6

Living Resources

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6 – 1 Horseshoe Crab

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Horseshoe crabs (*Limulus polyphemus*) are benthic (or bottom-dwelling) arthropods that use both estuarine and continental shelf habitats. Although it is called a "crab," it is grouped in its own class (Merostomata), which is more closely related to the arachnids than blue crabs and other crustaceans. Horseshoe crabs, range from the Yucatan peninsula to northern Maine, with the largest population of spawning horseshoe crabs in the world found in the Delaware Bay.

Each spring, adult horseshoe crabs migrate from deep bay waters and the Atlantic continental shelf to spawn on intertidal sandy beaches. Beaches within estuaries, such as the Delaware Bay, are believed to be preferred because they are low energy environments protected from wind and waves, thus reducing the risks of stranding during spawning events. Spawning generally occurs from March through July, with the peak spawning activity occurring on the evening new and full moon high tides in May and June.

Horseshoe crabs are characterized by high fecundity, high egg and larval mortality, and low adult mortality. Horseshoe crabs spawn multiple times per season, laying approximately 3,650 to 4,000 eggs in a cluster. Adult females lay an estimated 88,000 eggs annually. Egg development is dependent on temperature, moisture, and oxygen content of the nest environment. Eggs hatch between 14 and 30 days after fertilization.

Juvenile horseshoe crabs generally spend their first and second summer on the intertidal flats, usually near breeding beaches. As they mature horseshoe crabs move into deeper water, eventually into areas up to a few miles offshore. Horseshoe crabs molt at least 16 to 17 times over 9 to 11 years to reach sexual maturity. Based on growth of epifaunal slipper shells (*Crepidula fornicata*) on their prosoma, horseshoe crabs live at least 17 to 19 years.

Larvae feed on a variety of small polychaetes and nematodes. Juvenile and adult horseshoe crabs feed mainly on molluscs including razor clam (*Ensis spp.*), macoma clam (*Macoma spp.*), surf clam (*Spisula solidissima*), blue mussel (*Mytilus edulis*), wedge clam (*Tellina spp.*), and fragile razor clam (*Siliqua costata*).

Shorebirds feed on horseshoe crab eggs in areas of high spawning densities such as the Delaware Bay. Horseshoe crab eggs are considered essential food for several shorebird species in the Delaware Bay, which is the second largest migratory staging area for shorebirds in North America. Shorebird predation on horseshoe crab eggs has little impact on the horseshoe crab population since horseshoe crabs place egg clusters at depths greater than 10 centimeters, which is deeper than most shorebirds can probe. Eggs utilized by shorebirds are brought to the surface by wave action and burrowing activity by spawning horseshoe crabs. The eggs brought to the surface not consumed by shorebirds or other predators desiccate in a short time in the sun, so do not contribute to productivity of the horseshoe crab population.

It is believed that adult and juvenile horseshoe crabs may make up a significant portion of the loggerhead sea turtle's (*Caretta caretta*) diet. Horseshoe crab eggs and larvae and adults are also a seasonally preferred food item of a variety of invertebrates and finfish, including sharks.

Human activity probably accounts for the greatest proportion of adult horseshoe crab mortality. Between the 1850s and the 1920s, it is estimated that over one million horseshoe crabs were harvested annually for fertilizer and livestock feed. More recently horseshoe crabs have been taken in substantial numbers (eg. the ASMFC estimated that as much as 299,9491 horseshoe crabs were landed annually between 1995 and 1997) to provide bait for other fisheries, including (primarily) the American eel and conch fisheries.

Horseshoe crabs are also collected by the biomedical industry to produce Limulus Amebocyte Lysate (LAL). This industry bleeds individuals and releases the animals live after the bleeding procedure. LAL is used world-wide to test medical products such as flue serum, pace makers, artificial joints, and other items to help ensure public safety from bacterial contamination. No other known procedure has the same accuracy as the LAL test. If LAL became unavailable, it could take years to find a universally accepted replacement. Mortality associated with this use is estimated to be around 15 percent.

6 – 1.1 Description of Indicator

This indicator uses the spawning survey, which is conducted under the direction of the Atlantic States Marine Fisheries Commission's (ASMFC) Interstate Fishery Management Plan for Horseshoe Crab. The survey provides levels of spatial and temporal coverage that are effective for understanding trends in spawning activity at the bay-wide scale. Begun in 1999, this survey is published annually as a report to the ASMFC.

Beaches are sampled by volunteers using a stratified random approach. Sampling occurs 2 days prior, day of, and 2 days after the peak moon events (full and new moons) and at the highest of the daily high tides, which is the second or evening high tide. Protocol and data sheets and training are provided to volunteers. Each beach is sub-sampled using quadrats along transects that have random starts. Approximately 100 quadrats are sampled per beach. The quadrats are placed at the high tide line and all horseshoe crabs that are at least halfway in the quadrat are counted and differentiated by sex.

The objective of the spawning survey was to estimate an index of spawning activity based on horseshoe crab density. It is important to recognize that this survey gives an estimate of density and should not be used to estimate population size. Instead it provides a useful measure of relative abundance or density of spawners and trends in spawning density.

6 – 1.2 Present Status

The latest report available is the 1999-2010 Spawning Survey Report, published May 30, 2011. In 2010 spawning peaked in late May, and most spawning took place during May. Spawning is well correlated with water temperatures.

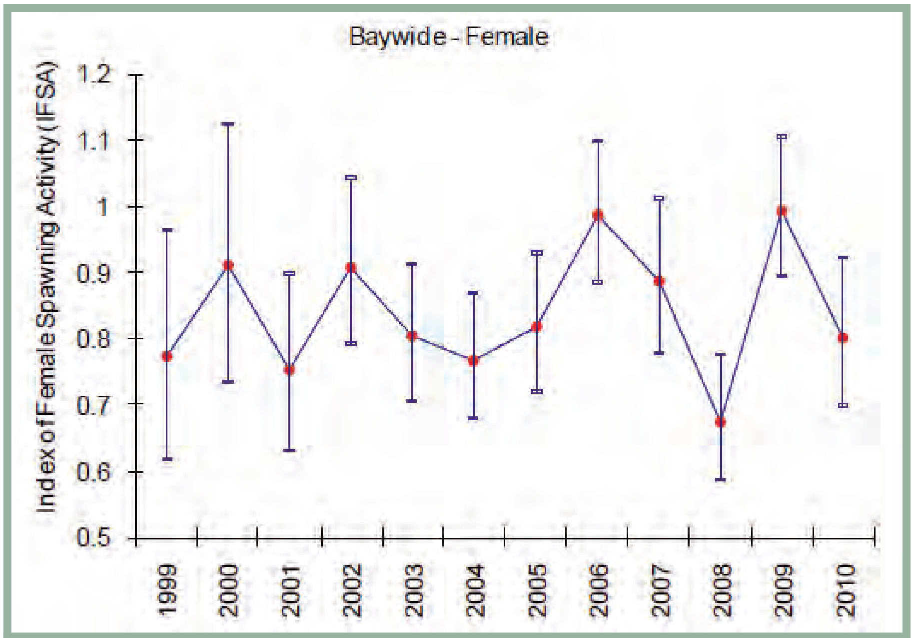

Fig. 6.1.1. Index of female horseshoe crab spawning activity (IFSA) for the Delaware Bay from 1999 to 2000. Error bars are 90% confidence intervals.

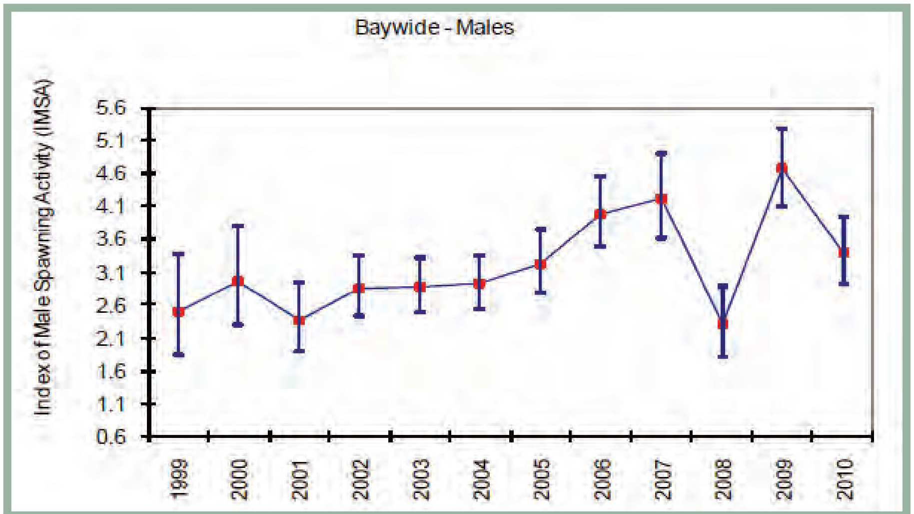

Fig. 6.1.2. Index of male horseshoe crab spawning activity (IMSA) for the Delaware Bay from 1999 to 2009. Error bars are 90% confidence intervals.

6 – 1.3 Past Trends

Little data is available for measuring trends prior to 1990, but the population probably declined in the early 1900s due to overharvest and then increased through the 1970s. Bait overharvest led to another decline in the 1990s. There was no significant trend in female spawning activity between 1999 and 2009. Male spawning activity shows a positive trend during this time period.

6 – 1.4 Future Predictions

The ASMFC has implemented monitoring programs and restricted harvest of horseshoe crab with stated goals of maintaining a sustainable population for current and future generations of the fishing and non-fishing public, migrating shorebirds, and other dependent wildlife, including federally listed sea turtles. The National Marine Fisheries Service has established a horseshoe crab sanctuary off the mouth of Delaware Bay, the Carl N. Shuster Sanctuary. Watermen have voluntarily implemented the use of bait bags that reduce their need for bait by preventing bait from being consumed by non target species. The biomedical industry has voluntarily implemented management practices to reduce stress to animals being held for bleeding. These measures can be expected to allow the spawning population to increase over time by reducing harvest and indirect mortality.

While there are indications that management actions to limit harvests, combined with voluntary reductions in bait use by watermen, are allowing the population to increase, the current population trend for females does not yet show a positive trend and does not appear to be spawning at densities high enough to provide sufficient surface eggs to support historic levels of shorebirds during the spring stopover. Because horseshoe crabs are long-lived and do not reproduce until at they are eight-to-12 years old, it can take a decade or more for management actions to result in a measurable increase in the spawning population.

6 – 1.5 Actions and Needs

In order to better understand horseshoe crab population trends and their interaction with shorebirds, a cooperative effort between the ASMFC, States, US Geological Survey, and the US Fish & Wildlife Service has resulted in an Adaptive Management Framework for recommending harvest levels based upon population models that link red knot populations with horseshoe crab populations. Under this framework, competing models that describe the dependence and interaction of red knots and shorebirds can be evaluated over time by monitoring the populations. Two monitoring programs are essential to implement this framework: The Horseshoe Crab Trawl Survey and the Shorebird Monitoring Program at Delaware Bay. It will be critical to ensure funding for these two monitoring programs in order to increase understanding and reduce uncertainty regarding how these two populations interact.

6 – 1.6 Summary

Management of horseshoe crab harvest coupled with voluntary measures by the bait and biomedical industries can be expected to allow spawning populations of horseshoe crabs in Delaware Bay to increase over time. However, due to overharvest in the past, and the length of time needed (8-12 years) for horseshoe crabs to reach maturity, populations have not yet shown significant increases in terms of spawning densities relative to what were believed to be historical levels. Shorebirds dependent upon eggs that are exhumed by wave action and high densities of spawning horseshoe crabs are still at low levels and it is unclear whether current levels of surface eggs are high enough to support current levels of red knots and other shorebirds during typical weather conditions.

Since a portion of the red knot population that passes through Delaware Bay winters at the tip of South America and breeds in the high Arctic, other factors outside of Delaware Bay can, and probably are, affecting these populations. Work to help better understand the dependence of red knots on Delaware Bay is being carried out, in part, through a cooperative Adaptive Management Framework.

Horseshoe Crab Glossary

Arachnid - terrestrial invertebrates, including the spiders, scorpions, mites, and ticks

Arthropod – animals that have an exoskeleton (external skeleton), a segmented body, and jointed appendages. Arthropods include the insects, arachnids, crustaceans, and others.

Benthic - relating to the bottom of a sea or lake or to the organisms that live there.

Crustacean – a very large group of arthropods which includes animals such as crabs, lobsters, crayfish, shrimp, krill, and barnacles.

Epifaunal - benthic animals that live on the substrate (as a hard sea floor) or on other organisms.

Estuarine – of or pertaining to a semi-enclosed body of water connected to the sea as far as the tidal limit or the salt intrusion limit and receiving freshwater runoff; however the freshwater inflow may not be perennial, the connection to the sea may be closed for part of the year and tidal influence may be negligible.

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Fecundity - generally refers to the ability to reproduce. It can be thought of as fertility, or the actual reproductive rate of an organism or population.

Horseshoe crab - arthropods that live primarily in shallow ocean waters and come on shore for mating. Horseshoe crabs resemble crustaceans, but belong to a separate subphylum, Chelicerata, and are therefore more closely related to spiders and scorpions. The earliest horseshoe crab fossils are found in strata from the late Ordovician period, roughly 450 million years ago.

Intertidal flats - non-vegetated, soft sediment habitats, found between mean high-water and mean low-water and are generally located in estuaries.

Merostomata - class of primitive arthropods of the subphylum Chelicerata distinguished by their aquatic mode of life and the possession of abdominal appendages which bear respiratory organs; the only three living species known today from this group are horseshoe crabs.

Mollusk - a large group of invertebrate animals generally called shellfish. Molluscs are highly diverse, not only in size and in anatomical structure, but also in behaviour and in habitat. Included in this group are squid, cuttlefish, and octopus (among the most neurologically-advanced of all invertebrates); snails and slugs (the most numerous mollusks); chitons (known for their segmented shells); and bivalves including clams, mussels, scallops, and oysters.

Molt - to cast off the outer shell as arthropods do when they grow.

Nematode – this group of organisms, also known as round worms, are the most numerous multicellular animals on earth. A handful of soil will contain thousands of the microscopic worms, many of them parasites of insects, plants, or animals. Free living species play an important role in the decomposition process. Parasitic species includes such well known examples as hookworms and heart worms.

Polychaete - a group of worms, generally marine, in which each body segment has a pair of fleshy protrusions called parapodia that bear many bristles, called chaetae, which are made of chitin. Common representatives include the lugworm and the sandworm or clam worm.

Prosoma – the head or front part of the body in horseshoe crabs.

Quadrats - a square (of either metal, wood, or plastic) used in ecology and geography to isolate a sample for study or measurement. The quadrat is suitable for sampling plants, slow-moving animals, and some aquatic organisms.

Red knot - a medium sized shorebird which breeds in the Arctic and winters in South America, passing through Delaware Bay where it eats horseshoe crab eggs.

Sanctuary - a place of refuge and protection, for example a refuge for wildlife where hunting or fishing is illegal.

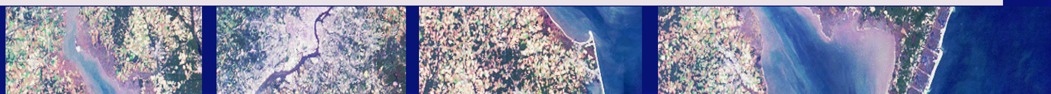
Shorebird – a group of birds characterized by long and thin legs with little to no webbing on their feet, generally found close to water. Shorebirds include the avocets, oystercatchers, phalaropes, plovers, sandpipers, stilts, snipes, and turnstones.

Spatial - relating to, occupying, or having the character of space.

Spawning - refers to the eggs and sperm released or deposited, usually into water, by aquatic animals.

Temporal - of or relating to time.

Transects - a path along which one moves and counts occurrences of the plants and animals.



6 – 2 Atlantic sturgeon

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Historically, Atlantic sturgeon, Acipenser oxyrinchus oxyrinchus, were reported in the Delaware River as well as most major rivers on the eastern seaboard of North America ranging from the Hamilton Inlet on the Atlantic coast of Labrador to the St. Johns River in Florida. Through biological classification, this species is placed in the family Acipenseridae, a category of ancient bony fishes that have been able to survive as a group in contemporary environmental conditions (Detlaff, et al. 1993). Atlantic sturgeon are late-maturing anadromous fish that may live up to 50 years, reach lengths up to 14 feet (4.3 m), and weigh over 800 pounds (364 kg). They are distinguished by armor-like plates called “scutes“ and a long snout. They are opportunistic benthic feeders filtering quantities of mud along with their food which consists of aquatic invertebrates (Vladykov and Greely 1963).

U.S. Fish & Wildlife Service

Fig. 6.2.1. Mature Female Atlantic sturgeon.

Mature Atlantic sturgeon (Fig. 6.2.1) migrate from the sea to fresh water in advance of spawning with females, first maturing at ages ranging from 7-19 years old in South Carolina to 27-28 years in the St. Lawrence River. Males can be somewhat younger at first spawning. The Delaware River population of Atlantic sturgeon has been determined to be genetically similar to those of the Hudson River, but through range-wide genetic analysis of nuclear DNA at least 6 sub-populations were suggested including one for the Delaware River distinguishable from the Hudson River stock (King et al. 2001). In the Delaware River, first-maturing females are likely to be at least 15 years old. Spawning occurs in flowing fresh or estuarine waters with a hard bottom. Shed eggs are 2-3 mm in diameter and become sticky when fertilized, frequently becoming attached to hard substrates or submerged detritus until hatching in several days. After hatching occurs, juveniles remain in fresh water for several years but have been documented to out-migrate to coastal areas in their 3rd year (Sweka, et al. 2006) found that juvenile sturgeon preferred soft bottom habitats at depths greater than 6.3 meters in the Hudson River. Once juveniles out-migrate from their natal river they are known to frequent distant estuary systems (Secor et al. 2000); tagged age-0 fingerlings stocked in the Hudson River in 1994 were found in the Chesapeake and Delaware Bays in 1997 (Bain 1998). Mature individuals also frequent estuaries distant from their natal river. Studies performed in the Hudson River using pop-up satellite archival tags showed that the majority of adult Atlantic sturgeon captured and tagged in the Hudson during spawning season eventually out-migrated to the mid-Atlantic Bight but one individual traveled north to the Bay of Fundy and another went south to coastal Georgia (Erickson et al. 2011). Mature Atlantic sturgeons are of great potential commercial value for both flesh and roe, the latter being known as caviar. Although there is an occasional report of Atlantic sturgeons being caught with rod and reel, the species is not known for recreational fishing importance.

6 – 2.1 Description of Indicator

The portion of the Delaware River basin available as habitat extends from the Delaware Bay to the fall line at Trenton, NJ; a distance of 140 river kilometers (rkm). There are no dams within this reach of the river, thus 100% of the habitat is accessible. However, habitat suitability is unknown due to anthropogenic effects on the historic habitat as a result of: industrial development, dredging, and water quality issues. Very little is known about adult stock size and spawning of Atlantic sturgeon in the Delaware river but based on reported catches in gill nets and by harpoons during the 1830s, they may have spawned as far north as Bordentown, south of Trenton, NJ (Atlantic Sturgeon Status Review Team [ASSRT] 2007). The status of this indicator investigated using data from the 2007 Status Review for Atlantic sturgeon (ASSRT 2007) and data provided by the Delaware Department of Natural Resources and Environmental Control, Division of Fish and Wildlife (DE DNREC) which has conducted directed gill net surveys using variable mesh gill nets. Surveys were conducted in 1991-1998, 2001, 2004, and 2007-2011 to assess the abundance of juvenile and sub-adult Atlantic sturgeon in the lower Delaware River. Collections were performed using gillnets at Fort Mifflin (rkm 148), Tinicum Island (rkm 142), Marcus Hook anchorage (rkm 127), Marcus Hook bar (rkm 122) and Cherry Island Flats (rkm 119) (Fig. 6.2.2). These were preferred areas as they were flat- bottom sites free of snags away from heavy ship traffic, near the freshwater-brackish water interface and out of the main channel in 3-8 meters of depth.

6 – 2.2 Present Status

Due to low range-wide population levels, in 1998 a moratorium on all Atlantic sturgeon harvest in U.S. waters was adopted by the Atlantic States Marine Fisheries Commission, enforceable under the provisions of the 1993 amendments to the Atlantic Coastal Fisheries Cooperative Management Act (P.L. 82-721). More recently, a formal Status Review of the Atlantic sturgeon was performed and published in 2007 resulting in recommendations by the status review team that the species be listed as "threatened" in 3 of the 5 Distinct Population Segments (DPS) identified over its U.S. range. The Delaware and Hudson Rivers together were termed the NY Bight DPS and were considered one of the DPS recommended for threatened status by the Status Review Team (ASSRT 2007). Using these recommendations and others, the National Marine Fisheries Service has issued a final rule with the determination that Atlantic sturgeon in four of the five DPS including the NY Bight are "Endangered", effective April 6, 2012. The only DPS that is considered "threatened" rather than "endangered" is the Gulf of Maine DPS which includes all Atlantic sturgeons that are spawned in the watersheds from the Maine/Canadian border and extending southward to include all associated watersheds draining into the Gulf of Maine as far south as Chatham, MA.

Fig. 6.2.2. 2009 sampling sites (yellow boxes) used as part of an early juvenile Atlantic sturgeon telemetry study by Delaware Department of Fish and Wildlife (DE DFW). Red dots are acoustic receivers. Map courtesy of DE DFW.

Once a species become listed as threatened or Endangered, the Cooperative Endangered Species Conservation Fund provides grants to States and Territories to participate in a wide array of voluntary conservation projects for the listed species. The most current Management Plan for Atlantic sturgeon was written by Taub (1990) and contains recommendations for increasing populations but this plan is somewhat outdated and will be replaced by a recovery plan as required by the Endangered Species Act. http://www.fws.gov/endangered/esa-library/pdf/ESA_basics.pdf.

For the Delaware River, DE DNREC surveys show some apparent decline since 1991 in the relative abundance of late-stage juvenile Atlantic sturgeon (>600 mm TL) in the lower Delaware River (Fig. 6.2.3) but since sub-adults may seasonally wander to non-natal estuaries, these data may not solely reflect fish natal to the Delaware River. However, catches of early stage juveniles (<600 mm total length) increased dramatically beginning in 2009 with the capture of 34 young-of-year fish ranging in size from 178 to 349 mm total length and 51 YOY fish in 2011 (M. Fisher, DNREC, personal communication)(Fig. 6.2.4). This shows that successful spawning took place in the Delaware in 2009 and 2011 and that there is some suitable spawning habitat available. Above average rainfall during the sampling period and a successful spawn as well as targeted sampling in early stage juvenile habitat with small mesh nets likely contributed to the increased early stage juvenile catch rates. Preliminary results of the DE DNREC surveys indicate tagged early-stage juveniles are ranging from New Castle flats, DE to Roebling, NJ with the highest concentration located in the Marcus Hook anchorage (M. Fisher, DNREC, personal communication).

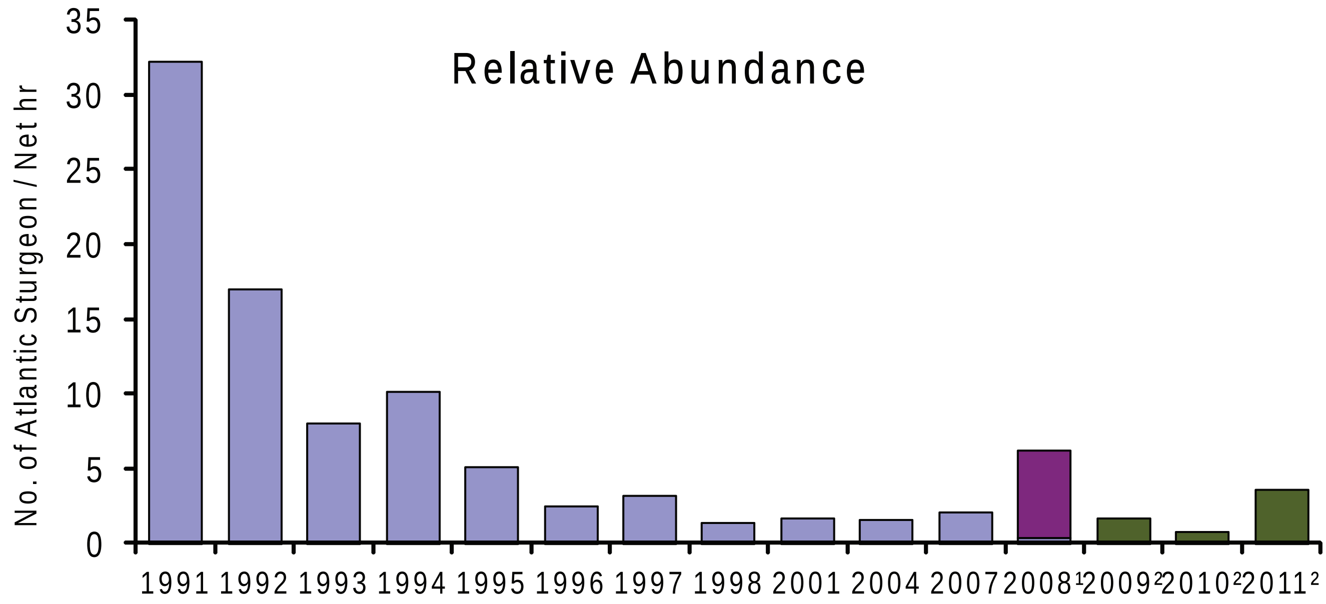


Fig. 6.2.3. Annual catch rates of Atlantic sturgeon in the lower Delaware River from 1991 - 2011 by the Department of Natural Resources and Environmental Control Division of Fish and Wildlife (DE DNREC).

2008[1] overall sampling efficiency increased due to the use of new sampling sites guided by telemetry locations (denoted in red). 2008 abundance at the traditional sites (blue) remained at post 1995 levels. 2009[2] through 2011[2] sampling included new sites and exclusive use of small mesh nets (5, 7.6cm stretch) to target early juvenile sturgeon. Post-2008 data should not be used with earlier data for trend analysis.

The presence of early-stage juveniles in the Marcus Hook anchorage is consistent with findings of Sommerfield and Madsen (2003), that the substrate composition between Marcus Hook and Tinicum Island (Fig. 6.2.2) may represent suitable spawning habitat for Atlantic sturgeon. The majority of the hard-bottom substrate zones, particularly the coarse-grained bedload areas, either neighbor or are within the shipping channel. However, the presence of hard-bottom substrate within the shipping channel may also be a limiting factor in terms of spawning success, potentially exposing adult Atlantic sturgeon to mortality due to boatstrike. Results from tracking acoustically-tagged sturgeon (Simpson and Fox 2006) indicated that the present day lower limit of Atlantic sturgeon spawning is likely the upper limit of salt water intrusion near Tinicum Island (rkm 136) while the upper limit is likely at the fall line near Trenton, NJ (rkm 211). The continued suppression of dissolved oxygen in the Delaware Estuary may also contribute to the limited habitat and spawning success of Delaware populations. With particularly high dissolved oxygen needs of juveniles, (Secor and Gunderson 1998) Atlantic sturgeon recovery may be suppressed by a persistent oxygen sag in the urban estuary corridor.

6 – 2.3 Past Trends

The Delaware River historically supported the largest population of Atlantic sturgeon over its U.S. range. In 1897, 978 fishermen, 80 shoresmen, and 45 transporters were engaged in the Delaware River sturgeon fishery (Cobb 1899).

