Project 3: 2009 Fisheries and Habitat Interactions Project: Development of Habitat-based Reference Points for Chesapeake Bay Fishes of Special Concern: Impervious Surface as a Test Case

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INTRODUCTION

Fisheries management uses biological reference points (BRPs) to determine how many fish can be safely harvested from a stock (Sissenwine and Shepherd 1987). The primary objective of Project 3 was to evaluate the concept of impervious surface reference points (ISRPs) as a similar tool for fish habitat management. The development of ISRPs involves determining functional relationships between a watershed's area covered in impervious cover (or IS; paved surfaces, buildings, and compacted soils) and habitat quality (water quality, physical structure, etc) or a species response (habitat occupation, abundance, distribution, mortality, recruitment success, growth, etc). Quantitative, habitat-based reference points based on impervious surface for estuarine watersheds are envisioned as a basis for strategies for managing fisheries in increasingly urbanizing coastal watersheds and for communicating the limits of fisheries resources to withstand development-related habitat changes to stakeholders and agencies involved in land-use planning.

Project activities in 2009 included investigating land-use indicators, spring stream anadromous fish icthyoplankton collections, spring yellow perch larval presence-absence sampling, and summer sampling of estuarine fish communities. These efforts were collectively aimed at defining the impact of impervious surface on target fish species populations and habitats.

INDICATORS OF LAND-USE

Introduction

Measures of urbanization are varied (National Research Council or NRC 2009). A recurring problem affecting our ability to relate urbanization to fisheries metrics is the lack of a standardized, readily updated, and accessible land-use data set. We have, by necessity, used several indicators of impervious surface (IS). The purpose of this section is to describe the indictors we have used, indicators that could be developed, and the associations among them. Measuring the strength of associations indicates how coherent these indicators are for describing trends in watershed urbanization.

Impervious Surface Estimates - We have primarily used IS estimates made by Towson University from Landsat, 30-meter pixel resolution satellite imagery (Eastern Shore of Chesapeake Bay in 1999 and western shore in 2001) for each watershed (Barnes et al. 2002) to develop IS reference points for brackish Chesapeake Bay tributaries (Uphoff et al. 2009). These "old" estimates have proven difficult to verify after we obtained them and additional ones could not be obtained for additional watersheds. IS estimates can be derived from Maryland Department of Planning (MDP) landcover estimates (available through Maryland's Surf Your Watershed http://www.dnr.state.md.us/watersheds/surf/) and have been used occasionally; 1994 land cover types (urban, forest, wetland, agriculture, etc) were assigned a coefficients for IS by MDP and summing the products of watershed cover type and IS coefficients would result in an estimate of IS (http://www.dnr.state.md.us/watersheds/surf/indic/metadata/pctimp_amet.pdf).

These methodologies were not identical, but estimates were generally close when both techniques were applied.

The Chesapeake Bay Chesapeake Bay Program (CBP) placed watershed profiles with estimates of IS, watershed area, and census-based estimates of human population (1970-2000 and projections for 2010 and 2020) for each watershed on their website until 2008. Unfortunately, these estimates are no longer supported or available online. While they were available, we created a spreadsheet with these data for tributaries that we were monitoring. Towson and MDP methodologies produced noticeably higher estimates for the same watersheds than CBP Regional Earth Science Applications Center (RESAC; http://www.geog.umd.edu/resac/lc2.html) based analysis of satellite imagery. RESAC based estimates of IS were about half of those estimated by Towson University, but trends were very similar (Uphoff 2008).

These data sets are becoming dated. Significant amounts of development can occur in 10-15 years and continued monitoring of fish and habitat conditions need to be matched with more concurrent measures of development. It is unknown when updated estimates of impervious surface may become available.

Tax Maps -The Maryland Department of Planning (MDP) annually updates the more than 2,800 property maps, or tax maps, for Maryland's 23 counties − Baltimore City maintains its own property maps (MDP 2010). Maryland's tax maps are updated and maintained electronically as part of MDP's Geographic Information System's (GIS) database. The tax maps are maintained in a Computer Aided Design (CAD) environment and updated on an annual cycle using new property plats and deed changes obtained from the State Department of Assessments and Taxation (Maryland Department of Planning 2010). Tax maps, also known as assessment maps, property maps or parcel maps, are a graphic representation of real property showing and defining individual property boundaries in relationship to contiguous real property. The primary purpose of the maps is to help State tax assessors locate properties for assessments and taxation purposes. Tax maps are also used by federal, State and local government agencies as well as private sector firms for a variety of analyses and decision making processes (Maryland Department of Planning 2010).

