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BASED ON PHYSICAL HABITAT AND LANDSCAPE VARIABLES**

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Prepared by: CARL HERSHNER

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**Identification of Potential American Shad (*Alosa sapidissima*) Spawning and
Nursery Habitats in the Mattaponi and Pamunkey Rivers Based on Physical
Habitat and Landscape Variables**

**Donna Marie Bilkovic
Carl Hershner**

**Virginia Institute of Marine Science
College of William and Mary
Gloucester Point, VA 23062**

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EXECUTIVE SUMMARY

The delineation of potentially important spawning and nursery habitat for the American shad (*Alosa sapidissima*) may aid in the restoration of this species in Chesapeake Bay rivers. This project initiated ichthyoplankton surveys of two rivers in the Chesapeake watershed where shad populations are historically low, but the highest found in Virginia. Comparisons of water quality, proximate and landscape features with the presence of shad eggs and larvae at various points in the Mattaponi and Pamunkey were completed. Important preliminary results include obvious differences in abundances of eggs and larvae between the two rivers, and an apparent relationship between current velocity and egg or larval densities.

In pursuit of this project, a Habitat Suitability Index (HSI) model was developed using proximate river parameters based on an extensive literature review. Ranges of parameter values were placed in three rating categories: optimum suitability index (SI = '3'), suboptimum (SI = '2'), inhabitable (SI = '1'). Likewise, a second level of the HSI model including landscape scale parameters was developed based on the literature. Both microscale and macroscale parameters have been sampled in the study area to enable application of the two HSI models. Preliminary statistical analysis of relationships between (1) station location or sample date and counts, (2) abundance, or presence or absence of eggs and larvae were completed. Initial scatter plots depicting relationships between physical and biological parameters were generated.

Two observations resulted from the second year sampling. First, it appears that we have successfully covered the reaches in which larvae are found, but spawning activity apparently extends even further upstream. Second, the yearly variation in flow during spawning periods suggests that the relevant habitat (that actually experienced by any given life stage) can vary significantly from one year class to the next within the same system. Perhaps this should have been an intuitive hypothesis, but the extremes of flow observed in the single season sampling caused us to re-examine discharge records and conclude that a geospatial/time series analysis of habitat would be required.

In the next year we propose to undertake several lines of research which will create the data necessary to examine relationships between reproductive success and position within these two rivers.

1. We will move the spawning season sampling even further upriver.
2. We will extend our current work characterizing river reaches to include more detailed descriptions of channel morphology and adjacent landuse/land cover.
3. The examination of discharge records and fisheries records will be extended to generate an analysis of all available information on these two systems.

ABSTRACT

The delineation of potentially important spawning and nursery habitat for the American shad (*Alosa sapidissima*) may aid in the restoration of this species in Chesapeake Bay rivers in several ways. It may help focus management effort to particular reaches of rivers, thus targeting areas for impediment removal, water quality improvement and habitat protection. Our project initiated ichthyoplankton surveys of two rivers in the Chesapeake watershed where shad populations are historically low, but the highest found in Virginia. Comparisons of water quality, proximate and landscape features with the presence of shad eggs and larvae at various points in the Mattaponi and Pamunkey were completed. Important preliminary results include obvious differences in abundances of eggs and larvae between the two rivers, and an apparent relationship between current velocity and egg or larval densities. Water quality parameters (DO, pH, temperature and secchi depth) were within similar ranges for both rivers which cannot account for the distinction between populations. Notable differences between the river basins are discharge, river morphology and/or varying fishing pressures which have the potential to influence early life stages of shad.

PURPOSE

Moratoriums have been the temporary solution applied to remedy the severe declines in American Shad (*A. sapidissima*) populations in Virginia and Maryland. Several causes have been postulated to explain declines, such as overfishing, blockage of spawning runs, water quality degradation and habitat destruction (Klauda *et al.*, 1991). Shad restoration projects are underway to restock the depleted spawning runs, especially in regions where stream impediments have been removed. In Virginia, shad restoration is taking place on the James, Pamunkey and Mattaponi. Although low, the strongest populations occur in the Pamunkey and Mattaponi and restoration efforts include stocking the James and restocking the Pamunkey with hatchery-reared larvae from the Pamunkey.

While the moratorium continues and efforts to restore the fishery in numerous Chesapeake Bay rivers takes place, it is imperative to garner information regarding habitat quality and quantity within these rivers for shad spawning and nursery areas. Management efforts may then be focused on particular reaches of rivers, thus targeting areas for impediment removal, water quality improvement and habitat protection.

Since water quality, physical elements, and surrounding landscape are integral components of shad habitat, all of these areas should be considered when attempting to understand American shad population influences. This study attempted to address several research needs including: 1) the development of a HSI model utilizing GIS used to discriminate optimal from suboptimal spawning and nursery areas for American shad in the Pamunkey and Mattaponi Rivers based on proximate habitat variables, as well as landscape features, 2) a description of where shad spawn in the Mattaponi and Pamunkey Rivers over a spatial-temporal scale (miles, weeks) was completed, and 3) the characterization of correlations between examined parameters and

densities of each of the 3 life stages of American shad (egg, pro- and post-larvae).

Previous HSI models developed for the riverine life stages of American shad have incorporated microscale measurements of physical habitat parameters, such as temperature, salinity and water velocity, and population assessments. As stated above, the proposed model would include similar physical parameters, and as an expansion of previous models a second model will attempt to incorporate landscape features in a macroscale watershed approach.

HSI models can be valuable management tools to enhance the understanding of species-habitat relationships, aid in impact assessment and habitat management decisions. HSI models, originally developed in the 1970s and 80s, are defined as "the numerical index that represents the capacity of a given habitat to support a selected fish or wildlife species" (USFWS 1981). A limitation of the above models is the narrowness of site applicability. Recent attempts to address the limited application of habitat models have involved basin-wide analysis which incorporates landscape patterns, as well as physical stream parameters (Richards and Host 1994; Osbourne and Wiley 1988). Lanka *et al.* (1987) noted that geomorphic variables could be used to predict trout standing stock as accurately as stream habitat variables indicating a link between geomorphic features and stream habitat quality. Although watershed and landscape scale influences on streams had been previously noted (Schlosser 1991; Forman and Godron 1986; Platts and Nelson 1988), methods for spatial assessment of landscapes, as well as digital spatial information have only recently been made accessible (Richards and Host 1994). With increased capabilities of spatial analysis tools and increasing knowledge of linkages between land use practices and stream habitat conditions, the interchangeable use of landscape variables for stream habitat parameters as predictors of habitat quality may be realized. Once links can be made between basin-level features and proximate habitat conditions in the stream, the subsequent effect on biological populations may be accessed (Rabeni 1992).

The majority of habitat studies that incorporate a landscape perspective tend to focus on small watersheds and are applied to Pacific coast areas and species. Declining salmon and trout populations that are in such high demand have facilitated numerous habitat studies (Platts and Nelson 1988; Nelson *et al.* 1992; Lanka *et al.* 1987; Hubert and Kozel 1993). There are limitations in comparisons between those systems and large rivers along the Atlantic coastal plain. However, many of these studies can be used as templates for work done on a larger scale, and should be discussed. Richards and Host (1994) examined 2nd and 3rd order streams for land use influences on stream habitats and macro invertebrates. Utilizing GIS they were able to ascertain relationships between agricultural and urban land use and substrate characteristics. The substrate characteristics and the presence of coarse woody debris were linked with macroinvertebrate assemblage richness and composition. Such correlations lend support to the possibility of watershed level approach to stream management. The authors postulate the ability to use such "watershed-scale variables as predictors of stream habitat quality".

APPROACH

Field Sampling 1998:

Ichthyoplankton sampling consisted of two parts: pushnet surveys and stationary net collections. The first protocol was utilized in the upper reaches of the Mattaponi and Pamunkey from 31 March through 20 May 1998. The sampling on each river consisted of weekly pushnet tows for a 5-7 minute duration at approximately 1 meter below the surface at each station. Tow duration was modified to meet a lower limit of 50m³ of water filtered through both nets, and with only a few exceptions this limit was met. A pushnet frame was fitted to the bow of a 14-foot jon boat (Mallard) and accommodated two plankton nets of equal mesh and diameter (333 μ m, 60cm). Eight stations per river were systematically sampled, beginning at M51 (Mattaponi 51 River mile) and P53 (Pamunkey 59 River Mile). The stations were spaced at two river miles intervals. In addition to the plankton tows, basic water quality and physical measurements were taken, such as water depth, dissolved oxygen, water temperature, pH, secchi depth and current velocity. Dissolved oxygen and water temperature was measured at 1-meter intervals. For the scatter plots, the DO and water temperature at the estimated sampling depth were used. pH and current velocity were measured once at approximately surface to 1-meter depths.

The second protocol involved community volunteers associated with the Mattaponi and Pamunkey Rivers Association. The volunteers set up stationary nets in shallow, nearshore habitats at designated locations near their residence. The volunteers were all located along the Mattaponi River from M42 to M62. The nets (20cm diameter, 202 μ m mesh) were fished for a 24-hour period once a week, the cod-end was retrieved, and the sample preserved. Sampling began 4 April and ended 31 May 1998.

Ichthyoplankton samples were then sorted and larval fish and eggs were enumerated and removed from the original sample. Eggs were preserved in formalin, and larvae were placed in 70% ethanol. *A. sapidissima* specimens were distinguished from other clupeids by size and myomere counts.

For the push-net survey data, general statistical comparisons of three categories were completed with a 2-way ANOVA without replication using QUATTRO-PRO software: 1) egg and larval counts, 2) density and 3) presence or absence. Density was calculated by dividing egg and larval counts by the volume of water (m⁻³) filtered through the nets during sampling tows. Presence was defined as any value greater than zero found in the egg and larval counts and was denoted with a "1"; absence was any zero value and was denoted with a "0". Volunteer survey data were compared as egg and larval counts and presence or absence. Density was not used, since the volume of water filtered during the 24-hour sampling period could not be estimated accurately. Scatter plots were generated (SIGMAPLOT) to illustrate the relationships between physical habitat parameters and egg and larval densities.

Landscape and habitat analysis

A Habitat Suitability Index (HSI) model was developed using proximate river parameters based on an extensive literature review. Ranges of parameter values were placed in three rating categories: optimum suitability index (SI = '3'), suboptimum (SI = '2'), inhabitable (SI = '1'). Likewise, a second level of the HSI model including landscape scale parameters was developed based on the literature.

Data have been gathered from various sources for use in the Geographic Information System (GIS) analysis. Habitat variables, such as, dissolved oxygen, water temperature, pH and secchi depth were measured during the preliminary season and data, measured for several years in the rivers, were acquired from the Alliance for the Chesapeake Bay. Landscape features, such as land-use utilizing MRLC data from EPA Region III Land Cover Data set, 1996 (using data from 1991, 1992 and 1993), were placed in the databases of the coastal comprehensive inventory located at Virginia Institute of Marine Science (VIMS), and coverages and maps for the areas of study were completed. Shoreline attributes of the downstream portions of the two rivers were also coded in the field using a hand-held GeoExplorer Geographic Positioning System (GPS) unit with a data dictionary created to include the following shoreline features: Upland developed, upland forested, upland scrub, tidal freshwater wetland, oligohaline wetland, tidal swamp, and eroding banks. Maps were created, using ARC/INFO software, depicting 1997 and 1998 station locations, shoreline features and land use for both rivers.

Tidal excursion was estimated to determine the horizontal distance of the river likely to be influenced by a given parcel of water during the ebb portion of a tidal cycle. Using average tidal amplitudes acquired from a VIMS-NOAA cooperative tide station obtained from the Physical Science department at VIMS, the average tidal excursion for an ebb cycle was estimated for both rivers. These values were used to determine distances between stations, as well as to determine the extent to which water quality values were applicable to a given portion of each river.

