

Comparative history of the Chesapeake, Delaware, and Hudson basins in the mid-Atlantic U.S.

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Abstract This article explores the Chesapeake, Delaware, and Hudson basins as three of the most historic and populous watersheds in the United States. This mid-Atlantic megabasin covers just 2 percent of the U.S. yet is home to 10 percent of the nation's population. Each of these interstate basins is managed with different emphasis on governance ranging from voluntary agreement (Chesapeake Bay) to compulsory compact (Delaware River) to advocacy (Hudson River). This perspective provides a comparative history of the discovery, decline, and recovery of some of the more famous river basins in America.

Keywords River Basin • Watershed •

Biography Gerald Kauffman is Director of the University of Delaware Water Resources Agency and holds joint faculty appointments in the School of Public Policy and Administration and Department of Civil and Environmental Engineering. He is a co-founder of the Interdisciplinary Graduate Program in Water Science and Policy and serves on the Undergraduate Environmental Academic Affairs Council at the University of Delaware. Jerry is co-chair of the Christina Basin Clean Water Partnership, an interstate effort between Delaware and Pennsylvania to cleanup the watershed that provides 60% of the drinking water supply to the First State.

History linked to hydrology

The Chesapeake, Delaware, and Hudson basins are linked by history and hydrology and stretch over 500 miles along the mid-Atlantic seaboard in the most populous watersheds in the United States (Figure 1). This megabasin lies at the crossroads of American history as 400 years ago Henry Hudson and Captain John Smith first explored the estuaries looking for gold and furs, the Revolutionary War and Civil War were fought along its rivers, and presidents John F. Kennedy, Richard M. Nixon, and Barack H. Obama adopted programs to protect its watersheds. The C-D-H basin covers just 2 percent of the U.S. land mass yet is home to 10 percent of the nation's population and includes the 1st, 5th, and 7th largest metropolitan economies in America, the capitals of six states, and the nation's Capitol. Each of these interstate basins is managed with a different emphasis on governance ranging from the voluntary interstate Chesapeake Bay Agreement, to the compulsory Delaware River Basin Compact, to the advocacy of the nonprofit Hudson Riverkeeper. This historic perspective provides a comparative analysis of the discovery, decline, and recovery of some of the more famous river basins in America.

Similar but different basins

While sharing similar geography, these contiguous Mid-Atlantic basins have contrasting characteristics (Table 1). The Hudson and Delaware basins are similar in area ($\approx 13,000 \text{ mi}^2$) but the Chesapeake is four times as large ($64,000 \text{ mi}^2$) which suggests the challenges of governing this vast watershed are correspondingly complex. The Chesapeake Basin is home to a population of 16 million or $1\frac{1}{2}$ to 2 times more people than the Hudson and Delaware basins but the Chesapeake's population density (250 people/mi^2) is less than the Delaware (590 people/mi^2) or Hudson (900 people/mi^2) which suggests less pressure per unit area from human pollution sources. While all three rivers are over 300 miles long (which is large as East Coast rivers go), the Chesapeake/Susquehanna, Delaware, and Hudson are just the 42nd, 55th, and 85th longest rivers in the U.S. The Chesapeake is the longest estuary in the U.S. (194 miles) and the Hudson (152 mi) and Delaware estuaries (96

mi) are the 3rd and 5th longest navigable tidal rivers. All three estuaries are drowned river systems that evolved from rising sea levels during the end of the last ice age. Only the Hudson Estuary is a fjord once carved by glaciers while the Chesapeake and Delaware estuaries are south of the glacial terminal moraine left from the last Ice Age.

Roman et al. (2000) suggested the Hudson might be expected to recirculate more rapidly as the ratio of watershed to estuary surface area (55) is three times higher than the Delaware and Chesapeake (18). By annual discharge, the Chesapeake (70,000 cfs) has a greater recirculation rate than the other two basins (14,000-15,000 cfs). In the Delaware and Chesapeake basins, ocean recirculation rates are similar as the bay mouths are 11 to 13 miles wide, much larger than the one mile mouth of the Hudson at the Verrazano Narrows Bridge.

The Hudson is a relatively murky estuary with a mean light extinction coefficient of 1.7, about 4 to 5 times higher than the Delaware and Chesapeake (0.3-0.4). The Delaware has a high peak light extinction coefficient (7.0) in the intertidal zone near the C & D Canal, much higher than peaks for the Hudson and Chesapeake (Roman et al. 2000).

Water pollution control programs have improved dissolved oxygen levels in the Delaware and Hudson basins while DO levels continue to decline in the Chesapeake (Fig. 2). All three basins have recovering American shad fisheries although juvenile abundance has declined lately perhaps due to increased striped bass populations who forage for the young shad (Fig. 3).

Land use proportions are similar as the urban I-95 corridor lies in the downstream reaches of the each basin while agriculture and forested land increases north to the headwaters (Table 2). The Delaware is more urbanized with 14% developed land compared to the Chesapeake and Hudson basins (8% developed). The three basins are covered by similar proportions of agriculture (22%-26%) and forests (55%-60%). Known for fisheries productivity, the Chesapeake has double the area of wetlands/water (9%) compared to the Delaware (5%) and Hudson (2%) basins.

Watershed Governance

The Chesapeake Bay cleanup is driven by a voluntary Federal-state partnership coupled with a river basin commission in the headwaters. The EPA hosts and funds the Chesapeake Bay Program through the Clean Water Act and National Estuary Program. The voluntary Chesapeake Bay Agreement was signed by the watershed states (Delaware, Maryland, New York, Pennsylvania, Virginia, and West Virginia), District of Columbia, and EPA. In the upper half of the basin, the bay's two largest tributaries are governed by the Susquehanna River Basin Commission (between Md., NY, Pa., and the U.S.) and Interstate Commission for the Potomac River Basin (between Md., Pa., Va., and the U.S.). The bay has a long history of activism influenced by a blend of nonprofits such as the Chesapeake Bay Alliance and Chesapeake Bay Foundation. If the density of capital cities in a watershed is a measure of political will toward restoration, then the Chesapeake ought to have a good chance of recovery as the basin includes the capitals of Maryland, Virginia, and Pennsylvania and the seat of Federal power along the banks of the Potomac.

The Delaware is the only basin governed entirely by compulsory interstate compact by a single coordinating entity. In 1961, JFK signed the Delaware River Basin Commission compact as the first Federal-state watershed accord to govern a basin as a single administrative agency. The DRBC governs by comity (one seat, one vote through a principle of reciprocal courtesy between the governments) through five commissioners representing the Governors of Delaware, New Jersey, New York, and Pennsylvania and the President of the United States. The Partnership for the Delaware Estuary provides a science-based approach to the tidal Delaware watershed as one of the 28 congressionally designated estuaries in the National Estuary Program. Over 300 river miles in the Delaware Basin are protected by the National Park Service through the National Wild and Scenic Rivers Act.

The Hudson Basin is protected by effective and committed nonprofit environmental groups such as the Hudson River Fisherman's Association, Hudson Riverkeeper, and Hudson River Greenway that grew out of the social activism of the turbulent 60's. Pete Seeger's Clearwater Sloop continues to reflect public attention on the health of the Hudson. The states never adopted the concept of an interstate Hudson Basin compact during the 1930s and 1960s. Today, a semi-formal interstate basin approach (up to the head of tide at Albany) is provided by the Hudson River Estuary Program and the Interstate Sanitation Commission between New York, New Jersey, and Connecticut.