It is clear that Atlantic sturgeon underwent significant range-wide declines from historical abundance levels due to overfishing in the late 1800s (U.S. Departments of Commerce and Interior 1998). During the season of 1898, the New Jersey fishermen caught 5,060 sturgeons valued at $19,375 and they prepared 1,067 kegs of caviar valued at $76,861. This does not include the catch from Delaware and Pennsylvania since their sturgeon fisheries were not canvassed that year (Cobb 1899). After the late 1800's, Atlantic sturgeon populations did not rebound to any appreciable extent in the Delaware as evidenced by the average annual landings of only 897 pounds (407kg) during the period from 1980 – 1987 (Taub 1990).

Historic habitat for Atlantic sturgeon in the Delaware River has been significantly altered. Large-scale dredging to accommodate commercial shipping traffic has changed substrate composition and tidal flows (Di Lorenzo et al.

Fig. 6.2.4. Young-of-year Atlantic sturgeon captured in the Delaware River in 2009.

Delaware Department of Fish & Game

1993; Walsh 2004). Within the period 1877 – 1987, the mean depth of the Delaware River increased by 1.6m and the mean cross-sectional area increased by nearly 3,000 m2 (Walsh 2004). By 1973, the US Army Corps of Engineers (USACE) estimated that nearly 154,000,000 m3 of material had been removed from the Delaware Estuary (Walsh 2004). The channel deepening process increased the tidal range in the upper estuary; simultaneously, extensive water removals and diversions were occurring within the non-tidal watershed, resulting in saltwater intrusion in the freshwater-tidal reach of the estuary. This displacement of freshwater habitat may have negatively affected any potential success for the contemporary spawning population (Simpson and Fox 2007).

Brundage and Meadows (1982) compiled records of Atlantic sturgeon captured in the Delaware River from 1958 – 1980 and found that out of the 130 reported captures, none were in spawning condition and most were sub-adults (less than the minimum size for sexual maturity). They were most abundant in the Delaware Bay (rkm 0-55) in the spring and in the lower tidal river (rkm 56-127) in the summer.
Due to their migratory nature, high age to maturity, high longevity, and variable spawning periodicity, it is difficult to assess the size of Atlantic sturgeon populations using traditional fishery methods such as mark-recapture. Therefore, there are no detailed past population trends available other than the large decline in harvest levels mentioned previously from the late 19th century to levels in the mid-late 20th century when commercial harvest was still permitted.

6 – 2.4 Future Predictions

Commercial and industrial activity will likely continue to be a factor which limits the growth of the Atlantic sturgeon population in the Delaware River. Since large sub-adult and adult Atlantic sturgeon prefer deep water habitat, they are continually at risk of mortality due to ship strikes since the deepest portions of the Delaware River are typically the maintained shipping channel. Increased shipping traffic and introduction of larger ships will likely increase the risk of ship strike mortalities for large sub-adult and adult fish. Between 2005 and 2008, a total of 28 Atlantic sturgeon mortalities were reported in the Delaware Estuary. Sixty-one percent of the mortalities reported were of adult size and 50% of the mortalities resulted from apparent vessel strikes. For small remnant populations of Atlantic sturgeon, such as that of the Delaware River, the loss of just a few individuals per year due to anthropogenic sources of mortality such as vessel strikes may continue to hamper restoration efforts. An egg-per-recruit analysis demonstrated that vessel-strike mortalities could be detrimental to the population if more than 2.5% of the female sturgeons are killed annually (Brown and Murphy 2010). Since small losses of broodstock can impact Atlantic sturgeon population growth in the Delaware, it is important to work with the shipping industry to develop means for reducing ship strikes.

Even though dredging of the tidal Delaware River will likely continue as maintenance dredging and for increasing channel depth to accommodate larger ships, updated dredging windows have been developed by the Delaware River Basin Fish and Wildlife Management Cooperative (Co-op). Using known life history data, these dredging windows are formulated to reduce impacts on sturgeon and other fish from dredging and related activities and are currently being considered for implementation by the U.S. Army Corps of Engineers in permitting dredging and related activities. To better characterize habitat use in the tidal Delaware River, Delaware River sturgeon researchers are continuing the use of acoustic tags on sturgeon to monitor their movements via an array of stationary acoustic receivers deployed in the Delaware River (Fig. 6.2.2)

Since the National Marine Fisheries Service has issued a final rule that Atlantic sturgeon in the New York Bight (including the Delaware River) are Endangered, a recovery plan for the species must be written that includes specific steps needed for population recovery. The Endangered Species Act also requires the designation of "critical habitat" for listed species when "prudent and determinable." Critical habitat includes geographic areas that contain the physical or biological features that are essential to the conservation of the species and that may need special management or protection. Critical habitat designations affect only Federal agency actions or federally funded or permitted activities. Federal agencies are required to avoid “destruction” or “adverse modification” of designated critical habitat. Relative to the Delaware River Atlantic sturgeon, this would apply to dredging activities which are currently permitted by the U.S. Army Corps of Engineers in areas known to be utilized by Atlantic sturgeon for completion of their life cycle. Critical habitat may include areas that are not occupied by the species at the time of listing but are essential to its conservation. An area can be excluded from critical habitat designation if an economic analysis determines that the benefits of excluding it outweigh the benefits of including it, unless failure to designate the area as critical habitat may lead to extinction of the listed species.

6 – 2.5 Actions and Needs

Actions that could improve the condition of the Atlantic sturgeon population in the Delaware River include continuation of telemetry studies for discovering areas of the river used by various life stages of the species. Locations of spawning areas and early life stage nursery areas for Atlantic sturgeon in the Delaware River need to be identified so management actions, such as instituting effective dredging windows, can be used to protect fish at times when they congregate in known areas. Expanded study of ship strikes on sturgeon in the Delaware River is also needed to determine the level of population impact occurring and to determine ways to minimize that impact. Since the species is highly migratory, actions to protect, conserve, and enhance Atlantic sturgeon in the Delaware River extend far beyond the geographical limits of the Delaware Basin. These actions include: (1) reducing by-catch from near-shore and ocean commercial fisheries on the east coast by increasing the number of observers on commercial fishing vessels and reducing the use and/or soak time of anchored gill nets, (2) designing and locating future tidal turbines for power generation in a manner which would strive to minimize mortality to distant migrants, and (3) continuing the use of the Coastal Sturgeon Tagging Database as a means to promote data sharing between sturgeon researchers.

In addition, revised dissolved oxygen criteria from the Delaware River Basin Commission and improvements to wastewater treatment in the estuary could significantly improve early-stage juvenile habitat conditions in the core Atlantic sturgeon zone. The need for continued improvements in dissolved oxygen has been articulated since the late 1970s, with the elevated oxygen conditions demonstrated as achievable through a multi-agency study in the 1980s. The listing of Atlantic sturgeon as “Endangered” necessitates immediate implementation of these recommendations.

Currently, there is no funding vehicle specific for protection and enhancement of the Delaware River sturgeon population. However, the Delaware River Basin Conservation Act of 2011 would establish a federal program at the U.S. Fish and Wildlife Service to coordinate voluntary restoration efforts for numerous species and habitats throughout the Delaware River watershed. This legislation is sponsored by Senator Tom Carper (D-DE) and co-sponsored by Sens. Coons (D-Del); Schumer (D-NY), Gillibrand (D-NY), Menendez (D-NJ), and Lautenberg (D-NJ) http://carper.senate.gov/public/index.cfm/pressreleases?ID=c85f7582-af71-400f-8a2c-9e56479e29da. Proposals targeting restoration activities that would benefit Atlantic sturgeon could be considered for use of a portion of these funds should the legislation be passed.

6 – 2.6 Summary

In summary, Atlantic sturgeon of the Delaware River are now considered federally Endangered. The current condition of the Atlantic sturgeon population in the Delaware River is poor compared to the historic condition. Furthermore, the industrialization and related shipping traffic in the very portion of the river which once supported the largest spawning population of this species over its historic range will likely limit the population to a small fraction of its historic size. However, recent discoveries of young-of-year individuals and their habitat along with refinement of information on sturgeon habitat use through acoustic telemetry studies are seen as positive developments concerning this indicator species. The overall condition of the Atlantic sturgeon population in the Delaware River is poor but showing some signs of movement in a positive direction with the capture of 34 and 51 YOY individuals in 2009 and 2011, respectively, proving that successful spawning took place. In addition, the listing of the species as threatened or endangered over all its U.S. range will afford Atlantic sturgeon populations a new layer of protection from which they have not previously benefitted. This will also result in increased funding opportunities for population recovery efforts in the Delaware, a river that is legendary for the size of its historic Atlantic sturgeon population.

6 – 3 American shad

Section Author: Jerre Mohler

American shad (*Alosa sapidissma*) is an anadromous species that is native to most major river basins on the Atlantic Coast of North America, including the Delaware. The species is in the family Clupeidae, or the herring family. The American shad has a lustrous green or greenish blue back with silvery sides and a white belly. Individuals may live up to 11 years and reach lengths over 20 inches (50.8 cm) (Fig. 6.3.1) They are a popular, hard- fighting sport fish that can be taken on rod and reel using lures known as shad darts and flutter spoons and they also have commercial value.

Fig. 6.3.1 Mature female American shad captured in the Delaware River

American shad are opportunistic feeders, whose freshwater diet includes copepods, crustacean zooplankton, cladocerans, aquatic insect larvae, and adult aquatic and terrestrial insects. After emigrating to offshore areas, American shad feed on the most readily available organisms, such as copepods, mysid shrimps, ostracods, amphipods, isopods, euphausids, larval barnacles, jellyfish, small fish, and fish eggs (ASMFC 2010). American shad spend most of their life at sea along the Atlantic coast and enter freshwater as adults in the spring to spawn. Stocks are river specific; that is, each major tributary along the Atlantic coast appears to have a discrete spawning stock due to high fidelity to return to their natal tributary to spawn. In the fall or subsequent spring, juveniles emigrate from freshwater and estuarine nursery areas and join a mixed-stock, sub-adult coastal migratory population. Three primary offshore summer aggregations of American shad have been identified: 1) Bay of Fundy/Gulf of Maine, 2) St. Lawrence estuary, and 3) off the coast of Newfound and Labrador.

After four to six years, individuals become sexually mature and migrate to their natal rivers during the spring spawning period. American shad that spawn north of Cape Hatteras are repeat spawners, while almost all American shad spawning south of Cape Hatteras die after one spawning season (ASMFC 2010). Repeat spawning has been documented for Delaware River shad via analysis of scales. In the Delaware, there can be as many as 5 year classes of adult shad participating in a spawning migration (M. Hendricks, PA Fish & Boat Commission, personal communication).

American shad have ecological, economic, cultural, and social significance (ASMFC 2010). Ecologically, they play an important role in freshwater, estuarine, and marine environments during their anadromous life cycle. They influence food chains by preying on some species and serving as prey for others throughout all life stages. Economically, American shad have supported valuable commercial fisheries along the entire Atlantic coast. In the late 1890s, the Delaware River had the largest annual commercial shad harvest of any river on the Atlantic Coast. The harvest began to decline rapidly in the early 1900s. Severe water pollution, removing oxygen, has been well-documented; there has been no analysis indicating that overfishing has occured, but it could have existed. All major tributaries were dammed. Despite efforts in the late 1800s to increase the shad population through legislation and a massive program of artificial propagation, the shad fishery eventually collapsed under the combined pressures. By the 1940s, the commercial shad fisheries were mainly limited to the lower reaches of the river and bay below Pennsylvania (ASMFC 2007). Culturally, American shad were and are of significance to Native Americans, European colonists and contemporary Americans who reside near and/or fish in rivers that supported or continue to support spawning runs. Many communities celebrated and still celebrate the arrival of shad by holding festivals to mark the occasion. The most comprehensive account of the role that American shad has played in the culture of North America since colonization by Europeans is that written by John McPhee. In "The Founding Fish," (McPhee 2002) his research documents the relevance of American shad in seventeenth and eighteenth-century America.

6 – 3.1 Description of Indicator

To investigate the status of this indicator, the following data were used:

- Juvenile abundance from beach seining and commercial harvest data from the New Jersey Division of Fish & Wildlife (NJ DFW)
- Gill net catch data at Smithfield Beach and fish passage data at the Easton dam from the PA Fish & Boat Commission (PFBC)
- Commercial harvest data from Delaware Department of Fish & Game(DE DFG)
- Schuylkill River fish passage data from the Philadelphia Water Department (PWD)
- Adult catch rates from the Lewis Haul Seine survey at Lambertville, NJ
- Hydro-acoustic population estimates provided by the Delaware River Basin Fish & Wildlife Management Cooperative (Co-op)

6 – 3.2 Present Status

The portion of the main stem Delaware River available as habitat extends up into the East and West Branches above Hancock, NY representing over 300 miles (483 km) of unobstructed main stem access. However, all major tributaries to the main stem Delaware are dammed creating numerous blockages to historic spawning and rearing habitat. The two major tributaries, namely the Schuylkill and the Lehigh Rivers, do have existing fish passage facilities in place at many of their dams but these are variable in their ability to facilitate upstream passage of American shad.

Tidal reach

There is commercial harvest permitted in the Delaware and New Jersey portions of the estuary with mandatory reporting beginning in 2000. In New Jersey, as of June 20, 2011 there were 86 permits issued (46 commercial and 40 incidental) to allow catch of American shad. Currently, only 76 of these permits are active due to attrition, and only 14 fishers landed shad in 2010. American shad are also caught as bycatch in Delaware's commercial striped bass fishery that has a season beginning on February 15 and extending through May 31. Currently, commercial harvest levels are low with only 5,019 pounds (2277 kg) of shad reported in Delaware and about 7,700 pounds (3493 kg) in New Jersey for 2010 (Fig. 6.3.2). The trend of decreasing commercial harvests is not viewed as a reflection of decreasing stock size but rather the result of fewer commercial fisherman in addition to a shift toward the harvest of the more valuable striped bass by Delaware fishers; stiped bass are present in the estuary at the same time that American shad migrate through (R. Allen, New Jersey Division of Fish & Wildlife and D. Kahn Delaware Dept. of Fish & Game, personal communication).

An additional perspective on the present status of adult American shad in the tidal reach is reflected by fish passage data for the Fairmount dam on the Schuylkill River. Fish passage facilities at the Fairmount Dam have recently been improved along with a concomitant improvement in upstream passage of American shad (Fig. 6.3.3). This is an encouraging trend that not only shows that the fish passage facilities are more efficient, but also shows that the stocking of larval shad, that has been on-going in the Schuylkill since 1985 is having a positive impact. Analysis by the PA Fish and Boat Commission shows that about 96% of the fish returning to spawn on the Schuylkill are of hatchery origin.

A juvenile relative abundance index for the tidal estuary has been developed via New Jersey beach seine surveys. The survey index shows a statistically significant increasing trend in catch-per-unit effort (CPUE) for juvenile American shad in the tidal estuary from 1980-2010 (Fig. 6.3.4). In the early years of this time series, oxygen levels were still low in summer and fall when the survey is conducted. Increases in juvenile CPUE indicate greater numbers of juveniles are available to out-migrate and return as adults 4 to 5 years later.

Non-tidal reach

Above the Trenton fall line there are 3 data sets that reflect the size of the adult American shad run: The Lewis Haul Seine survey at Lambertville, NJ, the fish passage data from the Easton dam on the Lehigh River, and the PFBC Smithfield Beach gill net survey. When data from 1995 – 2010 are plotted together these 3 indices of relative abundance show similar trends. A close correlation exists between Smithfield Beach and Lewis Haul Seine surveys with Easton dam upstream fish passage showing greater temporal fluctuation but a generally similar trend (Fig. 6.3.5). On the Lehigh River, the first three dams (Easton, Chain, and Hamilton Street dams, respectively) have fish passage facilities which can be very inefficient at passing shad upstream due to combinations of poor attraction flow and/or excessive step pool height (R. Quinn, U.S. Fish & Wildlife Service, personal communication). When very high Lehigh River flows coincide with shad migrations, high-water spillage over the Easton dam can mask the attraction flow exiting the fishway and cause poor upstream passage (D.Pierce, PA FBC, personal communication). Thus, the high variability seen in the Easton dam fish passage data is not surprising. The Lehigh River has also been stocked with larval shad each year since 1985 and the percentage of hatchery-origin fish returning as adults is about 74%. There are similarities in the trends of fish passage between the Fairmount dam (tidal reach) and the Easton dam on the Lehigh River (non-tidal reach) suggesting that hatchery fish stocked in both rivers are showing similar trends in survival from larvae to returning adults (Fig. 6.3.3).

6 – 3.3 Past Trends

In the late 1890s, the Delaware River had the largest annual commercial shad harvest of any river on the Atlantic coast having estimates of up to 19 million pounds (8.6 mil kg) in a given year. The harvest began to decline rapidly in the early 1900s. Water pollution was well-documented, eliminating oxygen for months at a time in the mid-lower tidal river; overfishing has not been documented, although it could have occured. All major tributaries were dammed by this time. Despite improved state legislation and regulation, and a massive program of artificial propagation of shad stocks in the late 1800s, the shad fishery eventually collapsed under the combined pressures. By the 1940s, the commercial shad fisheries were mainly limited to the lower reaches of the River and Bay below Pennsylvania. By 1950, the urban reach of the Delaware River was one of the most polluted stretches of river in the world (ASMFC 2007). Pollution continued to be a major factor until passage of the Federal Clean Water Act in 1972. This Act was instrumental in the elimination of the "pollution block" of low or no dissolved oxygen in the region around Philadelphia. By 1973 the majority of spawning took place above the Delaware Water Gap more than 115 river miles (185 km) upstream. American shad can now freely pass through this area during the spring spawning run as well as the fall out-migration.

In 2007, the American Shad Stock Assessment Subcommittee (SASC) completed a coast-wide American shad stock assessment report, that was accepted by the Peer Review Panel (PRP) and the Shad and River Herring Management Board in August 2007 (ASMFC 2007). The stock assessment found that stocks were at all-time lows and did not appear to be recovering to acceptable levels. It identified the primary causes for the continued stock declines as a combination of excessive total mortality, habitat loss and degradation, and migration and habitat access impediments. Although improvement has been seen in a few stocks along the coast, many remain severely depressed compared to their historic levels. In the Delaware River, the American shad is benefitting from continued efforts by the Delaware River Basin Commission and the Basin states to improve water quality and pursue improvements in fish passage on the tributaries.

The Delaware River shad population showed signs of recovery during the 1980s and into the early 1990s, but recent estimates of the adult stock have been well below the target of 750,000 adult American shad at Lambertville, NJ. This target was set by the Delaware Basin Fish and Wildlife Management Cooperative (Co-op) in 1982 as a result of a Peterson population study from 1981 that estimated a population of over 500,000 adult shad. Hydro-acoustic methods were used in 1992, 1995, and 1998 – 2007 to estimate population size at 23,000 to 880,000 individuals (Fig. 6.3.7). However, the hydro-acoustic estimates included wide confidence intervals and are not thought to be precise. There is disagreement as to whether they are reasonable estimates of the Delaware River American shad population. No population estimates have been performed since 2007, therefore the Co-op depends on analysis of trends from the various relative abundance indices to determine the population status. A better method for estimating the size of the shad population is needed for the Delaware River.

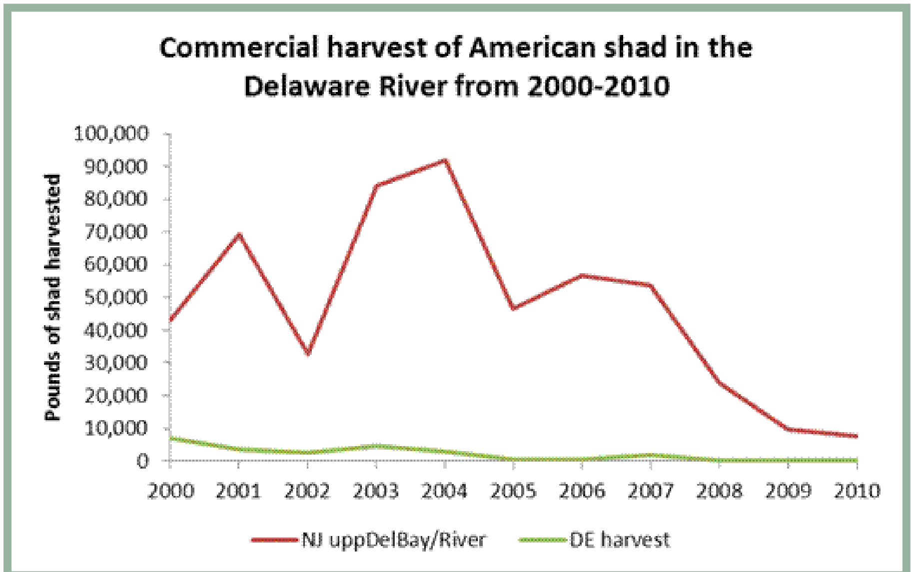


Fig. 6.3.2 A decreasing trend in Commercial harvest of American shad in the Delaware River from 2000-2010 reflecting fewer commercial fisherman in addition to a shift toward the harvest of the more valuable striped bass.

The relative abundance index with the longest time series is the Lewis Haul Seine survey that was first begun in 1890 but did not track catch per unit effort until 1925. This index shows that the Delaware population expanded during the 1980's and early 1990's and has since shown a contraction with some indication of an increasing trend beginning in 2008 (Fig. 6.3.8).

Although habitat degradation was mostly responsible for depleting the initial Delaware River American shad population, anthropogenic factors alone are not responsible for fluctuations in population size, but climatic and other environmental factors can also affect the population. For example, North Atlantic sea surface temperatures have been found to exhibit long-duration variability or oscillation (Schlesinger and Ramankutty 1994; Enfield et al 2001). Kerr (2000) termed this oscillation the Atlantic Multi-decadal Oscillation (AMO). The AMO delineates cool and warm phases that may last for 20 to 40 years at a time and represents a difference of about 1°F between extremes. These changes are probably a natural climate oscillation and have been measured for at least 150 years. A positive AMO indicates a warm phase while a negative AMO indicates a cool phase. The AMO is currently in what is considered a warm phase since the mid-1990s (AMO Kaplan SST V2 data is provided by the NOAA/OAR/ESRL PSD, Boulder, Colorado, USA, from their Web site at http://www.esrl.noaa.gov/psd/).

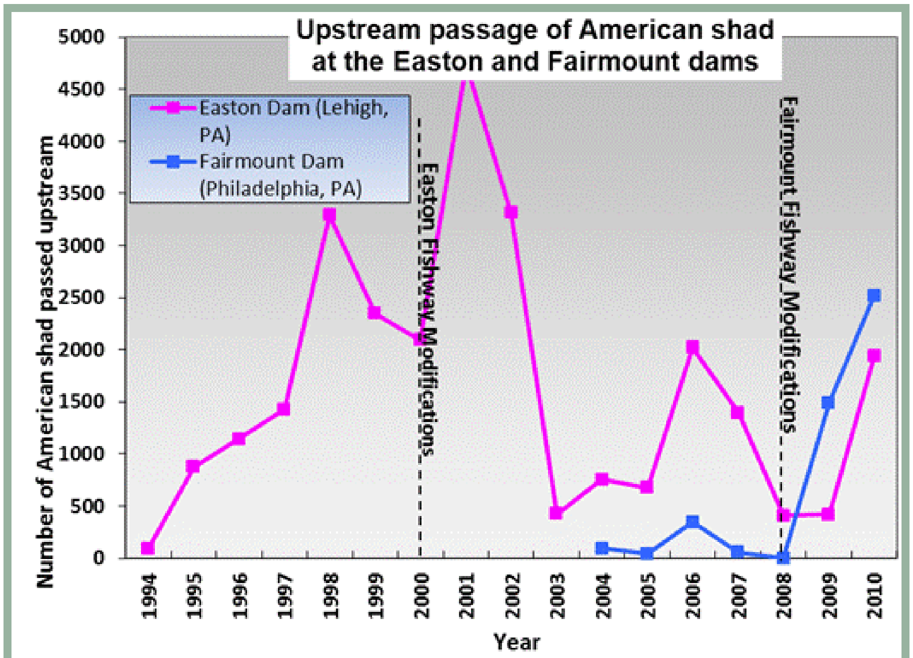


Fig. 6.3.3 Upstream passage of American shad at the Easton Dam (Lehigh River) and Fairmount Dam (Schuylkill River).

In an attempt to determine if there was any evidence of a relationship between the AMO and measures of the American shad stock within the Delaware River Basin, the Co-op compared the AMO to the Lewis haul seine CPUE (Fig. 6.3.8). This data set represents the longest catch per unit effort within the Basin. The Co-op analyzed various portions of the AMO dataset but determined the smoothed January to December average was the best fit for final analysis. A five-year moving average was developed for all data to decrease yearly variability. This was a similar methodology as used for the most recent ASMFC weakfish stock assessment that used a 10-year average (ASMFC 2009).

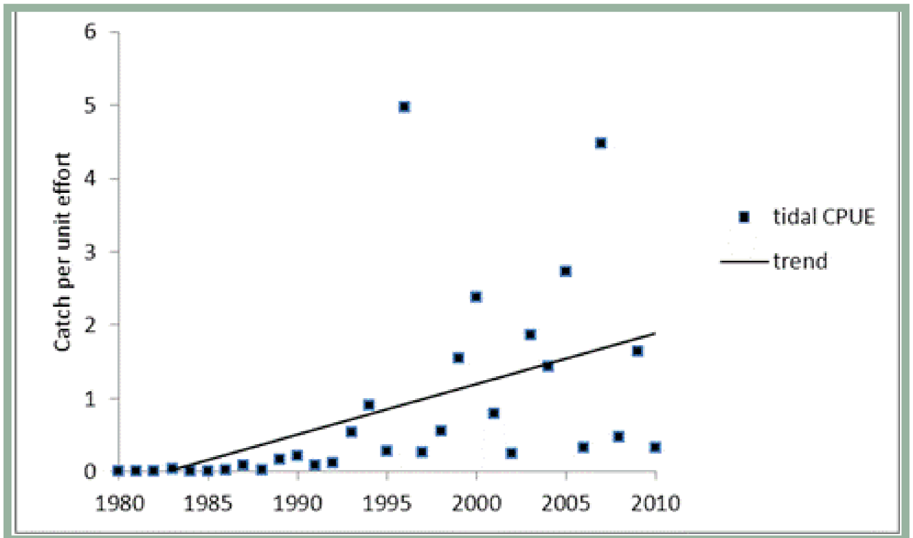


Fig. 6.3.4 Trend in catch-per-unit effort (CPUE) for juvenile American shad in the tidal estuary from 2000 -2010

No correlation is evident between the Lewis haul seine CPUE and the AMO from 1925 to 1971. It should be noted that this period also coincided with very poor water quality within the Delaware River. As water quality improved from the 1970s into the 1990s, the American shad population within the Delaware River also improved. From 1972 to 1989, the smoothed Lewis haul seine CPUE correlated well with the smoothed AMO but the correlation disintegrates during the 1990s suggesting a problem with the stock that should not have occurred according to the relationship with the AMO from 1972 to 1989. The Lewis haul seine to AMO analysis showed a negative correlation for the time period of 1990 to 2010.