Project Management:

During the field season portion of the work, Donna Marie Bilkovic coordinated scheduling and logistics and was present during the sampling. The boat operators included: Harry Berquist, Carl Hershner, John Olney, and Marcia Berman. Additional field help was recruited throughout the season. Billy and Sally Mills and the Mattaponi and Pamunkey River Association aided in the acquisition of volunteers for the second sampling protocol. The volunteers are as follows: Skip Beattie, Melinda Coleman, Valerie Crawford, Carl Custalow, Charles and Oma Rawls, Sybil Rose, Robert Stephens, and Ruth Williams. Laboratory and GIS work were completed by Donna Marie Bilkovic.

FINDINGS:

Table 1. depicts total catches characterized by cruise and river basin. Total egg and larval shad counts in the Mattaponi (93) exceeded counts in the Pamunkey (30) by two-thirds. Cruises Shad 11 and 16 were auxiliary and examined lower reaches of each river.

Mattaponi River

Ichthyoplankton Collection Results:

Eggs

Further examination of the Mattaponi cruises (excluding the auxiliary cruise) indicates that in only one station were shad eggs absent (M51, the lowermost). There was no statistical significant difference (alpha 5%) among stations for counts (2-way ANOVA, $p = 0.1798$), abundance of eggs (2-way ANOVA, $p = 0.167692$), or presence/absence (p/a) (2-way ANOVA, $p = 0.302495$). Significant differences were observed among cruises based on comparisons of egg counts, abundance, and p/a with sampling dates (2-way ANOVA, $p = 0.000057$, $p = 0.000029$, $p = 0.000008$, respectively) (Tables 1 and 3).

Larvae

Larval shad were absent in the uppermost stations (M61, 63 and 65) and present in the highest numbers at the lowermost station, M51. Comparisons between total larval counts (pro- and post-larval combined), abundance, p/a and station location showed significant difference (2-way ANOVA, $p = 0.006892$, $p = 0.001961$, $p = 0.001961$, respectively). Comparisons among cruises indicated no difference for larval counts, abundance, or p/a (2-way ANOVA, $p = 0.417967$, $p = 0.428852$, $p = .428852$, respectively) (Tables 1 and 3). The larval stages were further examined separately. There was no significant difference among cruises or stations for the prolarval stage in all three categories: counts, abundance or p/a. The postlarval stage, however, showed significant differences for comparisons of counts, density, p/a and stations ($p = 0.001815$, $p = 0.01174$, $p = 0.000346$, respectively). Comparisons of cruises and counts and density of postlarvae showed no significant differences ($p = 0.463981$, $p = 0.492444$), and significance for the p/a comparison ($p = 0.22594$) (Tables 1 and 3). General abundance for each river and life stage are depicted in Graphs 1 through 6. Graph 1 describes the total shad eggs collected in the Mattaponi throughout the field sampling, excluding the auxiliary cruise. Graphs 2 and 3 present pro- and post-larval abundances, respectively, delineated by date and station.

The auxiliary research cruise (Shad 16) took place on 20 May 1998 and the following trends were noted: eggs were absent in all stations except the uppermost (M55) station; larvae were present at M47, 49, 51 and M53 and absent at M41, 43, 45 and M55. There was one large larva/juvenile present at the lowermost station (M39) (Table 1).

Volunteer collections indicated a presence of shad eggs at or near river miles 44, 52, 61, 62 and 63. Eggs were absent at river mile 41, 42 and 55. Shad larvae were only present in 3 samples at river mile 42, 62 and 63 (Table 2, Graph 7 and 8). This may be attributable to the sampling method (stationary nets). During the last four weeks of sampling, it appeared as if egg collection

decreased in comparison to the first four weeks. Statistical comparisons (2-way ANOVA) among volunteer sites and sampling dates indicate no significant differences in shad egg, larval counts, or p/a of larvae. Comparisons of sites and p/a data for shad eggs, however, revealed a significant difference ($p = 0.0240$) (Table 4.), with no significant difference in station comparisons ($p = 0.2833$)

Water Quality

The relationship between shad egg and larval density and several physical parameters, including water temperature, station depth, dissolved oxygen (DO), pH, secchi depth, and current velocity were illustrated on scatter plots for each river.

Mattaponi (Graphs 9 through 14)

The density-versus-station depth scatter plot (Graph 9) depicts depths ranging from approximately 1 to 6.5 meters. There appears to be equal scatter among the life stages throughout the depths. Although the highest postlarval densities were observed at stations with depths exceeding 4.5 meters.

The density-versus-water temperature plot (Graph 10) illustrates a measured temperature range of 12 to 22° C. The highest shad egg and larval densities were predominately observed in the 15° to 16° C range, and the larval stages were dispersed throughout the 15 to 20.5° C range. Zero densities are evident in the lower temperatures of 12-14.5° C and the highest temperatures of 21-22° C.

The range of measured dissolved oxygen throughout the water column (Graph 11) was 8.0 to 12.7 mg/L. The egg stage was found in waters within the range of 10.8 to 12.5 mg/L. Shad larval stages were present throughout the measured DO range. The highest larval densities were located at approximately 10.5 mg/L.

The pH of the surface waters of each station was within a range of 5.8 to 8.7, with the majority of the measurements within a range of 6.5 to 7.5. Likewise, the presence of shad eggs and larvae chiefly occurred in this range with no apparent pattern.

The range of measured secchi depth (Graph 13) was 0.7 to 1.3 meters. When present, shad eggs and larvae appear throughout the entire range with no apparent pattern.

The current velocity observed at the stations exhibited the broad range of 0.05 to 3.5 ft/s (Graph 14). Egg stages were found at locations within the range of current velocities of 1.5 to 3.0 ft/s and were absent in the ranges of 0.05 to 1.4 and 3.1 to 3.5 ft/s. This observation relates to location on the river; upstream sites had higher current velocities, such as the ones where eggs were observed, than downstream sites where eggs were absent. In contrast, pro- and post-larval stages were observed in the ranges of 0.05 to 1.8 and 0.05 to 1.0 ft/s, respectively. This pattern may illustrate the apparent downstream transport of the egg and larval stages throughout development.

Pamunkey River

Ichthyoplankton Collection Results:

More specific examination of the Pamunkey river collections indicates differing trends from those observed in the Mattaponi. As previously stated, there were evident differences in total collection of shad eggs and larvae between the two river basins. Shad eggs were collected at every station for a total of 26, and relatively higher numbers of eggs were found in the uppermost stations (P69 and P71) (Table 1, Graph 4). A total of 4 larvae were collected from the Pamunkey stations (P59, P65 and P67), excluding the auxiliary cruise data (Table 1, Graph 5, 6).

Eggs

Comparisons among stations and egg counts indicated significant differences (2-way ANOVA, $p = 0.0478$). However, comparisons of density and p/a ($p = 0.386494$, $p = 0.209883$, respectively) were not significantly different among stations. Additional comparisons of cruises and counts, density and p/a were also not significant ($p = 0.4205$, $p = 0.32862$, $p = 0.438097$, respectively) (Table 3).

Larvae

All comparisons involving total larvae, as well as individual life stages were indistinguishable. Low larval numbers may have compromised the statistical analysis for the prolarvae and total larvae categories. Since, no postlarvae were collected throughout the sampling season on the Pamunkey, this category became obsolete for statistical examination.

The auxiliary research cruise (Shad 11) took place on 1 May 1998. Stations P49, 51, 53, 55 and 57 were sampled. Two larvae were collected on this date, one from P49 and one from P51. There were no eggs collected during this sampling session (Table 1).

Shad egg and larva specimens collected from the Pamunkey were in low abundance throughout the field season. This observation may be explained by any or combinations of the following: 1) a larger volume of water to filter at comparable stations to the Mattaponi may have diluted specimens, 2) the locations sampled may have not been the primary spawning or nursery areas, or 3) the population is less abundant than the Mattaponi population.

Water Quality

As with the Mattaponi, the relationship between shad egg and larval density and several physical parameters, were illustrated on scatter plots.

Pamunkey (Graphs 15 through 20)

Water depth for the stations on the Pamunkey were within the range of 0.9 to 7.0 meters (Graph 15). The egg and larval stages, when present, were dispersed throughout this range with no apparent pattern.

Water temperature exhibited a measured range of 13° to 19°C (Graph 16). Shad eggs, when present, were within the range of 13.1° to 19°C, the four prolarvae were observed within the range of 14.4° to 16.9° C. Conversely, in the Mattaponi, eggs and larvae were absent in the

cooler temperatures (12.1° to 14.5° C).

The measured DO range was 8.6 to 11.5 mg/L (Graph 17). Shad eggs, when present, were observed predominantly within a range of 10.0 to 11.1 mg/L, which was similar to trends in the Mattaponi data. The observed prolarvae were located within 9.4 and 10.6. mg/L.

When present, shad eggs and larvae were located within the entire measured range for pH (6.6 to 7.7), with no apparent trend (Graph 18). This was similar to the observations from the Mattaponi samples.

The measured secchi depth range was 0.5 to 1.3 meters (Graph 19), similar to the Mattaponi measurements. Likewise, shad eggs and larvae collected were present throughout all observed secchi depths, with no apparent pattern.

Current velocity ranged from 0 to 4.0 ft/s in the Pamunkey (Graph 20). Shad eggs and larvae, when present, were within the range of 0 to 3.2, and 0 to 1.2 ft/s, respectively. There is an apparent similar trend as the Mattaponi samples. Shad eggs were located at higher current velocities than larvae.

EVALUATION:

Several of the project goals have already been attained.

- 1) A habitat suitability model was developed for the egg and larval stages of American shad. This model includes proximate habitat parameters of the river basin, as well as landscape and shoreline attributes of the surrounding watershed.
- 2) Ichthyoplankton surveys of the Mattaponi and Pamunkey were completed, in conjunction with stationary net sampling along the Mattaponi.
- 3) Microscale habitat parameters were assessed for each station sampled during the push-net surveys.
- 4) Maps illustrating land use data for the river basins were created.
- 5) Shoreline attributes for the downstream portions of the river basins were collected and coded according to type of coverage.
- 6) Preliminary statistical analysis of relationships between (a) station location or sample date and counts, and (b) abundance or presence/absence of eggs and larvae were completed.
- 7) Initial scatter plots depicting relationships between physical and biological parameters were generated.

ADDITIONAL WORK:

In designing and pursuit of this project, we hypothesized that differences in the productivity of the

shad stocks between the Pamunkey and Mattaponi rivers, might be linked to some observable difference in the habitat suitability of the two systems. We believed that describing the relevant habitat would require locating the various life stages within each system, and we designed the sampling program with that objective in mind (constrained by logistics and available resources). The presence of shad larvae and juveniles within certain reaches of each system has been documented by various fisheries surveys over the years. We confirmed these observations in the first year of sampling, and extended the range of observations upstream slightly. From this work, we concluded that spawning was occurring upstream, potentially significantly upstream, from the first year's sampling locations. Since we are hypothesizing that description of the reaches occupied by eggs and larvae are critical to definition of habitat suitability, refining our understanding of spawning location and areas transited by eggs/larvae demanded sampling further upstream. We modified sampling protocols to accommodate the different environment, and undertook extensive sampling of upstream reaches in the second year of the project.

Two observations resulted from the second year sampling. First, it appears that we have successfully covered the reaches in which larvae are found, but spawning activity apparently extends even further upstream. Second, the yearly variation in flow during spawning periods suggests that the relevant habitat (that actually experienced by any given life stage) can vary significantly from one year class to the next within the same system. Perhaps this should have been an intuitive hypothesis, but the extremes of flow observed in the single season sampling caused us to re-examine discharge records and conclude that a geospatial/time series analysis of habitat would be required. To accomplish this we have begun characterizing the geomorphology and land-use/land-cover characteristics of both rivers from the fall line to the oligohaline reaches near West Point. We are also analyzing discharge records for the past 40 years, and attempting to develop a simple hydrodynamic prediction of reach residence time for parcels of water under varying flow regimes.

We may be able to use river discharge, in combination with knowledge about the maturation rate of shad eggs and larvae and an assumption about spawning location, to predict the potential habitat for early life stages. If we are able to satisfactorily characterize the various tidal freshwater reaches of both rivers and document differences within and between rivers, then we may hypothesize relationships between habitat suitability and year class success which might be examined using the fisheries independent juvenile surveys.