Chesapeake Bay

While gazing at the Potomac River from the White House, President John F. Kennedy may have thought about the Chesapeake Bay when he reportedly said that anyone who can solve the problems of water are worthy of two Nobel prizes - one for peace and one for science. The political complexity of governing this vast 64,000 square mile Chesapeake Bay watershed over six states and the District of Columbia is a major challenge in cleaning up the bay.

The *Chesepiooc*, known by the indigenous Algonquian people as the "village at a big river", is the largest of 130 estuaries in the United States and stretches from Havre de Grace, Md. at the mouth of the Susquehanna River to Virginia Beach, Va. at the Atlantic Ocean (Ernest 2003). The 4,480 square mile bay is long (194 miles), narrow (3 to 30 miles wide), and shallow (average depth 21 feet) and holds over 15 trillion gallons of water (Chesapeake Bay Program 2010). The bay shoreline (12,000 miles) is longer than the mainland Pacific Coast of the U.S. The bay is flushed with 50% saltwater from the Atlantic Ocean and 50% freshwater from the Susquehanna, Potomac, and Rappahannock rivers. The Coriolis effect from the Earth's rotation causes a clockwise tidal cycle where cleaner ocean water washes north up the Western Shore of the bay and more turbid river runoff flows south along the Eastern Shore.

The 64,000 square mile Chesapeake watershed extends 400 miles from Cooperstown, NY (home of the Major League Baseball Hall of Fame) to the Atlantic Ocean and drains parts of six states and the District of Columbia. In 2010, 16 million people lived in the bay watershed or double the 1950 population. Every year, 200,000 people move to the bay to work in or near Washington, Baltimore, Richmond, and Harrisburg (Chesapeake Bay Program 2010). While the Chesapeake watershed holds 5 percent of the U.S. population and is rapidly urbanizing near the big I-95 highway corridor cities, overall land use is still rural with 60 percent forest, 9 percent wetlands/water, 22 percent agriculture, and 9 percent urban/suburban land.

A 2004 study indicates the socioeconomic value of the bay watershed is \$1 trillion from fishery, recreation, tourism, and agriculture benefits (Chesapeake Bay Watershed Blue Ribbon Finance Panel, 2003). The bay has valuable blue crab, eastern oyster, clam, and striped bass fisheries that are threatened by low oxygen dead zones and loss of submerged grasses. Fishery moratoriums have successfully increased blue crab and striped bass abundance lately while overfishing and pollution continues to depress oyster and clam shellfisheries.

About 10,000 years ago, the glaciers melted and rising sea levels drowned the Susquehanna River valley and created the Chesapeake Bay. Approximately 3,000 years ago, the indigenous Algonquin tribe established villages near the bay and hunted with bow and arrow. By 1570, the Native American population was 24,000 as Father Segnra and eight Spanish Jesuits were among the first Europeans to discover the Chesapeake Bay.

In May 1607 Captain John Smith sailed into the bay to assume an appointment by King Charles II as Governor of Jamestown and noted the "clear rivers and brooks" which fed a "faire bay" (Horton 2003). In June 1608, the 27 year- old Smith explored the Chesapeake on a "two to three tons burden" boat to discover gold and look for the settlers from the Lost Colony of Roanoke (Chesapeake Bay Program 2010). Smith wrote that oysters "lay as thick as stones" and sturgeon were so plentiful "than could be devoured by dog or man." and "of fish we were best acquainted with sturgeon, grampus, porpoise, seals, stingrays ... brits, mullets, white salmon, trouts, soles, perch of three sorts (Chesapeake Bay Program, 2010)". In 1683, Chief Machaloha deeded English

Quaker William Penn the land between the Delaware and Susquehanna rivers as only 2,500 Native Americans remained.

In August 1777, Admiral Richard Howe sailed a 270-ship British fleet up the Chesapeake Bay and landed at Head of Elk, Md. and invaded the college town of New-ark, Delaware on a roundabout campaign to capture Philadelphia. On September 5, 1781, French Admiral de Grasse defeated the Royal Navy in the Battle of the Chesapeake Bay and 44 days later Lord Cornwallis and 7,000 men surrendered to George Washington at Yorktown, Va. near the mouth of the Chesapeake thus ending the eight-year American War for Independence.

In 1785, Virginia and Maryland signed a compact that gave ships unimpeded passage through the Chesapeake Bay and interstate fishing rights in the Potomac River. At Monticello, Thomas Jefferson urged neighbors to plow contours to prevent soil erosion and somehow found the time to invent the mold board plow, a device that eased cultivation but increased soil erosion in the Piedmont where the muddy James River flowed “like a torrent of blood” (Paul 2001).

The British sailed up the Potomac in August 1814 and burned down Washington, D.C. as President James Madison fled to Virginia and Dolley Madison saved her possessions in the Presidential mansion where British officers ate the supper prepared for the President. The British marched to capture Baltimore on September 13 but Fort McHenry withstood the bombardment and an inspired Francis Scott Key wrote the “The Star Spangled Banner”.

In 1829, Irish laborers dug the sea level Chesapeake & Delaware Canal along the narrow 12-mile waist of Delaware that connected the Chesapeake and Delaware bays and the Delmarva Peninsula became an “island”.

In July 1861 at Manassas, Va., Confederate forces under Stonewall Jackson halted Union troops at the First Battle of Bull Run, a tributary to the Potomac. In December 1862, the Confederate Army killed 12,000 Union soldiers at Fredericksburg along the Rappahannock near George Washington’s birthplace. During July 1-3, 1863 at Gettysburg, Pa., the Union halted Robert E. Lee’s advance on Harrisburg and Philadelphia at what became the “high water mark” of the Confederacy. On April 9, 1865, the South surrendered to the North at Appomattox Court House near the headwaters of the James River. Five days later Abraham Lincoln was shot at Fords Theatre in Washington, D, C. and assassin John Wilkes Booth was later captured trying to swim across the Potomac River from Maryland to Virginia.

In 1880, 20 million bushels of oysters were harvested by 7,600 oyster boats berthed in Md. and Va. By 1890, 70% of the forests between Washington and Baltimore were cut down and the Joppatowne port near Baltimore was closed by 1897 due to siltation from the deforested watershed (Paul 2001).

In 1924, the Governors of Maryland and Virginia held the first joint meeting to manage the Chesapeake blue crab fishery (Ernst 2003). In 1933, the U. S. Bureau of Fisheries held a regional Chesapeake Bay conference in Baltimore that recommended an interstate, bay-wide crab fishery management plan. In 1937, 30 boxcars a day full of oysters left Baltimore for Chicago (Paul 2001).

Bay water quality was still good during the 1950s in places as Maryland’s Bernie Fowler saw his white sneakers while wading 6 feet deep in the Patuxent River. In the late 1950’s, Chesapeake oysters were decimated by MSX and Dermo disease.

In 1965, President Lyndon Baines Johnson declared in his State of the Union address that the Potomac River will be a “model of beauty and recreation” for the nation (Ernst 2005). Congress passed the River and Harbor Act funding a \$15 million U. S. Army Corps of Engineers study to assess future water needs of the Chesapeake Bay through 2020. During the turbulent ‘60s, environmental activists formed the Chesapeake Bay Foundation.

In 1970, Richard Milhous Nixon and the Governors of NY, Pa., and Md. signed the Susquehanna River Basin Compact to jointly manage the upper half of the Chesapeake Bay watershed. In 1972, Congress overturned Richard Nixon's veto and passed the Federal Water Pollution Control Act amendments (Clean Water Act) that imposed fishable and swimmable goals for the cleanup of the waters of the United States. In the same year, activists formed the Alliance for the Chesapeake Bay to instill public input into bay policy debates.