In conclusion, this analysis provides evidence that long-term sea surface temperature change may have an impact on abundance of American shad within the Delaware

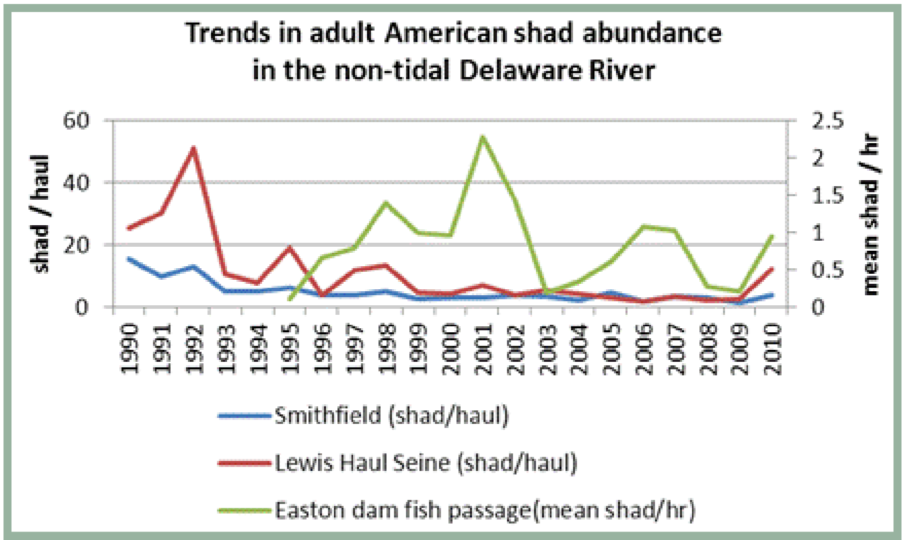


Fig. 6.3.5 Trends in adult American shad abundance in the non-tidal Delaware River: Smithfield Beach gillnet survey; Lewis Haul Seine survey (Lambertville, NJ); and Easton dam fish passage (Lehigh River)

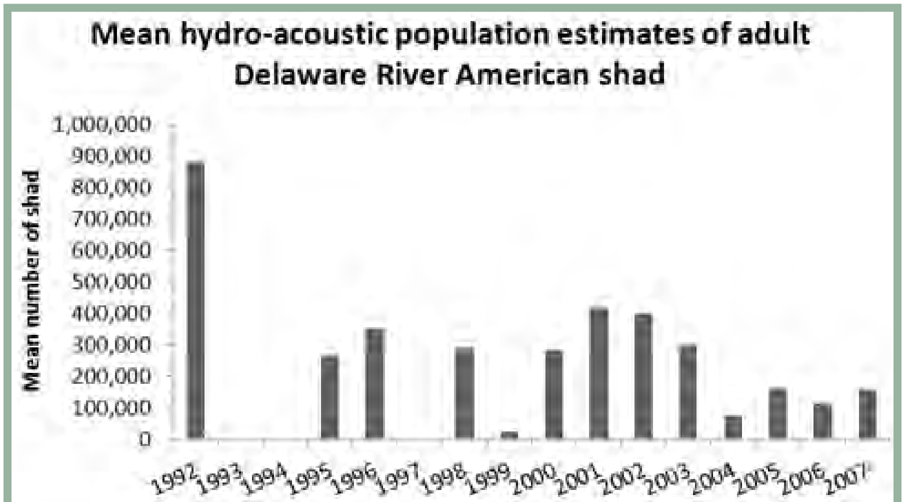


Fig. 6.3.6 Mean estimate of adult American shad population size derived from hydro-acoustic techniques from 1992 to 2007

Basin. The Lewis haul seine CPUE correlates well with the AMO during the AMO index's rise in the 1970s and 1980s but there is a disconnect that occurs during the 1990s that currently is unexplainable. Potential sources of the discontinuity include decline in adults due to overharvest; bycatch discards in ocean fisheries; increased predation from striped bass or other species; or other unknown interruption of the spawning runs during this time period. In recent decades, as oxygen levels improved in the tidal River, indices of relative abundance and commercial landings both increased in the 1980s. During the mid-1990s, however, some decline began which continued to lower levels in the 2000s. A highly significant negative correlation exists between this trend in shad abundance and the trend in abundance of striped bass. The primary prey of striped bass consists of members of the herring family, which includes shad (Fig. 6.3.9). During the peak years for shad in the 1980s, striped bass were at extremely low abundance; as bass recovered during the 1990s, shad began to decline. When bass attained their peak abundance during the later 2000s, shad were at their nadir.

6 – 3.4 Future Predictions

The Delaware River stock of American shad is currently thought to be sustainable under current recreational and commercial conditions but only with the establishment of benchmarks that would be used to trigger management actions designed to prevent stock collapse. These benchmarks are being established by the Delaware River Basin Fish and Wildlife Management Cooperative (Co-op) and will be used as triggers to elicit any of a number of management changes if juvenile recruitment declines or adult exploitation becomes excessive. An overall population increase should be realized with on-going attempts to improve fish passage on both the Schuylkill and Lehigh Rivers. Dam removal activities also on-going in the Brandywine and Musconetcong Rivers should also be instrumental in providing greater access to historic spawning areas for American shad with a concomitant increase in the population.

6 – 3.5 Actions and Needs

Any improvement in restoring access to blocked habitat through dam removal or improvements in fish passage devices on existing dams would facilitate population increases for American shad in the Delaware River. In that regard, continued negotiation by the PA Fish and Boat Commission to remove dams on the Lehigh River is needed. In order to facilitate restoration of tributaries that have obstacles to fish passage, efforts to spawn wild American shad to produce larvae for stocking should be continued in those areas until shad can access sufficient historic

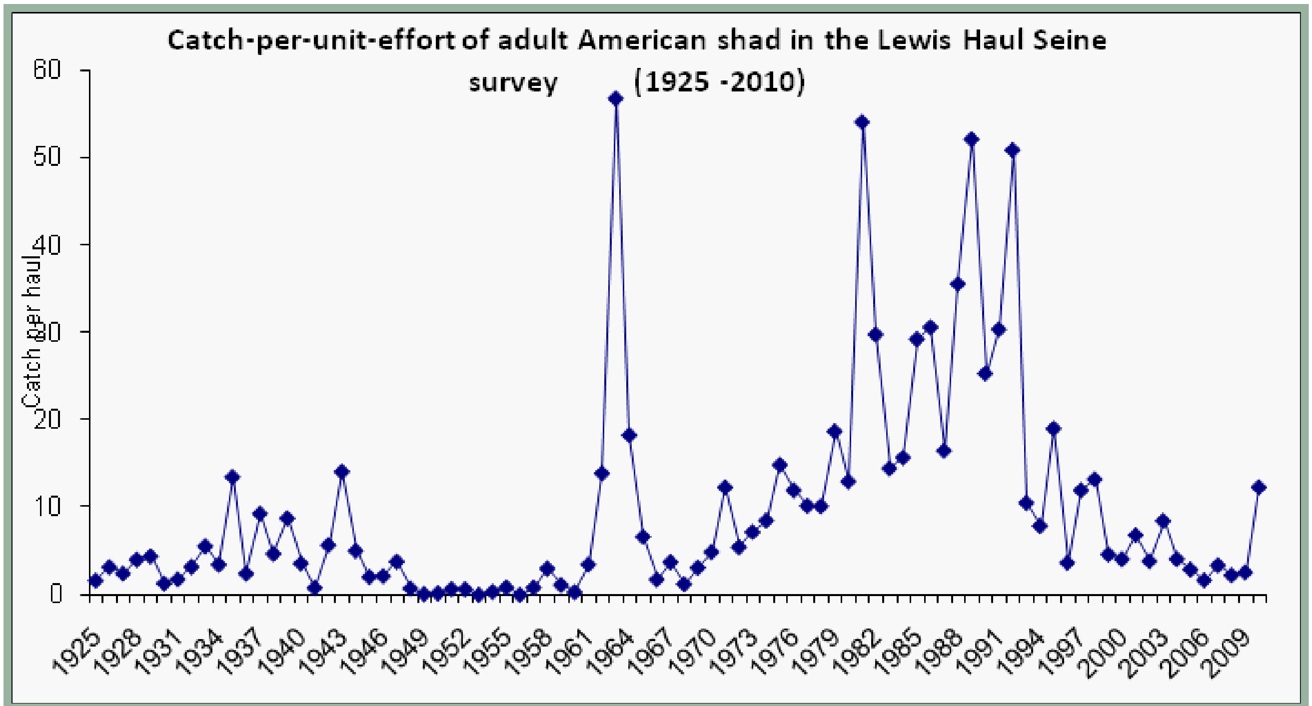


Fig. 6.3.7 Relative abundance of adult American shad reported as catch per haul in the Lewis Haul Seine survey performed at Lambertville, NJ from 1925-2010

habitat to reproduce naturally. There is also a need to re-establish the upper river juvenile abundance sampling that was once performed by New Jersey Division of Fish & Wildlife in order to monitor juvenile recruitment and compare it with existing lower river juvenile monitoring efforts. Computer modeling is also needed to determine the level of impact on the population occurring from mortality due to entrainment of eggs and larvae in industrial water intakes in the Delaware Basin. Dredging and blasting activities performed in the Basin under permit via the U.S. Army Corps of Engineers must be limited to those times of year recommended by the Co-op (dredging windows) to prevent excessive adverse impacts on all life stages of shad.

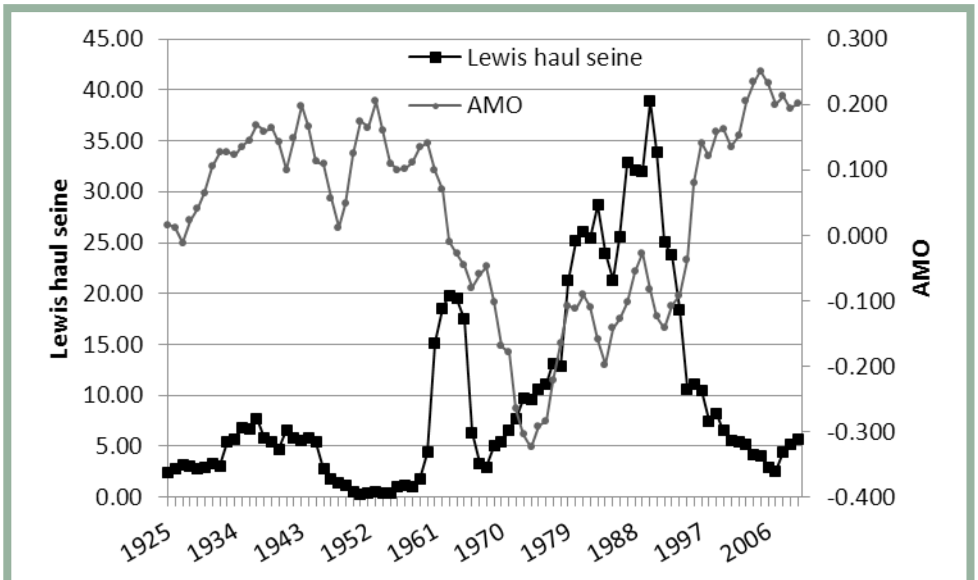


Fig. 6.3.8 Atlantic Multi Oscilation compared to Lewis haul seine catch-per-unit-effort for Amercican Shad (1954-2010). Data are 5-year moving averages to decrease variability.

Currently, there is no funding vehicle specific for protection and enhancement of the Delaware River shad population. The four Basin States have allocated some budget resources annually for population monitoring efforts that result in data reported annually to the ASMFC. Recent budget shortfalls in most States have resulted in reduced monitoring efforts, creating a potential discontinuity in numerous population indices that are useful to determine population trends. However, the Delaware River Basin Conservation Act of 2011 would establish a federal program at the U.S. Fish and Wildlife Service to coordinate and prioritize restoration efforts for numerous species and habitats throughout the Delaware River watershed. This legislation will be sponsored by Senator Tom Carper (D-DE) who will be joined in supporting the legislation by Sens. Coons (D-Del); Schumer (D-NY), Gillibrand (D-NY), Menendez (D-NJ), and Lautenberg (D-NJ) http://carper.senate.gov/public/index.cfm/pressreleases?ID=c85f7582-af71-400f-8a2c-9e56479e29da. Study proposals already developed by the Partnership for the Delaware Estuary as well as other proposals targeting restoration activities that would benefit American shad would be valid considerations for use of a portion of these funds should the legislation be passed.

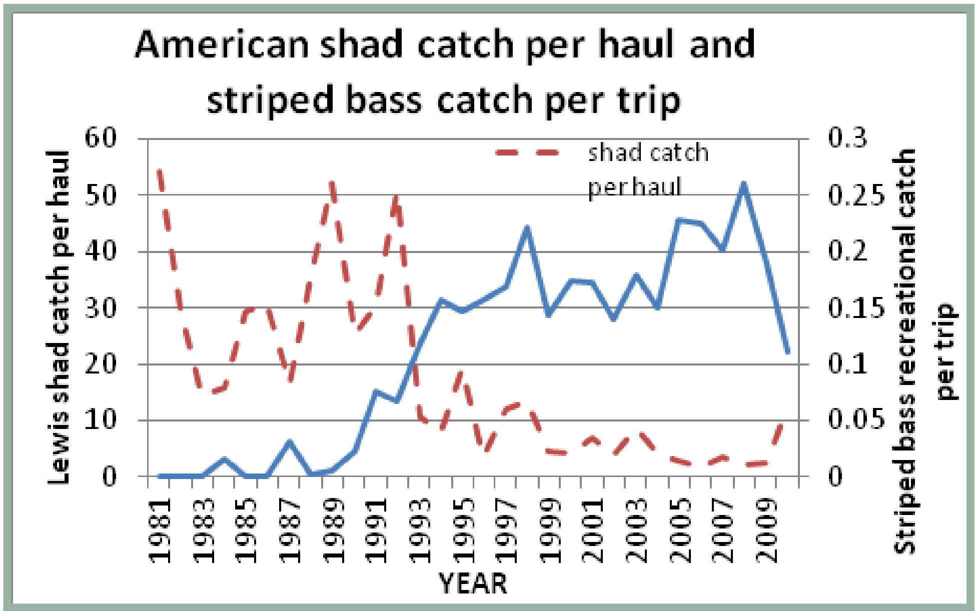


Fig. 6.3.9. Relative abundance trends of striped bass and American shad. Adult American shad catche per haul in the Lewis haul seine fishery, Lambertville, NJ and recreational catch per trip of striped bass in all Delaware waters, 1981-2010: Correlation coefficient, r= -0.757, n=28, P<<0.01.

6 – 3.6 Summary

In summary, the current condition of the American shad population in the Delaware River is low when compared to the original condition of the stock, but relative to other extant populations, the Delaware stock is fairly healthy with numerous indices of relative abundance indicating at least a temporal trend of population increase. In addition to environmental and social benefits, increases in the population of American shad would provide economic benefits through increased revenues for local communities from recreational angling, and commercial fishing. The Delaware River stock of American shad is currently thought to be sustainable under current conditions but only with the establishment of benchmarks established by the Delaware River Basin Fish and Wildlife Management Co-op. These benchmarks are designed to identify declining trends in juvenile recruitment and excessive adult exploitation. The trends are monitored by the Co-op using mandatory commercial harvest reporting from New Jersey and Delaware along with on-going sampling efforts to obtain relative abundance indices.

6 – 4 Striped Bass

Section Author: Desmond Kahn

NY DEC

While female striped bass (*Morone saxatilis*), in particular, are highly migratory, males can be found year-round in the Delaware River and Bay, unlike other potentially large predators such as weakfish, bluefish, large sharks, and sea turtles. The Delaware Division of Fish and Wildlife (DFW) and the PA Fish and Boat Commission conduct tag-recapture studies in the spring on the Delaware River spawning grounds. Tag returns indicate that mature females migrate in summer up the coast to southern New England and eastern Long Island. Some males move into Chesapeake Bay through the Chesapeake and Delaware Canal or out into near-by coastal areas during summer and fall. Migration patterns of immature females are unclear, since they are not tagged in the annual spawning ground survey in the River.

The Delaware River population is now one of the major spawning stocks on the Atlantic coast, along with the Hudson River and Chesapeake Bay stocks. The stock was declared restored by the Atlantic States Marine Fisheries Commission in 1998, based on a report by Kahn et al. (1998). The key to its recovery was the reduction in sewage pollution in the River due, in part, to the federal Clean Water Act. The upgrading of sewage plants was completed in 1987. That upgrade eliminated the anoxia which had existed in 20 or more miles of the tidal River between Philadelphia and Wilmington, the primary spawning and nursery grounds for the stock. Clark and Kahn (2009) reported that catch-per-unit effort (generally proportional to abundance) in the Delaware spring gill net fishery in Delaware Bay and River increased 3,000% to 6,000% between 1987 and 2002-2003.

There is no estimate of population size. Burton and Weisberg (1994) estimated the number of age 0 striped bass in 1990 at 972,937, with approximate 95% confidence limits of 765,916 to 1,241,104, using tagged hatchery age 0 fish stocked in the Delaware River. If this number is considered roughly representative of an average for age 0 fish, and if certain assumptions are made as to the annual survival rate of younger fish, the total stock size could be on the order of roughly three million fish. At any one point in time, however, they would not all be present in the estuary, due to migration.

Striped bass feed primarily on fish, but also consume larger invertebrates. Their predominant prey consists of various species in the herring family, including Atlantic menhaden and river herring. A recent study in the Connecticut River found that large striped bass consumed adult American shad. Striped bass are opportunistic predators, however, and have a broad range of prey. Their habitat includes tidal creeks and rivers, jetties, beaches and relatively open water in the Bay, River and ocean. They are known as rockfish because they are often found near jetties or other rock structures.

The current spawning grounds exist in tidal fresh water in the Delaware River above detectable concentrations of salinity. The spring spawning survey conducted by the DFW usually finds more fish In April in Delaware waters from the Delaware Memorial Bridge up to the Delaware-Pennsylvania line. The New Jersey shore has the majority of spawners, along with the Cherry Island Flats, which are shoals around Wilmington. As the season progresses into May, the temperature and salinity tend to increase, and spawning bass are more commonly collected in Pennsylvania waters up to and including the Philadelphia Navy Yard. Spawning is usually over by the end of May. By September, young-of-year bass are a few inches long. They do not generally exceed four inches by the end of the growing season. Striped bass do not consume fish in any number until their second year of life as one-year olds.

Delaware has a commercial fishery targeting striped bass. Currently, this fishery has the highest economic value of any of Delaware's commercial finfisheries, bringing fishers about $500,000 at the dock in 2010, not including the multiplier effect that economists calculate for such activity. New Jersey has outlawed commercial landing of striped bass. Both states support a recreational fishery, which ranks as one of the top fisheries in both states. Striped bass are one of a few inshore species that can achieve big game size. Fish up to fifty pounds are possible catches.

6 – 4.1 Description of Indicator

The indicator is a measure of the reproductive output of the stock. New Jersey's Division of Fish, Game and Wildlife conducts a beach seine survey in the tidal River from Trenton down to Augustine Beach just a mile above the beginning of Delaware Bay. Results of this survey have been the subject of several peer-reviewed papers. This survey targets young-of-year striped bass, and was begun in 1980, although the first few years were pilot studies. The survey develops a geometric mean catch per haul index, which is the average of catches in August, September, and October.

Catches were low in the first years, with a zero for 1981. Since then a gradual increase in catch-per-haul occurred, building to the first peak in 1989, two years after the upgrade of sewage plants was completed (Fig. 6.4.1). Since that year, the index has fluctuated without trend.

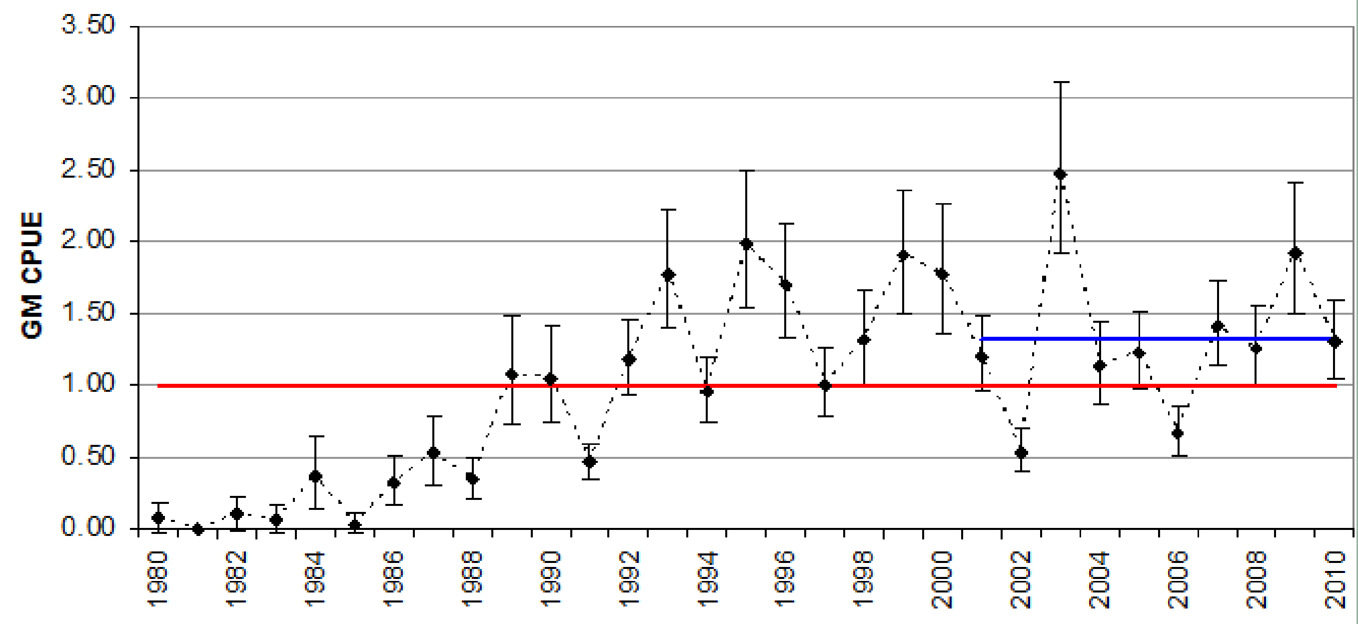


Fig. 6.4.1. The Delaware River striped bass young-of-year index, consisting of the geometric mean of the number caught per seine haul: 1980-2010. The survey is conducted in August, then repeated in September, and October. Survey sample sites are located from Trenton, New Jersey all the way down river to Augustine Beach, Delaware, below the Chesapeake and Delaware Canal. Bars represent 95% confidence intervals. The red line represents time series average (1980–2010). The blue line represents the average for the last ten years (2001–2010).

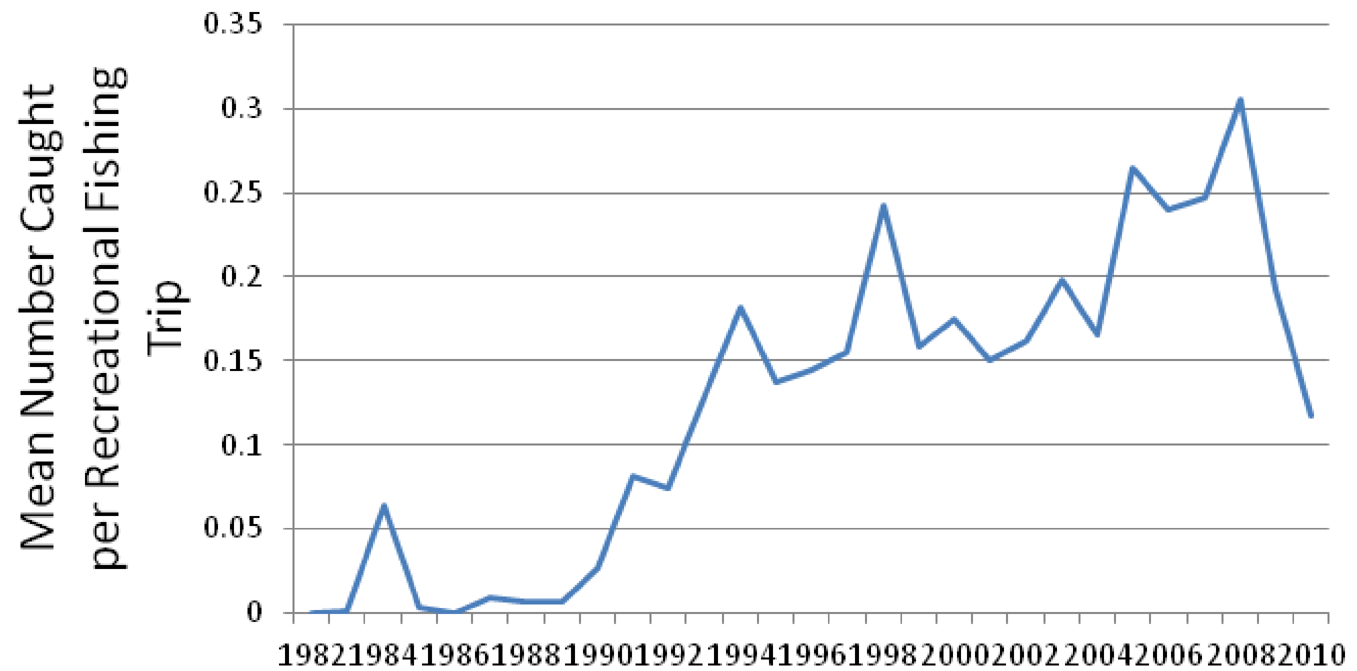


Fig. 6.4.2. Number of striped bass caught per trip by recreational anglers fishing from Delaware ports in the Delaware River and Bay (source: Marine Recreational Fisheries Statistics Survey, National Marine Fisheries Service).

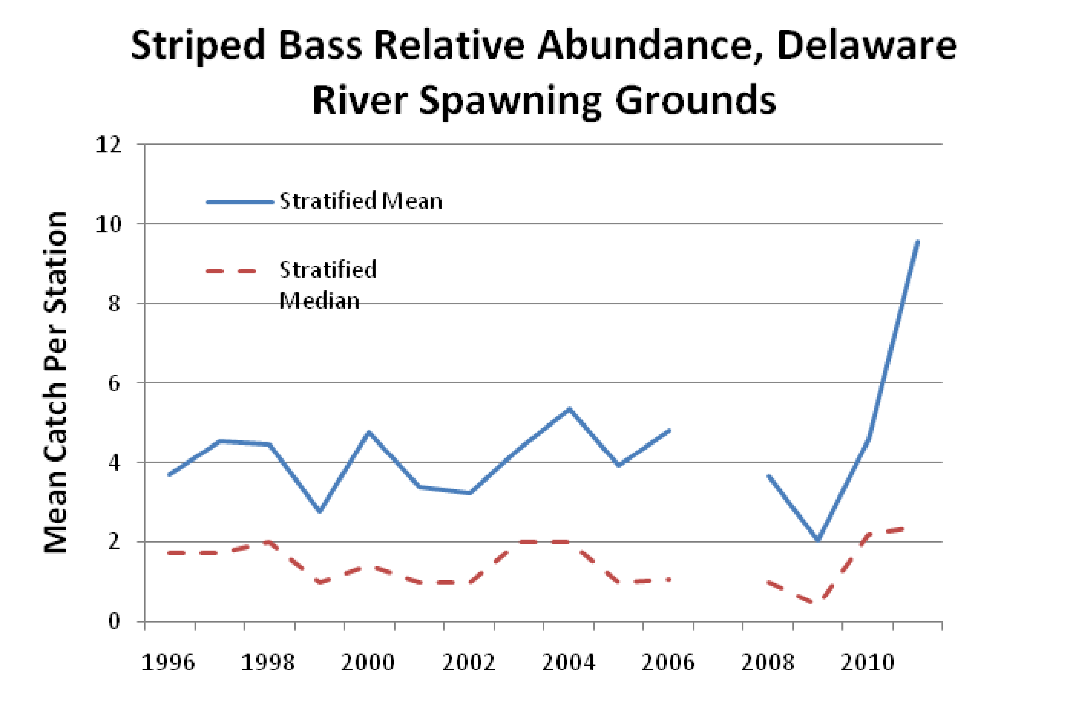


Fig. 6.4.3. Mean number of striped bass caught per station with electrofishing gear in the tidal Delaware River in April and May of each year by the Delaware Division of Fish and Wildlife during the annual Striped Bass Spawning Stock Survey. The survey is conducted from the Delaware Memorial Bridge through the Philadelphia Navy Yard.

6 – 4.2 Present Status

A recent peak in the young-of-year index occurred in 2007, indicating a potentially large year class. Although survival to age one is somewhat variable, a large year class at the young-of-year stage usually eventually recruits into the fishable stock as a large year class.

