give the P-value for a Monte Carlo test of significance as an indicator of the group, and the average importance value in the group (average abundance times average frequency.

Cluster	Taxa Group	Species Name	Average of p*	Average of IV
1	Annelida : Oligochaeta	Isochaetides freyi	0.2979	8.3
		Tubificidae imm. with capilliform chaetae	0.0002	21.9
	Arthropoda : Amphipoda	Leptocheirus plumulosus	0.0836	12.1
	Arthropoda : Chironomidae	Chironomidae pupae	0.8596	4.2
		Chironomus sp.	0.8610	4.2
		Cryptochironomus sp.	0.0706	13.0
		Procladius sp.	0.0182	20.8
	Arthropoda : Diptera	Ceratopogonidae	0.3005	8.3
	Arthropoda : Isopoda	Cyathura polita	0.0006	12.6
	Arthropoda: Chironomidae	Stenochironomus spp.	0.8646	4.2
	Mollusca : Bivalvia	Musculium spp.	0.8616	4.2
		Pisidium spp.	0.1630	12.5
1 Total			0.3651	
2	Annelida : Polychaeta	Marenzelleria viridis	0.0018	16.7
	Arthropoda : Isopoda	Chiridotea almyra	0.0002	33.1
2 Total			0.0010	24.9
4	Annelida : Oligochaeta	Branchiura sowerbyi	0.6549	5.0
	Arthropoda : Amphipoda	Apocorophium lacustre	0.0012	18.8
	Arthropoda : Chironomidae	Axarus sp.	0.4127	7.1
		Rheotanytarsus sp.	0.6549	5.0
	Mollusca : Gastropoda	Littoridinops tenuipes	0.2084	10.0
4 Total			0.3864	9.2
5	Arthropoda : Amphipoda	Gammarus daiberi	0.0124	18.0
	Arthropoda : Chironomidae	Polypedilum halterale-grp.	0.0014	27.2
		Tanypus neopunctipennis	0.2719	10.0
	Arthropoda : Cirripedia	Balanus improvisus	0.0108	25.5
	Arthropoda : Decapoda	Rhithropanopeus harrisii	0.0010	32.6
	Arthropoda : Isopoda	Cassidinidea ovalis	0.0018	45.5
	Arthropoda : Mysidacea	Mysidae	0.2707	10.0
	Mollusca : Bivalvia	Corbicula fluminea	0.0004	35.5
		Sphaeriidae	0.7660	3.7
	Mollusca : Gastropoda	Laevapex fuscus	0.2769	10.0
5 Total			0.1613	21.8
16	Annelida : Oligochaeta	Limnodrilus hoffmeisteri	0.0002	40.3
		Limnodrilus maumeensis	0.0656	13.2
		Limnodrilus spp.	0.1880	11.1
		Limnodrilus udekemianus	0.3023	7.3
		Quistidrilus multisetosus	0.1880	11.1
		Tubificidae imm. with capilliform chaetae	0.3035	8.1
16 Total			0.1746	15.2
22	Arthropoda : Amphipoda	Ameroculodes species complex	0.1698	9.8
22 Total			0.1698	9.8
34	Arthropoda : Chironomidae	Coelotanypus sp.	0.3785	8.3
	Mollusca : Bivalvia	Rangia cuneata	0.0018	30.9
34 Total			0.1902	19.6
53	Annelida : Polychaeta	Boccardiella ligerica	0.0002	54.1
	Platyhelminthes : Turbellaria	Euplana gracilis	0.1452	12.5
53 Total			0.0727	33.3

Table 1b. Organisms associated with groups (clusters) 56 through 91. The last two columns give the P-value for a Monte Carlo test of significance as an indicator of the group, and the average importance value in the group (average abundance times average frequency.

