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11-5-2005

Essential Fish Habitat of Atlantic Sturgeon *Acipenser oxyrinchus* in the Southern Chesapeake Bay

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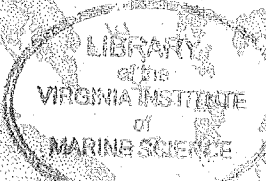
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Final Report
to
NOAA/NMFS
for NOAA Award NA03NMF4050200 (AFC) 37

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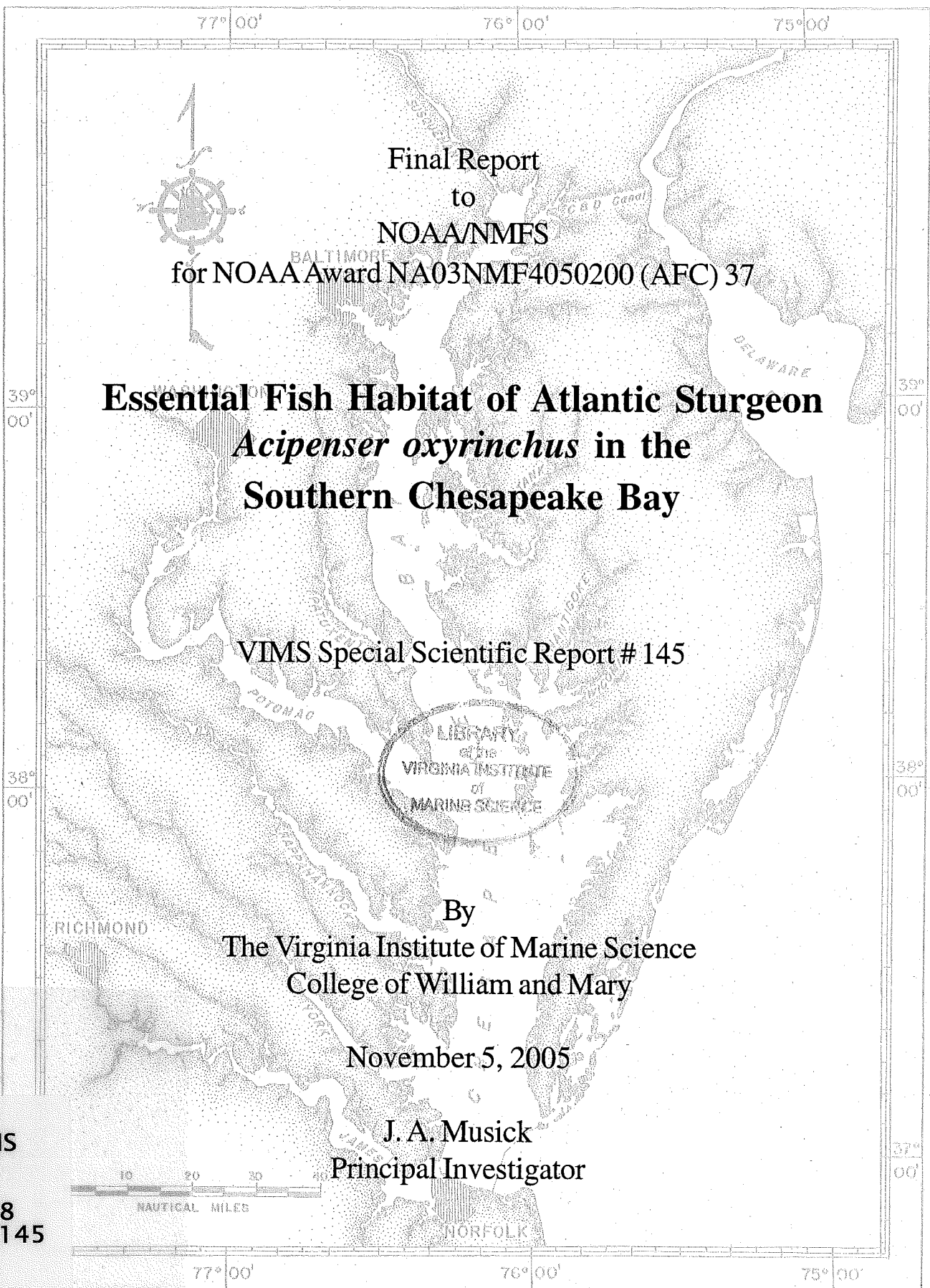
By
The Virginia Institute of Marine Science
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November 5, 2005

J. A. Musick
Principal Investigator



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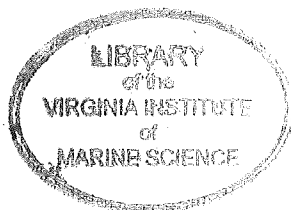
"Essential Fish Habitat of Atlantic Sturgeon *Acipenser oxyrinchus* in the Southern Chesapeake Bay"

By

THE VIRGINIA INSTITUTE OF MARINE SCIENCE
COLLEGE OF WILLIAM AND MARY

November 5, 2005

J. A. Musick Principal Investigator



**Summary: for objectives and Accomplishments
(as revised in December 2004)**

1.) Evaluate the suitability of Virginia tributaries for sturgeon restoration:

2.) Prioritize Virginia tributaries for Atlantic Sturgeon restoration:

This work has been completed as revised and an extensive environmental assessment was done to identify and prioritize Atlantic Sturgeon spawning and nursery area in Virginia (see Appendix 1)

3.) Coordinate objectives and activities of VIMS and VMRC with those of the Atlantic Sturgeon restoration team in Maryland including Md.DNR and US Fish and Wildlife Service: The P.I. (J.A. Musick) organized a meeting that was held in Annapolis Md. in April 2005. At that meeting Jack Travelsted (VMRC), Brian Richardson (Md. DNR), Steve Minkkenen (USFWS Md), and Albert Spell USFWS (Va), agreed to participate in a joint Atlantic Sturgeon Restoration Program for the Chesapeake Bay with VIMS as the lead research agency for the State of Virginia. On April 26 the P.I., representing Virginia, participated in a meeting with personnel from Md DNR, Mirant Mid-Atlantic (fish culture facility working with Md. DNR), the University of Maryland, Aquaculture and Restoration Ecology Laboratory (AREL) and USFWS. At this meeting a Chesapeake Bay Atlantic Sturgeon Culture Working Group was founded with Dr. Andrew Lazur (AREL) as its chair with members from all the organizations mentioned above. Subsequently VIMS personnel obtained three Virginia sturgeon of adult size that were successfully transferred to AREL where two were induced to produce sperm which was cryo-preserved)

4.) Genetic Studies: During the study period VIMS personnel collected 32 genetic samples for analysis by USFWS and USGS geneticists. We will continue to collect genetic samples from all sturgeon we handle. Attempts so far to recover genetic material from sturgeon scutes recovered from archaeological sites have not been successful, but the possibility remains that this historical source of genetic material may yet contribute information.

5.) Juvenile tracking:(from original proposal). As juvenile sturgeon became more available in Chesapeake Bay this year, VIMS personnel were able to track two more individuals. These short (8hr.) tracks in the York River show similar behavior patterns to the juvenile sturgeon tracked in the James River previously (figures 1 and 2). The fish spent the daytime hours in or close to the channel and moved with the tide. This information has implications for the potential effects of channel dredging on sturgeon. In the future we propose to increase our tracking efforts in the James River using a passive sonic receiver array which will allow observations to be made over 24 hour periods for several weeks.

Figure 1. Two Juvenile Sturgeon tracks in the York River (July 2005)