6 – 4.3 Past Trends

The stock had been considered virtually extinct by some authors in the mid-twentieth century. A remnant probably survived, however. Once water quality improved to the point that adequate oxygen was present in the nursery grounds all summer, the stock rebuilt quickly. It was officially declared restored by the Atlantic States Marine Fisheries Commission in 1998.

6 – 4.4 Future Predictions

The fishery is under fairly conservative restrictions. The abundance coastwide has declined in the last two to three years, reflected in the recreational catch per trip in the Delaware estuary waters in Delaware (Fig. 6.4.2). This index is affected by all the spawning stocks present in Delaware waters, including the dominant Chesapeake aggregation. The latter complex may be the source of the decline, due to an ongoing disease epidemic. The catch per effort index of the Delaware spawning stock survey in April and May does not show a decline in recent years (Fig. 6.4.3). The increase in abundance at the young-of-year stage in 2007 (Fig. 6.4.1) should keep adult stock numbers high in the near future.

6 – 4.4 Actions and Needs

Continue present monitoring and conservation regulations.

6 – 4.6 Summary

Once considered extirpated by some biologists, the Delaware River population is now one of the major spawning stocks on the Atlantic coast. This stock was declared restored by the Atlantic States Marine Fisheries Commission in 1998. The key to its recovery was the reduction in sewage pollution in the River due, in part, to the federal Clean Water Act. Annual surveys by the Delaware Division of Fish and Wildlife, the New Jersey Division of Fish and Wildlife and the Pennsylvania Fish and Boat Commission monitor abundance changes.

6 – 5 Blue Crab

Children's Museum of Indianapolis

The blue crab (*Callinectes sapidus*) is a member of the swimming crab family Portunidae, and inhabits primarily estuarine habitats throughout the western Atlantic, Gulf of Mexico, and Caribbean, from Nova Scotia (although rare north of Cape Cod) to northern Argentina, and along western South America as far south as Ecuador (Williams 1979).

The blue crab is the most valuable commercial fishery species in the State of Delaware. Eighty-two percent of the State's entire commercial landings (shellfish and finfish) came from blue crab harvest in 2009. The 2009 ex-vessel value of 5.4 million dollars was over six times greater than the combined ex-vessel value from all other Delaware fisheries combined.

The Delaware Bay blue crab stock supports commercial and recreational fisheries in Delaware and New Jersey. Since 1973, 2.9 million kg*y-1 (6.4 million lb) of blue crabs are harvested annually from Delaware Bay, with 51% of the total weight landed in the State of Delaware. The commercial fishery is responsible for the majority of the total annual harvest. Recreational harvest accounts for about 3% and 14% of the landings in Delaware and New Jersey, respectively, in 2009.

Total annual Delaware Bay blue crab landings increased by 1,175% from 1978 to 1995 causing concerns of overfishing and the development of fishery restrictions in both states. Total landings peaked at 5.4 million kg (11.9 million lb) in 1995, remained high for the next seven years (averaging 3.7 million kg), and then declined considerably in 2003 and 2004 (2.1 million kg*y^{-1}). Recent landings have rebounded again to historical high levels, averaging 3.8 million kg*y^{-1} since 2005.

Blue crab spawning occurs in the summer months in lower Delaware Bay with peak larval abundance occurring in August (Dittel and Epifanio 1982). Larvae are exported from the estuary into the coastal ocean where they undergo a 3-6 week, seven stage zoeal development in surface waters (Epifanio 1995; Nantunewicz et al. 2001). Quantitative models describe an initial southward transport of zoeae along the inner continental shelf within the buoyant estuarine plume after exiting the estuary (Epifanio 1995, Garvine et al. 1997). Northward transport back toward the estuary is provided by a wind-driven band of water flowing northward along the mid-shelf. Across-shelf transport into settlement sites in Delaware Bay is accomplished by coastal Ekman transport tied to discrete southward wind events (nor'easters) in the fall. These discrete wind events may have a large effect on larval recruitment and settlement success in the bay and strongly influence year class strength through juvenile and adult stages.

The larval crabs settle out as juveniles in late summer though early fall. Females mate immediately after their pubertal molt into sexual maturity, after about one year of life, usually late in their second summer. Females then store the sperm over the winter and produce eggs in the following summer. Prager et al. (1990) estimated fecundity per batch as over 3x106 eggs. Females may spawn twice in their first year of spawning (Churchill 1921; Van Engle 1958).

Juvenile and adult blue crabs hold an important ecological role as opportunistic benthic omnivores, with major food items including bivalves, fish, crustaceans, gastropods, annelids, nemertean worms, plant material, and detritus (Guillory et al. 2001). Post-settled blue crabs have been shown to have a key effect on infaunal community structure, particularly through major predation on bivalves such as the eastern oyster (*Crassostrea virginica*) (Eggleston 1990), *Mercenaria mercenaria* (Sponaugle and Lawton 1990), *Rangia cuneata* (Darnell 1958), *Mya arenaria* (Blundon and Kennedy 1982; Smith and Hines 1991; Eggleston et al. 1992), and other bivalve species (Blundon and Kennedy 1982), and through indirect mortality on infaunal species from mechanical disturbance of sedimentary habitats caused by foraging (Virnstein 1977).

Fish appear to be the primary predators on blue crabs, with more than 60 fish species listed as known predators (Guillory et al. 2001). Blue crabs are known to be a common component of both juvenile and adult striped bass diet in Chesapeake Bay, albeit with great variability in relative importance among studies (Speir 2001). Although there have been recent investigations on the potential negative effect of the recovered striped bass stock on the Chesapeake Bay blue crab stock, no connection with decreasing blue crab population numbers has been supported (Booth and Martin 1993; Speir 2001).

Another very important source of predation on blue crabs occurs from cannibalism, as cannibalized blue crabs make up as much as 13% of the diet (Darnell 1958). Cannibalism appears to increase with increasing crab predator size and is heaviest during the period of juvenile recruitment (Mansour 1992).

6 – 5.1 Description of Indicator

A 16 foot small mesh trawl survey is used to monitor blue crab abundance in Delaware Bay. The survey began in 1978 and is conducted by the Delaware Division of Fish and Wildlife (DDFW). Thirty-nine fixed stations are sampled monthly from April to October. Harvest is also monitored by DDFW from logbook reports submitted by commercial fishermen on a monthly basis. Given annual collections of biological and fishery data, DDFW can estimate the size of the stock, exploitation rates, and how they change from year to year. These stock assessments have occurred annually since 1999.

6 – 5.2 Present Status

Stock abundance can fluctuate widely from year to year. Since 1978, model estimates of annual blue crab abundance have ranged from 31 to 660 million, averaging 165 million. The most recent estimate of abundance was 115 million crabs in 2009 (Wong 2010). More than half of the legally harvestable stock was removed by crabbers, indicating the stock was fully exploited.

6 – 5.3 Past Trends

Severe winters in the late 1970s, especially the winter of 1977, produced high over-winter mortality and a major decline in stock size which persisted for about eight years. A general period of high productivity (i.e. elevated recruitment) occurred for about 15 years from 1985 to 1999 (Fig. 6.5.3). During this period, DDFW crab indices were at or above median levels for 13 of 17 years. In 2002, a very weak year class occurred, beginning a recent period of lower stock abundance.

6 – 5.4 Future Predictions

Blue crabs have been in the midst of a generally low-recruitment period for the past decade. Only two above-average young-the-of-year (YOY) recruitment events have been observed in the past 11 years. As a result, poor spawning stock abundance was observed from 2003 to 2006. A gradual recovery in spawning

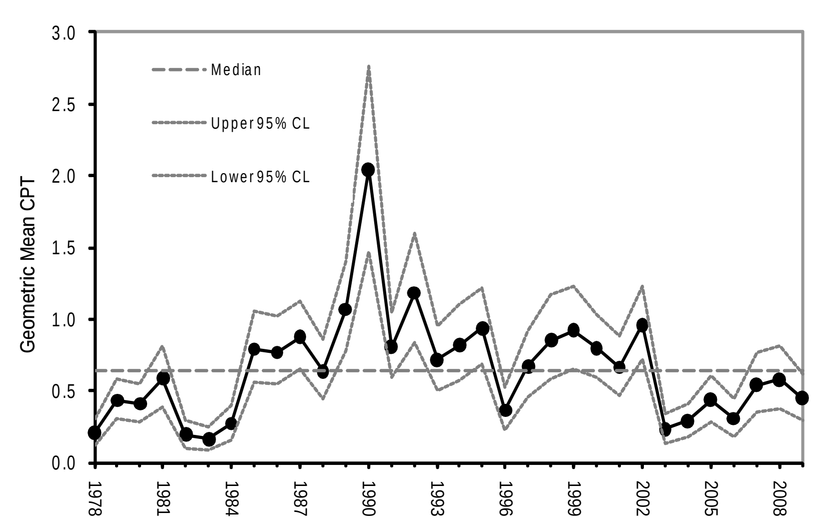


Fig. 6.5.1. Index of spawner abundance. Crabs >=120mm, Apr-May survey.

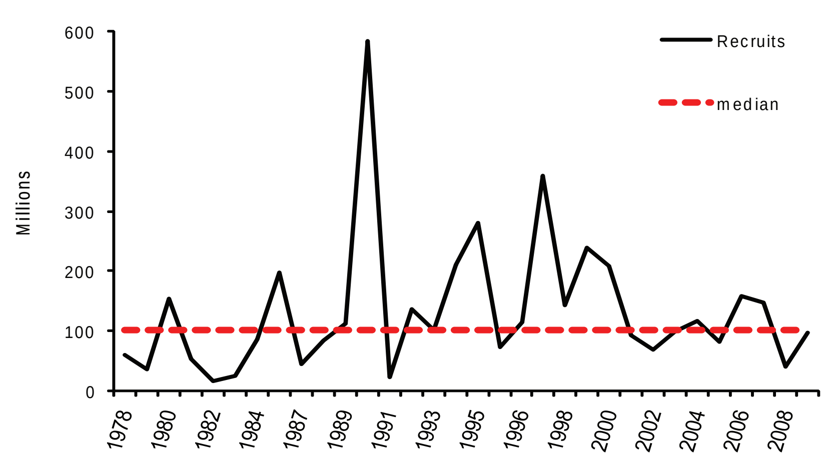


Fig. 6.5.2. Estimated stock size, recruit-size crabs < 120 mm.

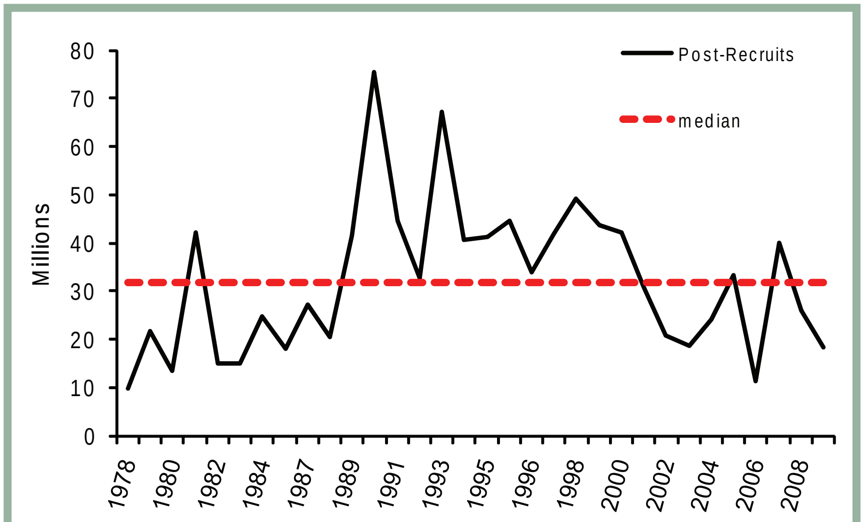


Fig. 6.5.3. Estimated stock size, adult (post-recruit) crabs >=120 mm.

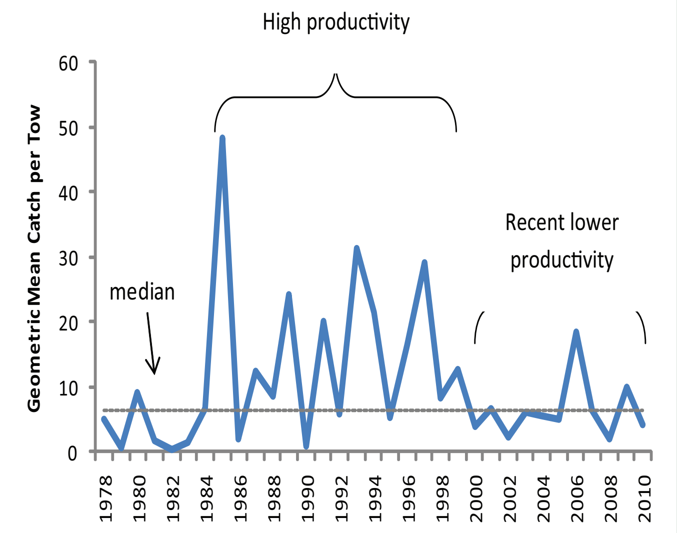


Fig. 6.5.4. Young-of-the-year index of abundance.

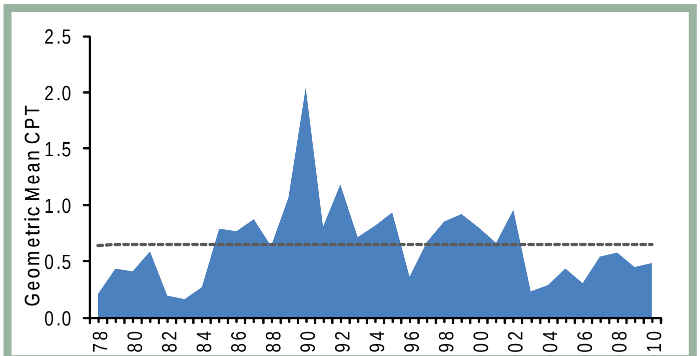


Fig. 6.5.5. Index of spawner abundance. Crabs >=120mm, Apr-May survey.

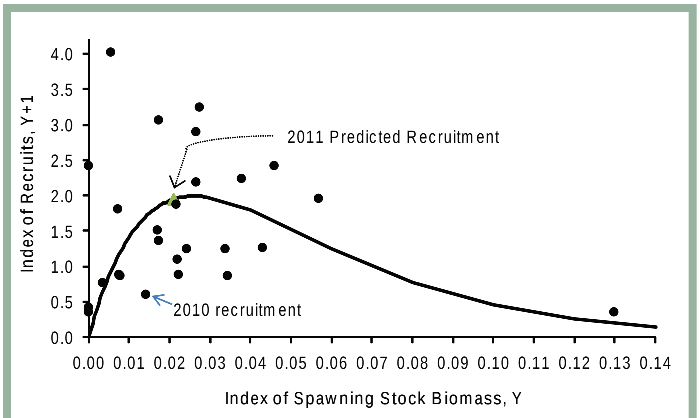


Fig. 6.5.6. Spawner-recruit relationship.

abundance has occurred, although levels remain below the median (Fig. 6.5.5).

Spawning stock biomass has gradually improved to levels that should support high recruitment events based on empirical observations (Fig. 6.5.6). Since environmental factors, particularly weather-driven coastal currents, can profoundly affect larval and YOY recruitment in the bay, it is very difficult to predict future stock dynamics with clarity, even with information about spawning abundance and mortality rates.

6 – 5.5 Actions and Needs

Nothing to report.

6 – 5.6 Summary

A 15-year period of high stock productivity has been followed by a relatively depressed period of low abundance for the past 11 years. Spawning abundance however has recovered enough to support sufficient recruitment in the near term future due to the blue crab's highly prolific reproductive biology. Harvest has remained elevated during this recent period of low recruitment, suggesting a fully exploited stock. Concerns of overfishing however are not yet critical since fishery effort has largely been constrained through caps on commercial licenses since 1994. Future stock dynamics may largely be affected by factors other than spawner abundance, such as oceanographic dynamics and cyclicity. All content in this technical report was taken from "Wong, R. 2010. 2010 Assessment of the Delaware Bay blue crab stock. Delaware Division of Fish and Wildlife, Dover, DE."

6 – 6 Weakfish

This member of the drum family (*Cynoscion regalis*) dominated Delaware's recreational and commercial finfish landings in the 1970s and 1980s, to the point that it was named as the State Fish. Weakfish return to the Bay in the spring from overwintering grounds off the North Carolina coast. Spawning occurs in May and then through the summer. The species is an indeterminate batch spawner. Larger weakfish, over several pounds, which were common in the 1970s and 1980s, were believed to spawn in the spring and then leave the bay. Younger, smaller weakfish stayed in the bay all summer, and could spawn more than once. Spawning occurs on shoals in the middle and lower bay. The young-of-the-year (YOY) are found from the lower Delaware bay well up into the tidal River, along with some adults. Young weakfish are first collected in May in most years.

Young weakfish are fast-growing, often reaching a length of six to eight inches by the end of their first summer, before leaving the Bay in the fall to migrate south. They feed heavily on opossum shrimp (known as mysids to biologists), which can be very abundant in mats of grass detritus washed out of marshes. The adults are carnivorous; in a study in the Delaware River in the 1970s, the only diet item found in a sample of adults was YOY weakfish. Other studies have found the preferred prey of adults is Atlantic menhaden, a member of the herring family, which has also been found to be the preferred prey of young and adult striped bass.

Weakfish abundance and catches have declined coastwide beginning in about 2000. A coastwide stock assessment completed in 2006 found that the rate of mortality due to natural factors had increased beginning in 1996, eventually causing the stock to decline. The assessment conducted screening of possible hypotheses to explain the increase in natural mortality. The results were that the impact of increasing striped bass abundance to unprecedented levels could not be rejected as a potential cause of the decline, due to possible impacts of the documented predation and competition for preferred prey. This hypothesis was strengthened by the fact that the boom in weakfish abundance which began in the 1970s coincided with widespread decline of striped bass, to the point that, by the 1980s, some authors worried that bass could go extinct. Striped bass were declared restored shortly before the decline of weakfish in the early 2000s.

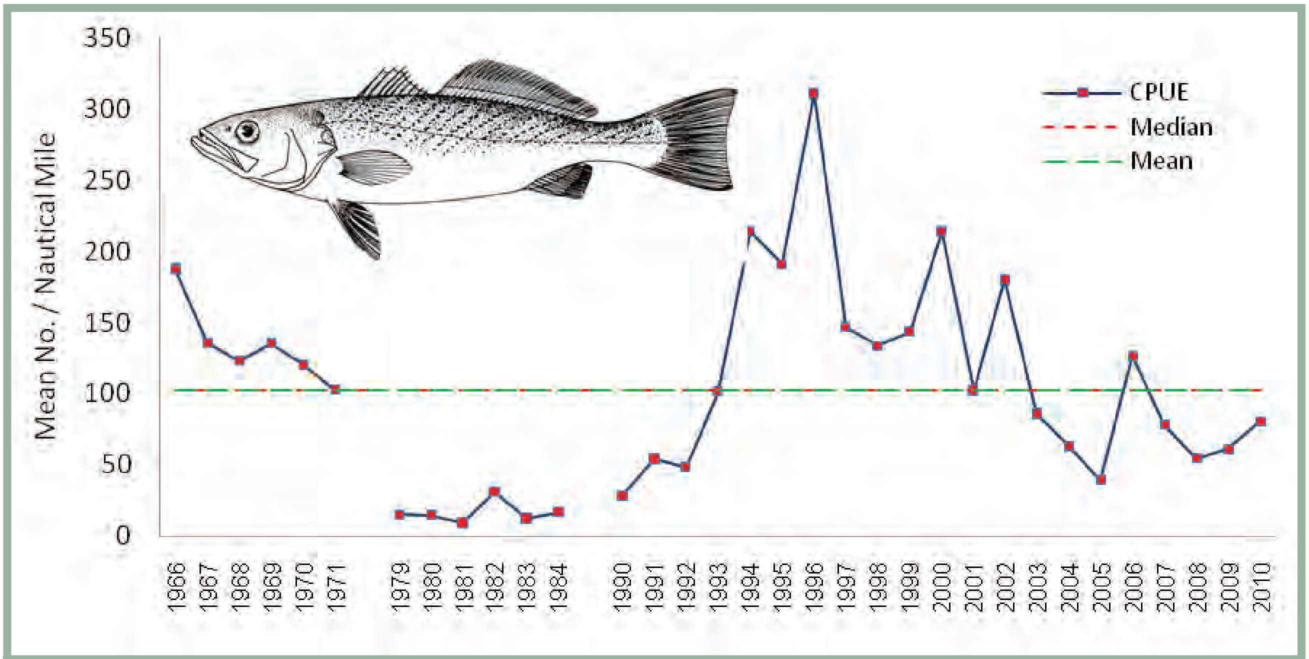


Fig. 6.6.1. Adult weakfish relative abundance (mean number per nautical mile), time series (1966 – 2009) mean and median as measured in 30-foot trawl sampling in the Delaware Bay.

6 – 6.1 Description of Indicator

The primary indicator is the mean catch per nautical mile of weakfish in the adult groundfish research trawl survey, conducted using a 30-foot (9.1 m) otter trawl net in Delaware Bay by the Delaware Division of Fish and Wildlife. This index is reported most recently in Michels and Greco (2011). The index is the mean number of weakfish caught per nautical mile at nine fixed stations in Delaware Bay for the months of March through December.

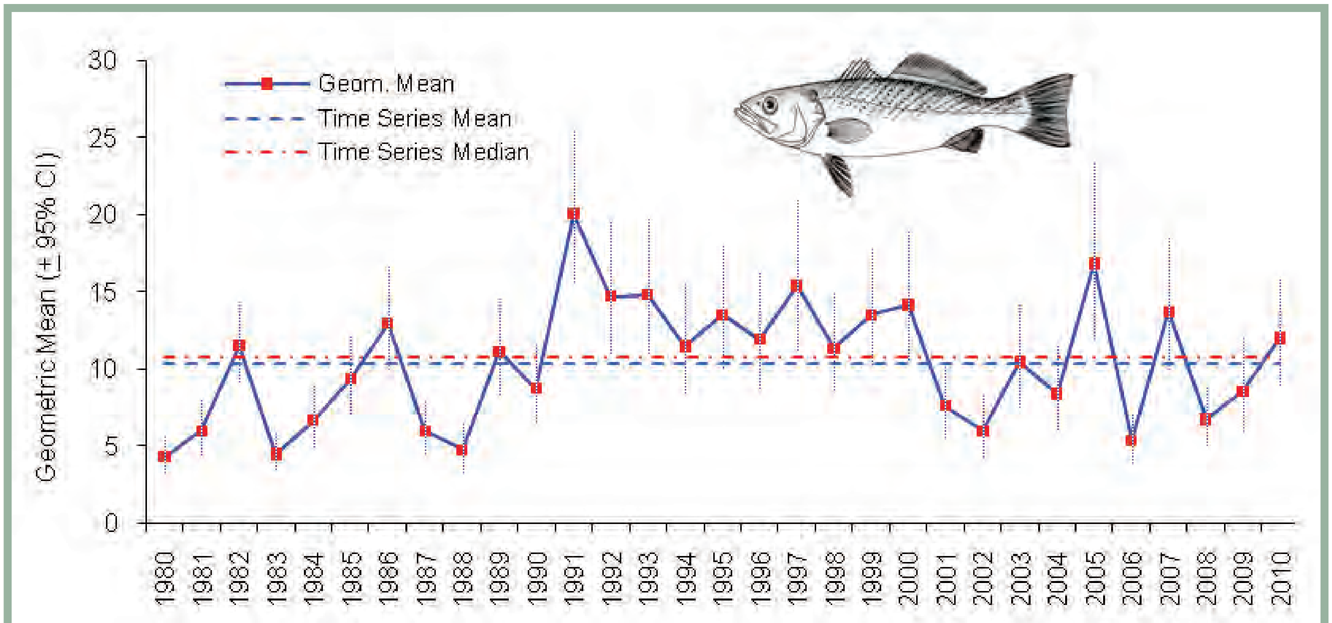


Fig. 6.6.2. Relative abundance of young-of-the-year weakfish from 1980 through 2010 with the mean and median for the last two decades (1990 – 2009) as measured by 16-foot trawl (9.1 m) sampling in the Delaware estuary.

A secondary indicator is the index of relative abundance of YOY weakfish as reported in Michels and Greco (2011), as measured by the Delaware Division of Fish and Wildlife's Juvenile Finfish Research trawl survey (Figure 6.6.2). This survey employs a 16 foot (4.9 m) shrimp try net.at 33 stations monthly from April through October in Delaware Bay and six stations in the lower Delaware River downstream from the Pennsylvania-Delaware border. The net has a 1.3 cm (0.5 inch) knotless stretch mesh liner in the cod-end.

6 – 6.2 Present Status

Weakfish relative abundance in the 30-foot (9.1 m) trawl survey has generally followed a declining trend since 1996 (Fig. 6.6.1) and total mortality estimates have correspondingly increased. The age structure of weakfish has become truncated back to the same level it had been in the early 1990s, with age three the oldest fish detected. In contrast, the age structure in the survey catches in 1999 and 2000 contained weakfish up to age eight. Over 95% of the 2010 catch was less than age two. On the other hand, weakfish was the most abundant finfish species in the survey.

Annual reproduction has continued at relatively high levels in terms of abundance of age zero fish (young-of-year), One reason for the continued levels of production of young weakfish, despite the decline in abundance and age-structure truncation affecting adults, is that 90% of weakfish are sexually mature at age one.

Currently, catches of legal weakfish (thirteen inches) in Delaware Bay are very uncommon, although sub-legal fish are present. The low abundance and truncated age-structure is a coast-wide phenomenon, not limited to Delaware Bay. The 2006 coastwide stock assessment conducted under the auspices of the Atlantic States Marine Fisheries Commission (Kahn et al. 2006) found that the stock was at low abundance due to a large increase in natural mortality. This assessment explored hypotheses concerning the cause of this increase, and found that a negative impact of striped bass was the hypothesis that could not be rejected, through predation, or competition for Atlantic menhaden or both.

A new assessment was conducted coastwide in 2009, and the same status was found, with lower abundance than that in the 2006 assessment. In this more recent assessment, a hypothesis that survived testing was that a combined negative impact of striped bass and spiny dogfish caused the decline through predation, competition or both. A second hypothesis was that the ratio of striped bass to Atlantic menhaden coastwide explained the decline of weakfish, implying competition with striped bass for menhaden, the preferred prey of both adult weakfish and adult striped bass (ASMFC 2009).

6 – 6.3 Past Trends

Weakfish were at moderate abundance prior to the 1970s, when they began an explosive rise in abundance and size. By the late 1970s, Delaware Bay had become famous throughout the Mid-Atlantic region as a destination for catching trophy weakfish in the spring spawning run. By the late 1980s, this fishery subsided. Coastwide fishery restrictions were imposed in the Mid-1990s, and abundance and catches began to increase. The fishery did not attain the high catches and trophy size seen in the 1970-1980 period, but it did produce higher catches of legal size weakfish for many, before it began tailing off in the 2000s.

6 – 6.4 Future Predictions

The 2009 stock assessment indicated that, unless natural mortality declined, even a moratorium would not produce a rebuilding of the Atlantic coast stocks of weakfish.

6 – 6.5 Actions and Needs

none

6 – 6.6 Summary

Currently, weakfish reproduction continues at moderate levels. Survivorship to catchable size, however, has declined greatly, to the point that catches of legal-size weakfish are uncommon in Delaware Bay. The cause of this decline has been determined to be an increase in natural mortality due to predation by, or competition with striped bass and spiny dogfish, possibly mediated by Atlantic menhaden abundance to a greater or lesser extent.