Tax map data appear to meet our requirements for a standardized, readily updated, and accessible data base. We estimated of number of structures and square footage of structures that existed during 2000 for comparison with the "new" Towson IS estimates.

Methods

New estimates of Impervious Surface - In December, 2009, we obtained land use area estimates for each watershed from D. Sides (Towson University) and calculated "new" Towson IS estimates of percent IS as Σ IA / Σ TA; where IA = impervious surface area estimated in the watershed and TA is the estimate of total area of the watershed. We used linear regression to determine the relationship of "old" and "new estimates".

Tax Map Indicators of Development – Two indicators of development were estimated, a count of structures and total building square footage. Count of structures could be obtained directly from the tax map data base. Total building square footage estimates for each watershed studied required multiple geoprocessing tools. Most files were managed using a file geodatabase in ArcCatalog 9.3.1 and geoprocessed using ArcMap 9.3.1 from Environmental Systems Research Institute (ESRI 2009). All feature datasets, feature classes, and shapefiles were spatially referenced using the NAD_1983_StatePlane_Maryland_FIPS_1900 projection to ensure accurate feature overlays and data extraction. North American Datum of 1983 (NAD 1983) describes earth's curvature and is used to position coordinates in North America. To reduce geographic distortion caused by mapping a three-dimensional surface in two dimensions, each state has a unique coordinate projection (Wade and Sommer 2006). Maryland's coordinate projection is StatePlane_Maryland_FIPS_1900.) Maryland 8-digit watersheds were extracted from a statewide shapefile provided by MD DNR and exported as separate feature classes (Figure 1).

All tax data were organized by county. Since watersheds straddle political boundaries, one statewide tax map was created for each year (1999 – 2008) digital tax maps were available by appending the county shapefiles into one feature class. Inconsistencies in the projection of 1998 and 1997 tax maps prevented their use. Statewide tax maps were generated for 1970 - 1998 from the 2008 tax map. A small portion of parcels had no coordinates and were omitted (Table 1).

Process models were developed using Model Builder in ArcMap to automate assembly of statewide tax maps, query tax map data, and assemble summary data. Each year's statewide tax map was clipped using the MD 8-digit watershed boundaries of interest (Bohemia River, Breton Bay, Bush River, Corsica River, Gunpowder River, Langford Creek, Magothy River, Mattawoman Creek, Middle River/Browns Creek, Miles River, Nanjemoy Creek, Northeast River, Piscataway Creek, Severn River, South River, St. Clements Bay, Tred Avon River, West River/Rhode River, Wicomico River/Gilbert Swamp/Zekiah Swamp, and Wye River) to create watershed tax maps (Figure 1). These watershed tax maps were queried for all parcels having foundation square feet greater than zero. A large portion of parcels did not have any record of foundation square feet or year built (Table 2) and all square feet and number of structure calculations are likely underestimates. The total foundation square feet in each watershed was calculated and appended into one file for each year.

Comparisons of Impervious Surface and Tax Map Indices of Development - "New" Towson IS, counts of structures, and square footage of structures were available for the 19 Chesapeake Bay subestuary watersheds we have studied. All comparisons were based on year 2000 estimates (Table 3). Counts of structures and square footage of structures in a watershed were standardized on a per area basis by dividing them by estimates of watershed acreage (available in the land use spreadsheet provided by D. Sides of Towson University). Linear and non-linear regression (Freund and Littel 2000) were used to determine the relationships of tax map indicators of development and IS. Nonlinear power functions were estimated with SAS Proc NLIN (Freund and Little 2000) as

$$IS = a*I^b;$$

where I = count of structures per area or square footage of structures per area, and a and b are coefficients for each indictor. Residuals were inspected for indications of bias or need for additional terms.

Results

The fit of the regression of old versus new IS estimates for systems studied since 2003 was very good ($r^2 = 0.99$, $P < 0.001$), but new estimates were slightly higher (slope = 1.14, SE = 0.04; intercept was not significantly different than 0). These "new" estimates were used in this report.

Linear regression analysis indicated that IS was positively and significantly ($P < 0.0001$) related to count of structures per acre of watershed ($r^2 = 0.93$) and square footage of structures per acre of watershed ($r^2 = 0.96$). In spite of these good fits, use of these linear equations for converting either indicator of development was limited at low IS because both counts and square footage became negative at IS lower than 3.5% and 2.6%, respectively.