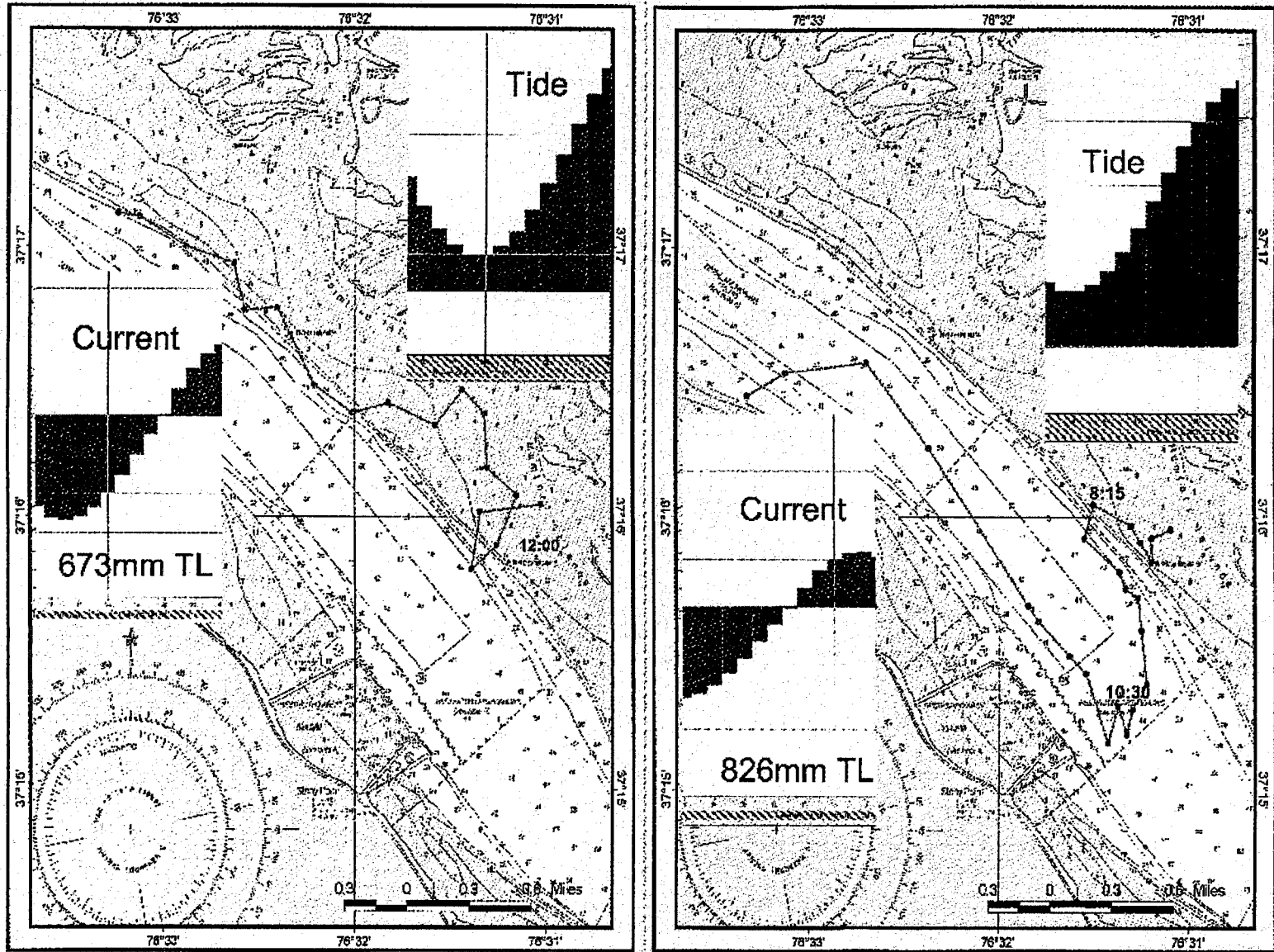
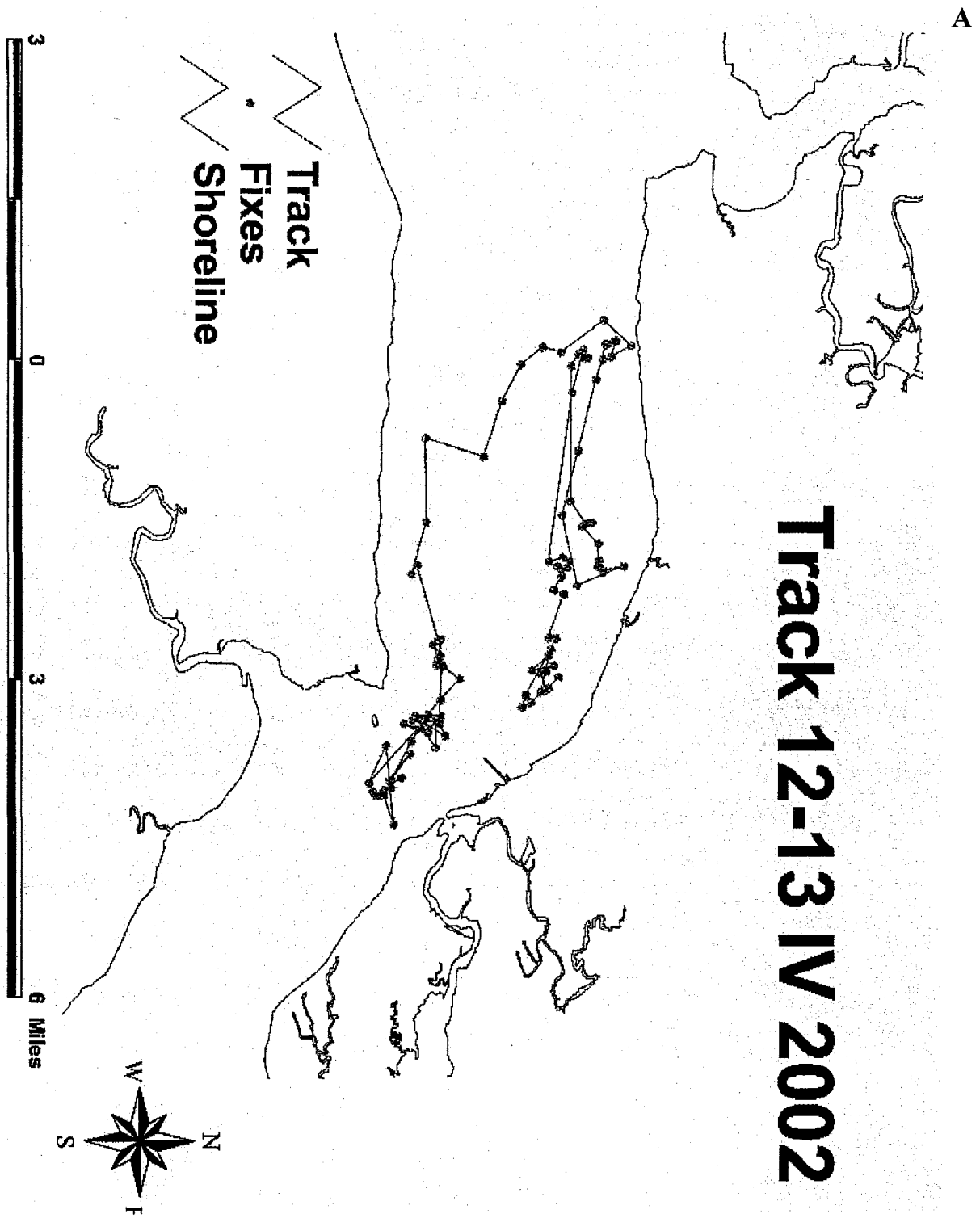


Figure 2. James River Juvenile sturgeon track (27 hrs.) (April 2002)



Appendix: 1

Essential Spawning and Nursery Habitat of Atlantic Sturgeon (*Acipenser oxyrinchus*) in Virginia

T. M. Bushnoe, J.A. Musick, D.S. Ha

Introduction

The Atlantic sturgeon (*Acipenser oxyrinchus*) is a member of the ancient family, Acipenseridae, which have been on Earth since the Cretaceous period more than 120 million years ago. They are slow-growing and late maturing anadromous fish that migrate from the ocean into the coastal estuaries and rivers to spawn. Atlantic sturgeon were once abundant in every major coastal river along the Atlantic coast of North America (Colligan et al. 1998), but presently populations are drastically reduced throughout their historic range. The Atlantic sturgeon is found from Hamilton Inlet, Labrador to the St. John's River, Florida, but spawning populations do not occur in many of the intervening systems (Murawski and Panfili 1977, Van Den Avyle 1983). The presence of a viable spawning population in Chesapeake Bay has recently been the subject of scientific debate. Our primary objective was to identify suitable spawning and nursery habitats for Atlantic sturgeon in Virginia. We designated potential habitats based on historical accounts, suitable habitat characteristics from the literature, and present conditions.

Atlantic sturgeon were common throughout the Chesapeake Bay and its tributaries prior to European settlement (Kahnle et al. 1998). For centuries, the Native Americans of this region were well aware of the timing of the spring spawning run. The capture of sturgeon was not only a source of food but also a way for a young warrior to prove his bravery (Woodlief 1985). Historian Robert Beverley in 1705 described how the Native Americans traditionally captured the sturgeon:

“The *Indian* way of Catching Sturgeon, when they came into the narrow parts of the Rivers, was by a Man's clapping a Noose over the Tail, and by keeping fast his hold.

Thus a Fish finding it self intangled, wou'd flounce, and often pull him under Water, and then that Man was counted a *Cockarouse*, or brave Fellow, that wou'd not let go; till with Swimming, Wading, and Diving, he had tired the Sturgeon, and brought it ashore" (Wright 1947).

The presence of the sturgeon in Native American legend and lore further emphasizes their knowledge and respect for the fish (Coleman 1892).

The first European settlers of the region were quick to use the plentiful sturgeon as a food source. Surprisingly no fishing gear of any type was brought to Virginia from England in 1607 and during the first weeks at Jamestown, the colonists ate many crabs and sturgeon because they could be captured in shallow water with minimal equipment (Pearson 1942b). Captain John Smith made numerous references to the fish in his accounts of the newly discovered Chesapeake Bay and tributaries: "Of fish we were best acquainted with sturgeon..." (Smith 1624). Additional accounts from Smith and others describe the abundance of sturgeon from spring through September and explain the methods used to harvest sturgeon in large quantities (Pearson 1942a; Wharton 1957, Earle 1979). The colonists at Jamestown were sustained by sturgeon meat during the starving times of April when food stocks were depleted (Woodlief 1985). The extent of sturgeon harvest is seen through archeological findings that identify thousands of sturgeon scute fragments from excavations of middens at Jamestown, Virginia and other sites along the James and York River (Bowen and Andrews 2000). As the colonies grew, the prospect of capitalizing on the abundance of sturgeon arose, however, attempts to transport sturgeon meat and caviar to England failed. After this initial unsuccessful attempts at creating a sturgeon fishery in Chesapeake Bay there is no record of a regular fishery until more than a century later (Tower 1908). During the 1700s, sentiment had changed, and some accounts describe a strong prejudice against the sturgeon. Shad fisherman routinely killed the fish because their nets were often severely damaged by entangled sturgeon.

During this time, sturgeon meat and roe held scarcely any value and were often used to feed hogs or for bait (Cobb 1900, Tower 1908, Hildebrand and Schroeder 1928).

The first successful Atlantic sturgeon fishery arose in the 1860s from the Delaware River and Bay and after 1870 sturgeon fishing expanded as smoked sturgeon and caviar gained acceptance (Ryder 1890, Cobb 1900). Soon after, regular fisheries developed in every major coastal river along the Atlantic seaboard (Tower 1908, Smith 1985). The rapid expansion of the Atlantic sturgeon fishery cannot be sufficiently characterized since records of landings were not kept until 1880 when the U.S. Fish Commission started compiling statistical information on commercial fishery landings (Taub 1990). We can, however, characterize its demise. Along the east coast, record high Atlantic sturgeon landings in the 1880s and 1890s dropped precipitously by the turn of the century; landings in 1908 were only 2.2% of the 1888 peak (Figure 1) (Murawski and Panfeco 1977). This same pattern is evident in Virginia's portion of Chesapeake Bay as well. Catch records from the 1880s show a great abundance of Atlantic sturgeon; with catches of 8,028 kgs (17,700 lbs) from the Rappahannock River, 23,433 kgs. (51,661 lbs.) from the York River and tributaries, and 49,396 kgs. (108,900 lbs.) from the James River. However, by 1920, the catch of Atlantic sturgeon for the entire Chesapeake Bay amounted to only 10,381 kgs. (22,888 lbs.) and the fish was considered scarce (Hildebrand and Schroeder 1928). By 1928 Virginia had enacted a law asserting, "that no sturgeon less than 4 feet long may be removed from the waters of the State" (Hildebrand and Schroeder 1928). The Chesapeake Bay Atlantic sturgeon fishery continued to harvest fish, but at a fraction of its previous rates. In 1956 records indicated a catch of 10,432 kgs. (23,000 lbs.) from Chesapeake Bay (Vladykov and Greeley 1963). A continued decline in Atlantic sturgeon prompted Virginia to impose a total moratorium on Atlantic sturgeon catches in 1974. The Atlantic States Marine Fisheries Commission enacted a Fishery Management Plan for Atlantic sturgeon in 1990 that called for rebuilding of the coast wide stock. A 1998 amendment included a stock rebuilding

target of at least 20 protected year classes of females in each spawning stock, to be achieved by imposing a harvest moratorium coast wide (Field et al. 1998).

The combined effects of overfishing and habitat deterioration have caused Atlantic sturgeon to decline to the point of extirpation in Chesapeake Bay (Secor et. al. 2000). Much, if not all, of the habitat loss can be attributed to a history of decreasing water quality and increased siltation of Chesapeake Bay and its tributaries. The water quality of Chesapeake Bay began to decline when Europeans settled in the region in the 17th and 18th centuries (Officer et al. 1984, Cooper and Brush 1991). In the James River these settlements started with Jamestown Island and continued up to the fall line at present day Richmond. The great resources and hydraulic potential of the river made its banks ideal for colonial establishments. The same pattern can also be seen in the York and Rappahannock Rivers and within the next 200 years, many towns had developed in the Chesapeake Bay region. This initial land clearance and deforestation in the region resulted in increased runoff marked in the sedimentary record of the Bay (Cooper and Brush 1991).