In 1980, the Maryland, Virginia, and D. C legislatures formed the Chesapeake Bay Commission (Chesapeake Bay Program 2010). In 1983, Md., Pa., Va., D. C., Chesapeake Bay Commission, and EPA signed the voluntary Chesapeake Bay Agreement as the first estuary restoration program in the U.S. Maryland imposed a moratorium on striped bass fishing in 1985. Maryland banned phosphate detergent followed by D.C. in 1986, Va. in 1988, and Pa. in 1990. The states, D.C., and EPA signed the 1987 Chesapeake Bay Agreement setting 40% nitrogen and phosphorus reduction goals by 2000. In 1988, Maryland State Senator Fowler waded into the increasingly muddy Patuxent River and barely saw his sneakers just a foot deep. In 1995, Maryland formed local tributary action teams to clean up 10 Chesapeake Bay watersheds. In 1997, *Pfiesteria piscicida* toxins caused by high nutrient loads and warm water temperatures resulted in blooms, fish kills, and rashes on bay watermen.

During 2000, the Clinton Administration signed the Chesapeake Bay Agreement that set goals to reduce nutrient and sediment loads by 40% to remove the bay from the EPA impaired waters list by 2010. Maryland watermen brought in just 20 million pounds of blue crabs, the lowest harvest on record. On the 400th anniversary of the circumnavigation of the bay, President G. W. Bush signed the Captain John Smith Chesapeake National Historic Trail Act as the nation's first water-based National Historic Trail. In 2008, Maryland and Virginia enacted emergency harvest regulations to reverse sharp declines in blue crab abundance. The U.S. Commerce Department declared the Chesapeake Bay blue crab fishery a disaster and issued payments to watermen to replace lost crab income. The Atlantic States Fisheries Commission imposed a 40-year moratorium on sturgeon fishing in the Chesapeake (and Delaware and Hudson) as these basins once were the largest sources of caviar which were shipped for consumption to Russia.

President Barack Obama issued Executive Order 13508 in May 2009 directing Federal agencies to restore the Chesapeake as a national treasure (Chesapeake Bay Program 2010). Annapolis was the first Chesapeake town to ban phosphorus lawn fertilizer. In 2010, EPA Administrator Lisa Jackson issued watershed Total Maximum Daily Loads (TMDLs) ordering states to develop biannual milestones to reduce pollutants 40 percent by 2017 and 100 percent by 2025 to restore the bay to fishable and swimmable Clean Water Act standards. In December 2010, the EPA approved state Chesapeake Bay watershed improvement plans (WIP's) that ushered in a new era of Federal/state cooperation in restoring the USA's largest estuary.

Delaware River

The Delaware is the longest undammed river east of the Mississippi, extending 342 miles from the Catskill Mountains near Hancock, NY to the mouth of the Delaware Bay at Cape May (www.drbc.net). The river is fed by 216 tributaries, the largest being the Schuylkill and Lehigh Rivers in Pennsylvania. The basin contains 13,539 square miles, draining parts of Pennsylvania (51%), New Jersey (23%), New York (18%), and Delaware (8%).

About 8 million people live in the Delaware Basin and 16 million people (5% of the nation's population) rely on the river for drinking water (such as New York City and Philadelphia), but the watershed drains only 0.4% of the coterminous United States. New York City draws 50% of its drinking water from three reservoirs located in the Catskill Mountain in the headwaters of the Delaware River. The river is the largest freshwater port in the world (\$19 billion in annual economic activity) yet sustains a recovering shad and striped bass fishery.

About 2600 years ago, the Lenni Lenape lived in the Delaware Valley, a land they called *Lenapehoking*. In August 1609, Henry Hudson discovered the Delaware Bay after the *Half Moon* got stuck on a sand bar off Cape

May, NJ during his unsuccessful quest for an inner trade route to Asia. Hudson called the bay *Zuyt* or “South River” and observed that “he that will thoroughly discover this great bay must have a small pinnacle that will draw but four to five feet of water, to sound before him (Kauffman 2010).”

In 1610, British Captain Samuel Argall sailed to the bay and named it after Lord De La Warre, the Governor of the Jamestown Colony. The native Lenni Lenape called the river *Pautaxat, Mariskitton, Makerishkisen, Lenape, or Whittuck*. During the 1630s, the Delaware teemed with fish as Dutchman De Vries observed that a single net caught enough perch to feed thirty men and Captain Young wrote back to Europe “of fish here is plenty, but especially sturgeon” (Kauffman 2010). William Penn founded Philadelphia in 1682 as he landed on the *Welcome* and wrote about six-inch oysters too big to be eaten whole and large sturgeon that played in the river all summer.

Thought of as America’s first environmentalist, Benjamin Franklin petitioned the Pennsylvania General Assembly in 1739 to remove the fetid tanneries and slaughterhouses near his Market Street print shop and wrote in the Pennsylvania Gazette that Dock Creek was choked with: “hair, horns, guts and skins” and fish “soon floated belly up (Kauffman 2010).” In 1769, Franklin led a Philadelphia committee to regulate water pollution between the Schuylkill and Delaware.

On July 4th, 1776, the Declaration of Independence was signed along the banks of the Delaware in Philadelphia, the largest city in America at the time and the 3rd largest port in the British Empire. On Christmas Day 1776, George Washington crossed the icy Delaware River from Pennsylvania to New Jersey and defeated the Hessians at Trenton, a watershed moment in the American Revolutionary War. In 1778, spring runs of American shad, celebrated as America’s founding fish by Pulitzer Prize-winning Princeton author John McPhee, reportedly swam up the Schuylkill from the Delaware River and fed General Washington’s starving troops at Valley Forge.

Concerned about polluted drinking water, in 1790 Ben Franklin willed funds to Philadelphia to build the first municipal water system in the U.S. In 1801, Philadelphia built the first municipal water system in the United States and later opened a water works on the Schuylkill near the Philadelphia Art Museum. In 1885, Engineer D. Barber from the Philadelphia Water Department meticulously recorded that the Pullman Palace Car Co. built privies for 250 men that emptied into a brook entering the Schuylkill and the J & P Baltz brewery leaked 60 gallons a minute of spoiled beer into the river. The Philadelphia Inquirer wrote in 1897 about a Philadelphia councilman who mistakenly thought the drinking water in his glass was lemonade. In 1904, contaminated drinking water in Philadelphia caused 44 typhoid cases prompting boil water alerts.

In 1880, 1,400 sailing vessels took over 20 million pounds of oysters from the Delaware Bay. In 1886, hotels in Gloucester, N. J. served 10,000 planked shad dinners at events that resembled modern day blue crab feasts. In 1896, 4 million pounds of shad were caught in the Delaware with a value of \$400,000. At the turn of the century, the American shad fishery in the Delaware crashed as 3 million pounds were harvested in 1905, down from 16 million pounds in 1900. The collapse of the American sturgeon fishery left Caviar, NJ a ghost town.

During World War I, ship builders dumped untreated sewage into the “American Clyde”. During the “Roaring Twenties”, the Schuylkill was so dirty Philadelphians joked that “people emerged from their tubs blacker than they had entered them (Kauffman 2010).” Only 200,000 oily shad were caught in the river. In 1930, Philadelphia discharged sewage in layers 12 feet thick that unveiled sulfur fumes driving sailors to sleep in port rather than in heir berths.

In 1927, the first interstate compact between the Federal government, NY, NJ, and Pa. was proposed to develop a Delaware River reservoir plan but was never adopted. The three states later created the Interstate Commission on the Delaware River Basin (INCODEL) in 1936 as the first serious watershed plan to clean up pollution.