To date we know there are some differences between the rivers in terms of structure, flow regimes, and fisheries production. These are all preliminary findings, but sufficient to encourage us to pursue the investigation in much greater detail. In the next year we propose to undertake several lines of research which will create the data necessary to examine relationships between reproductive success and position within these two rivers.

In particular, we will undertake the following efforts.

1. We will move the spawning season sampling even further upriver. We will attempt to document the extent of the spawning area along each river by sampling as far upstream toward the

fall line as resources and logistics will allow. This effort may involve deploying fixed plankton nets in order to increase sampling times at multiple sites. This approach was tested using volunteers along the Mattaponi River in 1998. In addition to sampling along the main channel, a number of the small tributaries to the main rivers will be examined for evidence that they are used as spawning habitat. This is a subject of some speculation, based on anecdotal and undocumented reports. The information is important in the development of the conceptual model for shad use of the system, since it may affect the relationship between actual spawning location and discharge (off stream spawning may be less responsive to channel flow conditions).

2. We will extend our current work characterizing river reaches to include more detailed descriptions of channel morphology and adjacent landuse/land cover. We are currently engaged in a detailed shoreline survey of both rivers with field crews in small boats using GPS. This work will be completed and combined with remotely sensed information including both satellite imagery and recently acquired aerial photography. In addition, we have tested application of a side scan sonar unit as a means of characterizing benthic habitat. The initial effort was promising, and development of the appropriate analytical protocols is currently underway. Assuming this succeeds we will attempt to survey as much of each river as the equipment requirements will permit.

3. The examination of discharge records and fisheries records will be extended to generate an analysis of all available information on these two systems. The discharge records are in good order, but the similarities and differences between the two rivers must be characterized over the period of record. The fisheries data is limited. The juvenile survey records are readily accessible. The fisheries landings data are somewhat problematic and complicated by the presence of native American fisheries on both rivers which are exempt from regulation (and reporting). We will work to construct as useful a data set as possible, given these constraints. Both rivers have been the subject of hydrodynamic modeling over the past several years. These models are being used to estimate residence times under different flow regimes.

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MATTAPONI

Stations	Shad1		Shad3				Shad6				Shad7				Shad9				Shad12				Shad14				Total counts		Density (m-3)				
	eggs		larvae		eggs		larvae		eggs		larvae		eggs		larvae		eggs		larvae		eggs		larvae		Totals egg	Totals larvae	egg	larvae					
	cts	d	cts	d	cts	d	cts	d	cts	d	cts	d	cts	d	cts	d	cts	d	cts	d	cts	d											
M51	n/a	n/a	n/a	0	0.00	0	0.00	0	0.00	4	0.04	0	0.00	2	0.01	0	0.00	11	0.10	0	0.00	2	0.02	0	0.00	10	0.06	29	0	29	0.00	0.23	
M53	n/a	n/a	n/a	0	0.00	0	0.00	1	0.01	1	0.01	0	0.00	1	0.01	5	0.03	0	0.00	0	0.00	2	0.01	2	0.02	1	0.01	13	8	5	0.05	0.04	
M55	0	0.00	0	0.00	0	0.00	0	0.00	2	0.01	0	0.00	0	0.00	3	0.02	0	0.00	1	0.01	0	0.00	3	0.02	2	0.01	0	0.00	11	4	7	0.03	0.06
M57	n/a	n/a	n/a	0	0.00	0	0.00	3	0.02	1	0.01	0	0.00	0	0.00	4	0.05	0	0.00	0	0.00	6	0.04	2	0.01	0	0.00	16	9	7	0.08	0.04	
M59	n/a	n/a	n/a	0	0.00	0	0.00	4	0.02	0	0.00	0	0.00	1	0.01	3	0.02	0	0.00	0	0.00	0	0.00	2	0.01	0	0.00	10	9	1	0.06	0.01	
M61	n/a	n/a	n/a	0	0.00	0	0.00	1	0.01	0	0.00	1	0.00	0	0.00	3	0.02	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	5	5	0	0.03	0.00	
M63	0	0.00	0	0.00	0	0.00	0	0.00	1	0.01	0	0.00	0	0.00	0	0.00	4	0.04	0	0.00	2	0.01	0	0.00	0	0.00	7	7	0	0.05	0.00		
M65	0	0.00	0	0.00	0	0.00	0	0.00	1	0.01	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	1	0.01	0	0.00	0	0.00	2	2	0	0.02	0.00		
Totals	0	0	0	0	0	0	0	13	0.08	6	0.05	1	0.00	7	0.05	19	0.16	12	0.11	3	0.02	13	0.09	8	0.06	11	0.07	93	44	49	0.32	0.38	

PAMUNKEY

Stations	Shad2		Shad4				Shad5				Shad8				Shad10				Shad13				Shad 15				Totals counts		Density (m-3)						
	eggs		larvae		eggs		larvae		eggs		larvae		eggs		larvae		eggs		larvae		eggs		larvae		Totals egg	Totals larvae	egg	larvae							
	cts	d	cts	d	cts	d	cts	d	cts	d	cts	d	cts	d	cts	d	cts	d	cts	d	cts	d													
P59	1	0.02	0	0.00	0	0.00	0	0.00	0	0.00	1	0.01	0	0.00	1	0.01	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	3	1	2	0.02	0.02
P61	1	0.01	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	1	1	0	0.01	0.00
P63	0	0.00	0	0.00	0	0.00	0	0.00	2	0.02	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	2	2	0	0.02	0.00		
P65	0	0.00	0	0.00	0	0.00	0	0.00	1	0.01	0	0.00	0	0.00	0	0.00	0	0.00	1	0.01	0	0.00	0	0.00	1	0.01	0	0.00	3	2	1	0.02	0.01		
P67	0	0.00	0	0.00	1	0.01	0	0.00	1	0.01	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	1	0.03	0	0.00	0	0.00	3	2	1	0.03	0.03		
P68	0	0.00	0	0.00	0	0.00	0	0.00	2	0.04	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	2	2	0	0.04	0.00		
P69	2	0.02	0	0.00	2	0.02	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	1	0.01	0	0.00	5	5	0	0.05	0.00		
P71	0	0.00	0	0.00	2	0.02	0	0.00	0	0.00	0	0.00	2	0.01	0	0.00	1	0.01	0	0.00	1	0.01	0	0.00	5	0.03	0	0.00	11	11	0	0.09	0.00		
Totals	4	0.05	0	0	5	0.05	0	0	6	0.09	1	0.01	2	0.01	1	0.01	1	0.01	1	0.01	1	0.01	1	0.03	7	0.05	0	0.00	30	26	4	0.27	0.06		

Stations	Shad11		Shad16						
	eggs		larvae		eggs		larvae		
	cts	d(m-3)	cts	d(m-3)	cts	d(m-3)	cts	d(m-3)	
P49	0	0.00	1	0.01	M39	0	0.00	1	0.01
P51	0	0.00	1	0.00	M41	0	0.00	0	0.00
P53	0	0.00	0	0.00	M43	0	0.00	0	0.00
P55	0	0.00	0	0.00	M45	0	0.00	0	0.00
P57	0	0.00	0	0.00	M47	0	0.00	4	0.02
Totals	0	0	2	0.01	M49	0	0.00	19	0.07
					M51	0	0.00	5	0.02
					M53	0	0.00	14	0.07
					M55	2	0.01	0	0.00
					Totals	2	0.01	43	0.189

Table 1. Enumeration of American Shad Eggs and Larvae for the Mattaponi and Pamunkey Rivers. Counts (cts) and density (d) in m-3 of eggs and larvae are noted for each river.

Name	Rivermile Location	Week1		Week2		Week3		Week4		Week5		Week6		Week7		Week8		Totals:		
		April 4-12		April 13-19		April 20-26		April 27-May 3		May 4-10		May 11-17		May 18-24		May 25-31		Eggs	Larvae	
Beattie	42	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	n/a	n/a	0	0
Custalow	44	2	0	0	0	0	0	0	0	n/a	n/a	n/a	n/a	n/a	n/a	0	0	2	0	
Coleman	46	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	
Crawford	52	8	0	4	0	0	0	0	0	1	0	0	0	13	0	0	0	26	0	
Rose	55	n/a	n/a	0	0	0	0	n/a	0	0	0	0	0	0	0	0	0	0	0	
Rawls	61	0	0	15	0	1	0	n/a	n/a	n/a	n/a	0	0	0	0	0	0	16	0	
Williams	61	4	0	2	2	1	0	25	0	1	0	0	0	n/a	n/a	0	0	33	2	
Stephens	62	0	0	0	2	1	1	0	0	0	0	0	0	0	0	0	0	1	3	
Totals		14	1	21	4	3	1	25	0	2	0	0	0	13	0	0	0	78	6	

Table 2. Volunteer Shad egg and larvae collection counts from April 4 through May 31, 1998 on the Mattaponi River (n/a = larval collections were not available for counts)

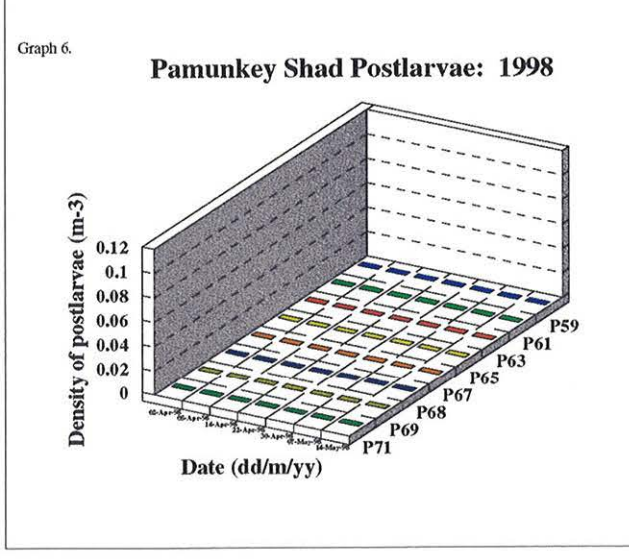
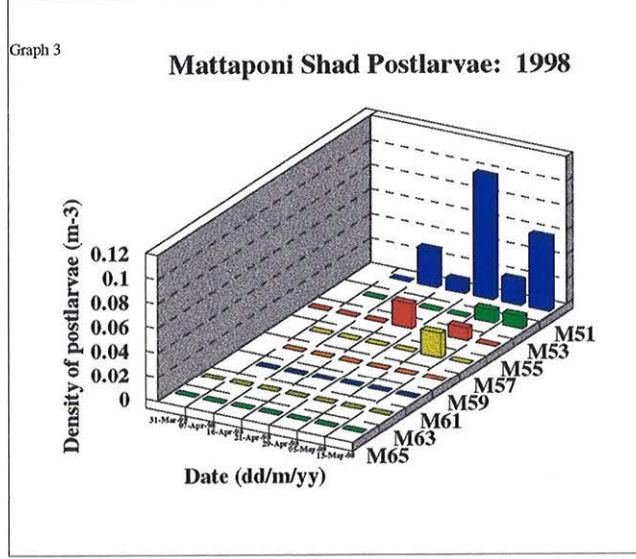
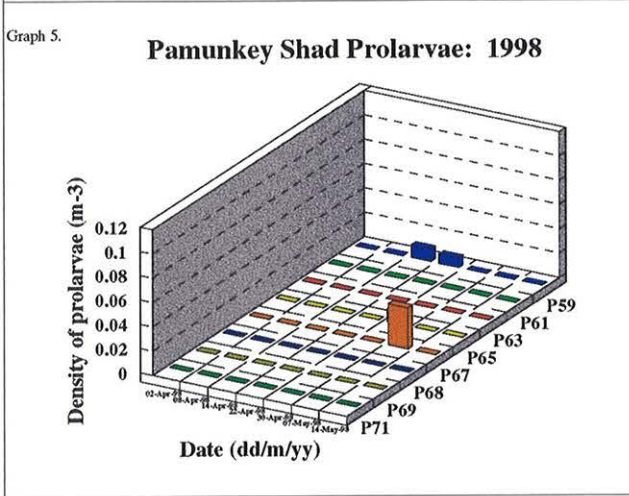
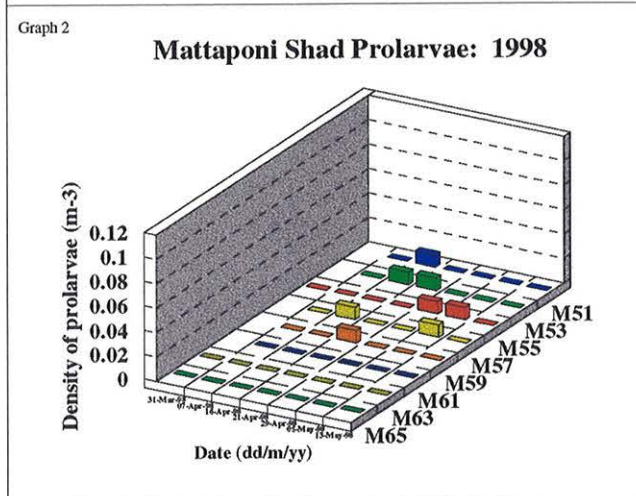
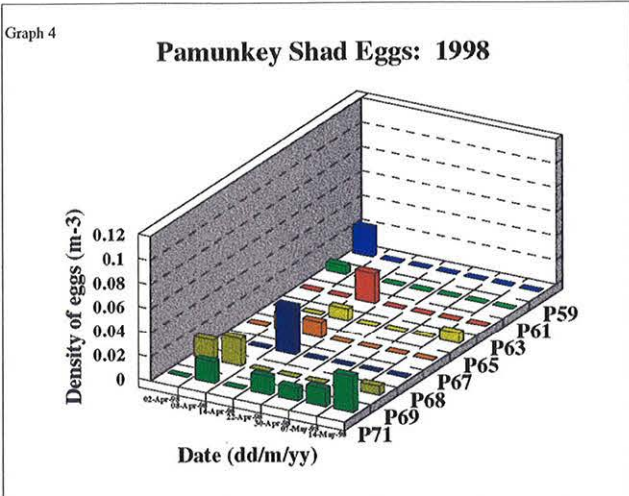
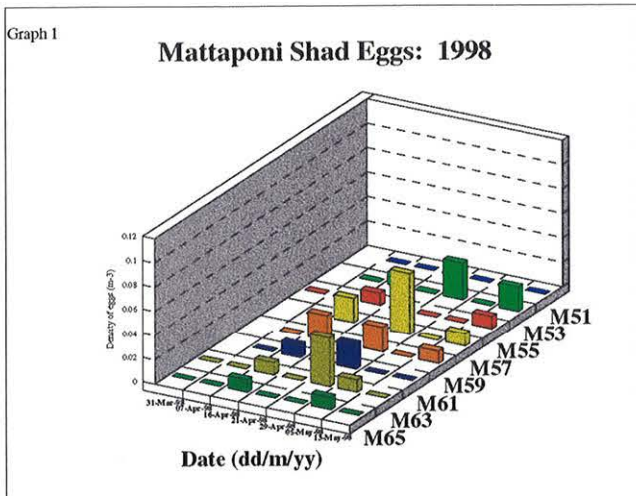
**Rawls 1: net was facing in the wrong direction