Cluster	Taxa Group	Species Name	Average of p*	Average of IV
56	Arthropoda : Amphipoda	Caprellidae	0.0736	20.0
	Arthropoda : Chironomidae	Harnischia sp.	0.0964	16.6
	Cnidaria : Anthozoa	Anthozoa	0.1976	10.9
		Diadumene leucolena	0.0078	29.7
	Mollusca : Bivalvia	Macoma balthica	0.0178	19.0
	Mollusca : Gastropoda	Pyramidellidae	0.5263	6.0
		Turbonilla interrupta	0.2160	10.7
56 Total			0.1622	16.1
81	Annelida : Polychaeta	Heteromastus filiformis	0.0036	18.9
	Arthropoda : Chironomidae	Parakiefferiella sp.	0.7506	4.3
	Arthropoda : Cumacea	Leucon americanus	0.0002	26.1
	Mollusca : Bivalvia	Mulinia lateralis	0.0070	23.5
		Mya arenaria	0.4021	6.4
	Nemertina	Carinoma tremaphoros	0.1938	9.5
81 Total			0.2262	14.8
91	Annelida : Polychaeta	Eteone foliosa	0.0768	20.0
		Leitoscoloplos spp.	0.0054	21.4
		Paraonis fulgens	0.0004	55.9
		Scoloplos spp.	0.0232	18.9
	Arthropoda : Amphipoda	Haustorius canadensis	0.0040	29.5
		Pseudohaustorius caroliniensis	0.0760	20.0
		Rhepoxynius hudsoni	0.1158	12.0
	Arthropoda : Decapoda	Ovalipes ocellatus	0.0760	20.0
	Arthropoda : Isopoda	Chiridotea caeca	0.0040	32.0
	Mollusca : Bivalvia	Gemma gemma	0.0056	22.3
		Mytilidae	0.0768	20.0
		Tellinidae	0.1272	15.2
	Nemertina	Micrura leidyi	0.0066	19.5
91 Total			0.0460	23.6
92	Annelida : Oligochaeta	Tubificoides spp.	0.0002	16.6
	Annelida : Polychaeta	Leitoscoloplos fragilis	1.0000	3.1
		Onuphidae	0.2681	9.4
		Polygordius spp.	0.2655	9.4
	Arthropoda : Decapoda	Pagurus longicarpus	1.0000	3.1
	Mollusca : Gastropoda	Ilyanassa obsoleta	0.0178	20.0
	Platyhelminthes : Turbellaria	Turbellaria	0.9646	2.3
92 Total			0.5023	9.1

Table 1c. Organisms associated with groups (clusters)92 through 98. The last two columns give the P-value for a Monte Carlo test of significance as an indicator of the group, and the average importance value in the group (average abundance times average frequency.

Cluster	Taxa Group	Species Name	Average of p*	Average of IV
92	Annelida : Oligochaeta	Tubificoides spp.	0.0002	16.6
	Annelida : Polychaeta	Leitoscoloplos fragilis	1.0000	3.1
		Onuphidae	0.2681	9.4
		Polygordius spp.	0.2655	9.4
	Arthropoda : Decapoda	Pagurus longicarpus	1.0000	3.1
	Mollusca : Gastropoda	Ilyanassa obsoleta	0.0178	20.0
	Platyhelminthes : Turbellaria	Turbellaria	0.9646	2.3
92 Total			0.5023	9.1
98	Annelida : Polychaeta	Exogone dispar	0.0044	31.2
		Glycera dibranchiata	0.1090	10.9
		Glycinde solitaria	0.0002	18.3
		Hydroides dianthus	0.3247	7.2
		Maldanidae	0.5447	4.9
		Mediomastus ambiseta	0.0002	15.6
		Neanthes succinea	0.0002	30.4
		Paranaitis speciosa	0.1600	12.5
		Pectinaria gouldii	0.0030	26.4
		Podarkeopsis levifuscina	0.2480	10.0
		Polycirrus eximius	0.0476	17.9
		Polydora cornuta	0.0008	35.8
		Sabellaria vulgaris	0.0002	37.3
		Sabellidae	0.5695	6.2
		Scoloplos rubra	0.1154	12.4
		Streblospio benedicti	0.0002	16.9
	Arthropoda : Amphipoda	Batea catharinensis	0.0664	15.5
		Elasmopus laevis	0.0508	18.8
		Gammarus palustris	0.0016	43.8
		Incisocalliope aestuarius	0.0420	18.3
		Melita nitida	0.0196	19.4
		Mucrogammarus mucronatus	0.7636	4.2
		Paracaprella tenuis	0.0160	21.6
		Unciola serrata	0.0128	20.1
	Arthropoda : Cumacea	Cyclaspis varians	0.0030	24.4
	Arthropoda : Decapoda	Dyspanopeus sayi	0.5695	6.2
		Euceramus praelongus	0.5695	6.2
		Eurypanopeus depressus	0.0026	31.2
	Arthropoda : Isopoda	Edotea triloba	0.0004	19.3
		Synidotea laticauda	0.0158	21.7
	Chordata : Ascidiacea	Molgula manhattensis	0.0004	49.1
	Mollusca : Bivalvia	Anadara ovalis	0.5695	6.2
		Anomia simplex	0.5715	6.2
		Crassostrea virginica	0.5673	6.2
		Geukensia demissa	0.8230	3.7
		Ischadium recurvum	0.5673	6.2
		Lyonsia hyalina	0.1370	12.6
		Mercenaria mercenaria	0.4147	6.3
	Mollusca : Gastropoda	Astyris lunata	0.0438	14.1
		Boonea seminuda	0.1264	12.0
		Busycon carica	0.5719	6.2
		Crepidula fornicata	0.0078	25.0
		Epitonium rupicola	0.1746	12.5
		Epitonium spp.	0.9636	2.3
		Eupleura caudata	0.1078	14.1
		Nudibranchia	0.0574	13.9
		Odostomia engonia	0.0044	23.7
		Urosalpinx cinerea	0.8608	3.1
98 Total			0.2256	16.4