Nonlinear power functions described these relationships better than linear regressions (count of structures per area $r^2 = 0.95$ and square footage per area $r^2 = 0.98$; $P < 0.0001$ in both cases) and became asymptotically low at low IS (Figure 2). The relationship of IS to count of structures per area (C) was described by the equation $0.0071C^{1.65}$ and the relationship of IS to square footage of structures per area (F) was described by $35.16F^{1.33}$. Plots of residuals versus predictions did not indicate bias or need for additional terms.

Discussion

We consider these tax map derived development indices as the best source for standardized, readily updated, and accessible development indicators in Maryland. Either index, counts of structures per acre or square footage of structures per acre, had a strong relationship with "new" Towson IS estimates for 2000 and predictions of IS developed from these indices are well within the "play" experienced when using other data sources to estimate IS. In the future, tax map data will be used as the basis for estimating target and threshold levels of development.

STREAM ICHTHYOPLANKTON SAMPLING

Introduction

A survey to identify anadromous spawning habitat in Maryland was conducted from 1970 to 1986 (O'Dell et al. 1970; 1975; 1980; Mowrer and McGinty 2002) with subsequent development of statewide maps detailing spawning habitat. Recreating these surveys provides an opportunity to explore whether spawning habitat has declined in response to urbanization. During 2009, stream sites in Piscataway and Mattawoman creeks (Figure 3) were sampled for eggs and larvae of herring, white perch, and yellow perch (hereafter "anadromous species") by citizen volunteers coordinated by program biologists. These two creeks were also sampled by volunteers during 2008. Methods of O'Dell et al. (1975) were used and sites that historically supported at least one of the three anadromous species were sampled.

Methods

In 2008-2009 ichthyoplankton samples were collected from Mattawoman and Piscataway creeks during March-May by citizen volunteers. These volunteers were trained and their subsequent collection activities monitored by Project staff. Of the 17 Mattawoman Creek stations sampled by O'Dell et al. (1975) in 1971 six were positive for the presence of one or more anadromous species. Consequently these six stations, plus three additional sites (based on volunteer interest) were sampled in 2008-2009 (Figure 4; Table 4). Thirty stations were sampled in Piscataway, Broad, and Swan creeks, and Oxon Run) in 1971 (O'Dell et al. 1975). Twelve stations were positive for anadromous fish presence in 1971 and nine were resampled by volunteers in 2008-2009 (Figure 5; Table 4).

Ichthyoplankton samples were collected at each site using stream drift nets constructed of 360-micron mesh material, attached to a square frame with a 300 X 460 mm opening. The frame was connected to a wooden handle so that the net could be held stationary in the stream. A threaded collar was placed on the end of the net where a mason jar was connected to collect the sample. Nets were placed in the stream with the opening facing upstream for five minutes. The nets were then retrieved and rinsed in the stream by repeatedly dipping the lower part of the net and splashing water on the outside of the net to avoid sample contamination. The stream drift nets and techniques were the same as those used by O'Dell et al. (1975). The jar was then removed from the net and an identification label describing site, date, time and collectors was placed in the jar. The jar was sealed and placed in a cooler for transport. Water temperature (°C), conductivity (µmho/cm) and dissolved oxygen (mg/L) were recorded at each site using a hand held YSI model 85 meter. Meters were calibrated for DO each day prior to use. All data were recorded on standard field data forms and verified at the site by a volunteer and signed off by a project biologist.

After a team finished sampling for the day, the samples were preserved with 10% buffered formalin by the biologist coordinating the day's collections. Two ml of rose bengal was added in order to stain the organisms red to aid sorting.

Ichthyoplankton samples were sorted in the laboratory by project personnel. All samples were rinsed with water to remove formalin and placed into a white sorting pan. Samples were sorted systematically (from one end of the pan to another) under a 10x bench magnifier. All eggs and larvae were removed and identified under a microscope. Eggs and larvae were retained in small vials and fixed with formaldehyde for verification.

Presence of white perch, yellow perch and herring eggs or larvae at each station in 2008-2009 was compared to their presence in 1971 to determine which sites still supported spawning. O'Dell et al. (1975) summarized spawning activity as the presence of any egg, larva, or adult (from wire trap sampling) at a site and we used this criterion (spawning detected at a site or not) as well in 2008-2009. Raw data of O'Dell et al. (1975) were not available to formulate other indicators of spawning.