During the Second World War, INCODEL called the tidal Delaware River below Trenton “one of the most grossly polluted areas in the United States (Kauffman 2010).” Shad were unable to swim past the zero oxygen barrier at Philadelphia to their ancestral upriver spawning grounds. Dumping continued unabated as defense industries along the river churned around the clock to meet the war effort. Navy pilots flying a mile overhead were instructed to ignore the sulfur stench from the Delaware River. President Roosevelt ordered an investigation in 1941 to determine if pollution was hampering the U. S. war effort. The Schuylkill was so choked with acid mine wastes at the Philadelphia Navy Yard that the British Admiralty gave officers on HMS Nelson extra allowances to replace gold braid tarnished by the corrosive river gases.

In 1946, pollution from war industries resulted in a U.S. Fish and Wildlife Service report that recorded all-time worse anoxia from shore to shore. After World War II, the Delaware was a dead river as summer oxygen hovered at less than 1 mg/l over a 20 mile section from Philadelphia to Marcus Hook. In 1949, only 38,000 pounds of shad were caught which led to a Pennsylvania law to preserve the shad from extinction. In 1952, ichthyologist Edward Raney lamented that the Delaware as an “outstanding example of destruction of (striped) bass habitat by industrial and domestic pollution.”

With the war over, INCODEL revived its wastewater control program and by 1954 Philadelphia, Camden, and Wilmington constructed new sewage treatment plants. In 1954, the Supreme Court issued an amended decree that permitted New York City to withdraw 800 mgd from the Delaware Basin headwaters in the Catskills provided the City released sufficient water from its reservoirs to benefit downstream states. In 1955, Hurricanes Connie and Diane hammered the Delaware Basin causing killer floods that left 99 people dead and caused \$150,000,000 in damages and left an “oily film of silt... and a terrible stench – an aroma of feces and rotting flesh” (Kauffman 2010). The hurricanes also washed toxic sediments downstream and temporarily purified the Delaware as shad came back to the river by the late 1950s.

In 1961, John F. Kennedy, Jr. signed the Delaware River Basin Compact as the first Federal/state water accord that appointed five commissioners (the governors of Del., NJ, NY, and Pa. and a Presidential appointee) to clean up water pollution and address flooding. Congress approved the DRBC compact noting: “The establishment of a single agency to coordinate federal interests in the Delaware River Basin is as much importance as the joining together of the four states and the resultant coordination of the various state activities. In brief, there is one river, one basin, all water resources are functionally inter-related, and each one is dependent on the other (DRBC 1961).”

In 1963, Dr. Harmic of the Delaware Fish and Game Commission remarked “the future outlook for the shad in the Delaware presents a rather gloomy picture” (Kauffman 2010). By 1966, the Delaware River Basin suffered through a multi-year drought of record, the driest spell in 100 years as dissolved oxygen between Wilmington and Philadelphia reached zero during the summer. In 1968, DRBC issued waste load allocations to 90 Delaware River dischargers to standards more stringent than later required by the Clean Water Act. Secretary of the Interior Stewart Udall who originally advised JFK to oppose the DRBC due to unconstitutionality stated: “Only the Delaware among the nation’s river basins is moving into high gear in its program to combat water pollution” (DRBC 2011).

During the 1970s, the Delaware River was still polluted as American shad landings were down to 500,000 pounds; 30 times lower than late 19th century levels. Ichthyologist M. E. Chittendon concluded that “gross pollution of tidal freshwater had extirpated the striped bass from its historical chief spawning and nursery areas in the Delaware River.” and later asserted that due to water quality concerns and threat of a Tocks Island dam at the Delaware Water Gap the “extirpation of the remnant (shad) runs is a distinct possibility” (Kauffman 2010).

During the 1980s, dissolved oxygen levels in the Delaware were rising as Trenton, Philadelphia, Camden, and Wilmington tapped over \$1.5 billion in EPA Clean Water Act funds to construct new wastewater plants that treated over 700 mgd of sewage. The DRBC reported that DO improved from 2 mg/l in 1968 to 5 mg/l by 1987. By 1988, DRBC historian Richard Albert called the Delaware Estuary cleanup “one of the premier water quality

success stories in the United States” as water quality was better than any time in a century due to wastewater treatment, reforestation, agriculture conservation, and acid mine drainage cleanup programs (Kauffman 2010).

By the 1990s, striped bass and American shad returned in large numbers and a revived Delaware Bay recreational fishery was worth \$25 million per year. In 1993, fisheries biologists found increased American shad, striped bass, and white perch landings statistically correlated with improved water quality in the Delaware. Dissolved oxygen in the Delaware at Philadelphia improved from 1 mg/l in 1958 to 5 mg/l by 1995. In 1996, over 90% of the Delaware Estuary met the fishable and swimmable goals of the Federal Clean Water Act. William D. Ruckelshaus, Nixon’s first Administrator of EPA remarked: “Looking back, the DRBC was the vanguard in the Johnny-come-lately march to manage water resources on a watershed basis.

By 2000, the Philadelphia Water Department reported “the Delaware River is a much healthier river now than it was over the past century. In 2003, the Lehigh River, the second largest tributary to the Delaware, was “cleaner than it had been in the last 150 years” mainly due to acid mine cleanup programs (Kauffman 2010). In 2005, 200,000 shad were caught at Lambertville, NJ. Delaware recreational anglers landed 20,000 striped bass weighing 250,000 pounds.

During 2010, the Delaware continued its revival with an abundant \$7 million blue crab shellfishery. For the first time in 50 years, Delaware fisheries biologists caught a 7-inch juvenile Atlantic sturgeon in the river near Wilmington. Over 50 bald eagle pairs returned to cleaner Delaware waters, even nesting in South Philadelphia in 2007. Delaware and New Jersey planted 500,000 shells for oyster restoration in the bay. By 2011, Congress designated 300 river miles in the Delaware Basin to the National Wild and Scenic River system.

Hudson River

In a foreword to the “The Riverkeeper” by John Cronin and Robert F. Kennedy Jr., Vice President Al Gore wrote “During the 1960s, the Hudson River was polluted, so polluted that some considered it to be dead ... the Hudson has shown a remarkable resilience in bouncing back from years of neglect (Cronin and Kennedy 1997).”

The Hudson River flows from Lake Tear in the Clouds from 4,293 feet Mount Marcy in the Adirondacks down past Albany and West Point to New York Harbor at the tip of Manhattan. While the 315-mile long Hudson is just the 85th largest river in the U.S., the Hudson Fjord is one of the nation’s longest estuaries, navigable to ocean-going shipping for 150 miles inland to the head of tide at Troy, NY. The 13,000 square mile Hudson Basin drains parts of New York, New Jersey, Massachusetts, and Vermont and three mountain ranges, the Berkshires, Catskills, and Adirondacks. Cutting through the Appalachians, the Hudson is the only river in the U.S. with sea level passage through a major mountain range (Suszkowski and D’Elia 2006).

Known as “America’s Rhine”, the Iroquois called it *Muh-he-kun-ne-tuk* and the Lenape called it *Muhheakantuck* or “the river that flows both ways” (Suszkowski and D’Elia 2006). Henry Hudson named it *Mauritius*, the “River of Mountains”. The Dutch called it the North River (the Delaware was the South River). During the 19th century, the rugged valley and 1,300 ft Storm King Mountain inspired the Hudson River School, an American style of pastoral landscape painting popularized by artists Thomas Cole, Frederic Edwin Church, and Albert Bierstadt. The romantic river provided the muse for authors Washington Irving (*Rip Van Winkle*), James Fennimore Cooper (*Last of the Mohicans*), and Hermann Melville (*Moby Dick*).