Table 3. Statistical comparisons (two-way ANOVA without replication) of the counts, density and presence/absence of each life stage among cruises and stations.

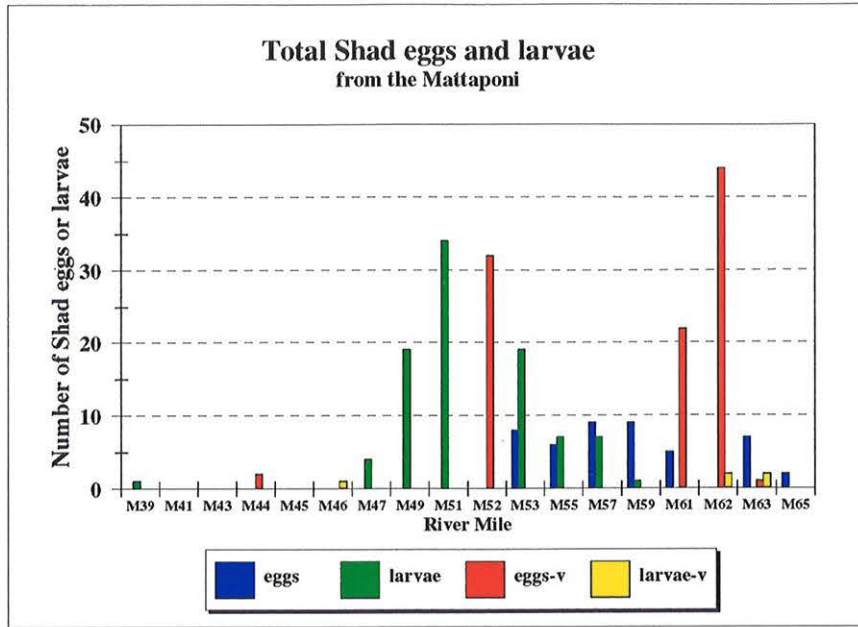
		Counts		Density (m-3)		Presence/Absence	
		<i>Cruises</i>	<i>Stations</i>	<i>Cruises</i>	<i>Stations</i>	<i>Cruises</i>	<i>Stations</i>
Mattaponi	<i>Eggs</i>	p=0.000057**	p=0.1798	p=0.000029**	p=0.167692	p=0.000008**	p=0.302495
	<i>Prolarvae</i>	p=0.215926	p=0.375231	p=0.175719	p=0.411284	p=0.175719	p=0.411284
	<i>Postlarvae</i>	p=0.463981	p=0.001815**	p=0.492444	p=0.001174**	p=0.022594**	p=0.000346**
	<i>Total</i>	p=0.417967	p=0.002688**	p=0.428852	p=0.001961**	p=0.428852	p=0.001961**
Pamunkey	<i>Eggs</i>	p=0.4205	p=0.0478**	p=0.32862	p=0.386494	p=0.438097	p=0.209883
	<i>Prolarvae</i>	p=0.7957	p=0.3399	p=0.651287	p=0.542759	p=0.79566	p=0.339888
	<i>Postlarvae</i>	n/a	n/a	n/a	n/a	n/a	n/a
	<i>Total</i>	p=0.7957	p=0.3399	p=0.651287	p=0.542759	p=0.79566	p=0.339888

Table 4. Statistical comparisons of the counts and presence and absence of each life stage among sampling dates and stations.

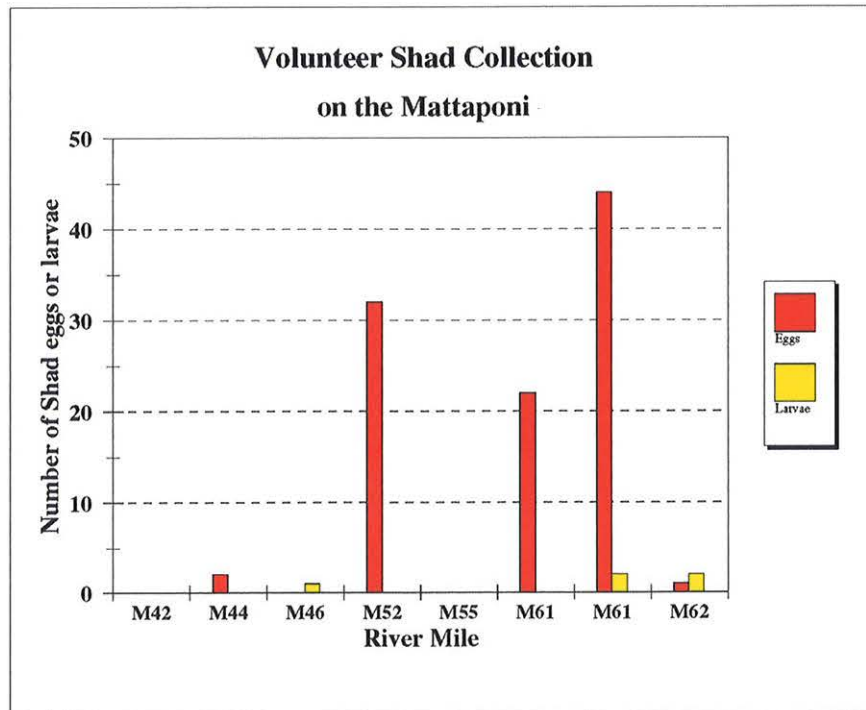
Volunteer Mattaponi Collections		Counts		Presence or Absence	
		<i>Date</i>	<i>Station</i>	<i>Date</i>	<i>Station</i>
	<i>Eggs</i>	p=0.22	p=0.625	p=0.0140**	p=0.2833
	<i>Larvae</i>	p=0.29	P=0.110	p=0.1224	p=0.2



Graphs 1-6. Relationship between American Shad egg and larval density in the Mattaponi and Pamunkey Rivers and station and date sampled in 1998.



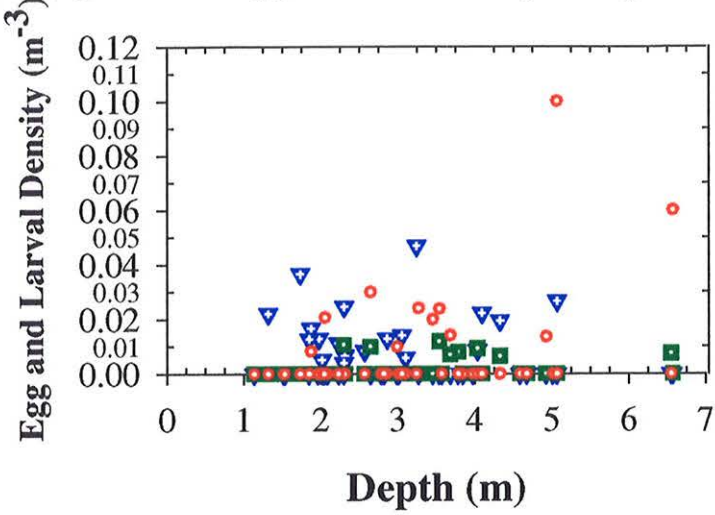
Graph 7. American shad egg and larvae counts for the Mattaponi ichthyoplankton surveys and volunteer collections. Eggs, larvae = eggs and larvae collected during ichthyoplankton surveys eggs-v, larvae-v = Shad eggs, larvae collected in 24-hour stationary nets placed by volunteers.