Four mainstem stations previously sampled by O'Dell et al. (1975) in 1971, were sampled by Hall et al. (1992) during 1989-1991 for water quality and ichthyoplankton. Comparisons of spawning activity of the four targeted species and water quality were made among the current study, Odell et al. (1975) and Hall et al. (1992) to detect changes. Hall et al. (1992) collected ichthyoplankton with 0.5 m diameter plankton nets (3:1 length to opening ratio and 363µ mesh set for 2 minutes) suspended in the stream channel between two posts instead of stream drift nets.

Changes in spawning sites were compared to land-use changes in both watersheds. Percent urban land use measured by the Maryland Department of Planning was available for 1973 MDP (2004a) and 2000 (MDP 2004b). Urban land consists of high and low density residential, commercial, and institutional acreages and is not a direct measure of IS.

Conductivity measurements collected for each date and stream site during 2008-2009 were plotted and mainstem measurements summarized for each year. Unnamed tributaries were excluded from calculation of summary statistics to capture conditions in the largest portion of habitat, but were included in plots. Conductivity distributions in both streams and years were compared to breakpoint conductivity (<171 µS / cm) needed for a "good" fish index of biotic integrity based on Morgan et al's (2007) analysis of Maryland Biological Stream Survey fish data. Comparisons were then made to conductivity ranges previously reported for Mattawoman Creek (Hall et al. 1992), and Mattawoman and Piscataway creeks (O'Dell 1975).

A water quality database maintained by DNR's Tidewater Ecosystem Assessment Division (S. Garrison, MD DNR, personal communication) provided historic conductivity measurements for Mattawoman Creek between 1970 and 1989. These historic measurements, along with those collected in 2008-2009, were used to examine changes in conductivity over time. Monitoring was irregular for many of the historic stations and Table 5 provides a summary of site location, month sampled, total measurements at a site, and what years were sampled. Historic stations and those sampled in 2008-2009 were assigned river kilometers (RKM) using a GIS ruler tool that measured a transect approximating the center of the creek from the mouth to each station location. Stations were categorized as tidal or non-tidal. Conductivity measurements from eight non-tidal and four tidal sites sampled during 1970-1989 were summarized as monthly medians. These sites bounded Mattawoman Creek from its mouth to the city of Waldorf (Route 301 crossing), the major urban influence on the watershed (Figure 6). Median monthly conductivities during the historic period at each site were regressed against distance from the mouth to examine the pattern present at that time and linear and quadratic regressions were developed to describe the relationship of distance and historic median monthly conductivity. Sites within 4.5 km of the mouth were not included in this analysis in order to eliminate large effects of Potomac River salinity intrusion during some years.

Historic monthly median conductivities at each site and their trend were plotted and 2008 and 2009 spawning season median conductivities from each non-tidal site were added to these plots. Continuous estuarine conductivity samples during March and April 2008-2009, were collected by a DNR continuous monitor located at Sweden Point Marina. (M. Trice, MD DNR, personal communication; site information available at http://mddnr.chesapeakebay.net/eyesonthebay/index.cfm).These results were summarized as monthly means and added to the plot of historic and 2008-2009 median conductivities.

Results and Discussion

In general, little change in anadromous fish stream spawning in Mattawoman Creek was indicated between 1971 and 1989-1991. Presence of spawning at these sites was stable (Table 6). However, by 2008-2009 spawning site losses were evident for all three species groups. Herring spawning was reduced from six sites in Mattawoman Creek in 1971 to three during 2008 and two by 2009. White perch stream spawning was detected at 1-2 sites in 1971 and 1989-1991, one in 2008, and none during 2009. Yellow perch stream spawning was detected at the most downstream stream site until 2009 (Table 6).

Stream spawning of anadromous fish nearly ceased in Piscataway, Swan, and Broad creeks, and Oxon Run between 1971 and 2008-2009. Spawning was not detected at any site in the Piscataway Creek drainage during 2008 and herring spawning was only detected on one date and location (one herring larvae on April 28 at PC2) in 2009 (Table 7). Spawning was not detected during 2008 or 2009 in the Oxon Run, Broad Creek and Swan Creek tributaries except for a single instance of herring eggs collected from Oxon Run on May 4, 2009.