The Hudson River, though still impaired, is recovering. Mercury levels in fish fillets have declined along the Hudson from the Adirondacks to New York City. Dissolved oxygen levels have improved near the City due to sewage treatment improvements that began in the 30s (NYDEP 2002).

About 10,000 years ago, the Wisconsin glaciers retreated north and the rising sea filled the incised valley creating the Hudson River, a drowned river system. Off the coast, the ancient riverbed follows the Hudson Canyon far out from New York Harbor to the edge of the Continental Shelf and good blue fin tuna fishing.

In 1524, Italian mariner Giovanni Da Verrazano was the first European to sail through the narrows between Staten Island and Long Island into New York Harbor. In August 1609, Englishman Henry Hudson sailed the “*Half Moon*” up the Hudson and noted the river “abounds in trees of every description” (Suszkowski and D’Elia 2006). After sailing 10 days with the tide for 100 miles through the Appalachian gap, Hudson was on the way to find an inner passage to Asia but his quest was cut short by the impassable falls above Albany at Troy. Hudson did not succeed in his original mission to find an inner trade route for the Dutch East India Company but he claimed the valley and its rich fur trade for the Dutch, a reign that lasted half a century with cultural influences that last to this day.

In 1664, the English took over the colony of Manhattan Island from the Dutch. A Dutch minister visited Albany in 1679 and wrote that clear water flowed over the falls at Albany (Suszkowski and D’Elia 2006). By 1730, much of the land along the eastern bank of the Hudson was cleared by logging and agriculture.

In August 1776, the British landed 22,000 men on Long Island and defeated the Americans at Brooklyn Heights. Only a miraculous nighttime evacuation by boat to Manhattan prevented a total rout of Washington’s forces during the largest battle of the war. In September the British under General Howe captured New York City. In October 1777, the British under General Burgoyne headed south from Canada through Lake Champlain with plans to capture Albany and advance down the Hudson River to New York City. An 8,000 man army under General Gates defeated the British at Saratoga, the first major American victory of the war.

In 1807, Robert Fulton captained his steam boat from New York City to Albany, signaling a new era of transportation but with this progress brought an appetite for burning wood for steam that consumed whole forests along the Hudson. By 1925, Governor DeWitt Clinton completed the Erie Canal that connected the Hudson with points west to the Great Lakes and made New York City a hub of commerce and finance. In 1829, the Delaware and Hudson Canal across New Jersey connected the Hudson to the Pennsylvania coal fields, Canadian fur trade, and agriculture of the Midwest.

In 1855, New York State passed the Harbor Commission Act that regulated navigation. Harpers Weekly published an 1870s cartoon about “Father Hudson” who complained about the dirty river. In 1885, New York protected the Adirondack Park as “forever wild” in a constitutional amendment that protected the Hudson headwaters from the political whims of Governors and legislatures. In 1890, the New York Times called the New York City sewerage system an “abomination” due to rampant sludge dumping in New York Harbor (Suszkowski and D’Elia 2006).

In 1906, New York State formed the Metropolitan Sewerage Commission to reduce raw sewage dumping into the Hudson River and New York Harbor. A year later, George Soper, a sanitary engineer for the NYC Health Department, tracked down the source of an epidemic to cook “Typhoid Mary”.

In 1931, New York City developed a financing plan and began construction of a new sewerage system as one of the great public works jobs projects during the Great Depression (Suszkowski and D’Elia 2006). In 1936, New Jersey, New York, and Connecticut adopted the Tri-State Compact and formed the Interstate Sanitation Commission to develop water quality standards and build sewage treatment plants along the Hudson River and New York Harbor.

During the 1960s, the New York Times condemned the Hudson as an open sewer. In 1964, New York City finished the Delaware Aqueduct that transported drinking water 100 miles from the pristine Delaware Basin headwaters in the Catskills to the impaired Hudson Basin. In 1966, New York Congressman Ottinger pushed legislation for a Hudson River Scenic Riverway Compact but the congressional deadline expired in 1974. Governor Rockefeller established a state Hudson River Valley Commission but it lost support (Suszkowski and D’Elia 2006). Folksinger Pete Seeger founded the Hudson River Sloop Clearwater in 1966 that provided river awareness and later helped to force General Electric to clean up PCB contamination (Cronin and Kennedy 1997).

During the 1970s, the Rockefeller Foundation funded the Hudson River Basin project that recommended strengthening environmental management institutions but the recommendations were never implemented. The U.S. Army Corps of Engineers commissioned a 1976 Hudson River Level B study that assessed water conditions through 2000 but these recommendations were never implemented (Suszkowski and D'Elia 2006).

In 1976, the New York State Department of Environmental Conservation issued a report that closed the Hudson's commercial fisheries due to PCB contamination in fish tissue. In 1977, General Electric plants at Ft. Edwards and Hudson Falls, New York released 1.3 million pounds of PCBs, a carcinogen, into the river. By 1983, EPA declared 200 miles of the Hudson River from New York City to north of Albany as a Federal Superfund site (Suszkowski and D'Elia 2006). In 2002, EPA issued a decision calling for dredging and removal of over 2.5 million cubic yards of PCB sediment from a 40-mile reach of the Hudson. In 2009, GE began dredging PCBs from the Hudson

In 1962, Consolidated Edison proposed a pump storage power plant at Storm King Mountain. The Hudson River Fishermen's Association (now Hudson Riverkeeper) challenged the proposal with a final settlement in 1980. As part of the settlement, ConEd provided a \$12 million endowment for environmental policy and science research at the Hudson River Foundation, a one of a kind financing mechanism for a US non profit (Cronin and Kennedy 1997).

During the 1970s, the City of New York proposed to rebuild the 4-mile West Side Highway (Westway project) and create 200 acres of landfill in Manhattan. The City filed a U.S. Army Corps of Engineers Section 404 Clean Water Act Wetland Permit and an Environment Impact Assessment under the 1969 National Environmental Policy Act. The EIA field studies found the highway would impact 25% of the juvenile striped bass population in a wintering area along the Hudson River. The Corps of Engineers approved the permit with a January 1985 finding that the striped bass in the Hudson would not be negatively impacted. The Sierra Club challenged the Corps in court and the court overturned the permit in August 1985 (Cronin and Kennedy 1997).

In 1982, the 750 foot tanker "Palm Beach" was caught flushing out its oil tanks and refilling with Hudson River water to transport to an Exxon oil refinery in arid Aruba (Cronin and Kennedy 1997). Exxon was fined and required to transmit \$41.5 million to the state and \$0.5 million to the Hudson River Fisherman's Association (now Hudson Riverkeeper).

During 1987, Robert F. Kennedy Jr. set up the Pace University environmental law clinic as the first legal arm of the Hudson Riverkeeper. RFK Jr. sued Hudson River polluters based on the public trust doctrine of U.S. water law (the people own the river) that is embedded in modern environmental statutes such the Clean Water Act, Clean Air Act, Endangered Species Act, and National Environmental Policy Act. The ConEd Storm King Mountain project during the 60s was a landmark legal battle over the right to a clean environment that was largely responsible for passage of NEPA by Congress in 1969. In 1995, RFK Jr. and Hudson Riverkeeper were involved when New York Governor Pataki, Mayor Guiliani, and EPA announced an agreement to implement a watershed plan to protect the reservoirs that deliver over a billion gallons of water daily to New York City (Cronin and Kennedy 1997).