Table 1d. Organisms associated with groups (clusters) 109 through 111. The last two columns give the P-value for a Monte Carlo test of significance as an indicator of the group, and the average importance value in the group (average abundance times average frequency.

Cluster	Taxa Group	Species Name	Average of p*	Average of IV
109	Annelida : Polychaeta	Diopatra cuprea	0.0758	16.1
		Dispio uncinata	0.5697	6.2
		Eteone longa	0.5661	6.2
		Loimia medusa	0.5625	6.2
		Lumbrineres hebes	0.5541	6.2
		Paraprionospio pinnata	0.0010	34.3
		Scolelepis texana	0.5697	6.2
		Spiochaetopterus costarum	0.0002	24.8
		Spionidae	0.5625	6.2
	Arthropoda : Amphipoda	Ampelisca abdita	0.0002	23.0
		Ampelisca vadorum	0.0300	18.3
		Cerapus tubularis	0.0020	28.7
	Arthropoda : Decapoda	Caridea	0.5541	6.2
	Arthropoda : Merostomata	Limulus polyphemus	0.1264	11.8
	Arthropoda : Mysidacea	Americamysis spp.	0.5697	6.2
	Cnidaria : Anthozoa	Edwardsia elegans	0.3709	7.1
	Echinodermata : Holothuroidea	Leptosynapta tenuis	0.5625	6.2
	Mollusca : Gastropoda	Acteocina canaliculata	0.0002	22.4
		Rictaxis punctostriatus	0.0002	32.9
	Nemertina	Amphiporus bioculatus	0.0158	17.1
	Platyhelminthes : Turbellaria	Stylochus ellipticus	0.0344	14.5
109 Total			0.2728	14.6
111	Annelida : Oligochaeta	Haplotaxis sp.	0.3219	9.1
	Annelida : Polychaeta	Arabellidae	0.3163	9.1
		Aricidea catherinae	0.0044	35.2
		Asabellides oculata	0.0002	35.9
		Eteone heteropoda	0.0322	14.5
		Glycera americana	0.0432	20.0
		Lumbrineridae	0.6337	5.4
		Microphthalmus sczelkowii	0.4331	6.8
		Microphthalmus spp.	0.0648	14.8
		Nereididae	0.1892	11.7
		Orbiniidae	0.3231	9.1
		Paranaitis speciosa	0.6327	5.4
		Phyllodoce arenae	0.0002	42.5
		Polynoidae	0.0594	18.2
		Terebellidae	0.3163	9.1
	Arthropoda : Amphipoda	Americhelidium americanum	0.0946	13.9
		Ampelisca spp.	0.6269	4.9
		Ampelisca verrilli	0.0006	39.3
		Caprella penantis	0.3245	9.1
		Caprella spp.	0.2999	9.1
		Ericthonius brasiliensis	0.0514	14.4
		Microprotopus raneyi	0.0208	18.8
		Monocorophium tuberculatum	0.0192	20.5
	Arthropoda : Cumacea	Oxyurostylis smithi	0.0002	36.7
	Arthropoda : Decapoda	Crangon septemspinosa	0.2999	9.1
		Pinnixa spp.	0.3587	7.9
	Arthropoda : Mysidacea	Neomysis americana	0.3289	8.0
	Echinodermata : Asteroidea	Asteroidea	0.3163	9.1
	Echinodermata : Echinoidea	Echinoidea	0.3193	9.1
	Echinodermata : Holothuroidea	Pentamera pulcherrima	0.6341	5.4
	Mollusca : Bivalvia	Nucula proxima	0.0004	38.8
		Pandora gouldiana	0.3177	9.1
		Tellina agilis	0.0090	21.0
	Mollusca : Gastropoda	Busycon canaliculatum	0.3187	9.1
		Crepidula convexa	0.2999	9.1
		Crepidula plana	0.5549	5.4
		Crepidula spp.	0.0086	24.5
		Kurtziella atrostyla	0.0354	18.7
		Polinices duplicatus	0.3421	8.1
	Nemertina	Carinomella lactea	0.0150	20.7
		Cerebratulus lacteus	0.0644	16.2
111 Total			0.2203	15.7