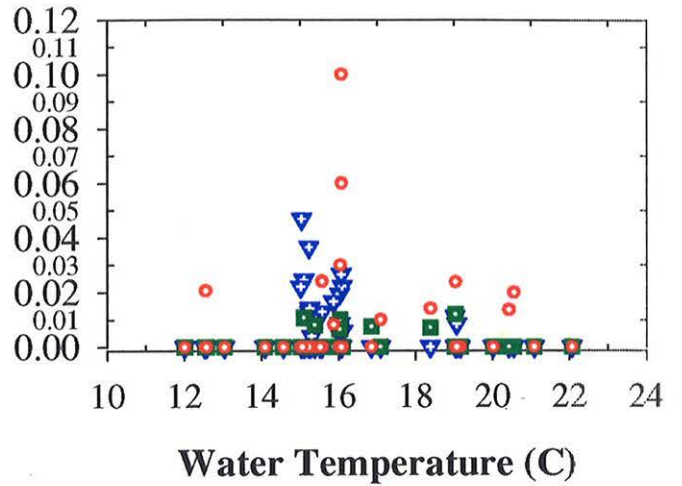
Graph 8. American shad egg and larval counts from volunteer collections

Mattaponi River: 1998

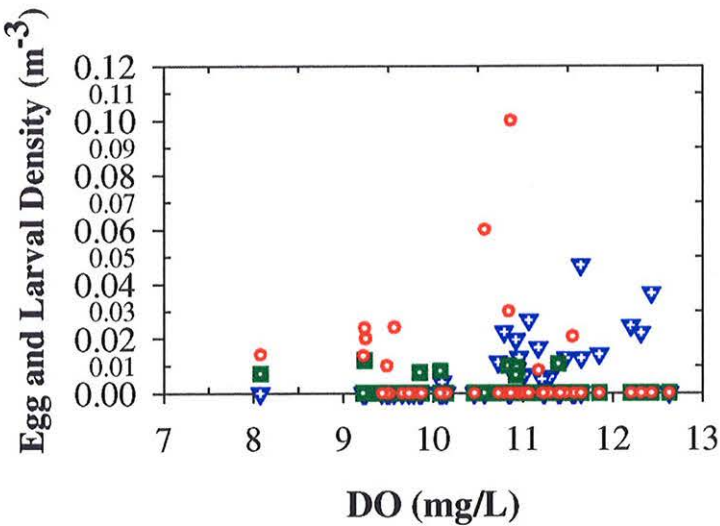
Graph 9. Shad egg and larval density vs. depth



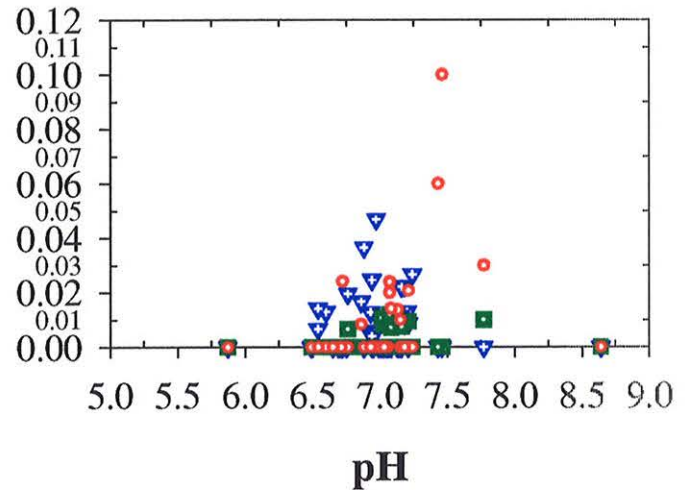
Graph 10. Shad egg and larval density vs. water temp.



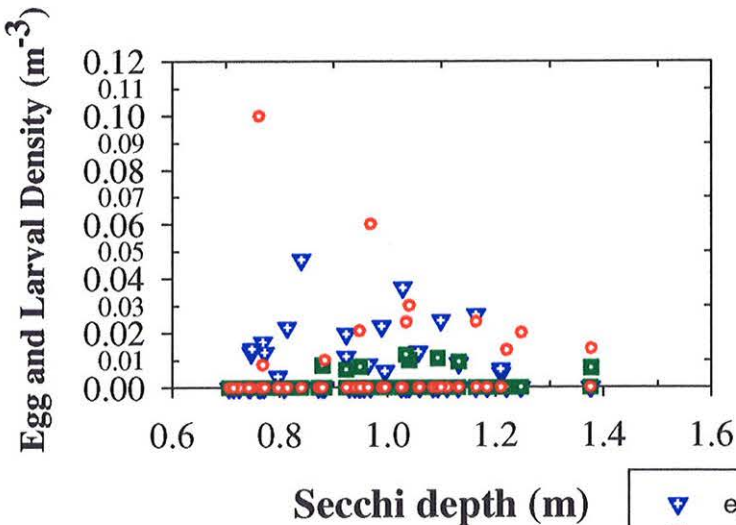
Graph 11. Shad egg and larval density vs. DO



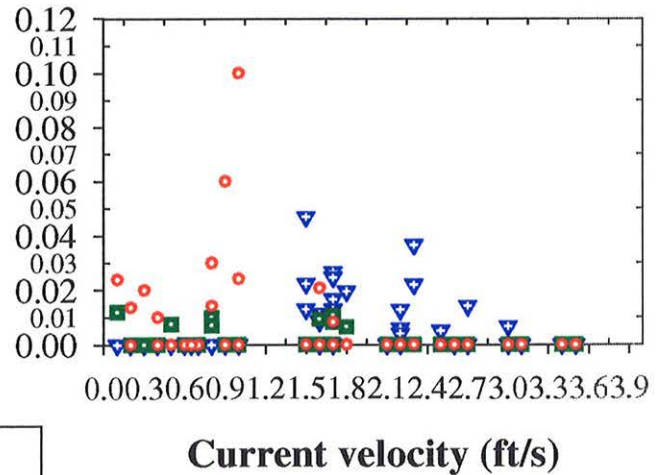
Graph 12. Shad egg and larval density vs. pH



Graph 13. Shad egg and larval density vs. secchi depth

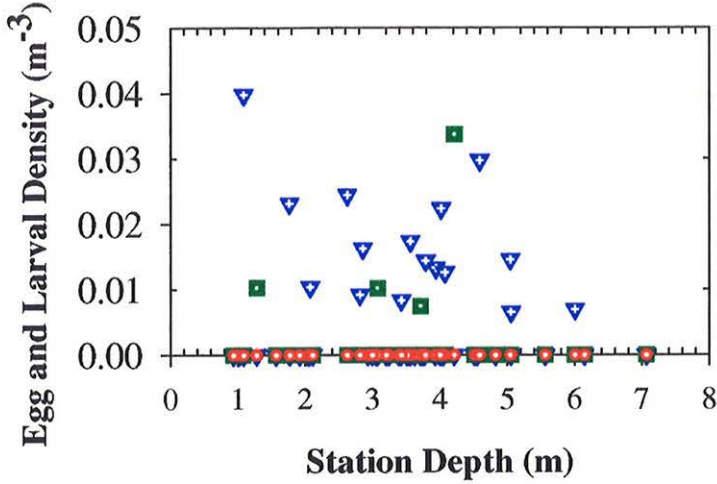


Graph 14. Shad egg and larval density vs. current

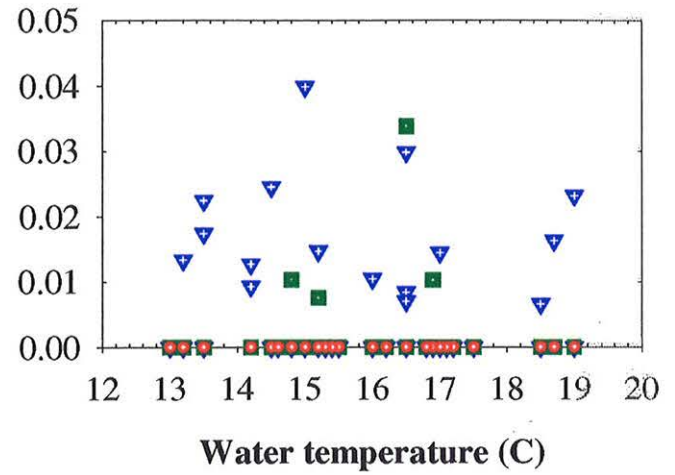


Pamunkey River: 1998

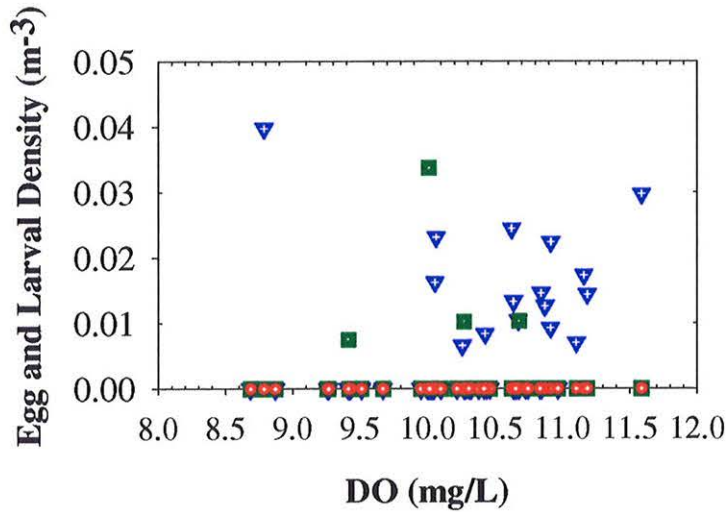
Graph 15. Shad egg and larval density vs. depth



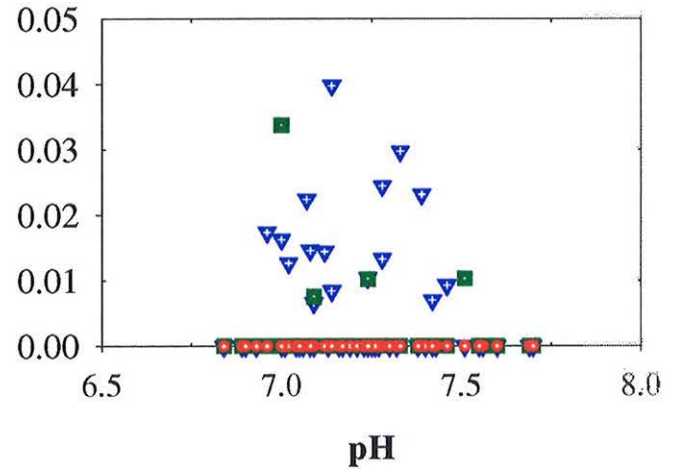
Graph 16. Shad egg and larval density vs. water temp.



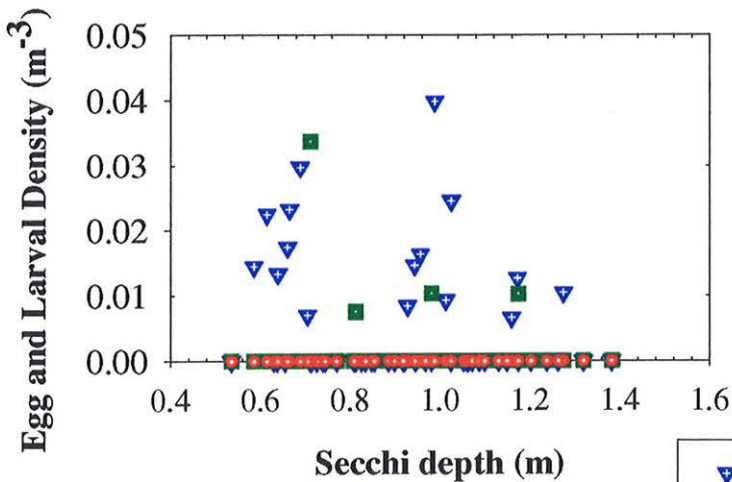
Graph 17. Shad egg and larval density vs. DO



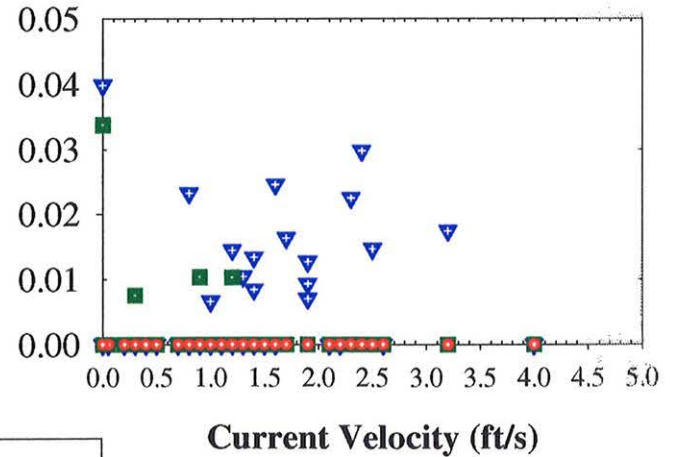
Graph 18. Shad egg and larval density vs. pH