During the 20th century the declining water quality of Chesapeake Bay accelerated abruptly, when immediately following World War II exponential increases in use of agriculture fertilizers and sewage discharge delivered massive nutrient loads to the Bay (Brush et al. 1998, Zimmerman and Canuel 2000). The resulting eutrophication and overall poor water quality affected many of Chesapeake Bay's resources; especially submerged aquatic vegetation, fish, and shellfish (Dauer and Alden 1995, Mountford 2000). Eutrophication is considered to be the dominant anthropogenic factor contributing to the measured increase in hypoxia and anoxia in the Bay (Officer et al. 1984). Summertime hypoxia or anoxia has become an annual occurrence in the mainstem Chesapeake Bay. Low dissolved oxygen levels, along with high temperatures and salinity are three factors which have greatly reduced the amount of available Atlantic sturgeon nursery habitat in the Bay. Siltation, along with dredging and dams have reduced the amount of available spawning habitat in the

freshwater tidal portions of the tributaries. Despite low population levels and severe habitat degradation, the restoration of an Atlantic sturgeon population in Virginia may be possible once essential spawning and nursery habitat have been defined, identified, and protected.

Suitable Habitat Characteristics

Reauthorization of the Magnuson-Stevens Fishery Conservation and Management Act in 1996 required the identification and protection of essential fish habitat in fishery management plans. The Atlantic sturgeon is a migratory fish that uses diverse habitats (oceans, bays, estuaries, rivers) to complete its life history. In addition, long life span and late maturity makes the species especially vulnerable to habitat alteration. All of these factors contribute to the difficulty in determining if essential fish habitat for Atlantic sturgeon exists in Virginia. Chesapeake Bay and its tributaries have undergone extensive changes that have altered the amount of spawning and nursery habitat available to the Atlantic sturgeon and have likely contributed to the failure of populations to recover to historic levels. In order to assess the viability of restoring a spawning Atlantic sturgeon population to the Bay, the existence of suitable spawning habitat parameters must be assessed. Since an insufficient number of Atlantic sturgeon utilize the James, York, or Rappahannock Rivers to directly observe their habitat use, the following characterizations are based on values of parameters in other systems (Table 1). The use of habitat profiles to locate probable spawning beds in other rivers has been successfully employed in Florida (Sulak et al. 2000). Our method considered known values for habitat parameters throughout the Atlantic sturgeon range and assigned the highest relevance to values from systems geographically closest to Chesapeake Bay.

Spawning Habitat

Atlantic sturgeon spawn between May and July (Leland 1968, Dovel and Berggren 1983, Bain et al. 2000). In Chesapeake Bay, their migration to the spawning grounds begins in April when historically, large numbers of adults were harvested near the mouth of the Bay and in the lower James River (Hildebrand and Schroeder 1928). These regions (Lynnhaven Roads, Buckroe Beach, and Ocean View) were considered staging areas where adults assembled before the run to the spawning grounds. Atlantic sturgeon spawning habitats are located between the salt front and the fall line, in narrow reaches of the river, downstream of bends, tributaries, and other features that result in hydrodynamic complexity (Huff 1975, Bain et al. 2000, Secor et al. 2000, Sulak et al. 2000). Atlantic sturgeon spawn directly on top of gravel in fast flowing sections often containing eddies or other current breaks. “Eddies promote position holding between spawning individuals, trap gametes facilitating fertilization, and diminish the probability of egg dislocation by current – facilitating immediate adhesion of eggs to the gravel substrate” (Sulak et al. 2000). In addition, flowing water provides oxygen, disperses eggs, and excludes predators. Crance (1987) devised a habitat suitability model for Atlantic sturgeon that predicted optimal flow in the spawning habitat to be 46 – 76 cm/s. Spawning substrate is classified as exposed or very thinly sedimented hard bottom that is abundantly covered with gravel and cobble particles (range 30.5 – 236 mm) (Sulak et al. 2000). The presence of this hard bottom substrate is considered the most important characteristic of suitable spawning habitat. Depth of known spawning sites ranges from 11 – 27 m and sites are often located in pools considerably deeper than the rest of the river (Borodin 1925, Leland 1968, Scott and Crossman 1973, Bain et al. 2000). Water temperature is 13.2 – 26 °C, 0 ppt salinity, slightly alkaline pH, 6 – 18 mg/L Ca⁺⁺ ion concentration, and a conductivity range of 10 – 110 µS (Hildebrand and Schroeder 1928, Borodin 1925, Vladykov and Greeley 1963, Huff 1975, Smith et al. 1980, Smith 1985, Van Eenennaam et al. 1996, Bemis and Kynard 1997, Sulak and Clugston

1999, Bain et al. 2000, Sulak et al. 2000, Caron et al. 2002, Hatin et al. 2002). High dissolved oxygen levels are also required and are probably ensured by the high flow requirement. Given the required conjunction of specific parameters, it is likely that only a few suitable spawning sites exist in any river (Sulak and Clugston 1998, 1999, Fox et al. 2000) and that they are limited to very short upriver reaches demonstrating a particular set of physical, chemical, and hydrological characteristics (Sulak et al. 2000). Bottom type is the critical parameter of suitable spawning sites and if appropriate substrate is present, a wider range of the remaining parameters will still be considered favorable. Once a suitable spawning site is located by sturgeon, it is generally used on an annual basis (Bain et al. 2000, Sulak et al. 2000).

Nursery Habitat

Unlike spawning habitat, Atlantic sturgeon nursery habitat spans a large area from bays and estuaries, to freshwater rivers (Table 2). These nursery areas are used by juveniles, ages 1 – 6, until the time they make their initial migration to the ocean (Murawski and Panheco 1977, Smith 1985, Secor et al. 2000, Sulak et al. 2000). Upon hatching, Atlantic sturgeon larvae are incapable of swimming or feeding and require a gravel matrix as a developmental refuge for the first few days of life (8 – 12 days), as in shortnose sturgeon (Kynard 1997). During the first few months, larval Atlantic sturgeon remain near the freshwater spawning habitat, with larvae extending downstream as they grow and attain the ability to endure brackish water (Bain et al. 2000, Sulak et al. 2000). During the first year, Atlantic sturgeon remain close to their natal habitats within estuaries (Dovel and Berggren 1983, Bain 1997, Leland 1968). Young-of-year avoid bottom habitats of silt, rocks, and vegetation and select sandy substrate (Sulak et al. 2000). Stomach content analyses of juveniles confirm feeding on tiny benthos over sand bottom (Mason and Clugston 1993). Juvenile Atlantic sturgeon have been captured at a wide range of depths and have been found congregating in deep

holes (Dovel and Berggren 1983, Savoy and Pacileo 2003). Juveniles overwinter in the deeper waters of the lower estuary and move upstream and inshore during spring in response to increasing water temperatures (Ryder 1890, Dees 1961, Brundage and Meadows 1982, Lazzari et al. 1986, Bain et al. 2000, Secor et al. 2000). Juveniles are found in waters ranging from 13.2 – 28 °C, and use deeper cooler regions in the summer (Dovel and Berggren 1983, Kieffer and Kynard 1993, Bain et al. 2000). Atlantic sturgeon avoid regions of hypoxia (dissolved oxygen < 4 mg/L), and laboratory studies have shown reduced growth rates and death when hypoxic conditions are coupled with high water temperatures (Secor and Gunderson 1998, Secor and Niklitschek 2001).

Although, Atlantic sturgeon may remain in their natal estuary until migrating to marine habitats, interestuarine migrations have been well documented in the literature (Dovel and Berggren 1983, Smith 1985, Savoy and Pacileo 2003). The non-natal riverine and estuarine habitats serve as nursery areas and are very important to Atlantic sturgeon life history. They can provide additional foraging opportunities as well as thermal and salinity refuges.

Present Conditions

Assessing the existence of essential habitat for Atlantic sturgeon spawning and rearing requires a review of the actual river conditions in reference to the suitable habitat profiles. James, York, and Rappahannock River substrate studies were used to locate regions of hard substrate suitable for spawning habitat and sandy substrate suitable for nursery habitat. The description of bottom sediments in the river estuaries was provided by Nichols et al. (1992). Comprehensive reports describing the substrate of the freshwater tidal portions of the James, York, and Rappahannock Rivers are not available and therefore anecdotal descriptions were referenced. These descriptions were found primarily in a 1995 report to the Norfolk District of the US Army Corps of

Engineers (Holton and Walsh 1995) and a 1973 assessment of sand and gravel pits by the Virginia Department of Conservation and Economic Development (Onuschak 1973).

Water quality parameters were analyzed from data recorded at fixed stations by the Chesapeake Bay Program and by citizen monitoring sites managed by the Alliance for the Chesapeake Bay (Alliance for the Chesapeake Bay 2005, Chesapeake Bay Program 2005). Monthly averages were calculated from the Chesapeake Bay Program data for each parameter at each sampling station from 1994 – present. Parameters included water temperature, dissolved oxygen, pH, salinity, hardness, and conductivity. Parameters were measured at surface, midwater, and bottom depths and therefore, monthly averages represent an integrated water column value. When possible, monthly averages were calculated in the same manner from the Alliance for the Chesapeake Bay water quality data. Several citizen monitoring sites were not active continuously from 1994 – present in which case any data available from that site was used to calculate monthly averages. Parameters from the Alliance for the Chesapeake Bay water quality data were measured at the surface only and include water temperature, dissolved oxygen, and pH.

Finally, Atlantic sturgeon catch records in Virginia since 1955 were examined to assess the existence of essential habitat for sturgeon and the presence of early juvenile sturgeon (< 400 mm). Catch data was provided by the Virginia Institute of Marine Science Juvenile Fish and Blue Crab Trawl Survey, the U.S. Fish and Wildlife Service, and the Virginia Department of Environmental Quality.

James River

The James River is formed by the confluence of the Jackson and Cowpasture Rivers at Iron Gate in Alleghany County, Virginia. The James River is 547 km (340 miles) long and drains 23164 km² (10,102 miles²), one-fourth of Virginia's land base and 47% of the state's Bay basin. Land use in the river basin varies considerably from the headwaters to the mouth. Approximately, 71% of the land is forested, 23% is agriculture, and 6% is urban. The tidal freshwater portion of the James River stretches from the mouth of the Chickahominy River to the fall line at Richmond.

In addition to the declining water quality throughout the Chesapeake Bay region, Atlantic sturgeon habitat in the James River was also threatened by obstructions and alterations, principally dams and dredging. The 1800s brought about the construction of many large dams, including Boshers Dam in 1823. These dams barred migratory fishes from their historic upstream spawning habitats, reducing the number of fish that returned each spring. The work of creating new fish passages in the James River began in 1989, when Manchester and Brown's Island dams were breached with explosives. A 9.1 m (30 ft.) wide by 0.8m (2.5 ft.) deep notch was cut into the Williams Island Dam in 1993, opening another 4.2 km (2.6 miles) of spawning habitat up to the base of Boshers Dam at the fall line in Richmond. However, the opening of the vertical slot fishway at Boshers Dam in March of 1999, ended nearly 200 years of blockage and provided access to 220 km (137 miles) of historical spawning habitat on the James River and 322 km (200 miles) on its tributaries. A camera at Boshers dam monitors use of the fishway and to date no Atlantic sturgeon have passed through the fishway. Therefore, the reach of available Atlantic sturgeon habitat in the James River is assumed to be from the mouth to Boshers Dam at 160 rkm.