Table 1e. Organisms associated with groups (clusters) 113 through 133. The last two columns give the P-value for a Monte Carlo test of significance as an indicator of the group, and the average importance value in the group (average abundance times average frequency.

Cluster	Taxa Group	Species Name	Average of p*	Average of IV
113	Annelida : Polychaeta	Amastigos caperatus	0.0012	35.0
		Apoprionospio pygmaea	0.2621	10.0
		Capitella capitata complex	0.2663	10.0
		Caulleriella venefica	0.1328	13.7
		Cirriformia grandis	0.2721	10.0
		Clymenella torquata	0.5055	6.2
		Dipolydora commensalis	0.2681	10.0
		Dipolydora socialis	0.7694	3.9
		Drilonereis longa	0.0066	26.4
		Glyceridae	0.6769	4.5
		Harmothoe extenuata	0.2681	10.0
		Nephtys picta	0.0022	38.9
		Polydora websteri	0.2663	10.0
		Polygordius spp.	0.3841	8.1
		Scoloplos spp.	0.2667	10.0
		Sigambra tentaculata	0.2667	10.0
		Spio setosa	0.2621	10.0
		Spiophanes bombyx	0.0344	15.8
	Arthropoda : Amphipoda	Listriella barnardi	0.0556	20.0
		Listriella smithi	0.2603	10.0
	Arthropoda : Decapoda	Pinnixa chaetopterana	0.2603	10.0
		Pinnixa retinens	0.0530	20.0
	Chordata : Cephalochordata	Branchiostoma caribaeum	0.0582	20.0
	Echinodermata : Echinoidea	Echinoidea	0.2667	10.0
	Mollusca : Bivalvia	Ensis directus	0.0012	33.1
		Tellina tenella	0.2721	10.0
	Mollusca : Gastropoda	Nassarius trivittatus	0.0790	12.4
		Vitrinella spp.	0.2721	10.0
113 Total			0.2370	14.0
117	Annelida : Polychaeta	Ampharetidae	0.0130	18.1
		Glycera spp.	0.4813	5.7
		Leitoscoloplos robustus	0.1520	9.6
		Nephtyidae	0.0590	14.7
		Nephtys incisa	0.1122	14.3
		Tharyx sp. A	0.0030	24.4
	Arthropoda : Amphipoda	Parametopella cypris	0.2410	8.7
	Arthropoda : Decapoda	Pagurus pollicaris	0.0998	14.3
		Pagurus spp.	0.0228	17.2
	Arthropoda : Mysidacea	Americamysis bigelowi	0.1058	14.3
	Mollusca : Bivalvia	Yoldia limatula	0.4287	6.1
117 Total			0.1562	13.4
133	Annelida : Oligochaeta	Oligochaeta	0.0034	28.2
	Annelida : Polychaeta	Brania wellfleetensis	0.0002	74.6
		Euclymene zonalis	0.0124	33.3
		Nephtys bucera	0.0004	41.7
		Parapionosyllis longicirrata	0.0002	71.4
		Sphaerosyllis erinaceus	0.0260	25.6
		Travisia sp. A	0.0124	33.3
	Arthropoda : Amphipoda	Acanthohaustorius intermedius	0.0002	66.7
		Acanthohaustorius millsi	0.0002	66.7
		Bathyporeia parkeri	0.0134	33.3
		Protohaustorius cf. deichmannae	0.0012	34.4
		Protohaustorius wigleyi	0.0134	33.3
	Arthropoda : Decapoda	Brachyura	0.0438	19.2
	Arthropoda : Tanaidacea	Tanaissus psammophilus	0.0002	100.0
	Chordata : Ascidiacea	Ascidiacea	0.0040	31.4
	Mollusca : Bivalvia	Cyclocardia borealis	0.0002	66.7
		Macoma mitchelli	0.0996	11.5
		Spisula solidissima	0.1080	13.3
	Nemertina	Nemertina	0.0184	19.9
133 Total			0.0188	42.3