In 1988, Congress designated the Hudson River Estuary Program and New York/New Jersey Harbor Estuary Program as estuaries of national significance as part of the National Estuarine Research Reserve System funded by the National Oceanic and Atmospheric Administration. In 1987, New York State passed the Hudson River Estuary Management Act to protect the estuary from Troy Dam to NY Harbor. During 1991, the State of New York designated the Hudson River Greenway with a mission of preserving scenic, historic, and cultural resources of Hudson Valley. By 1993, the Hudson River Foundation funded research on a declining Atlantic sturgeon population that led to moratoriums on commercial fishing by New York and New Jersey (Suszkowski and D'Elia 2006).

Similar but different basins

While sharing similar geography, these contiguous Mid-Atlantic basins have contrasting characteristics (Table 1). The Hudson and Delaware basins are similar in area ($\approx 13,000 \text{ mi}^2$) but the Chesapeake is four times as large ($64,000 \text{ mi}^2$) which suggests the challenges of governing this vast watershed are correspondingly complex. The Chesapeake Basin is home to a population of 16 million or $1\frac{1}{2}$ to 2 times more people than the Hudson and Delaware basins but the Chesapeake's population density (250 people/mi^2) is less than the Delaware (590 people/mi^2) or Hudson (900 people/mi^2) which suggests less pressure per unit area from human pollution sources. Population in the largest cities of the three basins (New York City, Philadelphia, and Baltimore) zoomed upward during the late 19th and early 20th century but have since leveled off (Fig. 2).

While all three rivers are over 300 miles long (which is large as East Coast rivers go), the Chesapeake/Susquehanna, Delaware, and Hudson are just the 42nd, 55th, and 85th longest rivers in the U.S. The Chesapeake is the longest estuary in the U.S. (194 miles) and the Hudson (152 mi) and Delaware estuaries (96 mi) are the 3rd and 5th longest navigable tidal rivers. All three estuaries are drowned river systems that evolved from rising sea levels during the end of the last ice age. Only the Hudson Estuary is a fjord once carved by glaciers while the Chesapeake and Delaware estuaries are south of the glacial terminal moraine left from the last Ice Age..

Roman et al. (2000) suggested the Hudson might be expected to recirculate more rapidly as the ratio of watershed to estuary surface area (55) is three times higher than the Delaware and Chesapeake (18). By annual discharge, the Chesapeake (70,000 cfs) has a greater recirculation rate than the other two basins (14,000-15,000 cfs). In the Delaware and Chesapeake basins, ocean recirculation rates are similar as the bay mouths are 11 to 13 miles wide, much larger than the one mile mouth of the Hudson at the Verrazano Narrows Bridge.

The Hudson is a relatively murky estuary with a mean light extinction coefficient of 1.7, about 4 to 5 times higher than the Delaware and Chesapeake (0.3-0.4). The Delaware has a high peak light extinction coefficient (7.0) in the intertidal zone near the C & D Canal, much higher than peaks for the Hudson and Chesapeake (Roman et al. 2000).

Water pollution control programs have improved dissolved oxygen levels in the Delaware and Hudson basins while DO levels continue to decline in the Chesapeake (Fig. 3). All three basins have recovering American shad fisheries although juvenile abundance has declined lately perhaps due to increased striped bass populations who forage for the young shad (Fig. 4).

Land use proportions are similar as the urban I-95 corridor lies in the downstream reaches of the each basin while agriculture and forested land increases north to the headwaters (Table 2). The Delaware is more urbanized with 14% developed land compared to the Chesapeake and Hudson basins (8% developed). The three basins are covered by similar proportions of agriculture (22%-26%) and forests (55%-60%). Known for fisheries productivity, the Chesapeake has double the area of wetlands/water (9%) compared to the Delaware (5%) and Hudson (2%) basins.

Watershed Governance

The Chesapeake Bay cleanup is driven by a voluntary Federal-state partnership coupled with a river basin commission in the headwaters. The EPA hosts and funds the Chesapeake Bay Program through the Clean Water Act and National Estuary Program. The voluntary Chesapeake Bay Agreement was signed by the watershed states (Delaware, Maryland, New York, Pennsylvania, Virginia, and West Virginia), District of Columbia, and EPA. In the upper half of the basin, the bay's two largest tributaries are governed by the Susquehanna River Basin Commission (between Md., NY, Pa., and the U.S.) and Interstate Commission for the Potomac River Basin (between Md., Pa., Va., and the U.S.). The bay has a long history of activism influenced by a blend of nonprofits such as the Chesapeake Bay Alliance and Chesapeake Bay Foundation. If the density of capital cities in a watershed is a measure of political will toward restoration, then the Chesapeake ought to have a good

chance of recovery as the basin includes the capitals of Maryland, Virginia, and Pennsylvania and the seat of Federal power along the banks of the Potomac.

The Delaware is the only basin governed entirely by compulsory interstate compact by a single coordinating entity. In 1961, JFK signed the Delaware River Basin Commission compact as the first Federal-state watershed accord to govern a basin as a single administrative agency. The DRBC governs by comity (one seat, one vote through a principle of reciprocal courtesy between the governments) through five commissioners representing the Governors of Delaware, New Jersey, New York, and Pennsylvania and the President of the United States. The Partnership for the Delaware Estuary provides a science-based approach to the tidal Delaware watershed as one of the 28 congressionally designated estuaries in the National Estuary Program. Over 300 river miles in the Delaware Basin are protected by the National Park Service through the National Wild and Scenic Rivers Act.

The Hudson Basin is protected by effective and committed nonprofit environmental groups such as the Hudson River Fisherman's Association, Hudson Riverkeeper, and Hudson River Greenway that grew out of the social activism of the turbulent 60's. Pete Seeger's Clearwater Sloop continues to reflect public attention on the health of the Hudson. The states never adopted the concept of an interstate Hudson Basin compact during the 1930s and 1960s. Today, a semi-formal interstate basin approach (up to the head of tide at Albany) is provided by the Hudson River Estuary Program and the Interstate Sanitation Commission between New York, New Jersey, and Connecticut.

Concluding Remarks

The environmental history of a river or bay is another instrument in the watershed manager's toolbox. Lessons from the past can instill a sense of ownership and stewardship and provide a cultural incentive for citizens to restore their home watershed. If an individual seeks to understand the unique historic character of a watershed and its own essential "sense of place", then one may be more committed to cleaning up its waters. The Chesapeake, Delaware, and Hudson basins have a very special place in American history. Knowledge of the past holds valuable lessons for the future as these famous watersheds continue to rebound from a polluted legacy under three different but somewhat effective watershed governance model.