6 – 7 American Eel

Section Author: Desmond Kahn

Ellen Edmonson & Hugh Chrisp

American eels (*Anguilla rostrata*) are unique among fishes of the Delaware Estuary, because to spawn, they must swim to the Sargasso Sea off the southern U.S. coast. They die after spawning. The larvae are leaf-like in shape and are known as leptocephali. Before entering estuaries in late winter, they transform into clear, very small eels known as glass eels. All Atlantic eels are currently believed to spawn in one aggregation, so that no matter how depleted the spawning population from the Delaware estuary may be, the supply of larvae that arrives is not affected. The only potential source of a reduction in larval supply would be severe decline coast wide in the number of spawning eels. The larval eels are not believed to return to the particular waters from which their parents came, but rather to migrate up the coast with the Gulf Stream en masse and to move into the coast in a more or less random order.

Some eels migrate into freshwater non-tidal tributaries, often very small streams. Others remain in brackish water in tidal tributaries of the Bay and River. Some migrate far up the River into New York State and northern Pennsylvania. American eels play an important role in the life history of some species of freshwater mussels. Mussel larvae have evolved to hitch a ride on the gills of eels as a critical part of their life history.

Delaware and New Jersey have significant commercial fisheries for eels, prosecuted in the Bay and its tidal tributaries. Delaware landings have ranged above 100,000 lbs. (45,360 kg) in some years. This is a specialized fishery requiring live tanks because eels must be held alive until buyers arrive to take the eels. There are two markets for eels. One is a market for bait used by recreational fishers targeting striped bass locally, as well as bait for cobia to the south. Even anglers fishing in large southeastern reservoirs use eels for large catfish and striped bass. These eels are small, but must exceed the legal minimum size of 6 inches. The second market is in Europe and Japan for live eels that are flown overseas and are considered to be delicacies.

The eel fishery is dependent on horseshoe crabs as bait; fishers say that much of the year, the only bait that will catch significant numbers of eels in their pots is half of a female horseshoe crab containing eggs. With the restrictions on landings of horseshoe crabs, the price for this bait has increased to about $1 per crab in some cases. This factor has made the eel fishery more difficult.

Coast-wide, the American eel population is managed by the Atlantic States Marine Fisheries Commission. Some populations have declined in recent years, thought to be due to several potential factors, one of which is the introduction of a parasite that lives inside the swim bladder of eels. Other factors could include the long time to reach maturity (8 to 24 years), concentration during certain life stages making them vulnerable to exploitation, fishing mortality occurring prior to spawning, continued habitat loss, and changes in oceanic conditions where they spawn. The US Fish & Wildlife Service is currently conducting a review of the species status in order to determine whether it should be listed under the Endangered Species Act. It is worth noting that the Service closed a previous investigation in 2007, concluding that there was no basis for listing eels as threatened or endangered.

6 – 7.1 Description of Indicator

The index of eel relative abundance is developed from 13 trawl survey stations in the lower Delaware River by the Delaware Division of Fish and Wildlife Juvenile Finfish Trawl Survey. The net is a 16-ft (4.8-m) semi-balloon trawl with a 0.5-in (1.3-cm) cod end liner towed by 62-ft (19-m) R/V First State. Data from April through June is employed. The geometric mean catch-per-tow is the estimator (Fig. 6.7.1). The catch consists of eels from ages 0 to 7, with the most common age about 3 years of age. All eels are juveniles until they migrate to the Sargasso Sea on their spawning run.

6 – 7.2 Present Status

Time series analysis produced a significant fit of a cubic polynomial regression line representing the index as a function of year, which explains a statistically significant portion of the variation ($P < 0.05$, $R2 = 27.4\%$). This fit to a curvilinear line suggests a cyclic pattern of abundance. Such patterns raise the possibility of some type of decadal-scale shifts in weather patterns affecting recruitment into the stock. Since larval eels depend on the Gulf Stream for transport up the coast, wind patterns could possibly affect the variation in the numbers of glass eels that reach the estuary.

Catch-per-tow declined in the later 1980s and increased into the mid-2000s. Recently catch per tow has declined somewhat to moderate levels.

6 – 7.3 Past Trends

Abundance declined somewhat during the 1980s, but increased to higher levels in the mid-2000s. Sykes and Lehman (1957) reported that eel weirs were so numerous on the non-tidal Delaware River that they trapped and killed many, if not most, YOY shad migrating downriver in early fall. These weirs targeted the so-called silver eel stage, which are adults migrating down river and out to spawn in the Sargasso. Smiley (1884) described "hundreds of traps" in the River between Lackawaxen and Hancock. This indicates much heavier fishing mortality on silver eels in the upper Delaware River many decades ago. In recent years, only one weir has been operating in the Delaware River, in New York State. However, even if fishing mortality was high on eels in the upper Delaware River, that would not affect the number of new recruits arriving from the Sargasso Sea annually, because the total coast wide stock would be little affected by reductions in the spawners from the Delaware River.

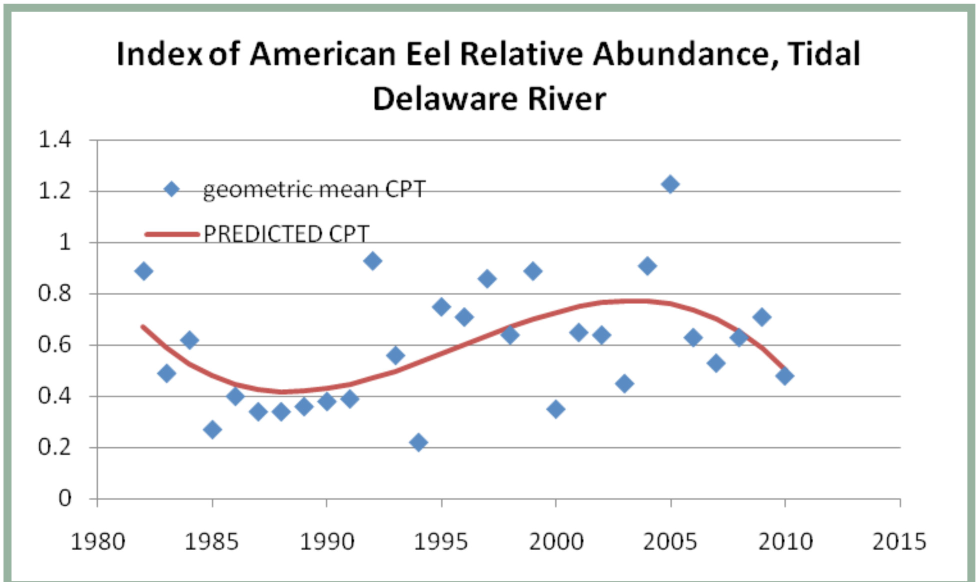


Fig. 6.7.1. Index of relative abundance of American eels in the tidal Delaware River, based on catch per tow at 13 stations from April –June annually. The index is the geometric mean catch per tow. The predicted line was fitted as a cubic polynomial regression, P = 0.0428, R2 = 27.4%.

6 – 7.4 Future Predictions

There are no apparent bases for future predictions, but the coast wide nature of the spawning aggregations (at least that is the current understanding), suggest that even if the Delaware Estuary spawning numbers would decline, the estuary would still get relatively high recruitment annually.

6 – 7.5 Actions and Needs

Although the main stem of the Delaware River is un-dammed, hundreds of dams still block passage along its tributaries; many are low head dams under private ownership and in poor condition. In addition, there are thousands of culverts for roads that cross the tributaries. And in many areas the riparian forested buffer along the streams has been removed, leaving the stream exposed to sun and dramatically increased non-point source sediment and pollution run off. Fish passage and riparian restoration would help improve habitat for eel by increasing connectivity and improving in-stream habitat by providing shade and structure in these tributaries.

6 – 7.6 Summary

Eel populations declined in the late 1980s and increased into the mid-2000s. Recently the population has declined somewhat to moderate levels. Annual recruitment is expected to remain high due to the coast wide nature of eel spawning at sea.

6 – 8 Eastern Oyster

Section Author: John Kraeuter


PDE

The eastern oyster, *Crassostrea virginica* (Gmelin, 1791), is a dominant structural and functional member of the Delaware Bay benthos. It supports a commercial fishery, aquaculture and provides a hard substrate in an environment otherwise dominated by sand and mud. In addition to providing structure, which is habitat for many other species, oysters filter large quantities of water thus enhance nutrient cycling within the system. Oysters have been harvested from the bay since pre-colonial times and current harvests are carefully managed.

The life cycle of the American oyster in Delaware Bay begins with a sperm and egg that are released into the water in the summer. Some years spawning can occur as early as May or as late as September, but most spawns take place in July and August. Females can release all their eggs at once or partially spawn multiple times, but an average female may produce 2 to 60 million eggs during a single spawn. Typical spawns in a hatchery yield 1 to 15 million eggs. The fertilized egg and the free swimming larvae remain in the water column for two to three weeks before attaching to some hard substrate (by setting or settling), preferably clean oyster shell. The subsequent growth rate depends on the temperature and salinity of the site where the oyster attaches. By fall the YOY oysters can range in size from ¾ mm to over 35 mm depending on location and when they set. Little or no growth takes place during the winter, and young oysters are heavily preyed upon by oyster drills, flatworms, small crabs and other predators. By the next fall most surviving oysters reach 30 to 65 mm depending on the location within the salinity gradient. Lower salinity areas have slower growth, but there are fewer predators so survival is better. Average growth to market size (3 inches) typically takes from 3 to 6 years in Delaware Bay, again depending on the location along the salinity gradient. Two oyster diseases are present in Delaware Bay: MSX, *Haplosporidium nelsoni* and dermo, *Perkinsus marinus*. Neither of these organisms affects humans, but they are eventually lethal to oysters. There is evidence that the native oyster population has developed some resistance to MSX. Since 1989 dermo has been a major factor controlling the oyster population levels on the higher salinity seed beds in Delaware Bay.

The oyster and the oyster assemblage are important to the general ecology of the bay. The assemblage of organisms that develop because the oyster provides a hard substrate and irregular spaces for attachment or shelter was recognized in the late 1800s as community and described as a biocoenose by Möbius. This concept was the forerunner of what we now know as community ecology. In addition to the structure provided by the oyster, it is a major functional part of the ecosystem because it filters the water for food. This filtration process removes particulate material from the water column and deposits it on the sediment surface where some of it becomes food for other organisms or is broken down by bacteria. This filtration and deposition is an important pathway for nutrient cycling in estuaries.

6 – 8.1 Description of Indicator

The oyster beds of the New Jersey portion of Delaware Bay have been surveyed in the fall and winter since 1953. In the earlier years the survey took place from September throughout the winter, but since 1989 the period has been reduced to about one week in the last part of October to early November. A random stratified sampling method divides each of the beds into 0.2-min latitude x 0.2-minute longitude grids (~ 25 acres or 10,171 m^2) (Fig. 6.8.1). Each bed is divided into three strata that are defined by surveys of the bed areas that are scheduled on a 10 year rotation. The bed area survey data are then divided into high quality, medium quality and low quality. These represent the areas with 50%, 48% and 2% of the oysters respectively. For the fall survey the grids in the high and medium quality categories are randomly allocated. The number of grids sampled in these two strata is dependent on the variability of the particular bed as determined by the area survey and past sampling.

A grid sample consists of a composite of 3 one-third bushel lots from 3 1-minute tows by a 1.27-m wide commercial oyster dredge on a commercial oyster boat. The length of the tow is measured by repeated (every 5 seconds) GPS positions for the duration of the tow, and the total volume of material brought up by the dredge is measured.

The bushel sample is sorted at the laboratory for total volume, and volumes of oysters, spat, boxes, cultch, and debris. Numbers of oysters, spat, boxes are recorded and all oysters and boxes are measured. Subsamples are set aside for condition index (dry meat weight), and pathology (MSX (*Haplosporidium nelsoni*) and dermo (*Perkinsus marinus*)). Dredge calibration studies are used with the other data to derive numbers per square meter information. Ancillary data are provided by a dock-side monitoring that collects information on the size and number of oysters going to market. A monthly mortality and dermo survey on selected beds along the salinity gradient that begins in April/May and terminates with the oyster survey each year also provides critical information to managers and the industry.

These data are combined into a report that is presented to a group of knowledgeable individuals from within and without the area in a stock assessment workshop held each February. The results of the survey are then presented to the New Jersey Department of Environmental Protection and the Oyster Industry at the next Shellfish Council meeting for management consideration and setting of the coming season's harvest.

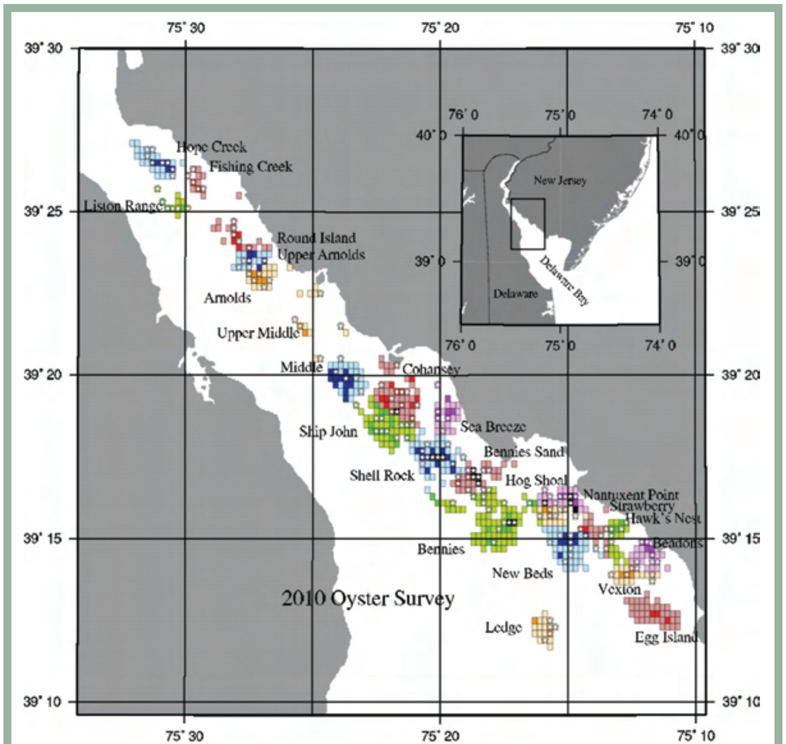


Fig. 6.8.1. New Jersey oyster seed beds. Dark colors represent grids with 50% of the total oysters on the bed, while the lighter colors represent 48% of the oysters. The remaining 2% are not surveyed annually.

The oyster resources in the State of Delaware are a fraction of those in New Jersey because the area in the lower bay on the Delaware side is less. The State of Delaware also conducts an annual survey of their oyster resources. It is less intensive than that of New Jersey, but it too relies on dredge samples and counts of live, dead and newly set oysters to set the following year's quota. In recent years representatives from the State of Delaware have presented information from their survey at the stock assessment workshop.

6 – 8.2 Present Status

Population levels and harvest levels have been static at about 1.9 x 10^9 individuals and 70,000 to 100,000 bu (bu = 37 qts = 35 L), respectively, since 2002 in spite of an historically unprecedented period of low settlement that extended from 2000 through 2007. The low recruitment coupled with the oyster disease dermo has reduced oyster stocks on the lower seed beds, but an active management program has sustained the overall levels of oyster abundance while permitting harvest. A welcome increase in settlement in 2009 and even larger set in 2010 should provide for expansion of adult oyster abundance in the next few years.

While per square meter quantitative data from Delaware are not available, data presented by the State of Delaware at the annual New Jersey stock assessment workshop indicate that population dynamic trends on the Delaware side of the Bay mirror those seen in New Jersey.

6 – 8.3 Past Trends

There were substantial oyster harvests from Delaware Bay in the middle 1800's, and by the latter part of that century extensive importation of seed enhanced the numbers of market oysters over what the bay alone could produce. Active survey of the seed bed resource did not take place until 1953, and annual records are available since that date (Fig. 6.8.2). The survey was initiated during a period of low abundance and just a few years before the oyster disease MSX substantially reduced the total numbers of oysters in the bay. The following decade was a period of low abundance, but it was followed, from the late 1960's until the mid 1980's, by a period of high abundance. This was terminated by another MSZ epizootic in 1985, and the emergence of dermo in 1989 which has dominated the population dynamics in the lower seed beds ever since. In the late 1950's the seed bed oyster population averaged 2.8 x 10^9 adult individuals and it currently is 1.9 10^9 individuals. In the peak years of the 1970's to the mid 1980's the average oyster population was ten fold higher at 1.7 x 10^{10}.

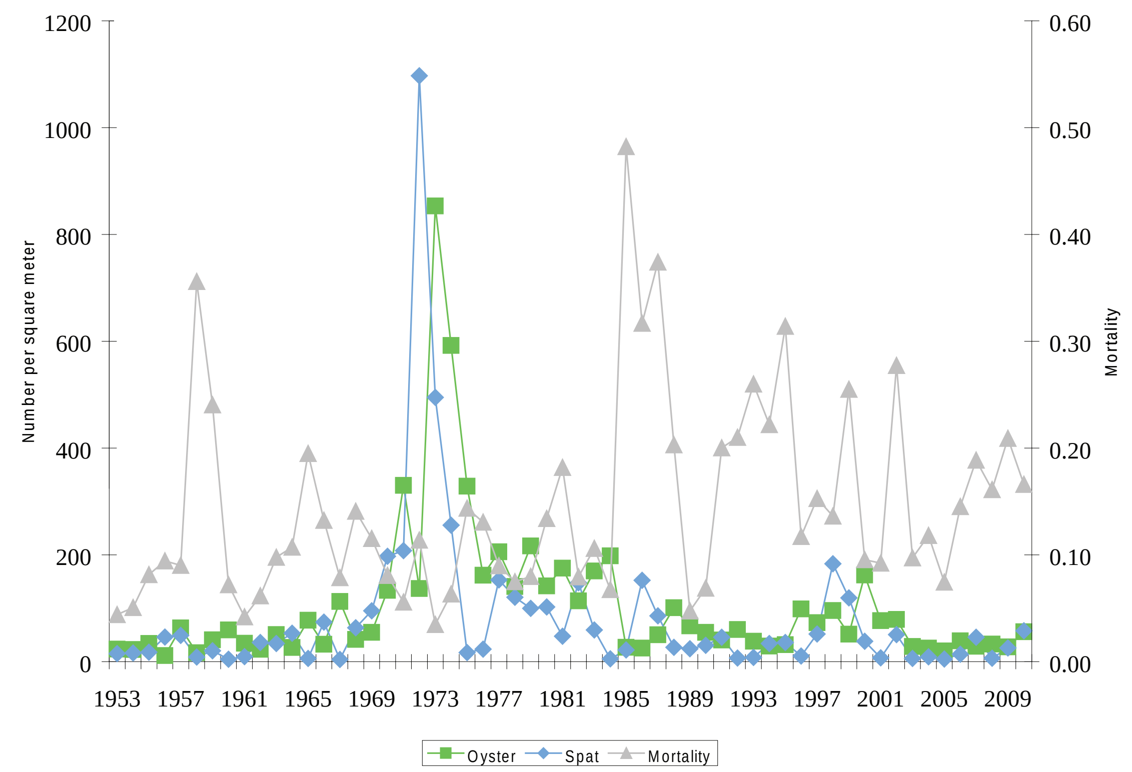


Fig. 6.8.2. Numbers of adult and spat (young of the year) oysters in the fall of each year on the New Jersey Delaware Bay seed beds, 1953 to 2010. Mortality is the fraction of adult oysters dead in the fall of each year.

6 – 8.4 Future Predictions

Management of this resource relies on annual survey data. Because the intensity of oyster diseases and recruitment success cannot be predicted, the only mechanism available for resource management decisions is the annual update of the oyster population information. There is no evidence that harvest has had substantial effects on the population dynamics of oysters in Delaware Bay since at least the late 1960's. Current recruitment levels should bring the population back toward the late 1950's levels. Unless dermo disease in the lower portion of the bay becomes substantially reduced it is unlikely that the higher levels of oysters experienced in the 1970's to the mid 1980's will return. An ongoing study that is attempting to link hydrodynamics and oyster population dynamics with detailed models of oyster diseases and the genetic structure of the Delaware Bay oyster stocks should provide additional information that will substantially inform the management process. The mapping of unutilized oyster beds in the Hope Creek area has offered a new resource for managers to consider.

More detailed data are available through the annual monitoring reports of the Haskin Shellfish Research Laboratory, Rutgers University at the web site: http://vertigo.hsrl.rutgers.edu.

Climate change

As long as the oyster population dynamics in higher salinity areas is controlled by dermo and MSX, changes in the oyster population will be linked to salinity levels. The funnel shape geomorphology of Delaware Bay makes the area available for development of oyster reefs less from the mouth of the bay toward the fall line. Combining this geomorphology with ongoing sea-level rise suggest that the area available for prime oyster habitat will be reduced in the future. Other factors such as channel deepening, extraction of ground water, and consumptive use of Delaware River freshwater supplies all imply that salinity will rise even if climate change causes increased rainfall. Because freshwater in the Delaware River/Bay system is actively managed, man made decisions may have more effects on the oyster population than modest climate change. If the most pessimistic climate change scenarios take place, there are likely to be such profound changes to the Delaware Bay system, and its human inhabitants that any change to the oyster resources will be of secondary or tertiary importance to the maintenance or movement of infrastructure.

6 – 8.5 Actions and Needs

The maintenance of the annual oyster population and oyster disease surveys is essential to management of this resource. Efforts need to be made to evaluate the Hope Creek, Fishing Creek, and Liston Range oyster bed population dynamics. Plans need to be developed to manage the likely continued rise in salinity in Delaware Bay and its importance to the long term viability of key oyster beds. At a minimum, development of a bay wide monitoring system for temperature and salinity should be implemented. As possible additional parameters such as pH, dissolved and particulate nutrients, chlorophyll and total suspended solids could be added. Plans for enhancing recruitment through shell planting need to be continued and expanded.

6 – 8.6 Summary

The oyster is a keystone species in the Delaware estuary in that it provides a habitat, a harvestable resource and a key link in ecosystem nutrient cycling. The oyster population abundance in Delaware Bay is currently controlled by a balance between recruitment and disease related mortality. Both of these processes respond to environmental factors such as the annual temperature cycle and salinity (freshwater input) and thus cannot be predicted. This unpredictability makes annual surveys a key to sustainably managing the resource. Recent good settlement of young indicates that the adult population will increase in the next few years. Shell planting to enhance recruitment is a mechanism for increasing population abundance, and should be continued and expanded.

6 – 9 Osprey

Section Author: Gregory Breese

One of the largest birds of prey in North America, the osprey (*Pandion haliaetus*) eats almost exclusively fish. It is one of the most widespread birds in the world, found on all continents except Antarctica. The osprey is a large raptor (bird of prey) usually seen near large bodies of water. Ospreys arrive in Delaware Bay in early March and begin nesting by mid March. Osprey use a variety of nest sites including: live or dead trees, man-made nesting platforms, utility poles/structures, channel markers, and duck blinds. Young fledge in the early summer. Wintering occurs in the Caribbean, Central America, and South America.

Osprey feed on live fish, which typically make up 99% of their diet. Highly adapted for capturing fish, osprey may plunge underwater in pursuit of their prey. Bald eagles and great horned owls are known to take fledgling osprey. Raptors and other birds will take over osprey nests. Bald eagles are well known to rob osprey of the fish they have caught.

Ron Holmes

6 – 9.1 Description of Indicator

Both New Jersey and Delaware have osprey monitoring and conservation programs. Nest checks by aerial or ground observers are conducted by staff and volunteers to determine active nests and productivity between the end of April and mid July. Each state works independently on their monitoring programs so timing and the survey areas are different (Delaware focused effort in Inland Bays until 2007 and New Jersey surveyed state-wide), and reports are provided separately.

6 – 9.2 Present Status

Ospreys appear to be doing well in Delaware Bay. Productivity, as measured by fledglings observed, is higher than needed for a stable population. Population levels may be close to what is believed to have been the level prior to the widespread use of DDT.

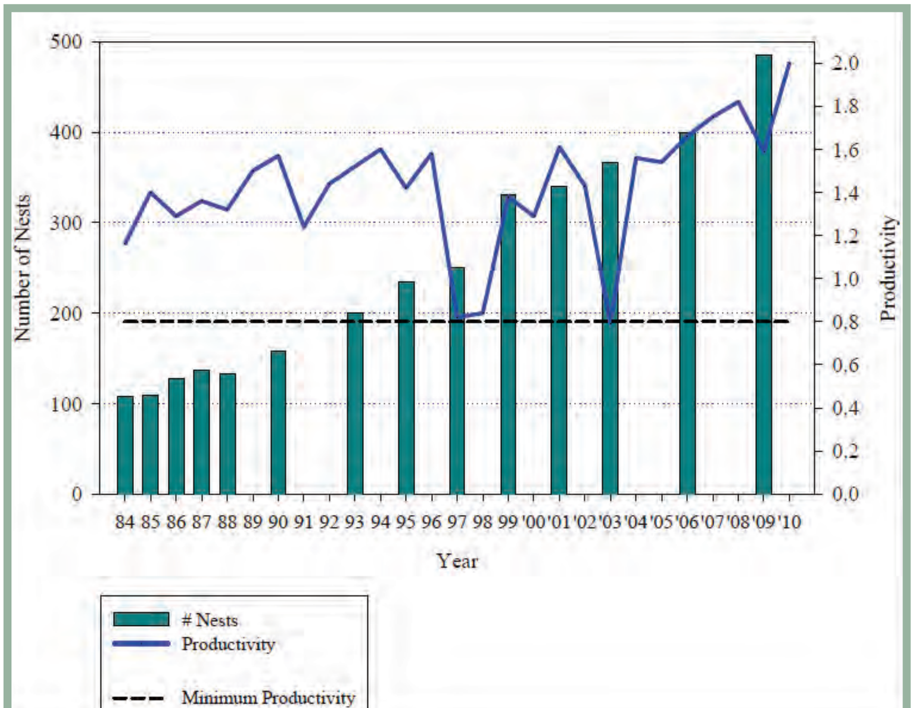


Fig. 6.9.1. Osprey nesting population (bar) and productivity (heavy line) 1984-2010 in New Jersey.

6 – 9.3 Past Trends

Historically abundant, osprey populations declined precipitously in the Northeast from the 1950s through the 1970s, due to the widespread use of DDT to control mosquitoes. Since DDT was banned, osprey populations have been slowly rebuilding, aided by reintroduction programs. Delaware Bay populations remained depressed due to high organochloride and PCB levels into the 1990s. Since then, levels of organochlorides have lowered and productivity has improved.

6 – 9.4 Future Predictions

The outlook for osprey is good in Delaware Bay. Disturbance is generally not an issue, they adapt well to man's activities. Contaminants have been reduced and levels in osprey continue to decline. Expectations are that osprey will continue to show success in Delaware Bay.

6 – 9.5 Actions and Needs

Volunteers are needed for monitoring nests and productivity. Since osprey readily use artificial platforms and structures for nesting, those interested in establishing nesting structures, or that have questions about osprey should contact the State agencies responsible for bird conservation (links to the right).

6 – 9.6 Summary

Osprey populations in Delaware Bay are a success story. They demonstrate the value of reducing contaminants in our environment and taking conservation actions. In addition, the success of osprey conservation shows how volunteers can make a difference.