Atlantic sturgeon are benthic feeders and spawners, therefore, any alterations to the river substrate would directly impact the amount of available habitat. Since European colonization, the bathymetry of the James River has been modified drastically by sedimentation on the channel floor,

shore erosion, and dredging. The demand to establish a major shipping port at Richmond became apparent in the early 1800s. However, as shipping vessels and the quantity of shipped goods increased, navigation up the river to Richmond became impossible. The major obstacles barring navigation were several sandy shoals and a region of legendary rock outcroppings called Rockett's. In an attempt to reduce damage to boats in the channel, many rocks were removed in 1843 (Holton and Walsh 1995). However, further alterations to the shipping channel were necessary to accommodate the desired shipping traffic. In 1854 the shoal at Richmond's Bar was successfully dredged and Rockett's remained the last obstacle to the desired 5.5 m (18 ft.) shipping channel from Richmond to Hampton Roads. Rockett's consisted of large and small boulders resting on a bed of granite. This substrate is the exact configuration of known Atlantic sturgeon spawning sites and therefore Rockett's may have been a location of historic Atlantic sturgeon spawning in the James River. Ultimately Rockett's was dredged to create a 5.5 m (18 ft.) deep 15.3 m (50 ft.) wide channel (Holton and Walsh 1995) and it is not know if any hard substrate remains in this region. Solid rock was also removed from the Drewry's Island channel in 1878 (Holton and Walsh 1995). Many subsequent alterations have been made to the James River and presently the navigational channel is maintained by dredging a 7.6 m (25 ft.) deep channel. Presently, the U.S. Army Corps of Engineers maintains the following shoals through dredging: Drewry's Bluff and Chaffin Bluff, Kingsland Reach, Power Plant Reach, Dutch Gap cut-off, Jones Neck cut-off, and Turkey Island cut-off (Figure 2).

The available substrate data for the James River downriver of Hopewell describes sediments based on the Shepard classification triangle. This classification describes sediments as varying forms of sand, silt, and clay. Downriver of Hopewell, mud is the primary bottom sediment in the main channel with sand becoming more common near the mouth (Nichols et al. 1992). Mean grain

size is minimal in the central funnel zone and increases along the channel both upriver and downriver (Nichols et al. 1992).

The James River segment between Hopewell and Richmond has not been similarly classified, but sediment grain size has been calculated for the regions of the six shoals (previously mentioned) currently maintained by dredging. At these locations average median grain size of sediments does not exceed 0.6 mm (Holton and Walsh 1995) – much smaller than the size of gravel (> 30 mm) required in Atlantic sturgeon spawning substrate. The Turkey Island cut-off channel suffers the most significant shoaling rate that is an order of magnitude greater than the average of the other five shoals (Holton and Walsh 1995). Since the creation of the cut-off channel at Turkey Island in 1937, the oxbow has accumulated a significant amount of sediment (Holton and Walsh 1995). The cut-off channel has reduced the flow through the oxbow thereby increasing sedimentation. In the absence of substrate sampling in the oxbow, it is assumed that these sediments are primarily sand and silt, however, actual examination may reveal other grain sizes. At the downstream end of the Turkey Island cut-off scouring has occurred since the creation of the cut-off channel and resulted in a hole over 60 feet deep (Holton and Walsh 1995). This region may contain areas of exposed hard substrate and high river flow, two characteristics of suitable spawning sites, but this data has yet to be collected. However, the high flow responsible for the scouring feature may actually be unfavorable if it exceeds the optimal river velocity for suitable spawning habitat. The locations of hard substrate in the tidal freshwater James River were also inferred from reports of sand and gravel resources by the state of Virginia (Wentworth 1930, Onuschak Jr. 1973). Gravel of coarse grades is available chiefly from the major streams near the fall line (Wentworth 1930). Specific locations were provided by Onischak (1973) in a report describing the geology of the Coastal Plain of Virginia where locations of known sand and gravel pits were mapped (Figure 3). In the freshwater tidal James three sites existed in the vicinity of the Turkey Island oxbow and

multiple locations along the Appomattox River. Although this map does not distinguish between sand and gravel pits and the locations are not from the riverbed, presence of gravel in the floodplain may be analogous with substrate of the adjacent river tract. Therefore, river segments adjacent to the gravel pits may contain the desired hard substrate suitable for Atlantic sturgeon spawning habitat.

Available water quality data from the databases for the Chesapeake Bay Program and the Alliance for the Chesapeake Bay was examined to determine if suitable Atlantic sturgeon spawning habitat exist in the James River. Salinity measurements positioned the approximate location of the salt front upriver of site J6 and downriver of J9 as indicated by dashed lines in Figure 4. Two locations are indicated for the salt front since it shifts based on water temperature and time of year. Since sturgeon spawn in freshwater (0-1 ppt), spawning site habitat is upriver of site J9 and values for water temperature, pH, dissolved oxygen, conductivity, and hardness were examined specifically in the river segment between J9 and J28 (Figure 5). Atlantic sturgeon spawn from May to July in water 13 – 26 °C. Stations J9 to J28 all exhibit favorable water temperatures for spawning in May. However, in June average water temperatures at the majority of stations J9 to J28 are above 26 °C and in July all stations demonstrate unfavorable water temperature (> 26 °C) for spawning Atlantic sturgeon. Therefore, based on water temperature, suitable spawning habitat exists in the James River in May and part of June, but not in July. When interpreting the remaining water quality measurements, focus was placed on parameter values for May and June only.

The dissolved oxygen requirement of greater than 4 mg/L was met at all stations J9 to J28. Dissolved oxygen levels were actually greater than 6 mg/L year round at the freshwater sites. Suitable pH for Atlantic sturgeon spawning sites is approximately 7.2 with pH values < 6 and > 8 considered unfavorable. All stations J9 to J28 measured pH values greater than 6; however stations J13, J15, J24, J25, and J26 exhibited pH values greater than 8 and are consequently considered to be

unsuitable spawning sites. A suitable conductivity range for spawning sites is 10 – 110 μ S based on literature values. In the James River, conductivity in the freshwater sites in May and June is 160 – 270 μ S. Conductivity in streams and rivers is affected primarily by the geology of the area through which the water flows. Areas of granite have higher conductivity and areas of clay lower.

Therefore, we consider the other water quality parameters to be more important than conductivity when determining suitable spawning sites since it can vary greatly between regions. Atlantic sturgeon spawn in water with moderate Ca⁺⁺ concentration (6 – 18 mg/L). Available water quality data for the James River measured CaCO₃ concentration, not Ca⁺⁺ concentration, as an indicator of hardness. Therefore we cannot directly compare known values with actual conditions for this parameter. Calcium ions and/or magnesium ions are known to play a critical role in gamete function in white sturgeon (Cherr and Clark 1984) and are therefore required in some concentration in spawning habitats. The freshwater James River stations measure 44 – 80 mg/L CaCO₃ in May and June. This concentration is not considered unfavorable since an exact measurement of hardness necessary for proper gamete function is not known.

Based on their statistical method, Grogan and Boreman (1998) calculated the James River Atlantic sturgeon population to be extirpated; however, there have been several encounters with early juvenile (< 400 mm) Atlantic sturgeon in the James River before and since. Reported catches of Atlantic sturgeon in the James River can help assess the presence of suitable habitat in the system. Forty-six sturgeon ranging 85 mm – 997 mm have been caught in the James River since 1955 by the Virginia Institute of Marine Science Juvenile Fish and Blue Crab Trawl Survey. The VIMS Trawl Survey concentrates its sampling at stations in the lower James River but occasionally sampled at stations in the freshwater tidal portion of the river. In February 1975, the VIMS Trawl Survey reported catching a 200 mm Atlantic sturgeon in the segment of the James River between Dutch Gap and Jones Neck. The upriver location and size of this fish indicate that it is a < age 1

Atlantic sturgeon. Based on movement patterns of Atlantic sturgeon in other systems, we can assume that this fish overwintered close to its natal habitat and has not yet migrated downriver, thus indicating that Atlantic sturgeon spawning occurred in the James River in 1974. In addition, the VIMS Trawl Survey has encountered fourteen Atlantic sturgeon < 400 mm in the Lower James River; the most recent of which was in July of 2005. Based on length, these fish are considered early juveniles that have not yet migrated from their natal river. A major sampling effort occurred in 1997 and 1998, when the U.S. Fish and Wildlife Service assessed the presence of Atlantic sturgeon in the primary western tributaries (James, York, Rappahannock River Systems) of Chesapeake Bay. Rewards were paid to watermen for Atlantic sturgeon captured and held alive during commercial fishing operations. A total of 273 Atlantic sturgeon ranging from 260 – 1390 mm were captured in the lower James River (Spells 1998). The weakness of this program is that it was fishery dependent and no catches were reported from the freshwater portions of the rivers.

In addition to the 1975 Atlantic sturgeon caught by the VIMS Trawl Survey, there have been other reports of early juveniles in the freshwater James River. In 1998 a Virginia Department of Environmental Quality employee observed a dead 300 mm Atlantic sturgeon in the vicinity of Farrar Island (Mark Ailling, Virginia DEQ, msalling@deq.virginia.gov, personal comm.). The discovery of a 150 mm Atlantic sturgeon just downriver of the mouth of Herring Creek in March of 2004 provided further evidence of a spawning population in the James River (Albert Spells, USFWS, albert_spells@fws.gov, personal comm.).

The nursery habitat profile for Atlantic sturgeon describes suitable habitat that is much more variable than the profile for spawning habitat. Juvenile sturgeon are found in a wide range of salinity concentrations, temperatures, depths, and over diverse bottom types. When these parameter values were compared with actual conditions, the entire lower James River exhibited favorable nursery habitat characteristics.

The Appomattox River is a main tributary of the James River and may contain suitable spawning habitat for Atlantic sturgeon as well. Upriver of the city of Petersburg, the river is obstructed by three major dams (Harvell Dam, Abutment Dam, Bransfield Dam) but all contain fish passage devices to facilitate the migration of anadromous species. The efficiencies of the fish passage devices have not been reported for Atlantic sturgeon. The Chesapeake Bay Program maintains only two water quality stations on the Appomattox, one at the mouth and one in the vicinity of Petersburg (Figure 5). Monthly averages of water quality parameters from the more upriver station, A2, do indicate a suitable Atlantic sturgeon spawning habitat. In addition, Onischak (1973) designated multiple locations of sand or gravel pits along the Appomattox River between Petersburg and its mouth (Figure 3). In the spring of 2005 a 213 cm (7 ft.) Atlantic sturgeon was found dead floating in the Appomattox River just upriver of its confluence with the James River (Albert Spells, USFWS, albert_spells@fws.gov, personal comm.). Despite the lack of early juvenile Atlantic sturgeon captures in the Appomattox River, we believe the river should be recognized as a potential location of suitable spawning habitat and should be considered for future research.

York River

The York River is a coastal plain tributary of the Chesapeake Bay. The river is 55 km (34 miles) long and remarkably straight between West Point and Gloucester Point. Upriver of West Point it divides into two major tributaries, the Mattaponi and the Pamunkey Rivers. The entire drainage basin occupies 6900 km² (2664 mi²), the third smallest in the Chesapeake Bay drainage system. Silty clay and high percentages of mud are widely distributed in the channel of the middle and upper York River. The lower estuary channel contains patches of clay/silt and sand extending to the mouth. Laterally, the sand passes channelward into patches of mixed sand-silt-clay (Nichols

et al. 1992). Dredging does occur in the York River, but to a much lesser extent than in the James River. The main dredge cuts are at four pier facilities on the south bank of the lower estuary and shoals downriver from West Point. No freshwater exists in the York River and the salt front is therefore located upriver of West Point in the lower reaches of the Mattaponi and Pamunkey Rivers. The 1997 – 1998 US FWS rewards program reported a total of 9 Atlantic sturgeon ranging from 615 – 1150 mm captured in the York River (Spells 1998). As with the lower James River, we believe the York River expresses suitable nursery habitat characteristics for Atlantic sturgeon.