APPENDIX VI:

RECOMMENDED CONSERVATION STRATEGIES BY WATERSHED

Appendix VI: Recommended Conservation Strategies by Watershed

Watershed Name	**Region**	**Priority Strategies**								
		Forest Conservation	Wetland Conservation	Agricultural Land Protection and Conservation	Aquatic Connectivity Restoration	Streamflow Management	Groundwater/ Baseflow Conservation	Tidal Marsh Restoration	Shoreline Conservation	Marsh Room-to-Move Protection
		F	**W**	**A**	**C**	**D**	**G**	**T**	**S**	**M**
Upper Delaware River	Upper Delaware	●	●	●		●	●			
Lower East Branch-Delaware River	Upper Delaware	●		●		●				
Lower West Branch-Delaware River	Upper Delaware	●		●		●				
Middle West Branch-Delaware River	Upper Delaware	●		●						
Upper West Branch-Delaware River	Upper Delaware	●		●						
Upper East Branch-Delaware River	Upper Delaware	●	●	●	●					
Middle East Branch-Delaware River	Upper Delaware	●		●		●				
Beaver Kill	Upper Delaware	●	●							
Willowemoc Creek	Upper Delaware	●	●				●			
Middle Delaware River	Upper Delaware	●		●		●				
Neversink River	Upper Delaware	●	●	●	●	●				

Appendix VI: Recommended Conservation Strategies by Watershed

Watershed Name	Region	Priority Strategies								
		Forest Conservation	Wetland Conservation	Agricultural Land Protection and Conservation	Aquatic Connectivity Restoration	Streamflow Management	Groundwater/ Baseflow Conservation	Tidal Marsh Restoration	Shoreline Conservation	Marsh Room-to-Move Protection
		F	W	A	C	D	G	T	S	M
Mongaup River	Upper Delaware	●	●	●	●	●				
Basher Kill	Upper Delaware	●	●				●			
Halfway Brook-Delaware River	Upper Delaware	●				●	●			
Shohola Creek	Upper Delaware	●	●			●	●			
Lackawaxen River	Upper Delaware	●	●			●	●			
Wallenpaupack Creek	Upper Delaware	●	●			●	●			
West Branch-Wallenpaupack Creek	Upper Delaware	●	●			●	●			
Middle Creek	Upper Delaware	●	●		●		●			
Lower Delaware River	Upper Delaware	●	●	●		●				
Dyberry Creek	Upper Delaware	●	●		●		●			
West Branch-Lackawaxen River	Upper Delaware	●	●		●	●	●			
Bushkill	Central Mainstem	●	●			●	●			

Appendix VI: Recommended Conservation Strategies by Watershed

Watershed Name	**Region**	**Priority Strategies**								
		Forest Conservation	Wetland Conservation	Agricultural Land Protection and Conservation	Aquatic Connectivity Restoration	Streamflow Management	Groundwater/ Baseflow Conservation	Tidal Marsh Restoration	Shoreline Conservation	Marsh Room-to-Move Protection
		F	W	A	C	D	G	T	S	M
Raymondskill Creek - Delaware River	Central Mainstem	●	●	●		●	●			
Flat Brook - Delaware River	Central Mainstem	●	●							
Paulins Kill River - Delaware River	Central Mainstem	●	●	●	●	●				
Brodhead Creek	Central Mainstem	●	●	●	●	●				
Pocono Creek	Central Mainstem	●		●	●					
Pequest River - Delaware River	Central Mainstem	●	●	●	●					
Bushkill Creek - Delaware River	Central Mainstem			●						
Musconetcong River	Central Mainstem	●	●	●	●	●				
Upper Delaware River	Central Mainstem	●	●	●						
Tohickon Creek - Delaware River	Central Mainstem	●	●	●	●	●				
Lower Delaware River	Central Mainstem	●	●	●		●				
Upper Lehigh River	Lehigh	●	●		●	●	●			