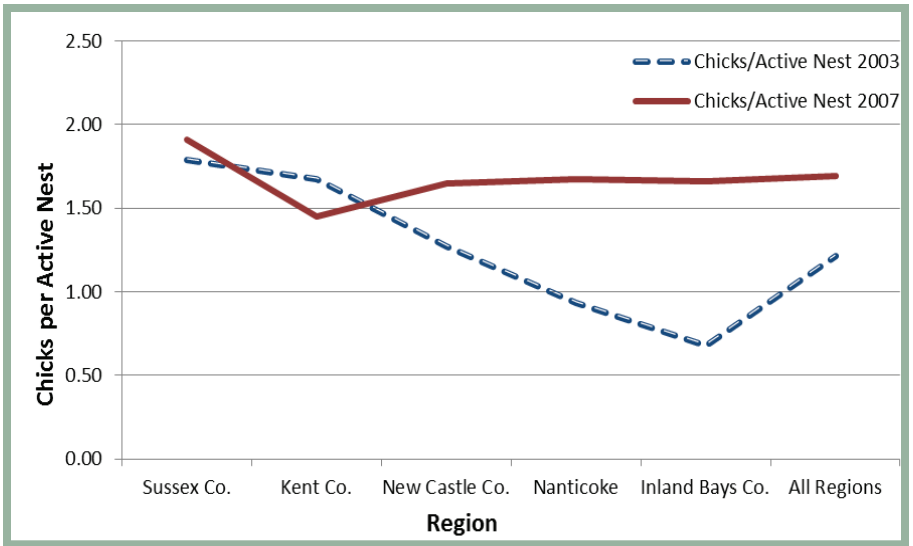


Fig. 6.9.2. Osprey productivity in Delaware by region in 2003 and 2007

NJ:
http://www.njfishandwildlife.com/ensphome.htm

DE:
http://www.fw.delaware.gov/Pages/FWPortal.aspx

6 – 10 White Perch

Section Author: John Clark

White perch (*Morone americana*) are one of the most abundant fish in the Delaware Estuary and probably the most widespread, found in nearly all the waters of the Delaware Estuary, from the Bay and the River to all their tidal tributaries. White perch support important recreational and commercial fisheries throughout the estuary. The Delaware Estuary white perch population is currently in good condition and is not overfished.

Duane Raver, USFWS

White perch are closely related to striped bass, but the white perch is a smaller fish. The Delaware state record white perch was 2 pounds 9 ounces, but any white perch over one pound is considered large. Delaware Estuary white perch display anadromous tendencies in that large numbers of white perch moved into the tidal tributaries in spring to spawn and then out into the deeper waters of the estuary to overwinter, but, unlike striped bass, white perch rarely leave the estuary. White perch numbers in the Delaware Bay and River typically increased during the fall and remained high through winter, then decreased during the spring and summer (Miller 1963, PSEG 1984), while white perch numbers in the tidal tributaries showed the opposite trend (Smith 1971). However, white perch were caught year-round in both the Delaware Estuary (de Sylva et al 1962) and the tidal tributaries (Smith 1971), so these migratory movements are not universal among perch. Landlocked white perch populations have thrived for years in most of the freshwater ponds in the headwaters of Delaware Estuary tidal tributaries (Martin 1976).

White perch spawn in the Delaware River (Miller 1963, PSEG 1984) and most of the Delaware Estuary tidal tributaries (Miller 1963, Smith 1971, Clark 2001). Spawning occurred from early April through early June, but May was usually the peak spawning month (Miller 1963, Smith 1971, PSEG 1984). YOY white perch, like the adults, were found in both the Delaware Estuary (PSEG 1984) and the tidal tributaries (Smith 1971). YOY white perch were found throughout the year in the lower salinity reaches of all sampled tidal tributaries (Clark 2001).

White perch feed almost exclusively on small invertebrates from their larval through juvenile stages, and then add fish to their diet as they reach maturity (PSEG 1984). Almost all male white perch are sexually mature in two years and almost all female white perch are sexually mature in three years (Wallace 1971). Delaware Estuary white perch have been aged to ten years old and some may live longer than that, but white perch older than six years old were rare (Clark 2001).

White perch tolerate a wide range of environmental conditions, as would be expected of such an ubiquitous fish. White perch were caught at water temperatures ranging from 2.2° C (Rohde and Schuler 1971) to 35.5° C (Clark 1995) and salinities ranging from freshwater (Shirey 1991) to 35 parts per thousand (Clark 1995). White perch catch per unit effort was greatest in fresh and oligohaline waters of Delaware tidal tributaries (Clark 2001), which may be explained by pointing out that the freshwater reaches of tidal tributaries are smaller, so the density of perch increases in such water, even if the abundance does not. Smith (1971) caught white perch at a dissolved oxygen level of 2.2 parts per million (ppm) in Blackbird Creek and Clark (1995) caught white perch at a dissolved oxygen level of 2.0 ppm in a high-level tidal impoundment near the Little River, but neither report indicated whether the fish showed signs of stress at these low dissolved oxygen levels.

White perch were among the top five finfish species landed commercially in Delaware during each year of the last decade, which is not surprising since gourmets consider the white perch to be one of the finest tasting fish in the world. Landings averaged 71,909 lbs. (32,618 kg) during 2000 through 2010, with the highest landings, 113,997 lbs. (51,709 kg), reported in 2000. Most fishing effort for white perch was expended during late fall through winter and into early spring. Delaware Bay was the source for most commercially-caught white perch, but substantial landings also came from the Delaware River and several tidal tributaries. New Jersey white perch landings in the Delaware Estuary counties (Salem and Cumberland) averaged 24,333 lbs. (11,037 kg) per year during 1995 through 2000, with the highest landings, 42,000 lbs. (19,051 kg), reported in 2000.

White perch were among the top 10 fish species harvested recreationally in Delaware during each year of the last decade. The mean estimated recreational harvest during 2000 through 2010 was 26,840 pounds, with the highest harvest, 45,626 pounds (45,626 kg), reported in 2010.

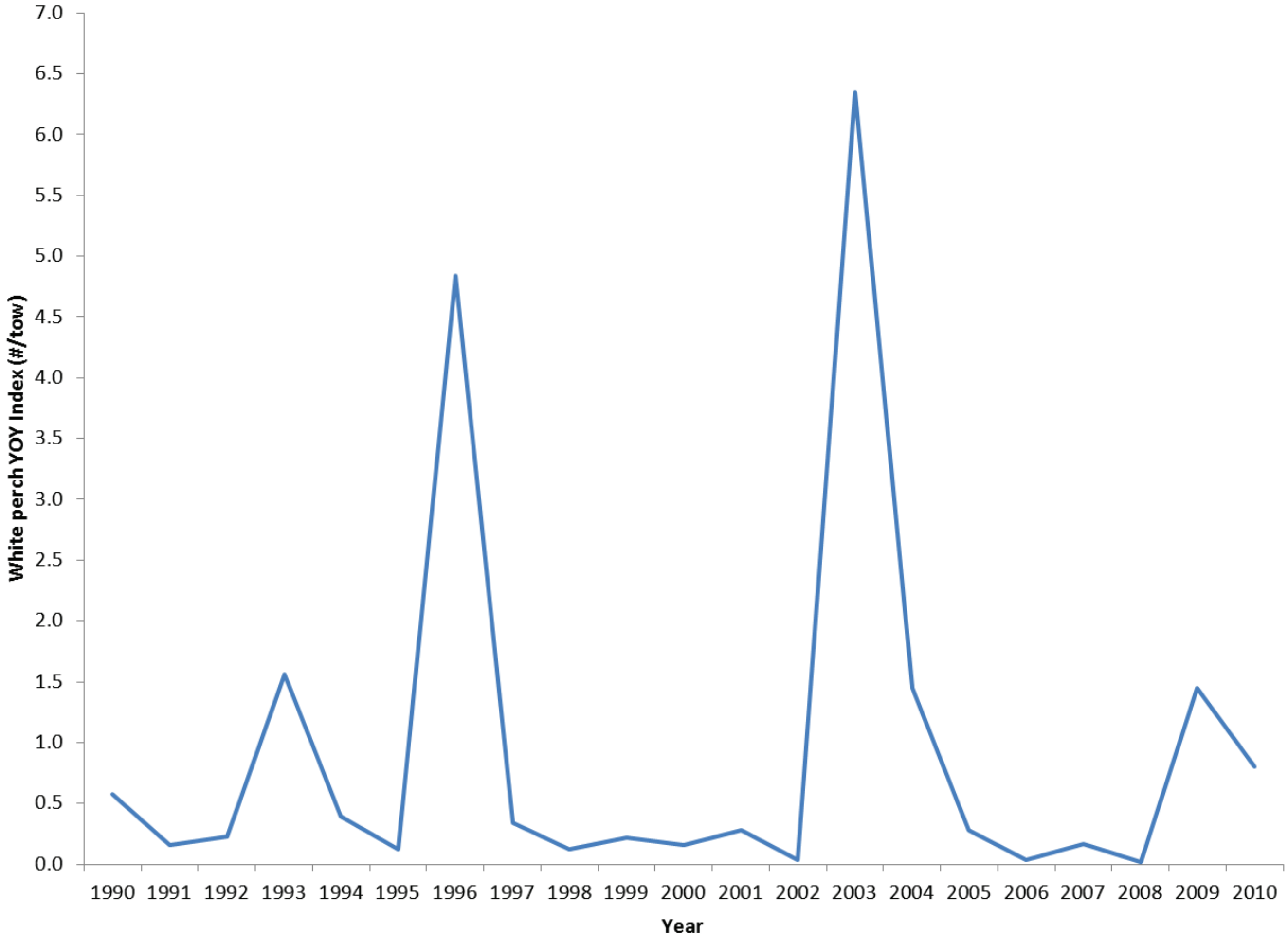


Fig. 6.10.1. White perch YOY index (number of YOY white perch caught per trawl tow) from the DDFW Juvenile Trawl Survey for 1990 through 2010.

6 – 10.1 Description of Indicator

This indicator uses the white perch YOY index derived from the Delaware Division of Fish and Wildlife's (DDFW) Juvenile Finfish Trawl Survey. The juvenile finfish trawl survey used a 16' trawl net to sample 39 inshore Delaware Bay and River stations monthly during April through October. The YOY index was calculated as the geometric mean number of YOY white perch caught by the juvenile finfish trawl survey during June through October in Delaware Bay and River (Michels and Greco 2011). The white perch YOY index is an indicator of year-class strength and indirectly an indicator of spawning stock abundance. The white perch YOY index has not been used as a predictor of future population size or future commercial catches. The median white perch YOY index for the 1990 through 2009 time series, 0.26 YOY white perch per tow, was exceeded in 2009 and 2010 (Fig. 6.10.1).

6 – 10.2 Present Status

The white perch YOY index was above the time series median YOY index value during 2009 and 2010, which suggested the Delaware Estuary white perch spawning population was large and spawning success was good. Delaware white perch commercial landings exceeded 100,000 lbs. (45,360 kg) in both 2009 and 2010; the first time landings exceeded 100,000 lbs. for two consecutive years in the 1951 through 2010 time series, which also suggested the Delaware Estuary white perch population was large.

6 – 10.3 Past Trends

Delaware white perch commercial landings were the longest term time series available to assess past trends in white perch abundance (Fig. 6.10.2), but white perch landings were affected by several factors other than the white perch population, such as fishing effort, conditions

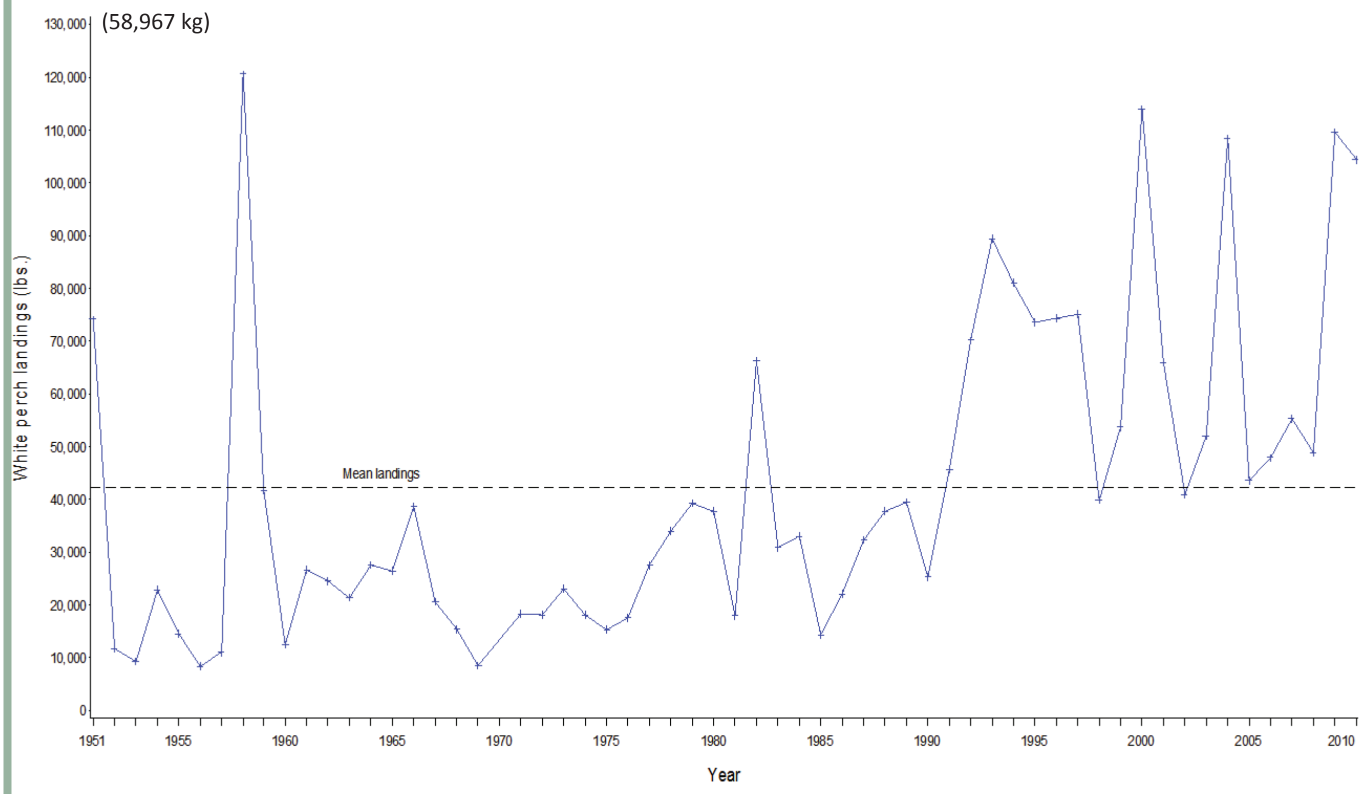


Fig. 6.10.2. Delaware commercial white perch landings (lbs.) during 1951 through 2010.

during the fishing season, gears used, etc. Delaware white perch landings were high for several years during the 1950s, were low during most of the 1960s and 1970s, rose during the 1980s and have been near or above the time series mean during the 1990s and 2000s. Whether the Delaware landings greater than 100,000 lbs. (45,360 kg) seen during 2009 and 2010 are sustainable is unknown.

6 – 10.4 Future Predictions

The white perch's ability to inhabit almost all waters of the Delaware Estuary may buffer it from some of the extreme population fluctuations seen in other species, but habitat protection, particularly for areas of the estuary in which white perch spawn, is important for the continued viability of this fish. Past trends suggest that white perch will continue to support important commercial and recreational fisheries in the Delaware Estuary for the foreseeable future.

6 – 10.5 Actions and Needs

The 8-inch (20.3 cm) minimum size limit for white perch established by Delaware in 1995 has been effective in allowing almost all white perch to spawn once, and for many white perch to spawn several times, before recruiting to the fisheries. White perch often spawn in areas of the Delaware River and in the upper reaches of Delaware Estuary tidal tributaries that have been subject to intense development pressure in the past 30 years. These are spawning habitats for many fish species in addition to white perch and these habitats should be protected.

6 – 10.6 Summary

White perch are one of the most abundant and widespread fish in the Delaware Estuary. The species supports important commercial and recreational fisheries.

6 – 11 Macroinvertebrates

Section Authors: David Burke and Gerald Bright

Freshwater benthic macroinvertebrates are a useful indicator of the ecological integrity of the Delaware River watershed for several reasons. A variety of macroinvertebrates live in every aquatic environment, and they are functionally important in several ecological roles. They are widely acknowledged to be good indicators of water quality because they are directly impacted by changes in water quality. Furthermore, they have been studied extensively in all parts of the Delaware Basin.

In spite of these facts, it is difficult to aggregate and summarize data about this indicator for a multi-state area like the Delaware Basin. This is because the various organizations that produce data (including state environmental agencies) all use different methods of sampling and analysis. Because of the differences in methods, only an approximate comparability between the data from different sources can be assumed. The best that can be done is take advantage of the fact that all states distill their findings into grades of condition (e.g. "good, fair, poor"). Assuming a rough comparability between these grades of condition, data from various sources can be brought together and presented side-by-side to approximate a basin-wide assessment.

An explanation of how this complex situation came about may help explain what this indicator tells us about the ecology of the Delaware Basin broadly. The discussion may also help readers to appreciate something about benthic macroinvertebrates and their importance, and to understand more about the way environmental agencies perform water quality management in the United States.

6 – 11.2 Description of Indicator

The word "benthic" indicates animals that live on, or in, the substrate at the bottom of a waterbody. The word "macroinvertebrates" designates invertebrate animals that are large enough to be seen without the aid of magnification. In aquatic habitats, benthic macroinvertebrates are a broad group of organisms representing several phyla. The group includes roundworms, flatworms, mollusks, and several kinds of arthropods. Insects are a particularly important class of animals in the group, because of their abundance and diversity in the freshwater biota.

To be more precise, the indicator being discussed here is freshwater benthic macroinvertebrates that live in streams. Thus, those macroinvertebrates that live in lakes, ponds, wetlands, and tidal waters are excluded. These distinctions are primarily made because the nature of the information most easily available, is mostly

David H. Funk

for "wadeable" streams. Wadeable streams are relatively easy to survey, and these smaller waterbodies are where most states have focused their sampling efforts.

Most states have been sampling and compiling data about benthic macroinvertebrates since the 1970s or 1980s. The reason lies in what these animals say about the water quality of the environments in which they live. Using a procedure called "bioassessment," the biological condition of macroinvertebrate communities is analyzed to provide information about pollution and other water quality problems. In most states, bioassessment is used for multiple purposes, but the most widespread application of bioassessment is for the purpose of assessing a state's streams for the attainment of water quality standards. This program of assessment follows from the states' obligations under the Federal Clean Water Act.

The Federal Clean Water Act (and its amendments through 1987) requires states to develop water quality monitoring programs. States report to the US Environmental Protection Agency (EPA) on the quality of their waters using the biennial "305(b) report" and the "303(d) list." In most states, these biennial reports are now usually merged into a single document called the "Integrated Assessment" or the "Integrated List." The states are charged with assessing their waterways' conditions for various water uses, including, for example, public water supply, recreation, or aquatic life. The condition of macroinvertebrate communities is usually connected specifically to aquatic life uses. Results of bioassessments are used to determine if a waterway is "attaining" or "not attaining" the State's water quality standard, a threshold condition determined by the state.

Over the past 20 to 30 years, bioassessment has become increasingly important to environmental agencies, as advances have been made in the scientific understanding of water pollution and its effects. It is now widely acknowledged that biological indicators represent an essential means of determining the condition of natural waters. Some of the reasons for this are:

• Bioassessments provide information that is directly relevant to the goals of water pollution law (that is, that waters should be able to support aquatic life), and

• Bioassessments provide information about long-term, chronic, or episodic stressors that are otherwise difficult to monitor.

Bioassessment methods can be used to assess fish or periphyton (algae) in addition to macroinvertebrates. However, macroinvertebrates may be the most broadly useful of these biological groups, for reasons that include the following:

• Macroinvertebrates are relatively easy to sample and analyze,

• Macroinvertebrates are less mobile than fish, and thus they provide a better representation of the condition of a particular location, and

• Macroinvertebrates are abundant and utilize diverse niches, which allows for a detailed determination of their condition over a wide gradient.

A bioassessment protocol is a set of standard practices describing how streams should be surveyed to produce data about ecological condition. Methods of collection and analysis must be standardized and consistently applied if data are to be comparable. However, there is no single macroinvertebrate protocol that is universally applicable in all circumstances. Natural variation sometimes dictates that protocols should differ, for the assessment of streams from substantially different environments. In addition, the needs and resources of the organization doing the sampling sometimes determines what protocol will be applied, since there are some protocols that demand more time and resources, while others can be done more rapidly. While there are broad similarities between many of the protocols, they usually differ from one another in their various details. A brief discussion of some of the variables will illustrate the reasons for all of this complexity. Every macroinvertebrate bioassessment protocol must include a description of each of the steps listed below. Within each of these four steps, there can be variations in methodology, as indicated by the following discussion.

1. Sampling: According to most protocols for wadeable streams, benthic macroinvertebrates should be sampled using hand-held nets. The bioassessment protocol specifies details such as the exact shape of the net, the size of the mesh, and how the net should be handled in a stream. The protocol describes how to select sampling sites in the field and how to combine the material from grab samples to make a composite. The protocol further specifies how many organisms are needed to make a representative sample (typically between 100 and 300 individuals), and provides techniques for ensuring that those organisms are picked from the sample using an unbiased randomization method.

2. Identifying organisms: The bioassessment protocol specifies whether a collection of organisms will be identified in the field and returned to the stream alive, or preserved and identified in a laboratory. Field methods usually involve family-level identification, while laboratory methods often provide for identification to genus or to species. Laboratory analysis requires more time and effort, but provides more information. Whether the identification is done in the field or the lab, the product of this step is a list of the macroinvertebrate taxa found at a site, along with the number of individuals of each taxon.

3. Applying bioassessment metrics: The list of organisms produced in the previous step is analyzed by applying bioassessment metrics. This involves various methods of grouping and counting the organisms by types (by taxa). A variety of bioassessment metrics have been presented in scientific literature. Some metrics involve counting the number of different taxa found in a sample (assessing sample diversity); while other metrics involve counting the number of individuals of certain taxa or in certain groups of taxa (assessing community structure). Applying metrics often requires grouping taxa together by what is known about their ecological roles or characteristics. For example, there are several commonly-used metrics that take into account the relative "pollution tolerance" of the various taxa. Applying any metric to the list of taxa for a sample produces a numerical score. It is generally agreed that no single metric provides enough information to stand alone as a means of assessing water quality. Therefore, most states apply a suite of several metrics.

4. Applying an index: An Index of Biological Integrity (IBI) is a method of combining and integrating the information from several bioassessment metrics. It involves applying a series of mathematical transformations to each sample's metric scores and then combining them to give a single numerical index score. Typically, an index score for the so-called "reference condition" is developed using data from sites that are known to be undisturbed and that are judged to be appropriate reference sites

based on regional and ecological considerations. Sample data are compared to reference conditions using the numerical scores calculated using the index. Increasing degrees of disturbance (or pollution) are indicated by scores that range farther and farther from the reference score. For state agencies, one of the main purposes of their bioassessment work is to identify those streams that are divergent enough from the reference condition that they are determined to be "not attaining" the state's water quality standards for aquatic life use. Typically, the threshold that is used to determine attainment are linked to a particular numerical score using the appropriate index.

The "Present Status" (6-11.2) and "Past Trends" (6-11.3) sections of this chapter are based on data from five different sources, namely the four Delaware Basin states and the Delaware River Basin Commission (DRBC). These five organizations all use different macroinvertebrate protocols in their programs for stream assessment. In addition to this interstate variability, there is also intrastate variability, because some states actually use more than one protocol to account for natural variation. A brief description is provided of how each of the organizations that contributed data has designed their respective programs for producing macroinvertebrate data.

Delaware:

Delaware is a small state with relatively little natural variability, but it does straddle a significant eco-regional divide. Delaware's land area is divided between the Middle Atlantic Coastal Plain eco-region and the Northern Piedmont eco-region. In the Coastal Plain, where streams have a low-gradient character, the state's bioassessment program specifies the use of the protocol developed by an EPA-sponsored multi-state workgroup called the Mid-Atlantic Coastal Streams Workgroup (U.S. EPA 1997). In the Piedmont, the state specifies the use of methods documented in EPA's 1999 Rapid Bioassessment Protocols report (Barbour et. al. 1999). The structural and ecological differences between coastal plain streams and piedmont streams dictate several differences between the two protocols. For both stream categories, Delaware specifies that macroinvertebrate samples are to be preserved and identified in a laboratory, with most taxa identified to genus. Both protocols also utilize a multi-metric index. Of the assessment stations that make up the data set for Delaware's Delaware Estuary basin, 46% are from the Piedmont and 54% are from the Coastal Plain.

Pennsylvania:

In 2006, after 10 years of effort, Pennsylvania completed their first statewide bioassessment survey, which was done using a modified version of the EPA Rapid Bioassessment II Protocol from the document referenced above (Barbour et. al. 1999). This method used field identification of organisms and family-level taxonomy. At about the same time, the state decided to refine their biomonitoring program and implement major changes to the bioassessment protocols. Pennsylvania's new program is called the Instream Comprehensive Evaluation (ICE). In it, the State's streams are divided into three major ecological categories, each of which is assessed by a different protocol. Each protocol specifies particular sampling methods, and how metrics and index calculations should be applied. These protocols are briefly described below.

The largest group of streams in Pennsylvania is categorized as riffle-run streams, which are assessed using the "Freestone Streams" protocol. The method specifies making a certain number of collections from shallow gravel-bottom or cobble-bottom riffle habitat, and then compositing and randomly sub-sampling to give a 200-organism sub-sample. The sub-sample is preserved and identified in a laboratory to genus, and a multi-metric IBI is applied to the taxa list. The preferred seasons for sampling are between November and May, so as to avoid sampling during the summer emergence period of many important insects. However, a method for "Freestone Streams, Summer Samples" is also available, for when agency workload requires that stream assessments continue through the summer months. The "Summer Samples" method provides a modified analysis to account for the effects of seasonal emergence on the invertebrate community. (During the summer months, many insects emerge as winged adults, and their aquatic forms are notably absent from stream-collected samples. In light of this, practitioners of bioassessment have two choices. They may avoid sampling during the time of year when the benthic community is likely to be altered by emergence, or they may develop protocols that are specifically tailored to each particular seasonal condition.) Freestone Streams account for 91% of the assessments performed in Pennsylvania's Delaware Basin.

Pennsylvania's second stream category is the low-gradient streams that are lacking in riffle habitat. Pennsylvania uses the phrase "Multi-Habitat" to refer to this stream category and protocol. For Multi-Habitat sites, the sampling methods are designed to provide a means of capturing representative organisms from several specific kinds of habitats (including, for example, coarse submerged debris, submerged aquatic vegetation, and deposits of coarse particulate organic matter). A specific multi-metric analysis and IBI are applied. This category is somewhat similar to the Mid-Atlantic Coastal Plain Streams "Coastal Plain" streams discussed above in the "Delaware" section, as well as to the "Coastal Plain (Non-Pinelands)" category discussed below in the New Jersey section. However, the analogy is not exact, because many of Pennsylvania's Multi-Habitat sites are not in the coastal plain but in low-gradient topography in plateau regions, such as the Pocono region of northeast Pennsylvania. Multi-Habitat assessments account for 7% of the assessments performed in Pennsylvania's Delaware Basin.

The third category of streams, limestone streams, is assessed using the protocol for '"True" Limestone Streams.' This method is specifically for spring-fed streams with high alkalinity and constant year-round temperature. These streams are considered ecologically unique and are important as cold-water fish habitat. The protocol specifies the collection of two samples from riffle habitat, composited and sub-sampled to make a 300-organism sample, followed by laboratory-identification of organisms to genus. A specific multi-metric analysis and IBI are applied. Limestone Streams account for 2% of the assessments performed in Pennsylvania's Delaware Basin.