The Pamunkey River is tidal for 73 km (45 miles) upriver of West Point. Varied textures in the Pamunkey River include patches of clay/silt or clay/sand and patches of sand from local bank erosion (Nichols et al. 1991). Onischak (1973) indicated multiple locations of sand or gravel pits along the Pamunkey River (Figure 3). Salinity measurements from the Chesapeake Bay Program's water quality stations place the salt front upriver of station P1 and downriver of P2 (Figure 4). Stations P2 to P11 all exhibit favorable water temperatures for spawning in May (Figure 6). However, in June average water temperatures at four of the stations are above 26 °C and in July all stations demonstrate unfavorable water temperature (> 26 °C) for spawning Atlantic sturgeon. Therefore, water temperatures favorable for spawning exist in May and part of June. All Pamunkey River stations have dissolved oxygen rates > 4 mg/L and monthly averages for May and June range from 5 – 8 mg/L. Optimal Atlantic sturgeon spawning site pH is slightly alkaline and the pH of the Pamunkey River ranges from 6.5 – 7.2. This range is slightly less than the optimal value of 7.2 but still with the acceptable range of > 6 and < 8. Neither hardness nor conductivity measurements are available for the Pamunkey River. Seven Atlantic sturgeon ranging from 129 – 450 mm have been captured in the Pamunkey River since 1955 by the VIMS Juvenile Fish and Blue Crab Trawl Survey. The smallest of these fish were a 129 mm individual captured in January of 1975 between water quality stations P2 and P3 and a 161 mm individual captured in April of 1997 between

stations P1 and P2. The lengths of these fish strongly suggest that they are early juveniles spawned in the Pamunkey River during the previous year.

Bottom sediments of the Mattaponi River are described as sand, silt, or clay based on the Shepard classification triangle (Hobbs 1994). During the same study, one location (indicated by G, Figure 6) was found to contain 74.5% gravel (grain size > 2 mm) (Hobbs 1994). This observation in conjunction with the locations of multiple sand or gravel pits along the river suggests the possibility of encountering hard substrate in the Mattaponi River (Onischak 1973) (Figure 3). Salinity data from the Chesapeake Bay Program place the salt front between stations M1 and M2 in the Mattaponi River. Water temperatures are favorable for Atlantic sturgeon spawning at all stations in May and all stations in June except for M2. In July, the majority of water quality stations indicated water temperatures that are too high (> 26 °C) for sturgeon spawning. All stations indicate favorable dissolved oxygen conditions in May – July ranging from 4.4 – 8.1 mg/L with the minimum occurring in July at station M2. The pH levels in the Mattaponi river are slightly acidic ranging from 6.3 – 6.8 in May – July at stations M2 – M13. Neither hardness nor conductivity measurements are available for the Mattaponi River. As with the Appomattox River, no Atlantic sturgeon have been reported in the Mattaponi River, however, we believe the river should be recognized as a potential location of suitable habitat and should be considered for future research.

Rappahannock River

The Rappahannock River flows from its origin at Chester Gap in Fauquier County approximately 295 km (184 miles) to Chesapeake Bay. The drainage basin covers an area of 7032 km² (2715 mi²), which accounts for approximately 6.8% of Virginia's total land base. Sixty-three percent of the basin is forested and 35% is covered by cropland and pasture. The tidal freshwater portion of the Rappahannock River stretches from Wilmot to the fall line at Fredericksburg (172 rkm). Embry Dam was built at Fredericksburg in 1910 and was the only blockage to migratory fish on the entire river. In 2004, the dam was breached with explosives and in early 2005 the remaining sections were completely removed. Breaching Embry Dam provided access to 114 km (71 miles) of historical spawning habitat for anadromous fish on the Rappahannock River. Dredging is limited to tributary creeks and shoals in the channel to a depth of 3 m (9.8 ft.), between Tappahannock and Fredericksburg (Nichols et al. 1992).

The available substrate data for the Rappahannock River downriver from Wilmot describes sediments based on the Shepard classification triangle. Mud is abundant in the channel of the lower estuary, but upriver of Wilmot it is replaced by mixtures of sand-silt-clay (Nichols et al. 1991). Laterally, the sand passes channelward into mixtures of sand-silt-clay with oyster reefs or into mud at about 5 m to 7 m depth (Nichols et al. 1992). The Rappahannock River segment between Wilmot and Fredericksburg is not similarly classified and the locations of hard substrate in the tidal freshwater region were inferred from a geological study by the state of Virginia (Onuschak Jr. 1973). This study indicates the location of multiple sand or gravel pits in the freshwater tidal region of the Rappahannock River with a high concentration of sites immediately downriver of Fredericksburg (Onuschak Jr. 1973) (Figure 3). Salinity measurements from the Chesapeake Bay Program's water quality stations place the approximate location of the salt front upriver of R9 and

downriver of R12 as indicated by dashed lines in Figure 4. Stations R10 – R26 all exhibit favorable water temperatures ($< 26\text{ }^{\circ}\text{C}$) for Atlantic sturgeon spawning in May (Figure 7). In June all station R10 – R26 display temperatures $< 26\text{ }^{\circ}\text{C}$ except for R18, however, in July the average water temperature at the majority of the stations is $> 26\text{ }^{\circ}\text{C}$ and all are $> 25\text{ }^{\circ}\text{C}$. Therefore, favorable water temperatures for spawning exist in May and June. All Rappahannock River stations upriver of R4 have dissolved oxygen rates $> 4\text{ mg/L}$ and monthly averages for May and June range from 6.6 – 10.5 mg/L at the freshwater stations. Optimal Atlantic sturgeon spawning site pH is slightly alkaline and the pH of the Rappahannock River ranges from 6.4 – 8 with the majority of stations ranging between 7.0 and 7.5. Conductivity measured at the freshwater stations in May and June ranged from 85 – 274 μS . Only one Atlantic sturgeon has been captured in the Rappahannock River by the VIMS Juvenile Fish and Blue Crab Trawl Survey. This fish measured 590 mm and was captured in August of 1968 between stations R8 and R9. Even though no Atlantic sturgeon have been recorded in the Rappahannock River by the Trawl survey in recent years, we believe the river should be recognized as a potential location of suitable spawning and nursery habitat and should be considered for future research.

Chesapeake Bay

The Chesapeake Bay is the largest estuary on the U.S. east coast and one of the largest in the world. It drains a watershed of 71,250 km² (27,510 mi²) in the Susquehanna basin and covers a surface area of 6,500 km² (2,510 mi²) without the tributaries. The Bay is 290 km (180 miles) long and has a width of 4 km (2.5 miles) to 48 km (29.8 miles). The Bay's configuration is highly dendritic and indented with numerous tributaries and creeks that lead headward to streams. The upper Bay is marked by an abundance of mud while the lower Bay near the mouth contains mostly sand (Nichols et al. 1991).

The entire Chesapeake Bay historically served as nursery habitat for Atlantic sturgeon spawned in its tributaries and portions of it still should be considered despite relatively low abundance (Field et al. 1998). The primary factor reducing the amount of available nursery habitat in Chesapeake Bay is the presence of hypoxic regions which are most widespread during periods of high summertime temperatures and low rainfall conditions. Niklitschek (2001) generated bioenergetic models to predict the amount of suitable summer habitat for juvenile Atlantic sturgeon during the decade 1990 – 1999 in Chesapeake Bay. The predicted amount ranged between 1 and 4,200 km² with extremely dry years resulting in almost no suitable habitat for juvenile Atlantic sturgeon. The total area supporting suitable habitat under average July conditions is 1,586 km² representing 8.5% of the total surface area of the mainstem and tidal sections of Chesapeake Bay tributaries. In addition to portions of the Bay we also consider the lower James, York, and Rappahannock Rivers to contain suitable nursery habitat for Atlantic sturgeon.

Additional Considerations and Conclusions

Artificial spawning reefs

Artificial spawning reefs are used to enhance the amount and quality of spawning habitat in systems with limited natural reproduction. They have been successfully implemented and utilized by several sturgeon species in the Volga River, Russia and by the lake sturgeon (*Acipenser fluvescens*) in Wisconsin. In the Volga River, artificial spawning sites consist of a bed of stones 10 – 12 m wide and 1 km long constructed of medium size gravel (5 – 10 cm) with a 5 – 10% admixture of coarse chippings (Khoroshko and Vlasenko 1970). The spawning substrate was deposited along the slope of the bank to simulate a bank ridge that duplicates the natural bend of the

river. The thickness of the layer of spawning substrate is related to the underlying bottom material and may vary in the range 20 – 30 cm (Khoroshko and Vlasenko 1970). The artificial spawning reef was placed in an area of the river that exhibited favorable physical and chemical parameters. Lake Winnebago, Wisconsin contains one of the largest sport fisheries for lake sturgeon in the world. To improve and conserve the fishery Wisconsin Department of Natural Resources biologists placed rock riprap (7 – 10 cm) on the outside of bends of tributary rivers below areas of natural rapids (Folz and Meyers 1985, Lee Meyers, Wisconsin DNR, lee.meyers@dnr.state.wi.us, personal comm.). These artificial spawning reefs have increased the amount of spawning habitat for lake sturgeon and are partly responsible for the present high rate of recruitment into the harvestable stock of Lake Winnebago (Folz and Meyers 1985). Atlantic sturgeon in Virginia may also benefit from the implementation of artificial spawning reefs if they are placed in a region that represents suitable spawning habitat characteristics as outlined in our spawning habitat profile.

Stocking

Suitable spawning and nursery habitat for Atlantic sturgeon exists in Virginia and therefore, stocking may be appropriate to supplement natural reproduction. Stocking of Atlantic sturgeon has been employed as a management technique in other systems. Informed management of Atlantic sturgeon demands a detailed knowledge of its population structure, genetic diversity, and likelihood to home to natal rivers (Wirgin et al. 2002). The Atlantic States Marine Fisheries Commission has outlined a breeding and stocking protocol for cultured Atlantic sturgeon (ASMFC 1996). The Commission recommends obtaining brood fish from the same river where stocking will occur in order to preserve stock structure. These recommendations are based on genetic research that has shown pronounced stock structure and low gene flow rates in Atlantic sturgeon (Waldman et al. 2002). Specifically, studies have revealed a significant cline in haplotype diversity among Atlantic

sturgeon populations and suggests that most river populations may support genetically distinct stocks (King et al. 2001, Waldman et al. 2002, Wirgin et al. 2002). In addition, research indicates the probable existence of a unique stock in the James River and lower Chesapeake Bay (Waldman et al. 2002). Tagging studies of lake sturgeon have shown strong homing fidelity; a behavior which is also interpreted as evidence of highly structured populations (Folz and Meyers 1985, Lyons and Kempinger 1992). Therefore, if stocking of Atlantic sturgeon is to be considered in Virginia, much attention should be placed on the importance of obtaining brood stock from the State's waters to supplement the Hudson River brood stock presently available. In addition, practices should be employed that facilitate sufficient imprinting of stocked fish to their natal rivers.