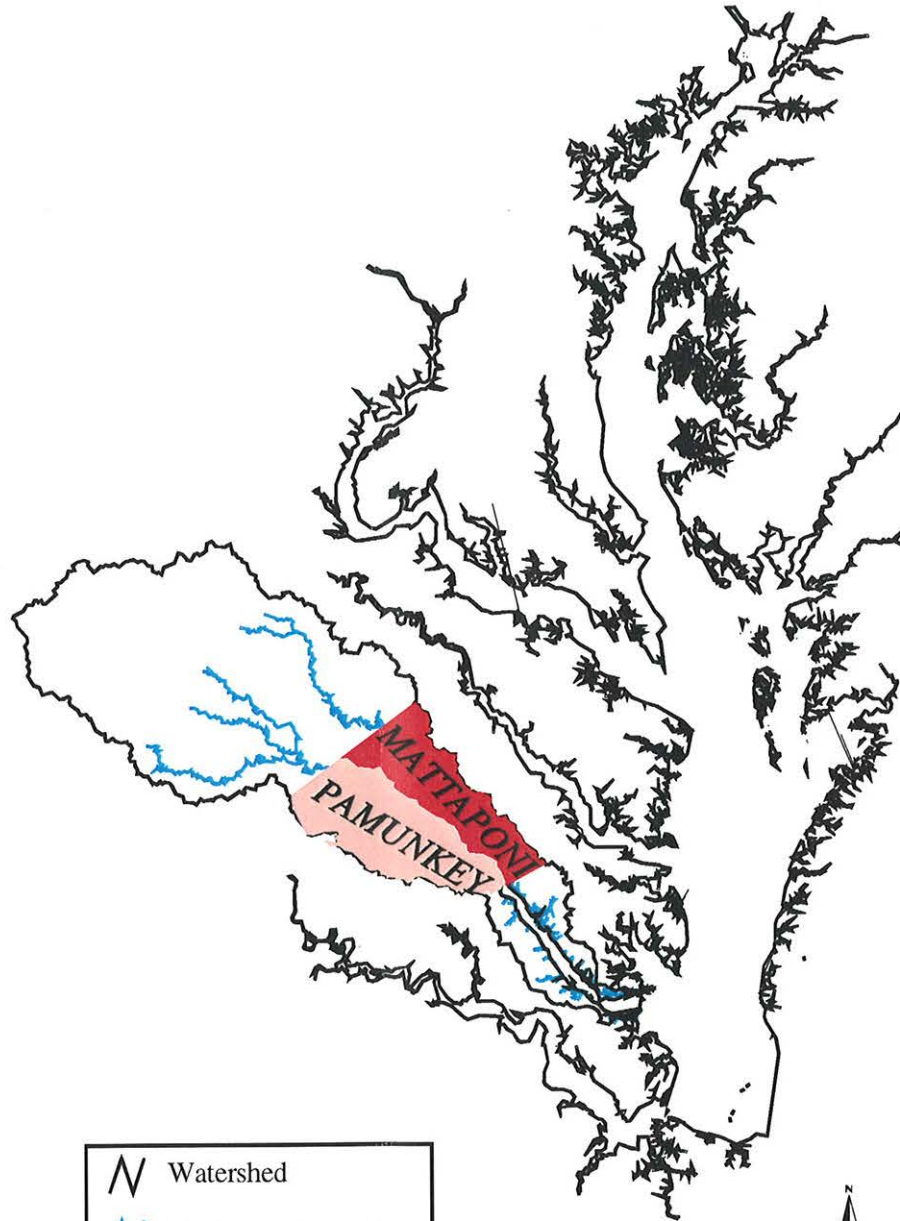
Graph 19. Shad egg and larval density vs. secchi depth



Graph 20. Shad egg and larval density vs. current



Survey Location in the York River Basin



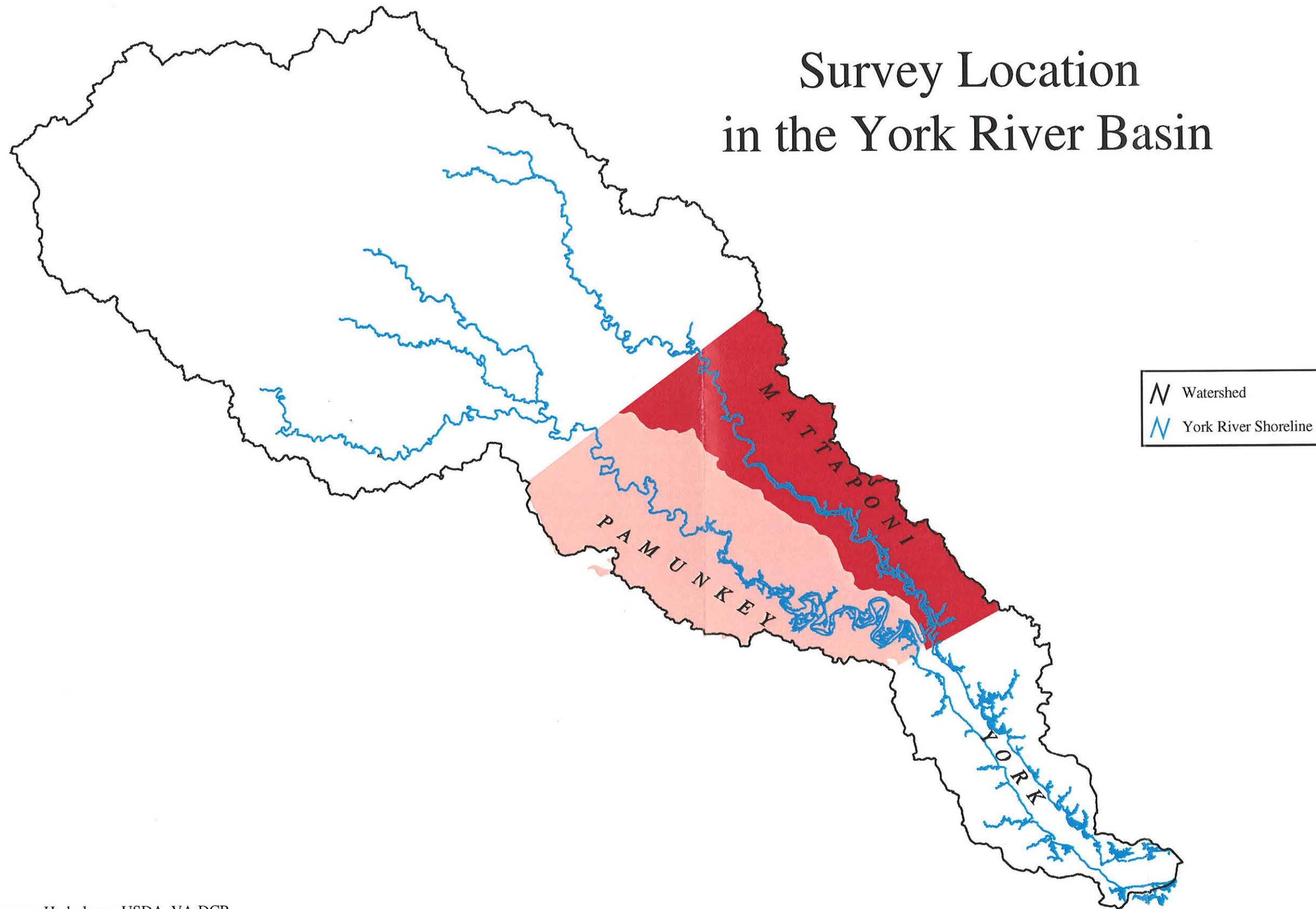
W Watershed
B York River Shoreline



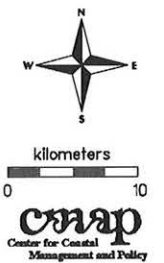
CCMP
Center for Coastal
Management and Policy