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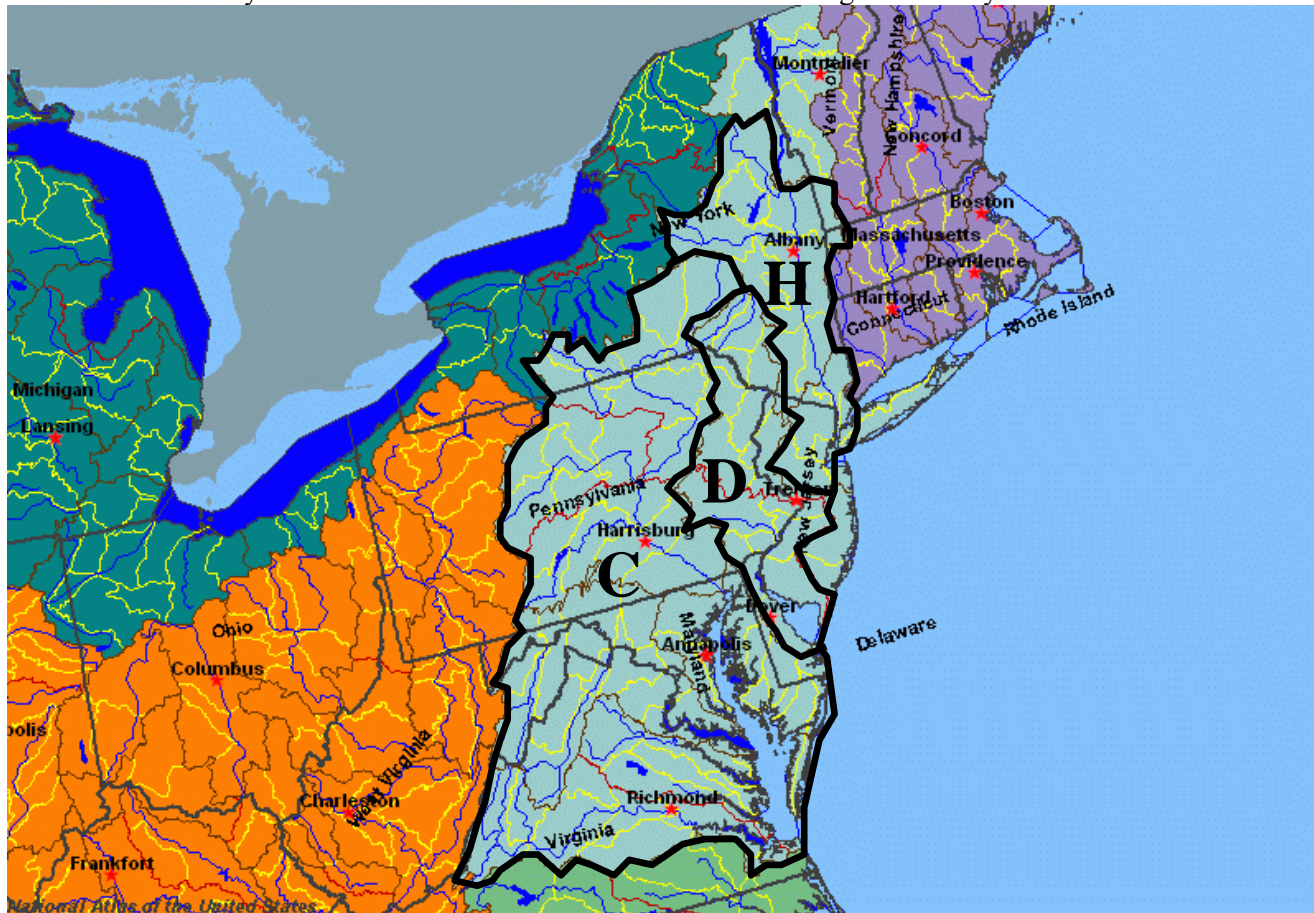


Fig 1 The Chesapeake, Delaware, and Hudson basins along the Atlantic seaboard (www.nationalatlas.gov)

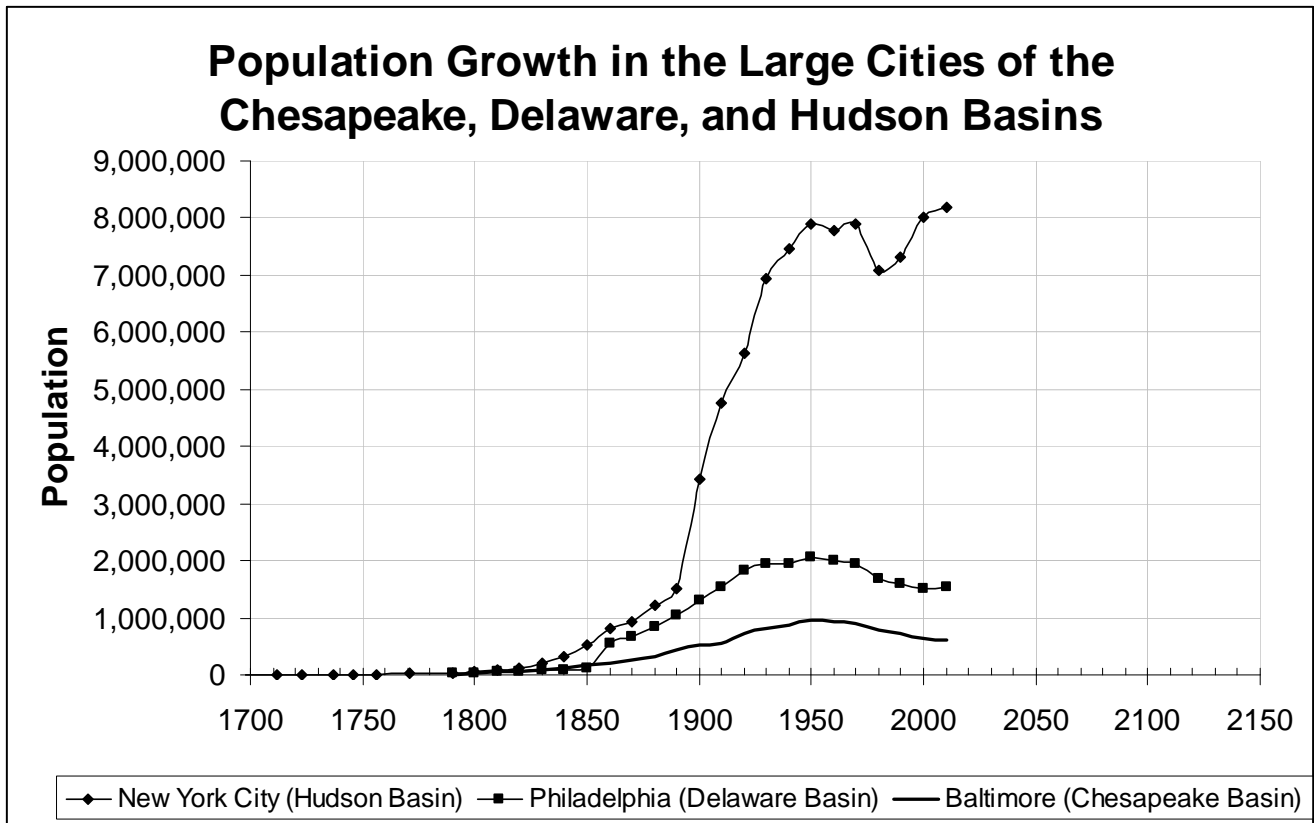


Fig. 2 Population growth in the large cities of the Chesapeake, Delaware, and Hudson Basins (U.S. Census)