Recommendations of spawning locations

Atlantic sturgeon spawning does occur in Virginia as evidenced by the presence of early juvenile sturgeon (< 400 mm). The number and exact location of the spawning grounds remain unknown. Based on the substrate and water quality analyses included in this study we believe directed investigations may uncover the location of spawning habitat. We feel the following areas represent the parameters established in the spawning habitat profile and should be the focus of future investigations: In the James River, the Turkey Island oxbow and the Jones Neck oxbow are considered potential spawning habitat due to their hydrodynamic characteristics. Directed water quality and bottom type investigations should be conducted in these areas. The Appomattox River also presents favorable spawning habitat parameters and should be the focus of additional studies. In the York River system, the Mattaponi and Pamunkey Rivers may also contain areas suitable for Atlantic sturgeon spawning. The presence of multiple gravel pits and favorable water chemistry in the Rappahannock River suggests conditions suitable for Atlantic sturgeon spawning in this system as well. Since bottom type is the most important characteristic of suitable spawning habitat for

Atlantic sturgeon, substrate mapping of the freshwater tidal portions, specifically of the aforementioned locations, is the most imperative research need.

Tables

Table 1. Spawning habitat profile based on research and published information

Parameter	Value	Source
Time of Year	May to July	Leland 1968, Dovel and Berggren 1983, Bain et al. 2000
River Location	Between the salt front and the fall line Downstream of major bends or tributaries Narrow river stretches Discrete section of river 1000-5000 m ³ One side of river usually outside bend	Huff 1975, Bain et al. 2000, Secor et al. 2000, Sulak et al. 2000
Substrate	Rubble, cobble, gravel-size rocks, free of sediment	Ryder 1890, Borodin 1925, Dees 1961, Vladykov and Greeley 1963, Leland 1968, Huff 1975, Smith 1985, Van Eenennaam et al. 1996, Smith and Clugston 1997, Colligan et al. 1998, Hatin et al. 2002
	Exposed or very thinly sedimented hard bottom that is abundantly covered with gravel and cobble particles (range 30.5-236 mm)	Sulak et al. 2000
Salinity	Freshwater: 0-1 ppt	Van Eenennaam et al. 1996, Bemis and Kynard 1997, Bain et al. 2000, Sulak et al. 2000
Temperature	13.2 – 26 °C	Hildebrand and Schroeder 1928, Borodin 1925, Vladykov and Greeley 1963, Huff 1975, Smith et al. 1980, Smith 1985, Bain et al. 2000, Sulak et al. 2000, Caron et al. 2002, Hatin et al. 2002

Table 1. continued

Parameter	Value	Source
Dissolved Oxygen	Non hypoxic, > 4 mg/L	Smith et al. 1980, Sulak personal comm.
pH	7.2, slightly alkaline	Smith et al. 1980, Sulak et al. 2000, Sulak personal comm.
Depth	11 – 27 m Pools considerable deeper than the rest of the river	Borodin 1925, Leland 1968, Scott and Crossman 1973, Bain et al. 2000
Velocity	46 – 76 cm/s Eddies or current breaks; Stable high current velocities during spring high water conditions	Crance 1987 – model Sulak et al. 2000
Hardness	Moderate Ca ⁺⁺ ion concentration 6-18 mg/L Ca ⁺⁺	Sulak et al. 2000 Sulak and Clugston 1999
Conductivity	10-110 μ S	Sulak and Clugston 1999, Fox et al. 2000

Table 2. Nursery habitat profile based on research and published information

Parameter	Value	Source
Amount of time used	1 – 6 years up to 122 cm	Murawski and Pancheco 1977, Smith 1985 Secor et al. 2000, Sulak et al. 2000
River Location	Brackish waters close to mouth of the estuary during colder months and move upstream during warmer months	Ryder 1890, Dees 1961, Lazzari et al. 1986, Bain et al. 2000, Secor et al. 2000
Substrate	Sand, rocks, cobble, mud, shale	Smith et al. 1982, Kynard et al. 2000, Sulak et al. 2000, Savoy and Pacileo 2003
Salinity	Remain in freshwater for first few months Tidal freshwater in summer Brackish estuaries in winter	Bath et al. 1981, Smith et al. 1982, Dovel and Berggren 1983, Kieffer and Kynard 1993, Moser and Ross 1995, Sulak et al. 2000
Temperature	13.2 – 28 °C Deeper cooler areas in summer	Dovel and Berggren 1983, Kieffer and Kynard 1993, Bain et al. 2000
Dissolved Oxygen	Non hypoxic, > 4 mg/L	Secor and Gunderson 1998, Secor and Niklitschek 2001
Depth	Congregate in deep holes > 7m	Dovel and Berggren 1983, Savoy and Pacileo 2003

Figures

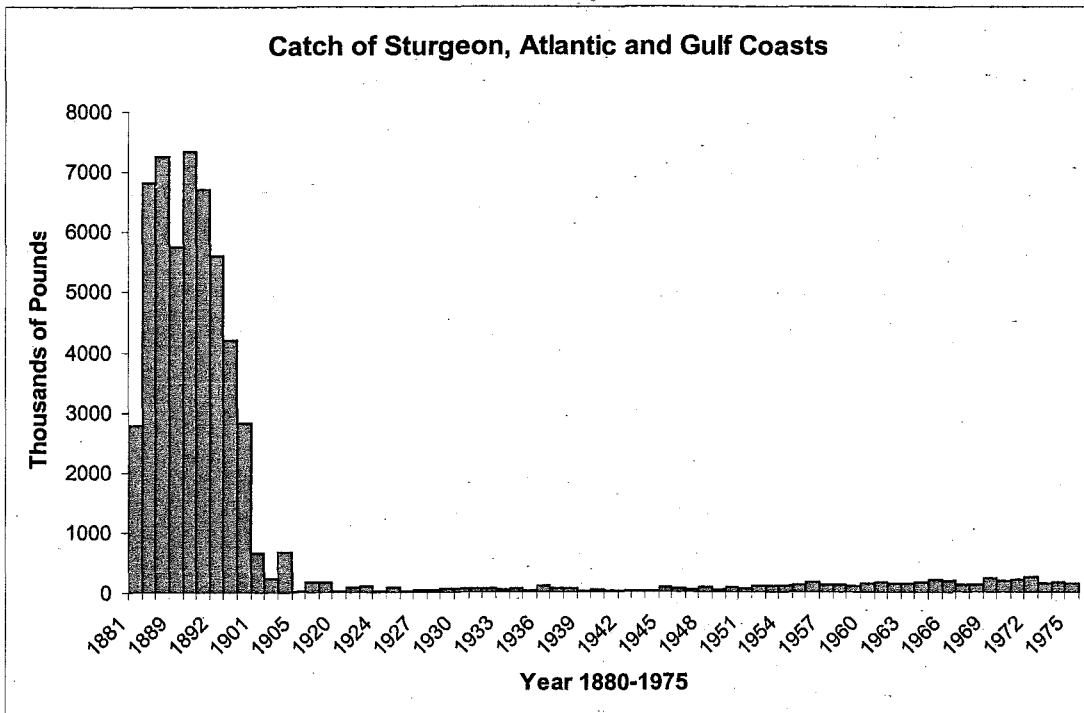


Figure 1. Sturgeon landings from Atlantic and Gulf coast states in thousands of pounds. Data from Murawski and Pancheco (1977).

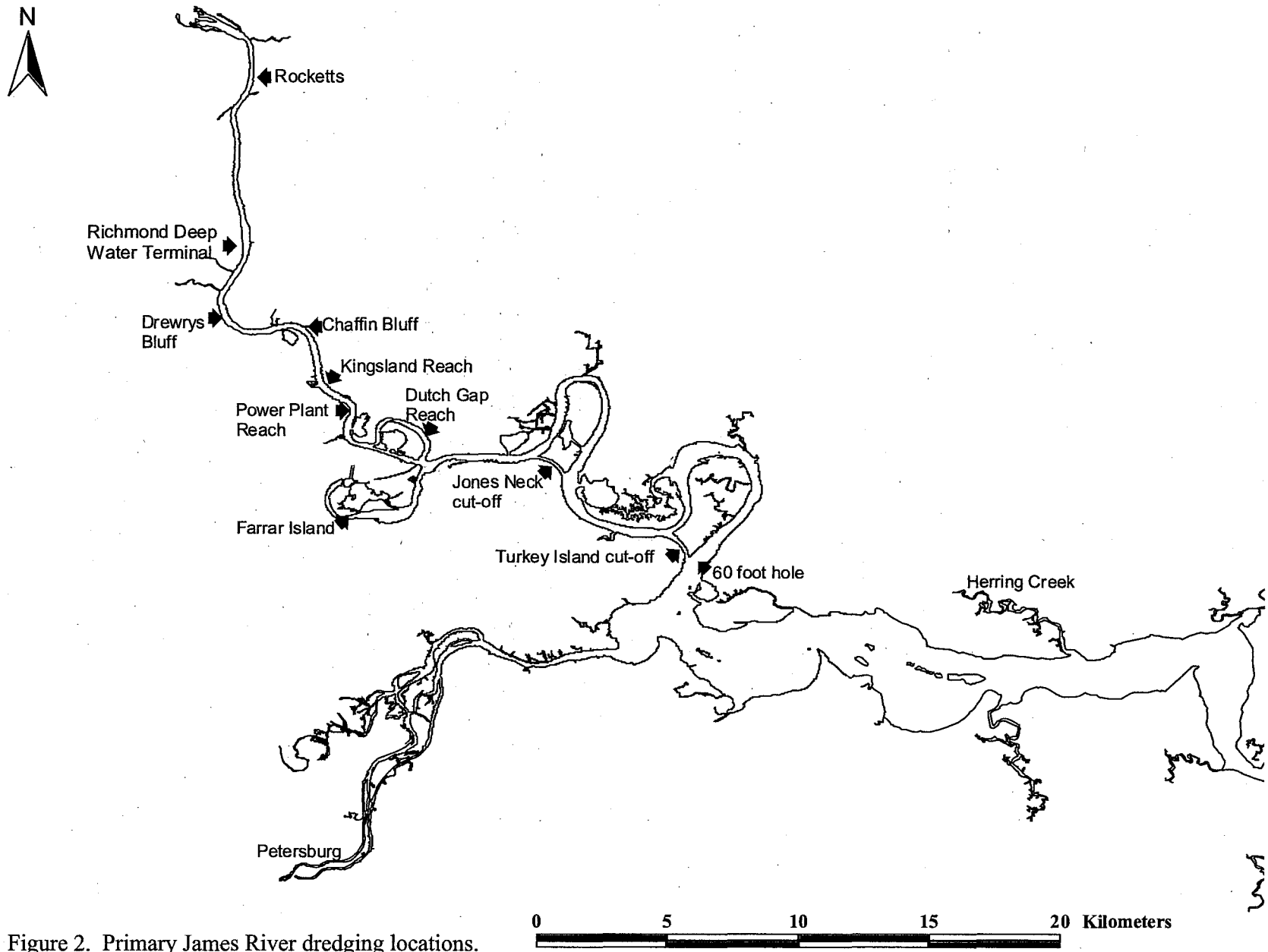


Figure 2. Primary James River dredging locations.