Source: Hydrology: USDA, VA-DCR

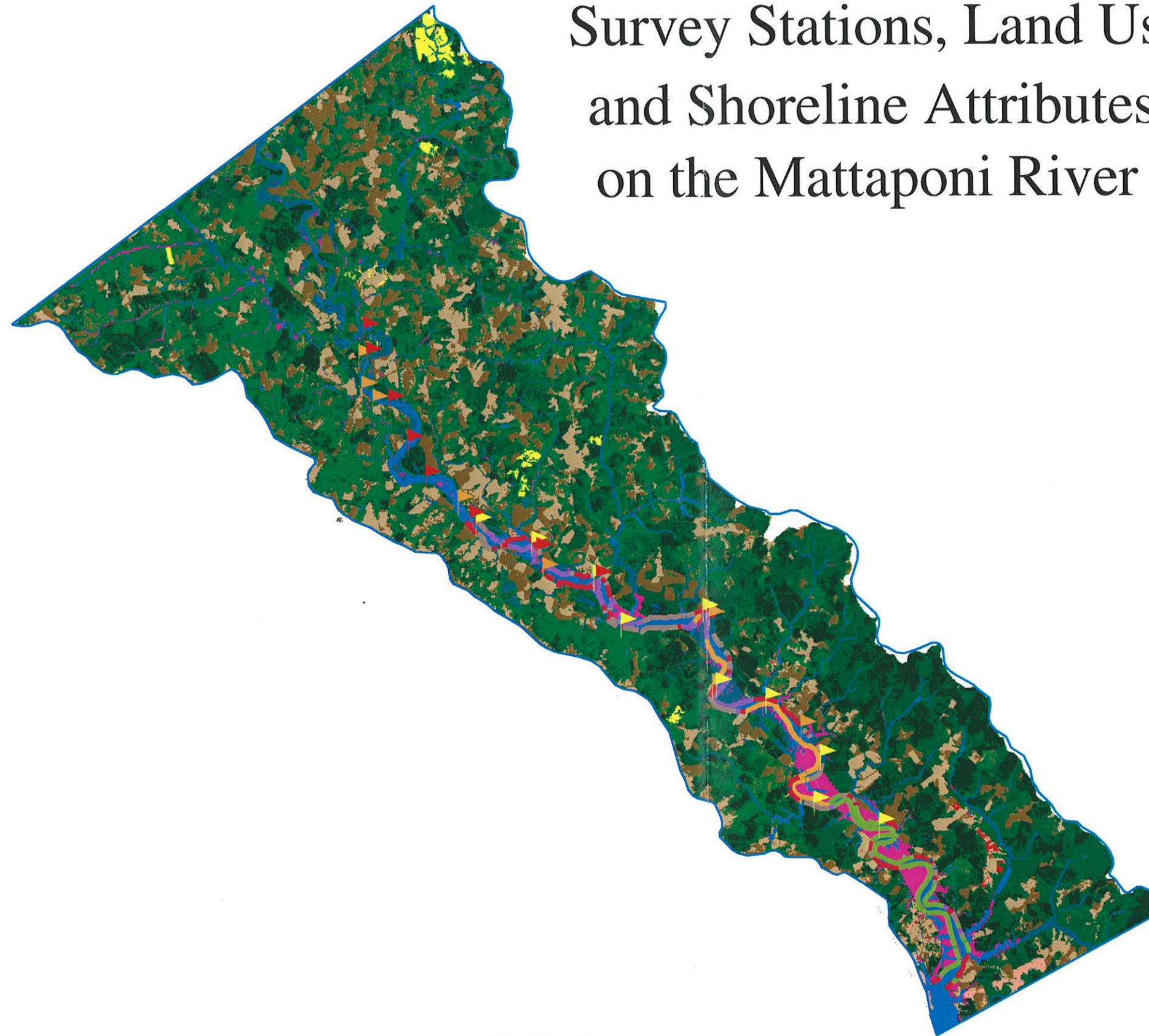
Survey Location in the York River Basin


























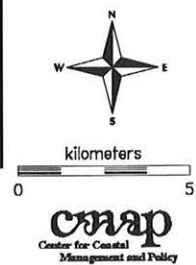
Source: Hydrology: USDA, VA-DCR



Survey Stations, Land Use and Shoreline Attributes on the Mattaponi River



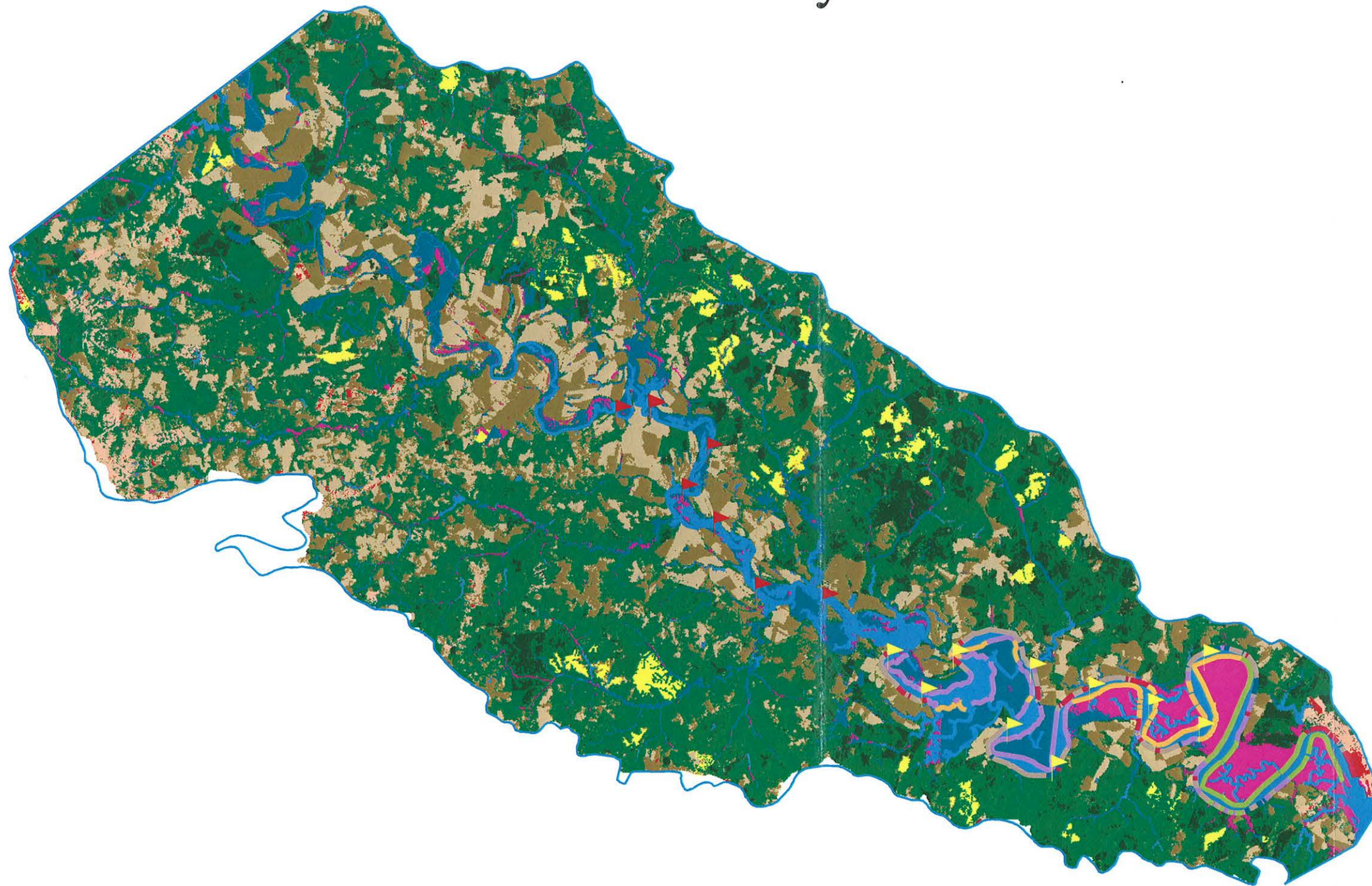
-  Tidal Freshwater Marsh
-  Tidal Swamp
-  Oligohaline Marsh
-  Eroding Banks
-  Upland Developed
-  Upland Forested
-  Upland Scrub
-  Watershed
-  1998 Pushnet Stations
-  Volunteer Stations
-  1997 Bongo net Stations
-  Low Intensity Developed
-  High Intensity Developed
-  Hay/Pasture/Grass
-  Row Crops
-  Probable Row Crops
-  Evergreen Forest
-  Mixed Forest
-  Deciduous Forest
-  Woody Wetlands
-  Emergent Wetlands
-  Barren: Transitional
-  Water

























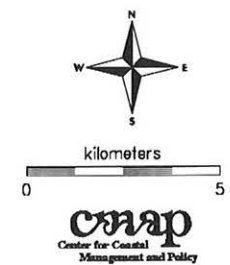
Source: Land Use: EPA Region III Land Cover Data Set, 1996

Hydrology: USDA, VA-DCR

Survey Stations, Land Use, and Shoreline Attributes on the Pamunkey River








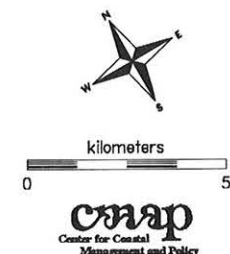
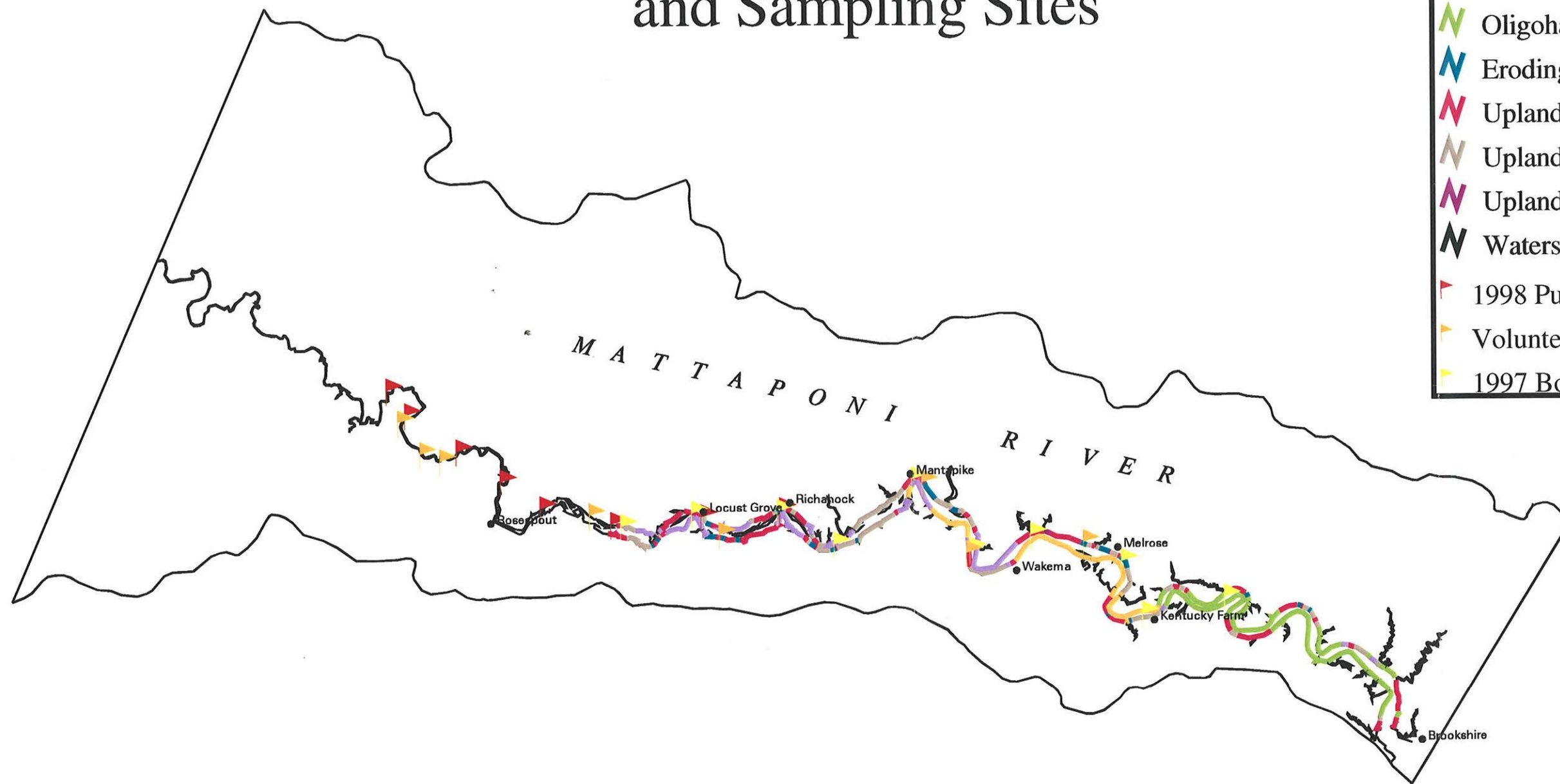
-  Tidal Freshwater Marsh
-  Tidal Swamp
-  Oligohaline Marsh
-  Eroding Banks
-  Upland Developed
-  Upland Forested
-  Upland Scrub
-  Watershed
-  1998 Pushnet Stations
-  1997 Bongo net Stations
-  Low Intensity Developed
-  High Intensity Developed
-  Hay/Pasture/Grass
-  Row Crops
-  Probable Row Crops
-  Evergreen Forest
-  Mixed Forest
-  Deciduous Forest
-  Woody Wetlands
-  Emergent Wetlands
-  Barren: Transitional
-  Water



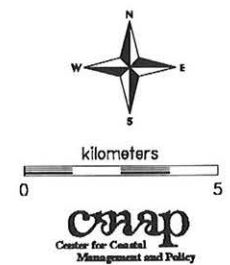
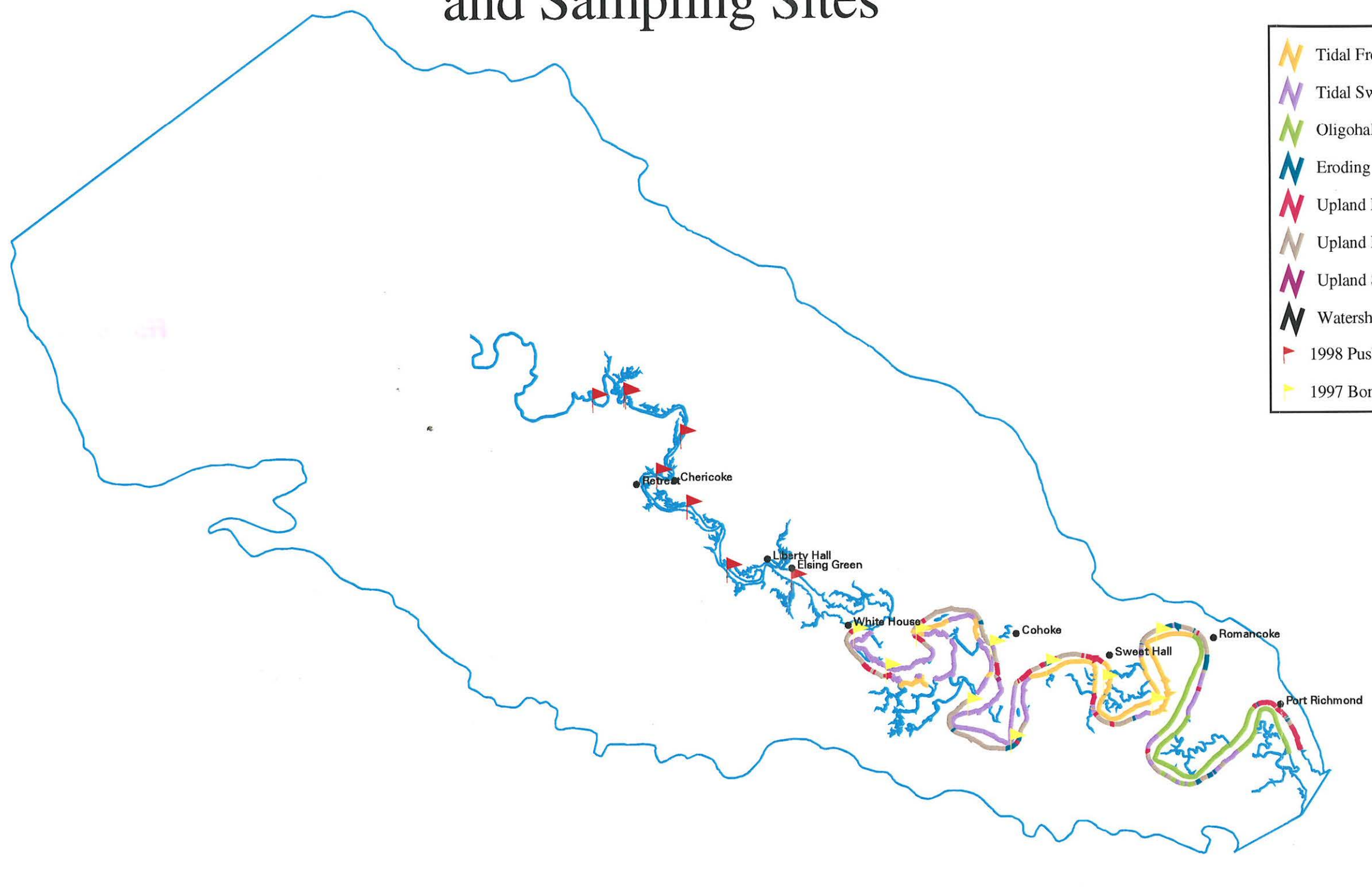
Source: Land Use: EPA Region III Land Cover Data Set, 1996
 Hydrology: USDA, VA-DCR