Appendix VI: Recommended Conservation Strategies by Watershed

Watershed Name	**Region**	**Priority Strategies**								
		Forest Conservation	Wetland Conservation	Agricultural Land Protection and Conservation	Aquatic Connectivity Restoration	Streamflow Management	Groundwater/ Baseflow Conservation	Tidal Marsh Restoration	Shoreline Conservation	Marsh Room-to-Move Protection
		F	**W**	**A**	**C**	**D**	**G**	**T**	**S**	**M**
Tobyhanna Creek	Lehigh	●	●		●	●	●			
Middle Lehigh River	Lehigh	●				●	●			
Pohopoco Creek	Lehigh	●		●	●	●	●			
Aquashicoloa Creek	Lehigh	●		●			●			
Jordan Creek	Lehigh			●						
Lower Lehigh River	Lehigh	●	●	●						
Little Lehigh Creek	Lehigh			●						
Little Schuylkill River	Schuylkill	●				●				
Upper Schuylkill River	Schuylkill	●			●	●				
Maiden Creek	Schuylkill	●		●						
Tulpehocken Creek	Schuylkill	●		●						
Manatawny Creek	Schuylkill	●	●	●	●					
Middle Schuylkill River	Schuylkill	●	●	●		●				

Appendix VI: Recommended Conservation Strategies by Watershed

Watershed Name	Region	Priority Strategies								
		Forest Conservation	Wetland Conservation	Agricultural Land Protection and Conservation	Aquatic Connectivity Restoration	Streamflow Management	Groundwater/ Baseflow Conservation	Tidal Marsh Restoration	Shoreline Conservation	Marsh Room-to-Move Protection
		F	W	A	C	D	G	T	S	M
French Creek	Schuylkill	●	●	●	●					
Perkiomen Creek	Schuylkill	●	●	●	●					
Wissahickon Creek	Schuylkill			●	●					
Lower Schuylkill River	Schuylkill			●	●	●				
Upper Neshaminy Creek	Estuary	●			●	●				
Lower Neshaminy Creek	Estuary	●	●		●	●		●		
Assunpink Creek-Delaware River	Estuary	●	●	●	●	●				
Crosswicks Creek	Estuary	●	●	●	●					●
Assiscunk Creek-Delaware River	Estuary	●	●	●	●	●				
North Branch Rancocas Creek	Estuary	●	●		●					●
South Branch Rancocas Creek	Estuary	●	●		●	●	●			●
Pennypack Creek-Rancocas Creek	Estuary	●		●	●			●		●

Appendix VI: Recommended Conservation Strategies by Watershed

Watershed Name	Region	Priority Strategies								
		Forest Conservation	Wetland Conservation	Agricultural Land Protection and Conservation	Aquatic Connectivity Restoration	Streamflow Management	Groundwater/ Baseflow Conservation	Tidal Marsh Restoration	Shoreline Conservation	Marsh Room-to-Move Protection
		F	W	A	C	D	G	T	S	M
Cooper River-Delaware River	Estuary							●		
Darby Creek-Mantua Creek	Estuary	●	●	●	●			●		
Raccoon Creek-Delaware River	Estuary	●	●	●						●
Salem River-Delaware River	Estuary	●	●	●						●
Alloway Creek	Estuary	●	●	●				●		●
East Branch Brandywine Creek	Estuary	●		●						
West Branch Brandywine Creek	Estuary	●		●	●	●				
Brandywine Creek	Estuary	●	●	●	●	●				
White Clay Creek	Estuary		●	●	●					●
Christina River	Estuary		●	●				●		●
C&D Canal-Red Lion Creek	Estuary			●				●		
Appoquinimink River-Delaware River	Estuary	●	●	●	●					●

Appendix VI: Recommended Conservation Strategies by Watershed

Watershed Name	Region	Priority Strategies								
		Forest Conservation	Wetland Conservation	Agricultural Land Protection and Conservation	Aquatic Connectivity Restoration	Streamflow Management	Groundwater/ Baseflow Conservation	Tidal Marsh Restoration	Shoreline Conservation	Marsh Room-to-Move Protection
		F	W	A	C	D	G	T	S	M
Cohansey River	Delaware Bay	●	●	●		●				
Stow Creek	Delaware Bay	●	●	●				●	●	●
Upper Maurice River	Delaware Bay	●	●	●	●					
Lower Maurice River	Delaware Bay	●	●				●	●	●	●
Dennis Creek	Delaware Bay	●	●		●		●	●	●	●
Smyrna River	Delaware Bay	●	●	●						●
Leipsic River	Delaware Bay	●	●	●				●	●	
St. Jones River	Delaware Bay		●	●	●		●	●	●	
Murderkill River	Delaware Bay	●		●			●	●	●	
Mispillion River	Delaware Bay	●		●			●	●	●	●
Broadkill River	Delaware Bay	●	●				●			●