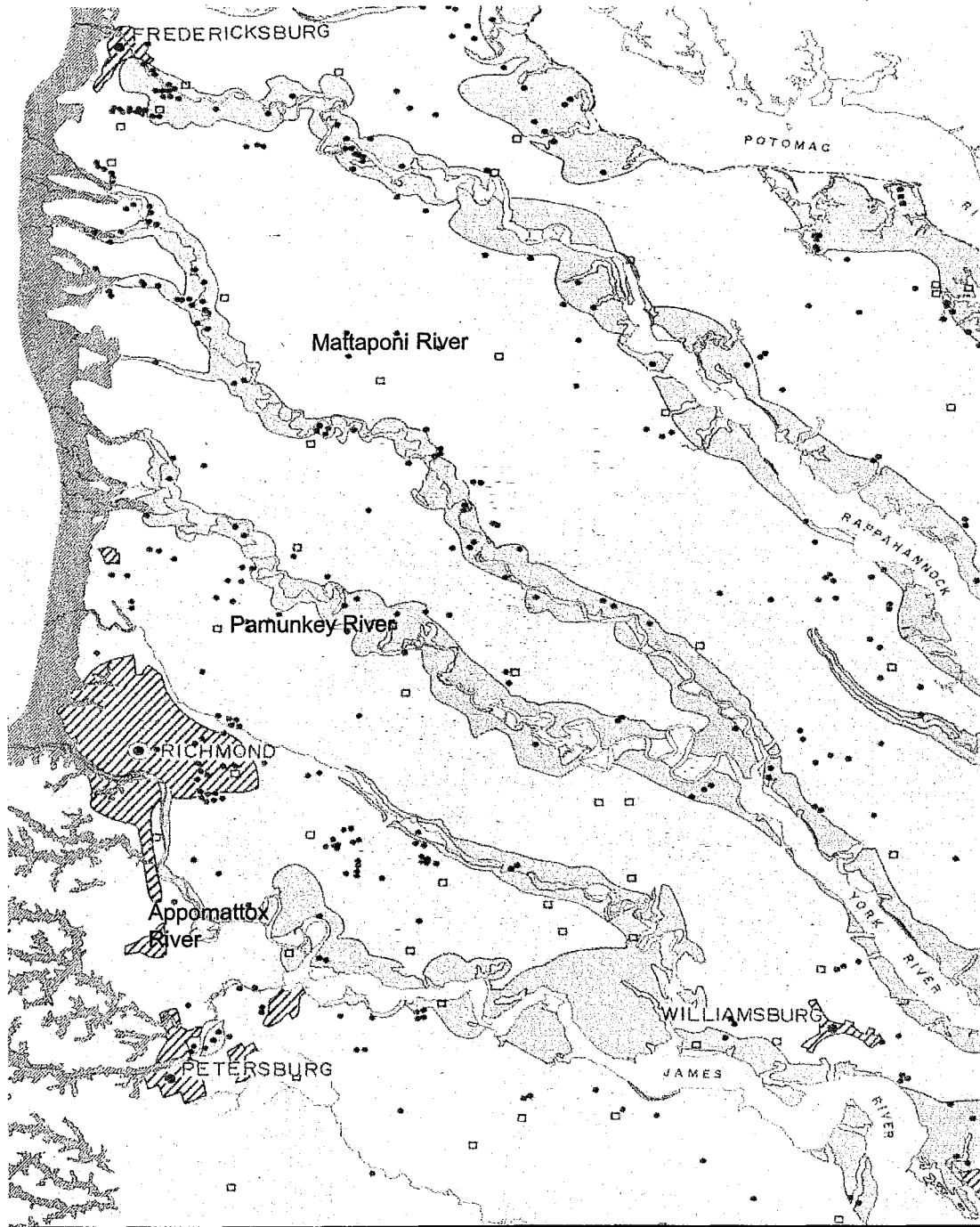


Figure 3. Locations of active or abandoned sand and gravel pits indicated by ● (Onuschak 1973).

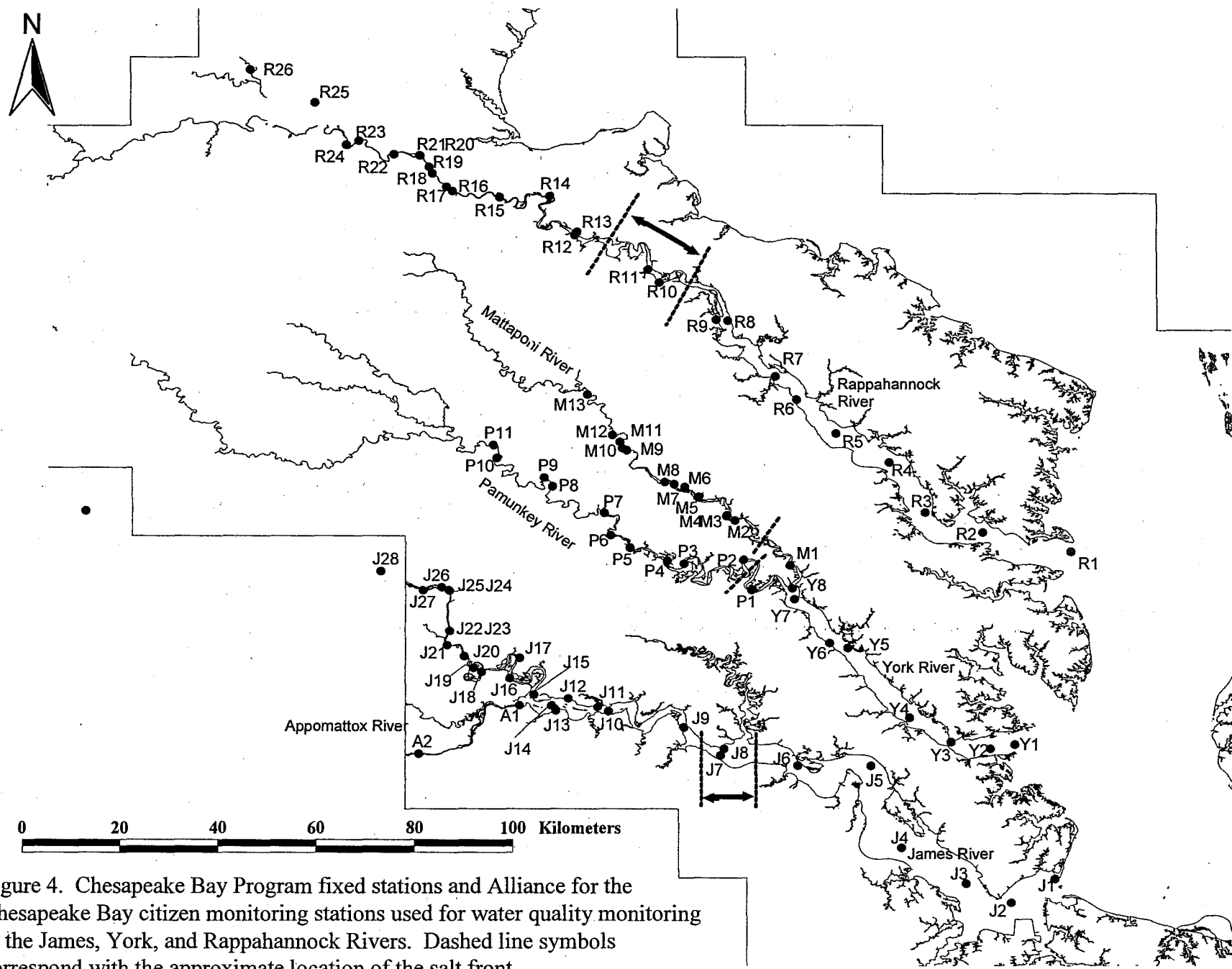


Figure 4. Chesapeake Bay Program fixed stations and Alliance for the Chesapeake Bay citizen monitoring stations used for water quality monitoring in the James, York, and Rappahannock Rivers. Dashed line symbols correspond with the approximate location of the salt front.

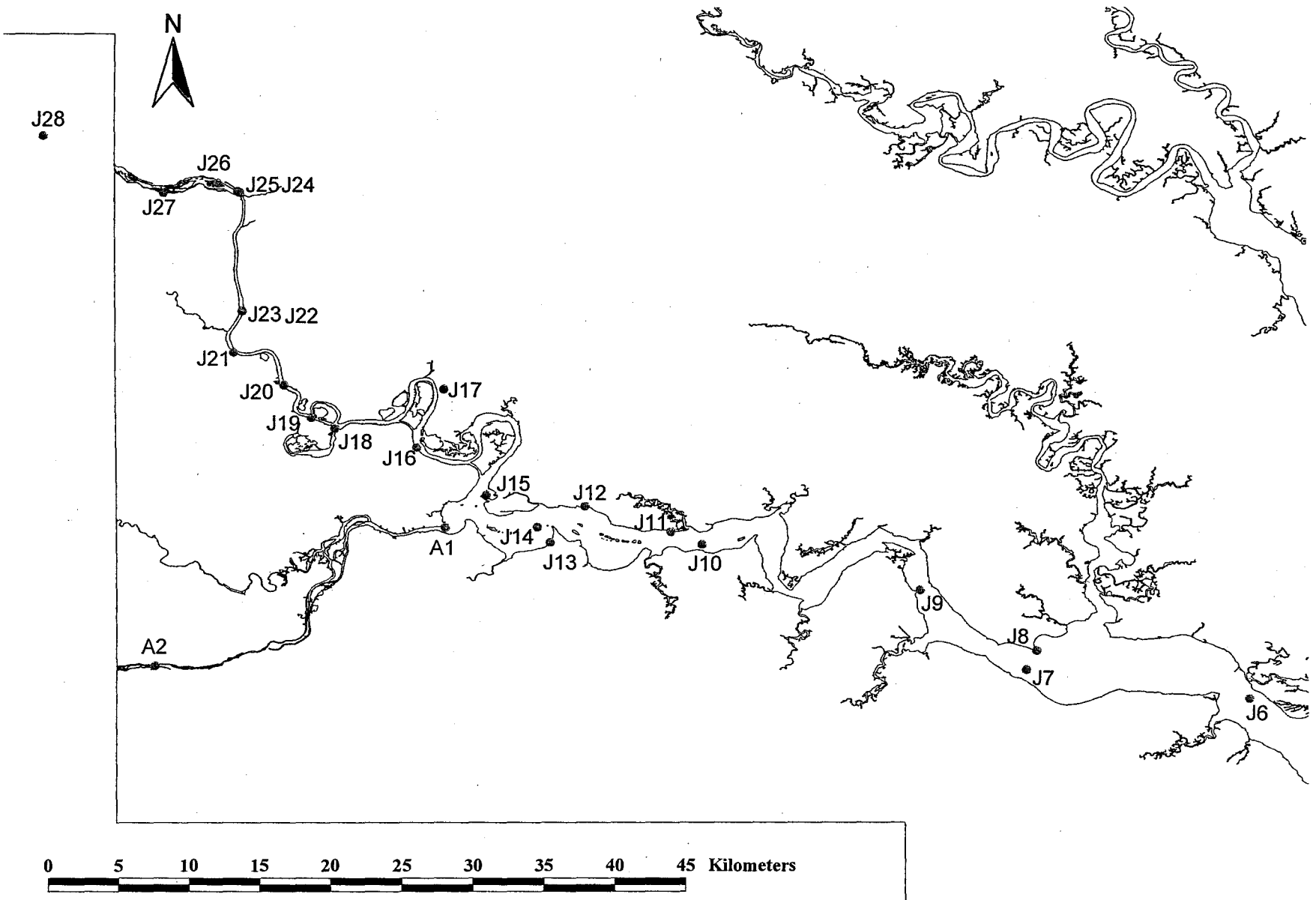


Figure 5. Chesapeake Bay Program fixed stations and Alliance for the Chesapeake Bay citizen monitoring stations used for water quality monitoring in the James River.