New Jersey:

From the early 1990s through 2008, New Jersey's biennial Integrated Assessment reports were based on a type of Rapid Bioassessment Protocol that used family-level taxonomy. During this period, all of the state's freshwater streams were assessed using the same index, which was known as the "New Jersey Impairment Score" (NJIS). However, like Pennsylvania, New Jersey revised their bioassessment program in the 2000's to make it more technically rigorous. Stream assessments are now based on genus-level taxonomy; and three different protocols are used, according to the major ecoregions of the state. The three protocols are: the High Gradient Macroinvertebrate Index (HGMI), which applies to the streams of Highlands, Ridge and Valley, and Piedmont ecoregions; the Coastal Plain Macroinvertebrate Index (CPMI), which applies to the Coastal Plain excluding waters considered Pinelands waters; and the Pinelands Macroinvertebrate Index (PMI), which applies to Pinelands waters. Each of these three protocols has particular sampling methods, assessment metrics, and an index. In the network of assessment stations for New Jersey's Delaware Basin, 44% of stations are assessed by the HGMI, 37% by the CPMI, and 19% by the PMI.

New York:

New York's biological monitoring program began in 1972, with the first surveys done on the state's large rivers, using artificial substrate samplers. Since 1984, New York has used a "Rapid Assessment" method in the state's wadeable streams, for both special studies and as part of the statewide ambient water quality monitoring program. In 1987, the statewide program was re-designed, to use a rotating cycle of monitoring and assessments called Rotating Integrated Basin Studies (RIBS). Under the current RIBS schedule, chemical and biological monitoring is conducted in all of the state's 17 major drainage over a five-year period. Riffle habitat is targeted for biological sampling of wadeable streams. Non-wadeable waters are monitored using artificial substrate samplers. The index period for wadeable stream sampling is from July through September. Individual metrics characterizing the benthic macroinvertebrate community are combined to form a multi-metric index called the Biological Assessment Profile. There is no differentiation of streams by eco-region; however, modification of the sampling methods and assessment metrics are used for low-gradient, sandy-bottom streams. Samples are preserved, and identified in the laboratory to genus or species.

DRBC:

As an interstate agency, DRBC takes responsibility for assessing the mainstem Delaware River where it forms a border between states. Since 2001 DRBC has collected benthic macroinvertebrate samples annually at about 25 fixed sites on the Delaware River. These sites range from Hancock, NY (River Mile 331/533 km) to just above the head-of-tide at Trenton, NJ (River Mile 137/220 km). All samples are collected from gravel- or cobble-dominated riffle habitats. Sampling generally occurs in the late summer, with the central sampling window being August and September. The samples are preserved for laboratory identification, and the organisms are generally identified to genus. The analysis methodology used for the 2010 Integrated Assessment is based on a multi-metric IBI with a 100-point range. In their Integrated Assessment report, DRBC discusses how these numerical results can be graded for the purpose of assessing attainment of water quality standards, but they also indicate that this analysis is preliminary. The agency plans to refine it with additional data and additional statistical work.

6 – 11.2 Present Status

For this Technical Report, the status of macroinvertebrates in the non-tidal Delaware Basin is determined using the data produced by the States for their biennial water quality reporting. All four basin states and DRBC report results of water quality monitoring to EPA for the biennial 303(d) list, sometimes called the Integrated List of Waters, or the Integrated Assessment. For this Technical Report, the states have provided the most recent bioassessment data were able to share, and for the most part it comes from the data that they used to prepare the 2010 Integrated List. Some state-by-state details are given in the sections below, and in the accompanying Figures.

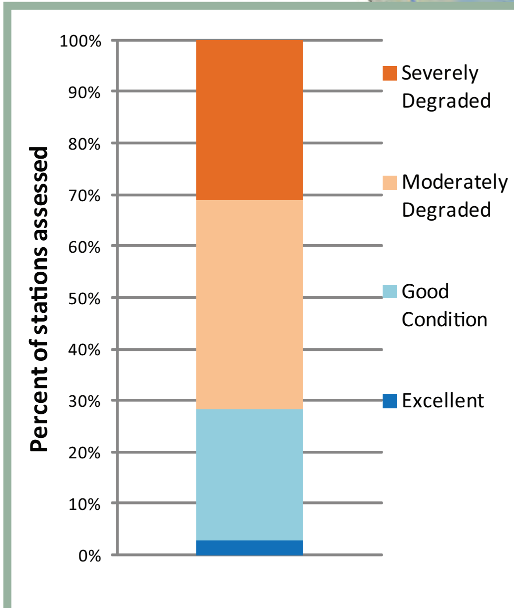


Fig. 6.11.2. Bioassessment Station Data for Delaware's Delaware Estuary Basin (87 stations).

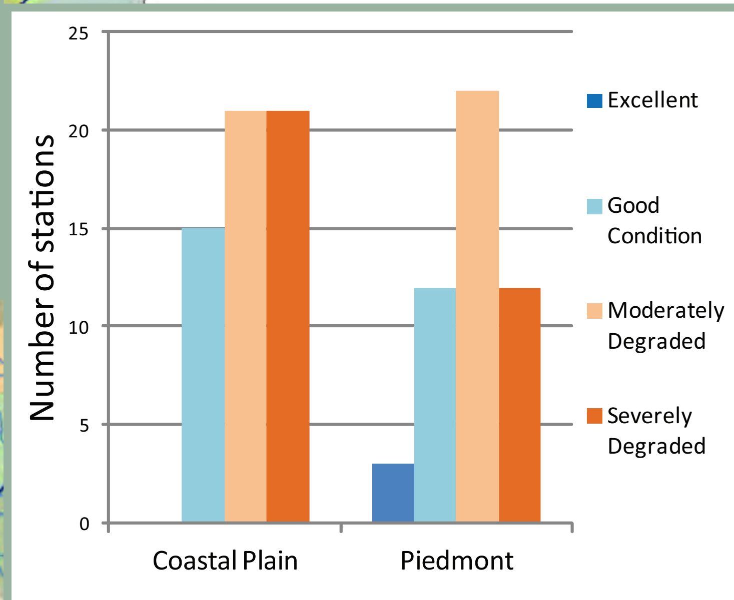


Fig. 6.11.3. Bioassessment Station Data for Delaware's Delaware Estuary Basin, Data grouped by Eco-Region/Index (87 stations).

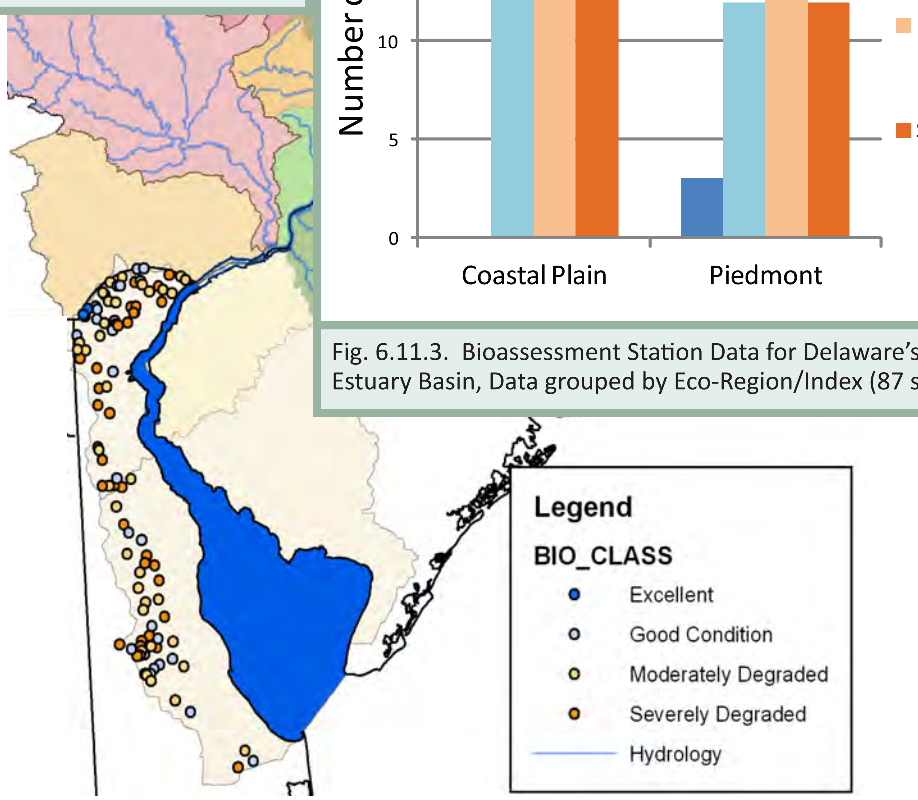
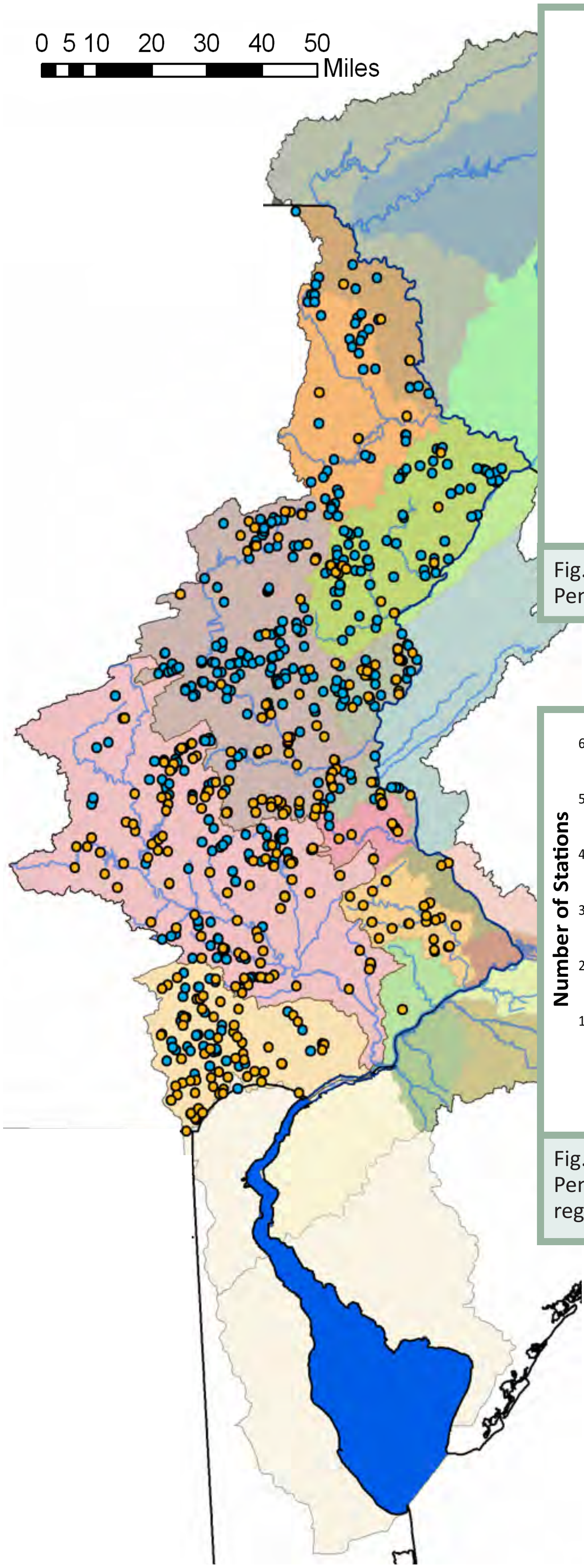


Fig. 6.11.1. Delaware's Delaware Estuary Basin: Map showing the locations of macroinvertebrate bioassessment stations.



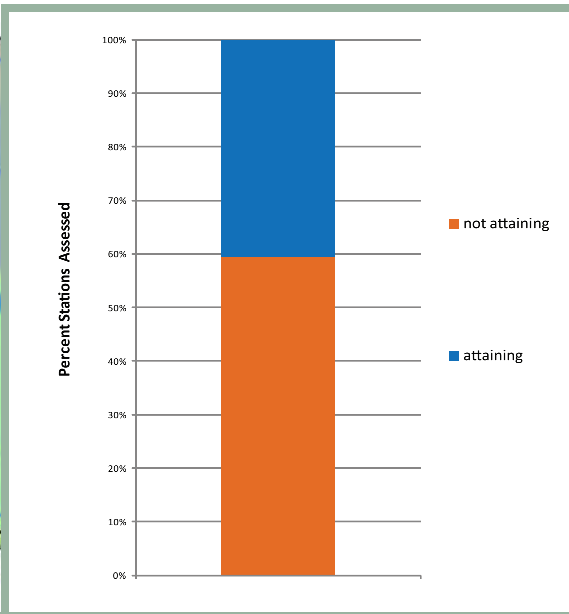


Fig. 6.11.5. Bioassessment Station Data for Pennsylvania's Delaware Basin (914 stations).

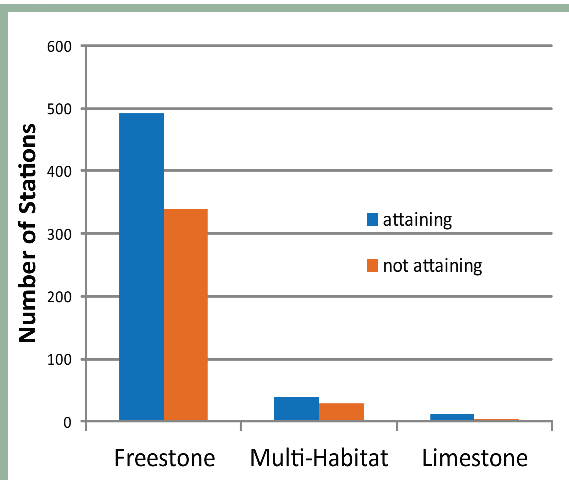


Fig. 6.11.6. Bioassessment Station Data for Pennsylvania's Delaware Basin, Grouped by Eco-region/Index (914 stations).

Fig. 6.11.4. Pennsylvania's Delaware Basin: Map showing the locations of macroinvertebrate bioassessment stations.

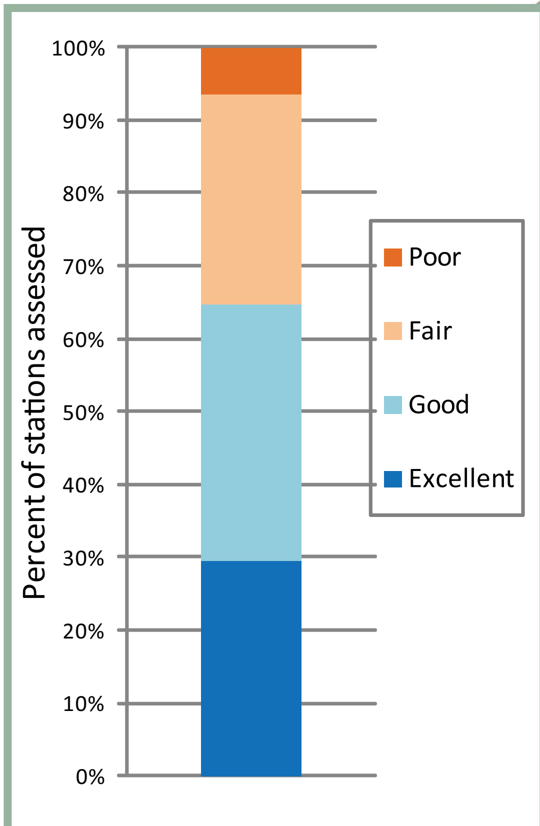


Fig. 6.11.8. Bioassessment Station Data for New Jersey's Delaware Basin, AMNET 4 Survey with 141 stations (2007-present).

Fig. 6.11.9. Bioassessment Station Data for New Jersey's Delaware Basin, AMNET 3 Survey with 301 stations (2002-2007).

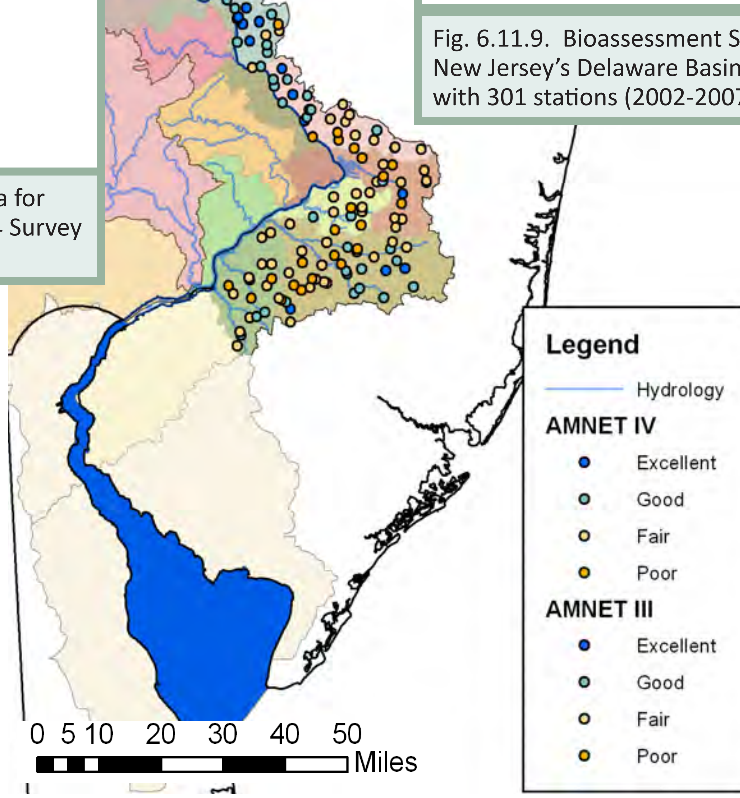


Fig. 6.11.7. New Jersey's Delaware Basin: Map showing the locations of macroinvertebrate bioassessment stations.

Delaware:

Present status is given by data from 87 individual assessments, performed between 2006 and 2009. Four grades of condition are reported: excellent condition, good condition, moderately degraded, and severely degraded. The aggregated data are presented in Fig. 6.11.1 - 3.

Pennsylvania:

Present status is given by data from 914 assessments, spanning more than ten years of time. Each station is reported as either "attaining" or "not attaining" the state-determined regulatory threshold for aquatic life use. The aggregated data are presented in Fig. 6.11.4 - 6.

New Jersey:

Present status is given by data from 301 stations. The statewide program, called "AMNET" (for "Ambient Biomonitoring Network") has produced several rounds of survey results for each of the state's major basins. However, the current survey, known as AMNET Round 4, is not yet complete, and NJ DEP was not able to share the unfinished data for the Lower Delaware Basin. Therefore, this report presents recent data (AMNET Round 4, performed between 2007 and the present) for only the Upper Delaware Basin (141 stations), and older data (AMNET Round 3, performed between 2002 and 2007) for the entire Delaware Basin (301 stations). Four grades of condition are used: excellent, good, fair, and poor. The aggregated data are presented in Fig. 6.11.7 - 11.

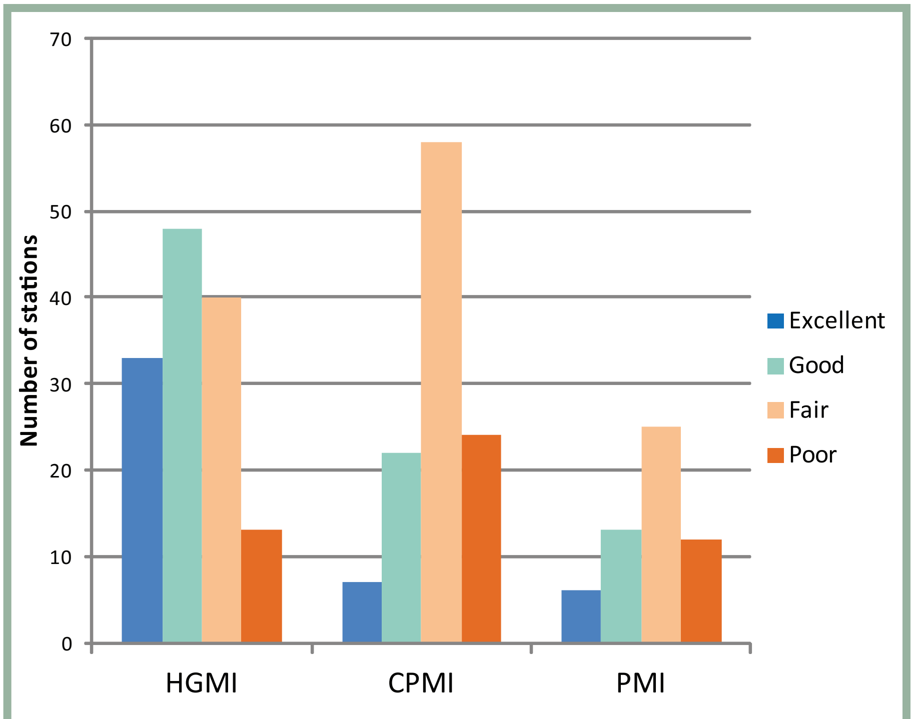


Fig. 6.11.10. Bioassessment Station Data for New Jersey's Delaware Basin, Data Grouped by Eco-region/Index (301 stations)

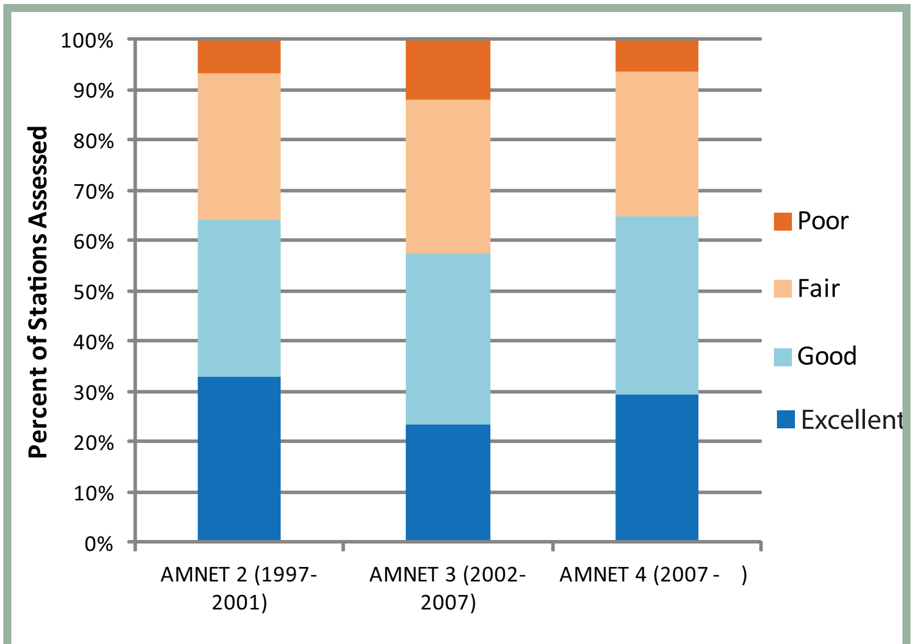


Fig. 6.11.11. Bioassessment Data for Three Successive Surveys of New Jersey's Upper Delaware Basin. (The number of stations is approximately 140.)

New York:

Present status is given by data from 78 stations, collected 10 ten years' time. Four grades of condition are reported: non-impacted, slightly impacted, moderately impacted, and severely impacted. The aggregated data are presented in Fig. 6.11.12 - 14.

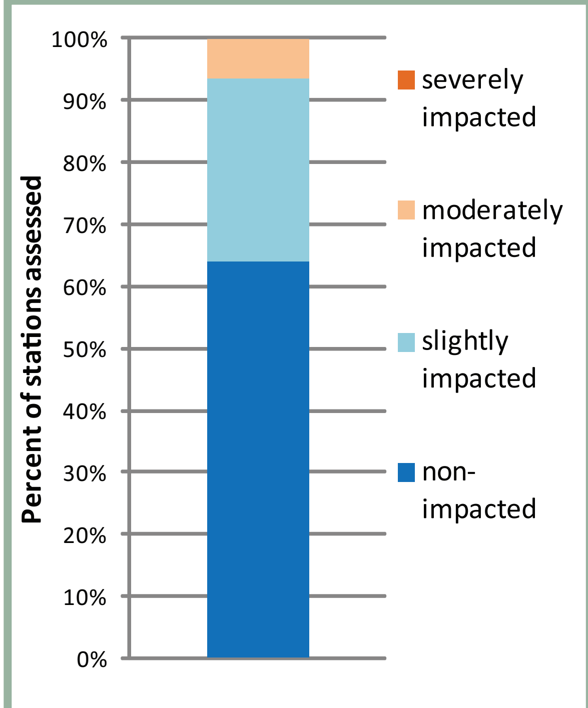


Fig. 6.11.13. Bioassessment Station Data for New York's Delaware Basin. (78 stations)

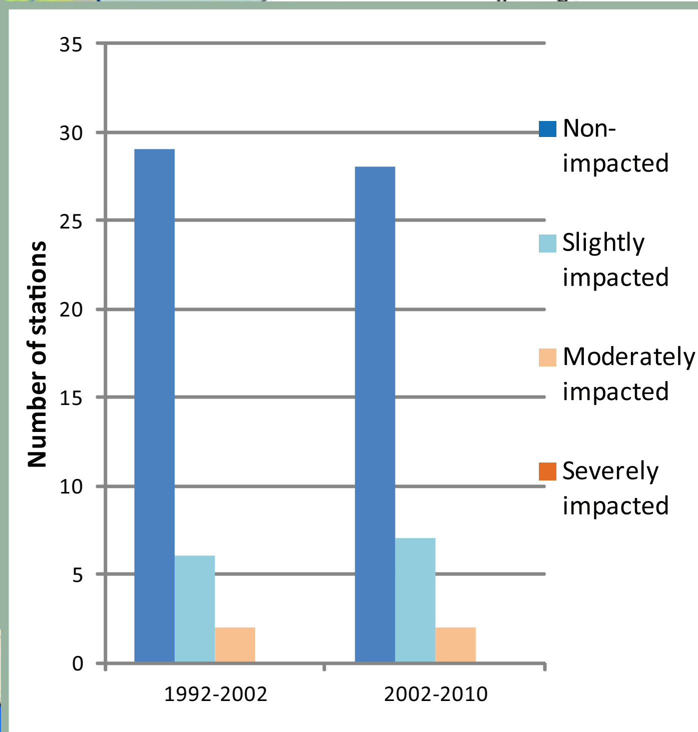


Fig. 6.11.14. Bioassessment Station Data for New York's Delaware Basin, Comparing Data from Two Successive Decades. (37 stations)

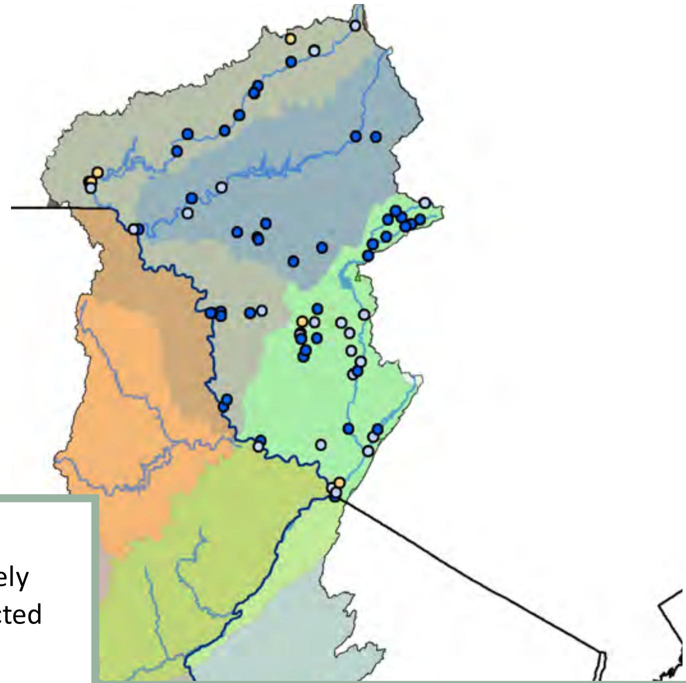


Fig. 6.11.12. New York's Delaware Basin: Map showing the locations of macroinvertebrate bioassessment stations.