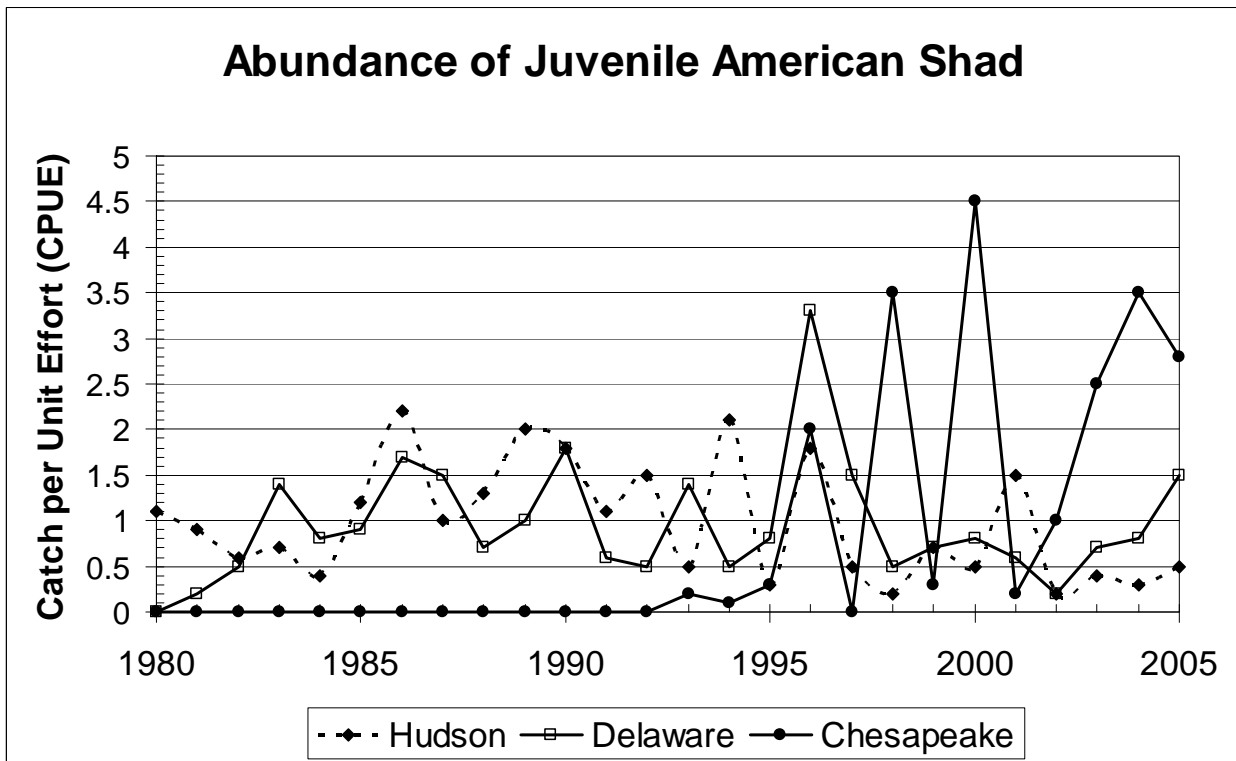


Fig. 3 Abundance of juvenile American shad in the Chesapeake, Delaware, and Hudson basins (ASFMC)

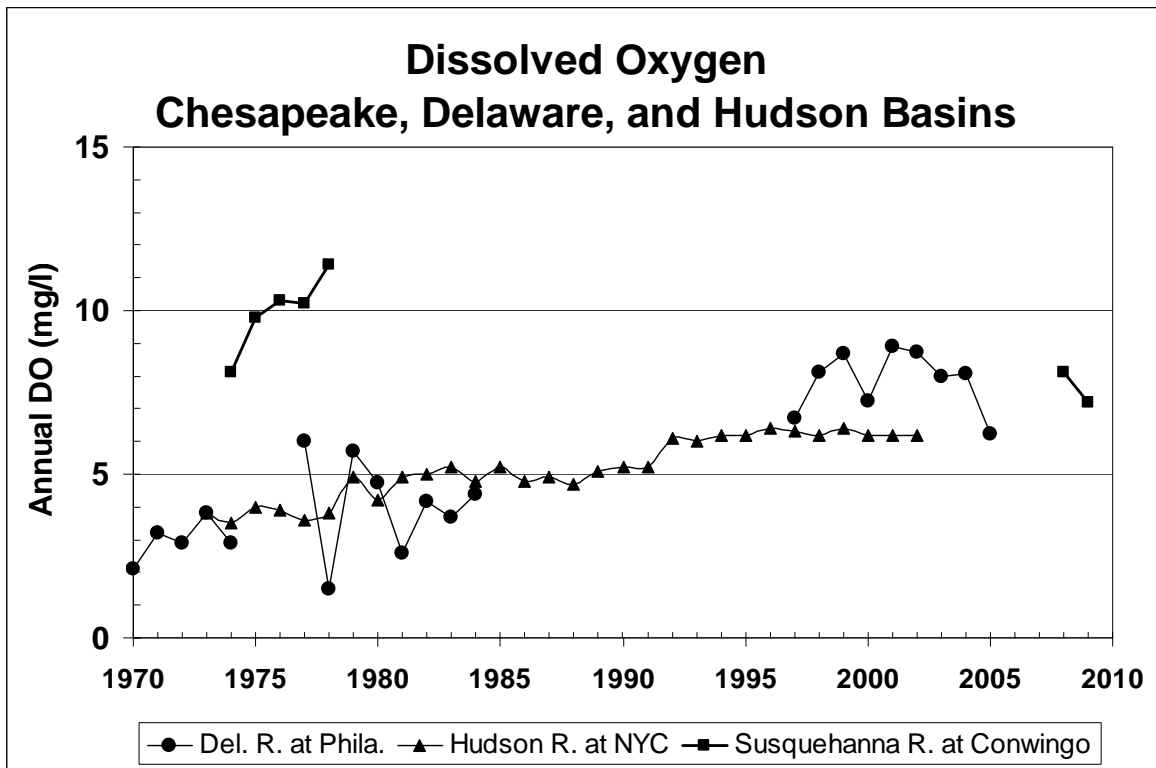


Fig. 4 Dissolved oxygen in the Chesapeake, Delaware, and Hudson basins (USGS)

Table 1 Characteristics of the Chesapeake, Delaware, and Hudson estuaries

Estuary	Watershed Area (sq mi)	River Length ¹ (mi)	Nontidal Length ¹ (mi)	Tidal Length ¹ (mi)	Annual Discharge (cfs)	Bay Mouth (mi)	Watershed/ Estuary Ratio ²	Light Extinction Coefficient ³
Chesapeake	64,000	449	255	194	70,000	13	18	0.4-2.0
Delaware	15,732	342	256	96	15,000	11	18	0.3-7.0
Hudson	13,557	317	165	150	14,000	1	55	1.7-2.8

1. Nontidal and tidal river lengths, Paul 2001.

2. Estuary recirculation increases with increasing watershed to estuary area ratio, Roman et al. 2000.

3. Water clarity increases with decreasing light extinction coefficient, Roman et al. 2000.

Table 2 Comparative summary of the Chesapeake, Delaware, and Hudson basins

Parameter	Chesapeake	Delaware	Hudson
Founded	1570 Father Segura	1609 Henry Hudson	1524 Giovanni Da Verrazano
Area (sq mi)	64,000	13,600	13,400
Population (million)	16	8	12
States	DE, MD, PA, NY, VA, WV, D.C.	DE, NJ, NY, PA	NY, NJ, CN, MA, VT
Major Cities	Baltimore	Philadelphia	New York City
Capitals	D. C., Annapolis, Richmond, Harrisburg	Trenton, Dover	Albany
Urban/suburban	9%	14%	8%
Agriculture	22%	26%	25%
Wooded	58%	55%	60%
Wetlands/water	9%	5%	2%
Luminaries	Captain John Smith Lord Richard Howe Richard Nixon, Barack Obama	William Penn Ben Franklin George Washington, John F. Kennedy	Henry Hudson, Robert F. Kennedy, Jr., Rudolf Giuliani
Governance	Chesapeake Bay Program, Susquehanna River Basin Chesapeake Bay Alliance Interstate Comm. Potomac Basin, Chesapeake Bay Foundation, Chesapeake Bay Commission	Del. River Basin Commission Partnership for Del. Estuary Delaware River Keeper	Hudson Riverkeeper, Hudson River Estuary Prog. Hudson River Greenway Interstate Sanitation Comm.