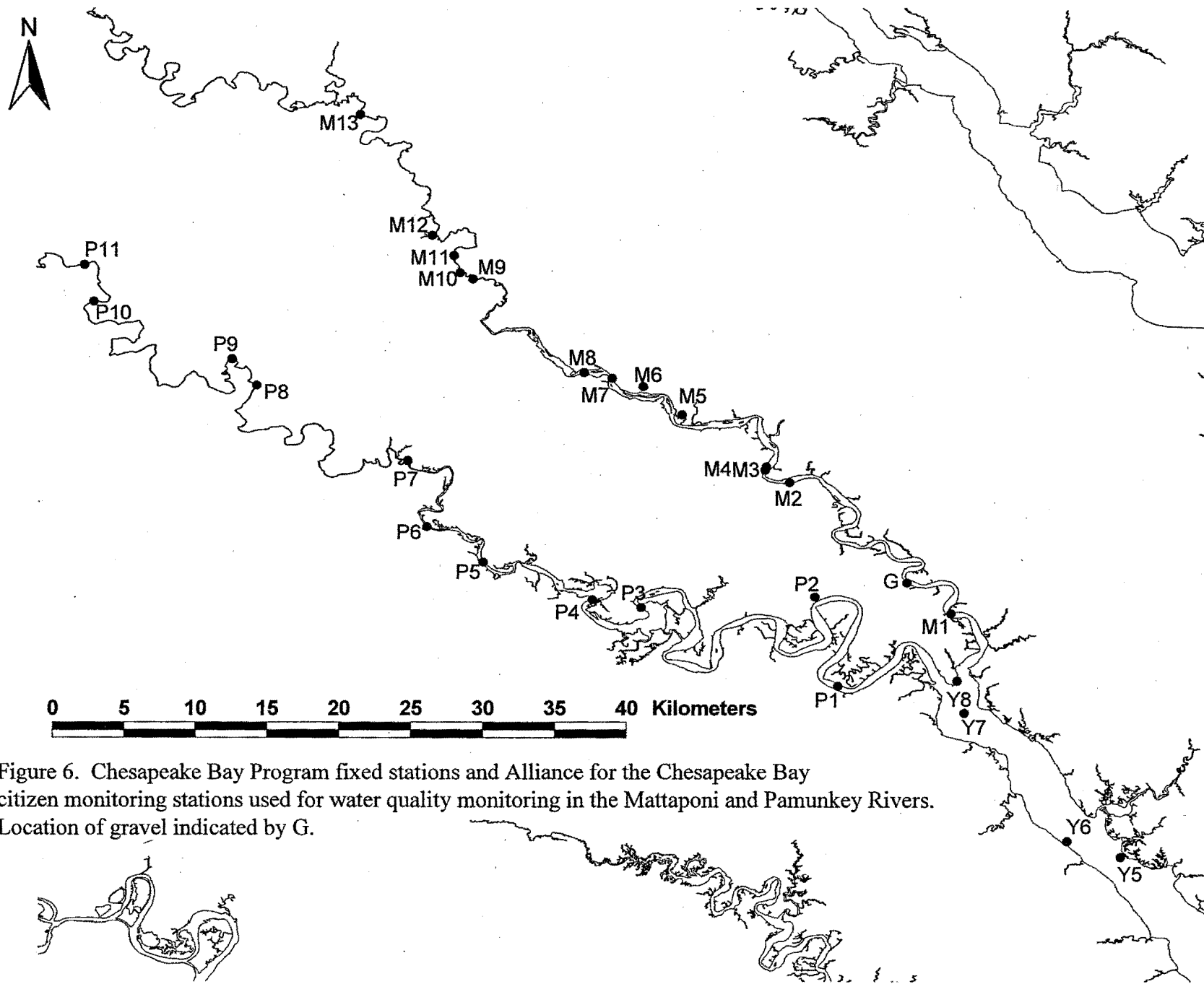


Figure 6. Chesapeake Bay Program fixed stations and Alliance for the Chesapeake Bay citizen monitoring stations used for water quality monitoring in the Mattaponi and Pamunkey Rivers. Location of gravel indicated by G.

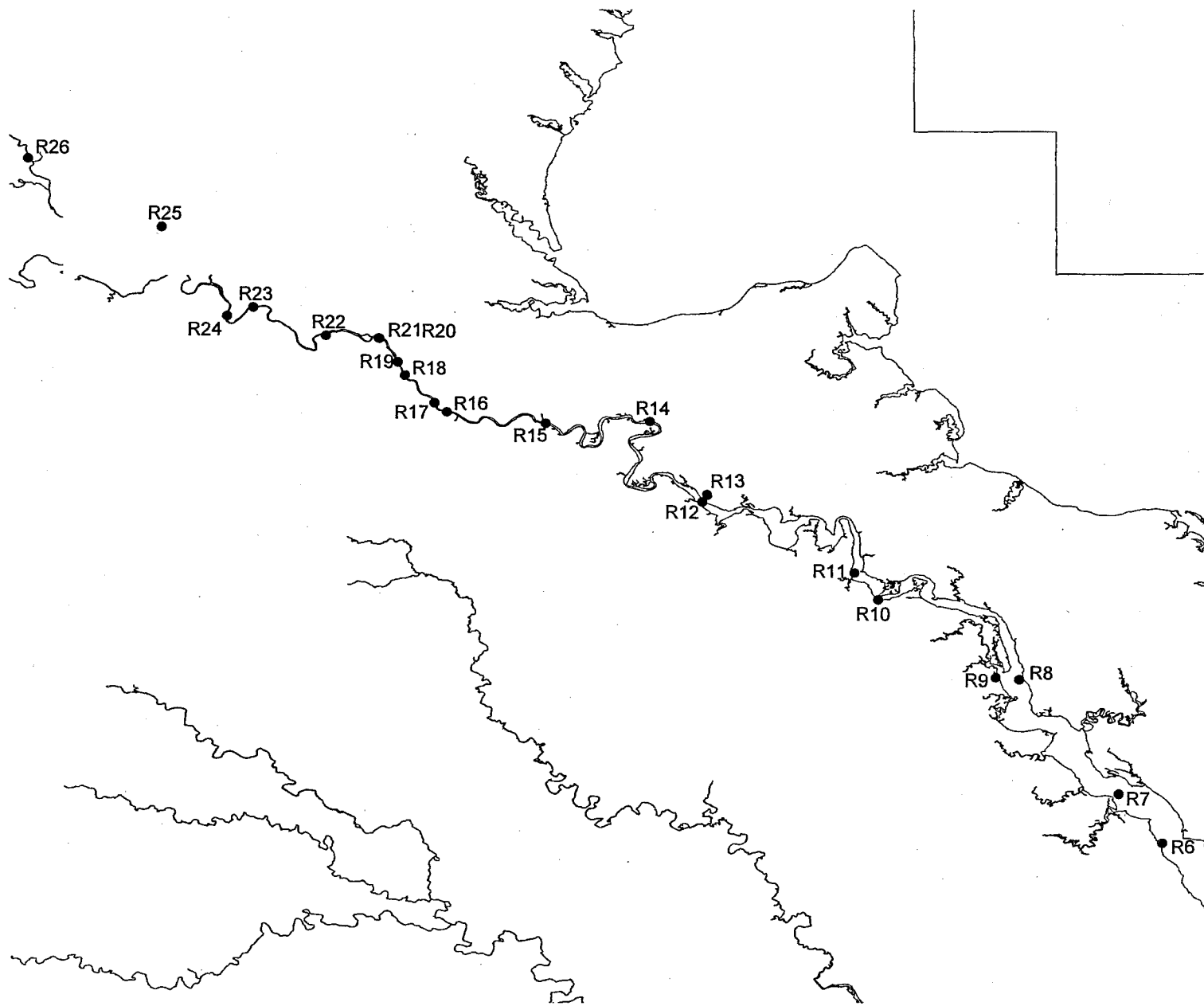


Figure 7. Chesapeake Bay Program fixed stations and Alliance for the Chesapeake Bay citizen monitoring stations used for water quality monitoring in the Rappahannock River.

0 5 10 15 20 25 30 35 40 Kilometers

Tables

Table 1. Spawning habitat profile based on research and published information

Parameter	Value	Source
Time of Year	May to July	Leland 1968, Dovel and Berggren 1983, Bain et al. 2000
River Location	Between the salt front and the fall line Downstream of major bends or tributaries Narrow river stretches Discrete section of river 1000-5000 m ³ One side of river usually outside bend	Huff 1975, Bain et al. 2000, Secor et al. 2000, Sulak et al. 2000
Substrate	Rubble, cobble, gravel size rocks, free of sediment	Ryder 1890, Borodin 1925, Dees 1961, Vladykov and Greeley 1963, Leland 1968, Huff 1975, Smith 1985, Van Eenennaam et al. 1996, Smith and Clugston 1997, Colligan et al. 1998, Hatin et al. 2002
	Exposed or very thinly sedimented hard bottom that is abundantly covered with gravel and cobble particles (range 30.5-236 mm)	Sulak et al. 2000
Salinity	Freshwater: 0-1 ppt	Van Eenennaam et al. 1996, Bemis and Kynard 1997, Bain et al. 2000, Sulak et al. 2000
Temperature	13.2 – 26 °C	Hildebrand and Schroeder 1928, Borodin 1925, Vladykov and Greeley 1963, Huff 1975, Smith et al. 1980, Smith 1985, Bain et al. 2000, Sulak et al. 2000, Caron et al. 2002, Hatin et al. 2002

Table 1. continued

Parameter	Value	Source
Dissolved Oxygen	Non hypoxic, > 4 mg/L	Smith et al. 1980, Sulak personal comm.
pH	7.2, slightly alkaline	Smith et al. 1980, Sulak et al. 2000, Sulak personal comm.
Depth	11 – 27 m Pools considerable deeper than the rest of the river	Borodin 1925, Leland 1968, Scott and Crossman 1973, Bain et al. 2000
Velocity	46 – 76 cm/s Eddies or current breaks; Stable high current velocities during spring high water conditions	Crance 1987 – model Sulak et al. 2000
Hardness	Moderate Ca ⁺⁺ ion concentration 6-18 mg/L Ca ⁺⁺	Sulak et al. 2000 Sulak and Clugston 1999
Conductivity	10-110 µS	Sulak and Clugston 1999, Fox et al. 2000

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