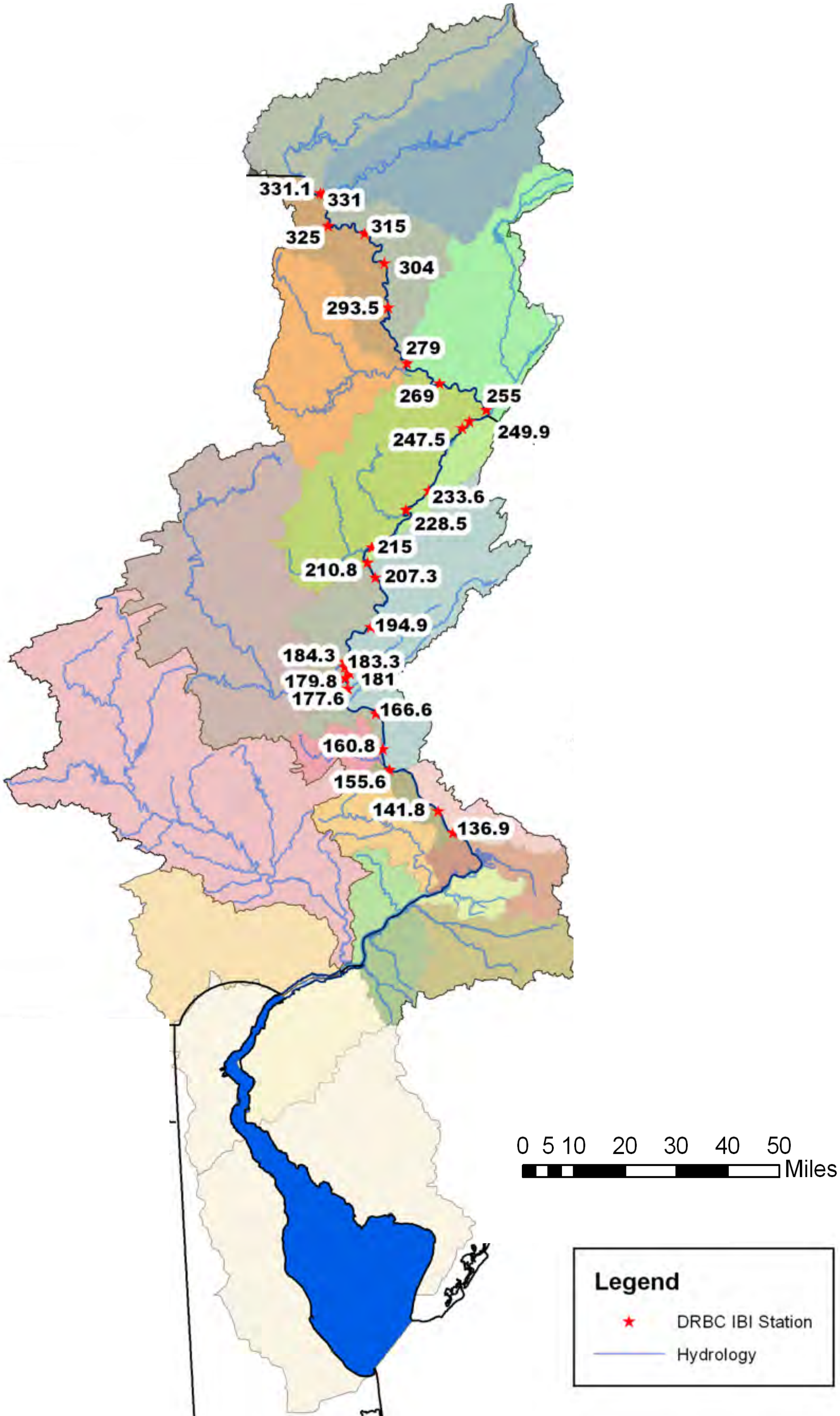


Fig. 6.11.15. DRBC Mainstem Sampling Locations.

DRBC:

Present status is given by data from 23 stations, collected in 2008 and 2009. Stream condition is given as a numerical score according to the IBI that the agency uses. The aggregated data are presented in Fig. 6.11.15. (Certain stations sampled by DRBC are not included in this Figure because they were not sampled throughout the entire period.)

Considering the Delaware basin as a whole, it appears that there may be some broad regional conclusions that can be drawn from the bioassessment data. New York is the state with the lowest percentage of low-scoring stations, and apparently the best overall condition. Delaware is the state with the highest percentage of low-scoring stations; and New Jersey and Pennsylvania are in between.

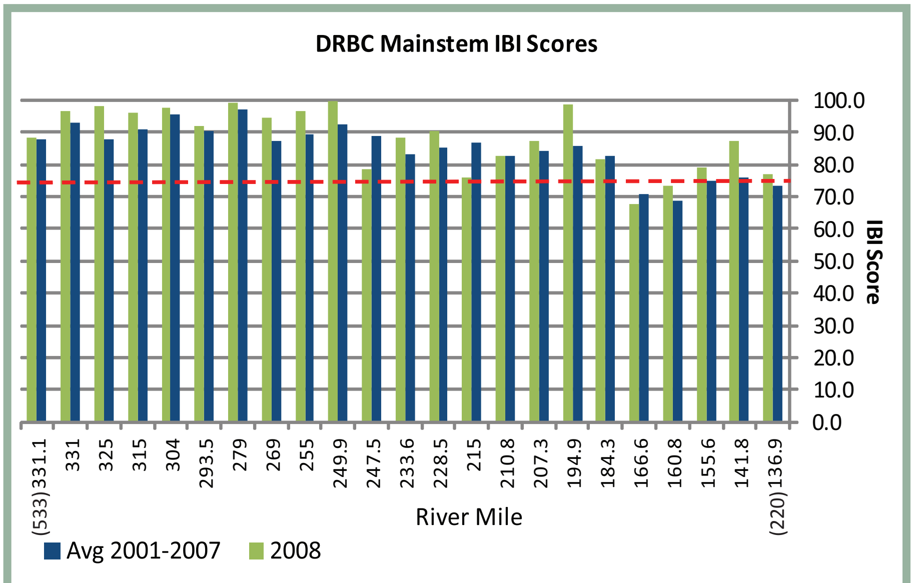


Fig. 6.11.16. Bioassessment Station Data for the Mainstem Delaware River: By River Mile (kilometer)

For the three states whose bioassessment programs include multiple ecoregional indices, a comparison of the ecoregional differences shows somewhat similar trends in each state. The analogous categories of Piedmont (Delaware), Freestone (Pennsylvania), and High-gradient (New Jersey) have somewhat better conditions than the corresponding low-gradient categories: Coastal Plain (Delaware and New Jersey) and Multi-habitat (Pennsylvania). These observations suggest that the condition of benthic macroinvertebrates is generally better in the upper portions of the Delaware Basin, farther from the coast, and closer to "headwaters." This corresponds to what may be expected based on a general understanding of water quality problems in this basin. Good water quality is generally expected (hence macroinvertebrate quality) to correlate negatively with urban land cover, which is mostly in the lower basin, and positively with forested land cover, which is mostly in the upper basin.

The data suggested the above conclusions, as if the data was from a basin-wide survey, however this is not exactly the case. The data presented in this report, particularly for the states of Delaware and Pennsylvania, may not represent a random selection of sites, as would have been ideal if this had truly been a basin-wide survey of ambient conditions. In Pennsylvania this is due to the fact that the state has not yet completed a full survey of the basin using their revised bioassessment protocol. In Delaware, the available data is skewed towards lower-quality waterways, which were prioritized for monitoring in recent years.

Benthic macroinvertebrate community condition is affected primarily by water quality and habitat disturbance. There are many reasons why conditions at a particular site may appear to be degraded. Furthermore, the basin being discussed is large and diverse. For these reasons, it would probably be inappropriate to draw further conclusions from the data presented. When biomonitoring results cause a state agency to list a stream as "impaired," the agency is supposed to attribute the impairment to a "source" and a "cause." The Integrated List for each state contains information about these "source" and "cause" determinations for each listing, but the terminology that is used is complex. Because of this complexity, an attempet was not made to gather or analyze "source" and "cause" information for the present report. Readers who are interested in examining the sources and causes of impairments listed by the states are referred to the Integrated List documentation for each of the states.

6 – 11.3 Past Trends

Monitoring of trends is one of the stated goals of the biomonitoring program in most of the states. However it is more easily said than done. Reporting trends is difficult at the present time, because of the nature of the available data. In Delaware and Pennsylvania, sufficient data was not obtained to present any kind of trend. Several more years of work will be necessary before meaningful time series will be generated for Pennsylvania and Delaware. We can discuss trends for New Jersey, New York, and for the mainstem Delaware river (DRBC data), based on the collected data.

New Jersey:

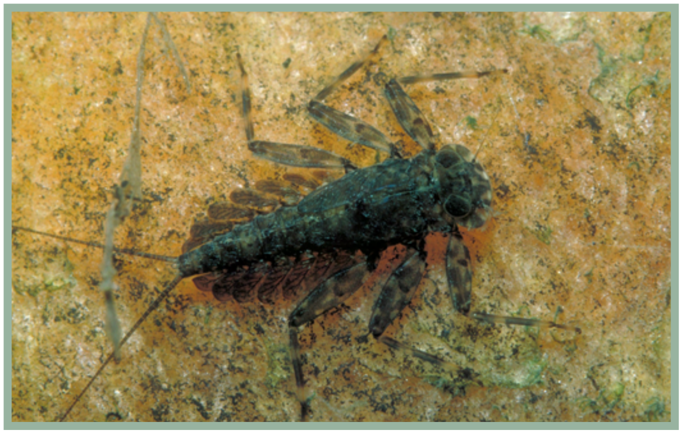
New Jersey's AMNET Program has completed several rounds of sampling at an established set of stream stations. Round 2 of the AMNET program was performed between 1997 and 2002, round 3 between 2002 and 2007, and round 4 began in 2007 and is still unfinished. (There was a round 1 in the 1990s, but it was not as comprehensive as the subsequent surveys, and cannot be compared with the others on a station-by-station basis.) Although results for AMNET rounds 2 and 3 were originally reported using the NJIS index, the New Jersey Department of Environmental Protection (NJDEP) was able to re-analyze the original data from those surveys using the more detailed taxonomy of the new indices. They have prepared a table which shows condition assessments for 144 stream stations in the Upper Delaware Basin for these three rounds of survey. (The agency's analysis of data for the Lower Delaware Basin for AMNET 4 is still incomplete.) These Upper Basin results are presented in aggregate in our Fig. 6.11.11.

Based on the data as shown in Fig. 6.11.11, the general condition of benthic macroinvertebrates in the streams of New Jersey's Upper Delaware Basin appears to have fallen slightly between round 2 and round 3, and then improved again in round 4. However, it would be inappropriate to draw firm conclusions from such a limited set of data. In fact, the data do not necessarily indicate a general degradation of conditions between rounds 2 and 3, followed by a recovery. Instead, it seems likely that the apparent differences between these respective surveys may be within the range of variation that can be expected for repeat applications of the bioassessment method.

New York:

Over the years, New York has collected multiple rounds of data for a certain number of stations in the Delaware basin. In 2004, the state published a report entitled "30-Year Trends in Water Quality of Rivers and Streams in New York State Based on Macroinvertebrate Data, 1972-2002." (The report is available on line at http://www.epa.gov/bioindicators/pdf/NYSDEC30yrTrendsReport.pdf). That report compared the results of surveys conducted between 1992 and 2002 to an earlier set of data collected before 1992.

For the present report, the recent data (2003 – 2010) was compared to the data from the 1990s that appears in the state's "30-Year Trends" report. The comparison reveals that the changes that occurred from the 1990s to the 2000s were very small. The total number of stations with assessment data in both decades was 37. Of those, 28 scored the same both times, while 9 scored differently. Five stations changed from "non-impacted" to "slightly impacted," and four others changed from "slightly impacted" to "non-impacted." Thus the overall difference in the basin appears to be very small. Fig. 6.11.14 presents this comparison as a chart.



David H. Funk

DRBC:

Because DRBC's sampling team has returned to the same stations for several years on a regular basis, their data set appears to offer an opportunity to look at bioassessment data in a time series. Some of this data is presented as a chart in Fig. 6.11.15. Based on the data, there is year-to-year variability, but it appears that there are no clear trends.

DRBC's technical staff believe that some of the variability observed here can be attributed to particular events or conditions. It is thought that a severe summer drought or a major flood can affect aquatic life enough to produce anomalous scores using the bioassessment metrics and index. At least one example of this seems to be evident in DRBC's data. There is a noticeable drop in bioassessment index scores for 2006 at several stations along the River, which may be attributed to the effects of a major flood that occurred in late June of that year, shortly before the macroinvertebrate sampling was conducted (Personal Communication, Erik Silldorff).

6 – 11.4 Future Predictions

The future condition of the benthic macroinvertebrates in the Delaware Basin can be expected to follow the various causes of waterway impairment. Any attempt to project future conditions in the basin would be speculative, particularly in light of the challenges of determining past trends from macroinvertebrate data.

6 – 11.5 Actions and Needs

Bioassessment of macroinvertebrates is a well-established practice in state environmental agencies, and it may be expected to continue for the foreseeable future. Bioassessment has become a core element of the regulatory system for protecting water quality in the United States. Over time, it may be expected that the uses of bioassessment data will be refined as the datasets grow and as organizations gain experience with the interpretation of information produced.

The fact that the states all use different methods is frustrating to anyone who is interested in making interstate comparisons. At present, there is no particular movement towards requiring the standardization of methods. However, as states gather more data and gain a better understanding of how to use it, and with continued improvements in data management, there is reason to hope that meaningful interstate comparisons may become more readily available in time.

6 – 11.6 Summary

Benthic macroinvertebrates are a diverse and important natural resource. They are well known to people who are concerned with water quality and watershed health, but ignored or taken for granted by most people in the general public. Macroinvertebrates are not normally considered for specific management actions of any kind. The management actions that affect benthic macroinvertebrates are essentially the same management actions that affect water quality and aquatic habitats. It is expected that macroinvertebrates can be allowed to thrive by preventing water pollution and by protecting or restoring natural habitat conditions in waterways.

6 – 12 Freshwater Mussels

Section Author: Danielle Kreeger

6 - 12.1 Description of Indicator

Freshwater mussels are filter feeding bivalve mollusks that live in lakes, rivers, and streams (Fig. 6.12.1). Similar to oysters, freshwater mussels benefit clean water, enrich habitats, and furnish other important ecosystem functions such as stabilizing bed erosion (for summaries of ecosystem services, see: Kreeger and Kraeuter 2010; Anderson and Kreeger 2010). For example, freshwater mussels may be abundant enough in the Delaware River Basin to improve water quality by their filtration. Kreeger (2008) measured the abundance of *Elliptio complanata* in the Brandywine River and also used survey data from Dr. W. Lellis (USGS Wellsboro) to estimate that there are at least 4 billion adult mussels of this species across the basin. Based on these numbers and measured physiological processing rates, this species was estimated to filter about 10 billion liters of water per hour across the basin, which is roughly 250 times the volume of freshwater entering the tidal estuary (Kreeger and Kraeuter 2010).

Sylvan Klein, Academy of Natural Sciences

Fig. 6.12.1. Freshwater mussels living *in situ* in the tidal freshwater portion of the Delaware River in June 2011

Freshwater mussels grow more slowly than their marine counterparts. They also live longer (80 years or more) and have complicated reproduction strategies dependent on fish hosts. As long-lived, relatively sedentary creatures that process large amounts of water over their soft tissues, freshwater mussels are particularly sensitive to water quality and contaminants. Freshwater mussels are typically not sampled effectively as part of traditional macroinvertebrate assessments (Section 6-11). The health, population abundance, and species diversity of freshwater mussels therefore represent excellent bioindicators of freshwater systems, particularly over long periods of time.

Fig. 6.12.2. Shells of seven native species of freshwater mussels found in the tidal Delaware River in 2009-2010: Pond Mussel, *Ligumia nasuta* (Ln); Eastern Floater, *Pyganodon cataracta* (Pc); Yellow Lamp Mussel, *Lampsilis cariosa* (Lc), Eastern Elliptio, *Elliptio complanata* (Ec); Creeper, *Strophitus undulatus* (Su); Tidewater Mucket, *Leptodea ochracea* (Lo); and the Alewife Floater, *Anodonta implicata* (Ai).

6 - 12.2 Present Status

Freshwater mussels are the most imperiled of all animals and plants in North America, which has the world's greatest diversity of this taxonomic group (> 300 species). More than 75% have special conservation status (Williams et al. 1993). At least twelve species are native to the Delaware River Basin (Ortmann 1919, PDE 2008, Campbell and White 2010); however, all but one species is reported to now be uncommon (PDE 2008).

The leading causes of mussel decline in the Delaware River Basin are habitat and water quality degradation. Since freshwater mussels rely on fish for successful reproduction, usually species-specific relationships, dams that block fish passage can disrupt reproduction and gene flow (McMahon 1991, Neves 1993).

To assess present status we analyzed survey data for the past 15 years from southeastern Pennsylvania and Delaware. Data were not able to be obtained for the State of New Jersey, therefore, it is not currently possible to examine the status of the freshwater mussel assemblage across the Delaware River Basin. Our analysis suggests that the overall condition of freshwater

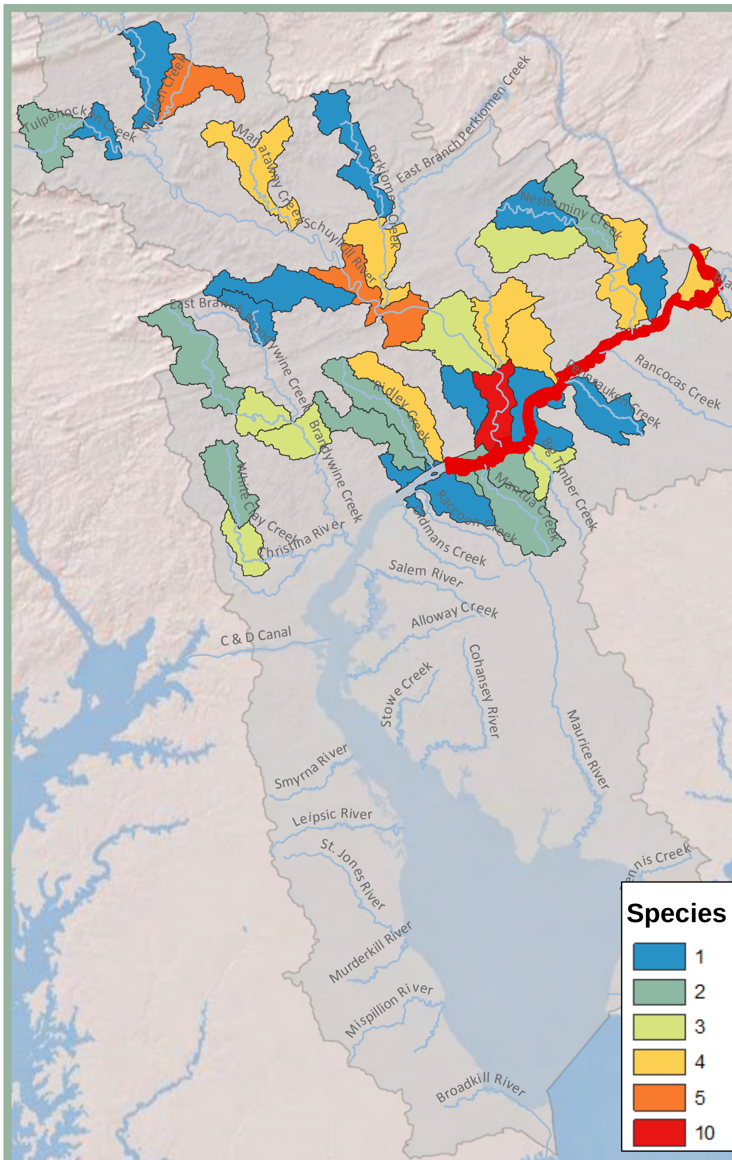


Fig. 6.12.3 Species richness of native freshwater mussels reported in surveys conducted between 1919-1996 in southeastern PA, based on available data obtained by PDE.

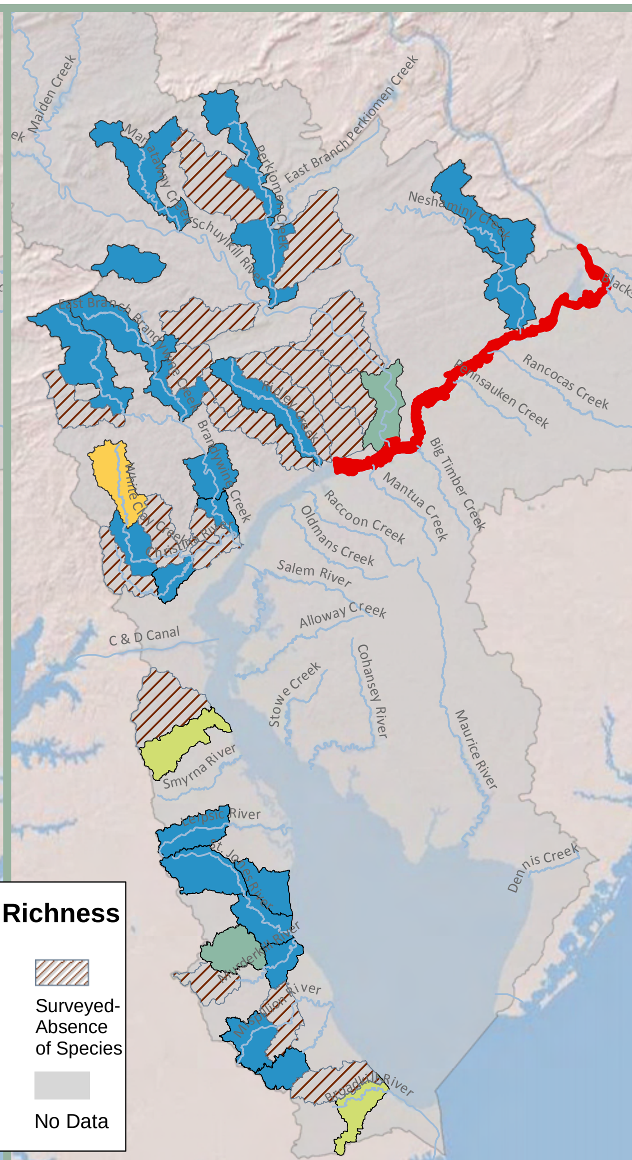


Fig. 6.12.4. Species richness of native freshwater mussels reported in surveys conducted between 1996-2011 in southeastern PA. Surveys were conducted by PDE with the Academy of Natural Sciences.

mussel populations is poor in streams where dams and other factors appear to have progressively eliminated or reduced mussel populations over the past 100 or more years (Thomas et al. 2011). Joint surveys in southeast Pennsylvania by the Partnership for the Delaware Estuary (PDE) and the Academy of Natural Sciences between 2000 and 2010 found that only 4 of >70 stream reaches contained any freshwater mussels (Thomas et al. 2011). Even the most common native species are presently patchy in distribution, limited in abundance and may not be successfully reproducing in streams.

In contrast to the low biodiversity, abundance, and limited distribution of native freshwater mussels in streams, recent surveys indicate that the assemblage is still reasonably intact in the undammed and tidal reaches of the mainstem Delaware River (Lellis 2000, 2001, Kreeger et al. 2011). Several species found recently (Fig. 6.12.2) were believed extirpated from the basin because they had not been reported in the published literature since Ortmann's surveys 100 years earlier (Ortmann 1919). Preliminary examination suggests that the beds of mussels in the tidal freshwater stretch of the Delaware River are healthy, having broad size class distribution and lower shell erosion compared to mussel populations in smaller, non-tidal streams (Kreeger and Padeletti 2011).

6 - 12.3 Past Trends

The most comprehensive historical regional mussel survey was conducted in Pennsylvania between 1909 and

1919 (Ortmann 1919). However, even by that time, dams and water quality degradation may have already affected mussel communities. Nevertheless, the study provided an excellent benchmark for gauging long-term trends in the mussel assemblage for the past 100 years.

Ortmann (1919) reported about 12 species of native mussels from the Delaware River Basin, most of which were present at that time in southeastern Pennsylvania (Fig. 6.12.3). Although species richness was highest in the mainstem Delaware River even then, at least five species were present in several tributary watersheds, including the Schuylkill and Brandywine.

In contrast, Fig. 6.12.4 depicts the current species richness of native mussels (Thomas et al. 2011). Although the richness appears to have been preserved in the mainstem Delaware River, only one or no species has been in recent years in most tributary streams of southeast Pennsylvania (Fig. 6.12.4).

A comparison of Fig. 6.12.3 and 6.12.4 also suggests that the range of native mussel occurrence has shrunk significantly in these streams during the last 100 years. This decline appears to be continuing. For example, no mussels have been found since 2002 in the upper White Clay Creek, Pennsylvania, despite annual surveys by PDE; whereas, 2 species were found there as recently as 1998-2001 (leading to the higher richness there in Fig. 6.12..4).

6 -12.3 Future Predictions

Since the decline of native mussel biodiversity has been attributed to habitat development and degraded water quality, the future prospects for freshwater mussels are likely to hinge on careful watershed management. Human population is expected to grow by 80% this century in the basin, which threatens to exacerbate the stressors that have been affecting mussels for probably hundreds of years.

Climate change also threatens freshwater mussels (Kreeger et al. 2011) because of increased thermal stress and stormwater and salinity rise in freshwater tidal areas. Since freshwater mussels depend on fish hosts for larval dispersal, it is unlikely that southern mussel species will be able to expand northward to fill niches that open if northern species are extirpated. The northern pearlshell, *Margaratifera margaratifera,* is an example of a coldwater-loving species that uses brook trout as a host – its present distribution in southeast Pennsylvania is constrained to a few cold headwater streams and below reservoirs in the upper Schuylkill Basin which release colder water from the bottom.

Enhanced conservation and restoration efforts have the potential to offset projected continued declines in freshwater mussels (Kreeger and Padeletti 2011). Although some streams may no longer be as suitable for mussels as they were historically, the carrying capacity for a diverse and abundant mussel assemblage is thought to remain very high. Interest in remediating water quality and habitats has the potential to energize mussel restoration because of the advent of new restoration technologies and growing awareness for the many ecosystem services provided by healthy mussel communities.

6 - 12.4 Actions and Needs

More proactive freshwater mussel monitoring for species presence and population health is needed across the Delaware Estuary and River Basin. Freshwater mussels are not targeted in routine macroinvertebrate assessments, and so mussel surveys are rarely performed despite their value for assessing long term status and trends of aquatic health. Improved coordination and data sharing among states and PDE would also facilitate indicator development and watershed restoration planning. For the mussels themselves, there are numerous new technologies to rebuild native populations (e.g., Kreeger and Padeletti 2011), including surveys, reintroduction via relocation studies, and hatchery propagation of mussel seed for restocking. In addition, critical habitat for mussel beds should be mapped and protected. These types of efforts should be supported to help preserve biodiversity and promote ecosystem services of freshwater mussels (Kreeger 2005), which are the most imperiled of all animals and plants.

6 - 12.5 Summary

A robust community of freshwater mussels should be spread throughout the freshwater ecosystem and include diverse species that fill different ecological niches. Unfortunately, the present status of the 12 or more native species of freshwater mussels is poor across the Delaware River Basin, as judged by the best possible analysis of limited survey data, which show reduced biodiversity, abundance, and range for this taxonomic group. A notable exception is the mainstem Delaware River which appears to retain an intact, remnant community of healthy and diverse mussel species. If carefully protected, this population could be used to restore freshwater mussels throughout much of the lower basin, likely yielding significant improvements for water and habitat quality.

Chapter 6 – References

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