Mattaponi River: Shoreline Attributes and Sampling Sites

-  Tidal Freshwater Marsh
-  Tidal Swamp
-  Oligohaline Marsh
-  Eroding Banks
-  Upland Developed
-  Upland Forested
-  Upland Scrub
-  Watershed
-  1998 Pushnet Stations
-  Volunteer Stations
-  1997 Bongo net Stations



Pamunkey River: Shoreline Attributes and Sampling Sites



Source: Hydrology: USDA, VA-DCR

Egg and Larval Distribution of American Shad in the Pamunkey and Mattaponi Rivers, Virginia

By: Donna Marie Bilkovic, John E. Olney and Carl H. Hershner
Virginia Institute of Marine Science

NA 76 FA 0361, AFE-27

Abstract
American shad populations have declined steadily since the 1890s, and severe declines occurring over the past few decades have led to moratoriums in Maryland and Virginia. Overfishing, blockage of spawning runs, water quality degradation and habitat destruction are all postulated causes of population decreases. While the moratoria continue, and efforts to restore the fishery take place, it is imperative to garner information regarding habitat quality and quantity within these rivers for shad spawning and nursery areas. Management efforts may then be focused on particular reaches of rivers, thus targeting areas for impediment removal, water quality improvement and habitat protection. Shad eggs and larvae were collected during 1997 and 1998 spawning events as direct evidence of nursery habitat use and indirect evidence of spawning sites. The chosen areas of study are the Mattaponi and Pamunkey Rivers, where shad populations are historically low, but the highest found in Virginia. Information from a preliminary ichthyoplankton sampling season in the Mattaponi and Pamunkey during spring 1997 was used to modify sampling locations and techniques for the second year of sampling. Important results from the 1997 and 1998 ichthyoplankton surveys include obvious differences in abundance of eggs and larvae between the two rivers. Hydrographic parameters were within similar ranges for both rivers, and potential associations between the presence of eggs and dissolved oxygen, secchi and station depth, are predicted with a principle components analysis of 1997 and 1998 data. Potential differences between the two river basins that may influence the populations may include discharge, tidal excursion, river morphology and/or varying fishing pressures.

Study Objectives:

- 1) A description of where shad spawn in the Mattaponi and Pamunkey Rivers over a spatial-temporal scale (miles, weeks).
- 2) To ascertain possible correlations between the examined parameters and the presence/absence of American shad eggs in the selected rivers.

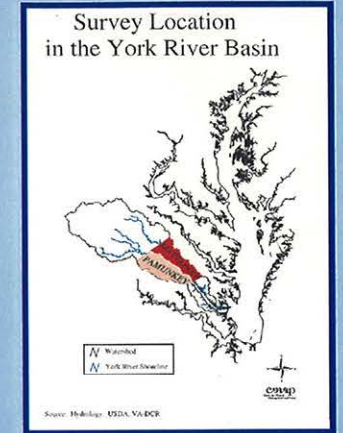
Methods:

Ichthyoplankton Sampling:
1997:
• Weekly oblique tows at 10 stations per river for 4-5 weeks.
1998:
• Weekly push-net deployments at 8 stations per river for 7 weeks.
• Stationary nets deployed for a 24-hour period, weekly for 8 weeks by volunteers in 8 locations on the Mattaponi River.

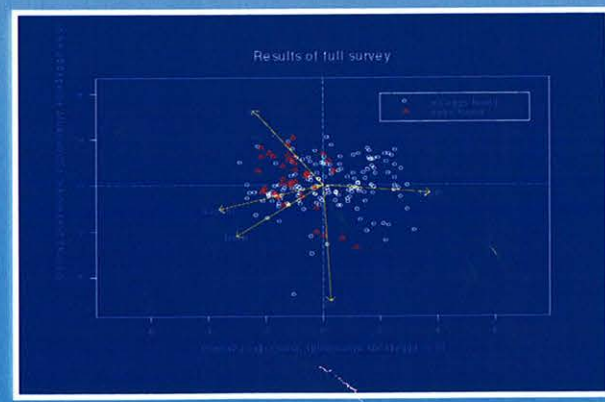
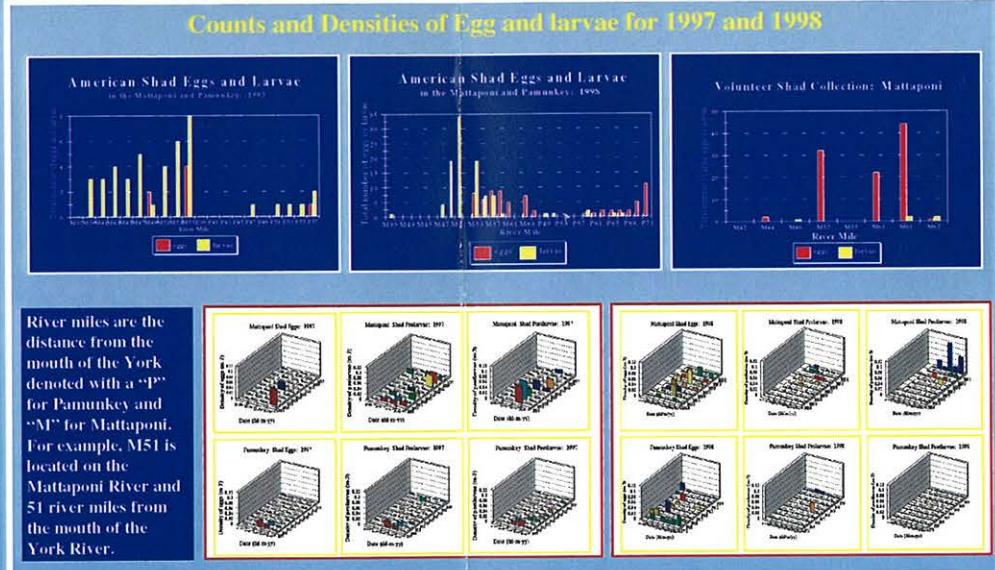
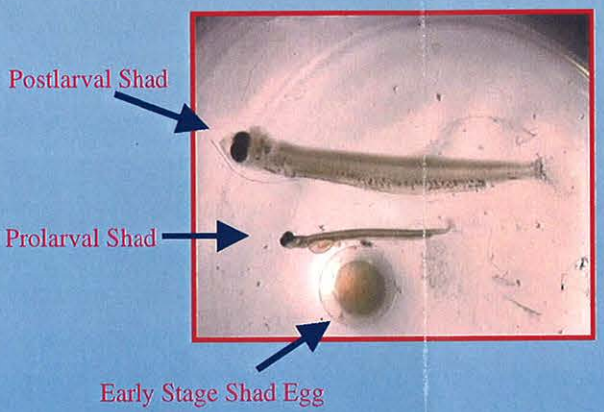
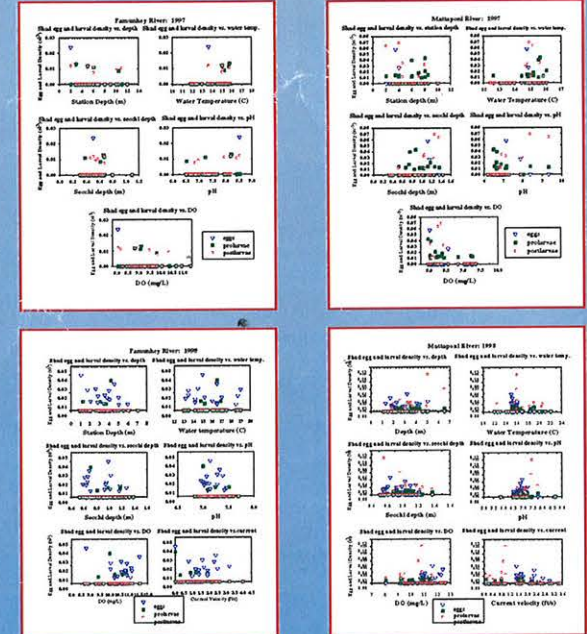
Hydrographic Measurements:
• Dissolved Oxygen
• pH
• Secchi depth
• Water temperature
• Current velocity (1998 only)

Ichthyoplankton Collection Analysis:
• Shad eggs and larvae were sorted and enumerated in whole samples.

Statistical Analysis:
• PCA performed on hydrographic variables measured during 1997 and 1998 sampling.
• Egg densities were overlaid for examination of associations with hydrographic features.



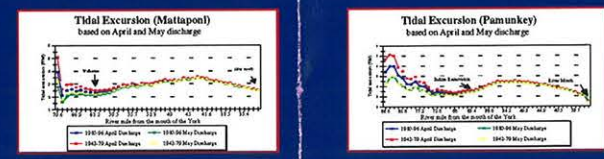
Scatter Plots of Water Quality Measurements vs. Egg, Larval densities



Initial PCA of hydrographic parameters including data from 1997 and 1998 for both rivers indicates association of shad eggs with high DO, high secchi, shallow depths and intermediate temperatures.

Results and Conclusions

- For both years, American shad eggs and larvae were collected in low densities. Of those collected, egg and larval densities in the Pamunkey River were lower than the Mattaponi River by approximately a factor of three.
- In 1997, shad egg and larvae densities were very low, but the highest in the upper limits of the sampled reaches, thus in 1998 sampling was extended upriver. In 1998, eggs were observed in the uppermost stations from M52 through M65, and P59 through P71. Larvae were observed in the highest densities from M49 through M53, and in low abundance from P49 through P67. In both rivers, larvae were not collected in the upper sampled stations (M63-M65; P68-P71).
- In 1997, for both rivers and 1998 Pamunkey River collections, evidence of the presence of early life stages of shad was observed throughout the sampling period. In 1998 Mattaponi River collections, eggs and larvae were not observed during the first two sampling dates (31 March and 7 April).
- Water quality measurements were within similar ranges for both years and rivers, except in 1997 secchi depths were higher in the Mattaponi than the Pamunkey.
- Shad eggs were primarily located in higher current velocities than larval shad in both rivers.
- PCA for hydrographic data of five parameters from both years and rivers indicate that shad eggs are associated with shallow depths, high dissolved oxygen, high secchi depth and intermediate temperatures.
- The inclusion of additional hydrographic and river morphology parameters, including discharge, tidal excursion, and river sinuosity, is necessary for a more complete analysis of influences on the early life stages of shad. For example, tidal excursion estimation (shown below) indicates that both rivers have specific areas of low tidal excursion that may act as refuge locations for larval shad.



Tidal excursion data estimated with cross-sectional area, maximum tidal current, and discharge. Discharge is a median monthly value based on data from 1942-1979 and 1980-1996. Discharge measurements were obtained from USGS at Banksville, Mattaponi River and Hanover, Pamunkey River.

Future Work

- Further exploration of the impacts of discharge, tidal excursion, and channel morphology on the early life stages of shad, including:
 - 1) Historic discharge comparisons between rivers.
 - 2) Historical discharge records for the Pamunkey and Mattaponi may be examined for apparent correlation with juvenile shad indices.
 - 3) Further characterization of channel, sediment type, shorelines and adjacent land use will be completed.
- Continued ichthyoplankton sampling in the upper reaches of the rivers to determine the upper limits of spawning.
- Further PCA incorporating additional hydrographic and landscape parameters to explore potential egg and larval stages associations.

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