Mattawoman and Piscataway creeks are adjacent watersheds that represent a continuum of response along an urban gradient (Limburg and Schmidt 1990) emanating from Washington, DC. In 1973, two years after O'Dell et al. (1975) surveyed these watersheds, the estimated percent urban cover for the Piscataway watershed was 23.6% and 12.2% for the Mattawoman. By 2000, urban land use in the Piscataway Creeks' watershed had increased to 39.9% (16.5% IS) and 25.9% (9.0% IS) in the Mattawoman Creek's watershed. Increases in urban land use between 1971 and 2008-2009 were subsequently followed by loss of over half of the herring stream spawning sites in Mattawoman Creek and the possibility that white and yellow perch no longer spawn in this system at all. Stream spawning of anadromous fish has largely ceased in Piscataway Creek, a watershed both smaller and closer to Washington, DC, than Mattawoman

Creek. These changes in anadromous spawning patterns were similar to those described for Hudson River tributaries by Limburg and Schmidt (1990). Urbanization of the Hudson watershed became greater as the New York metropolitan area expanded and the smaller tributaries (< 40 km^2) became more susceptible to capture by urban sprawl. As a consequence, alewife herring and white perch egg and larval densities exhibited a strong negative threshold response to this urbanization (Limburg and Schmidt 1990). Development leads to altered hydrologic features (Konrad and Booth 2005) and altered water quality (Morgan et al. 2007) needed for anadromous fish spawning habitat.

Projected growth in the Mattawoman Creek watershed at build-out (all buildable land developed) will result in IS that is, at best, equal to that of Piscataway Creek at present (16.5% IS), and is likely to approximate 22% IS (USACOE 2003; Beall 2008). If the status of anadromous fish spawning in Piscataway Creek is an indicator, stream spawning will disappear from Mattawoman Creek at projected levels of development.

Prior to the late 1980's much of the development across the U.S. occurred with little or no stormwater management and current management is still hampered by incomplete understanding, and contradictory and/or ineffective approaches (NRC 2009).
Development proponents for the Mattawoman Creek watershed have stated that "newly created impervious surfaces [in Mattawoman Creek] will be subject to offsetting controls not used in the past…" that would disconnect impervious surface effects from the watershed (i.e., new development will have little effect; Beall 2008). However, techniques for minimizing this impact on fish habitat or restoring biotic integrity in streams are poorly developed (Wheeler et al. 2005; Palmer 2009). A recent review of stormwater management in the U.S. (NRC 2009) recommended considering impervious cover as a proxy for stormwater pollutant loading and

provides further indication that impervious surface is unlikely to be decoupled from stormwater effects.

Conductivity levels for 2008 and 2009 were elevated in Piscataway Creek when compared to Mattawoman Creek, with lower levels recorded in 2008 for both systems (Table 8). Summary statistics indicated highly variable distributions by system and year. Based on comparisons with the 171 µmho / cm critical value for the MBSS fish IBI (FIBI; Morgan et al. 2007), Piscataway Creek was often (>90% of measurements) in excess of this criterion during the 2008-2009 anadromous fish spawning seasons. Mattawoman creek did not display values higher than the FIBI threshold in 2008, but 63% of the measurements were in excess of the FIBI conductivity criterion in 2009 (Table 8). Although not directly related to egg and larval survival, it provides a benchmark for good or bad conditions for fish diversity in Maryland streams (Morgan et al. 2007).

Plots of conductivity by system, year, and site indicated lower measurements in unnamed tributaries that were generally more isolated from roads (Figures 7-10). Conductivity declined as the surveys progressed from March into May in both watersheds during both years. Patterns of decline were different for each year, but similar between the two within a year. During 2008, conductivities in mainstem stations (Mattwoman Creek range = 47-148 µmho / cm; Piscataway Creek range = 163-301 µmho / cm, including TCM1) were stable during March and remained stable until mid-April before falling to a lower level for the remainder of the surveys. During 2009 (Mattwoman Creek's range = 97-737 µmho / cm; Piscataway Creek's range = 115-610 µmho / cm), conductivity was highly elevated in early March in both creeks (≈ 390-620 µmho / cm) following a significant snowfall at the beginning of March before steadily declining through May.

Conductivities had increased in a manner consistent with urbanization in both watersheds, with Mattawoman Creek during 2008 exhibiting measurements closer to historic, presumably more rural, conditions than Piscataway Creek. Conductivities measured in Mattawoman Creek during 2008 fell near or within ranges reported in 1971(O'Dell 1975) and 1989-1991 (Hall et al. 1992) but were mostly in excess of these two studies in 2009. O'Dell (1975) reported conductivity ranges of 50-200 µmho / cm in Mattawoman Creek and 60-220 µmho / cm in samples drawn from Piscataway Creek. Minimum conductivities for Piscataway Creek in 2008-2009 were lower than the maximum of the May 1971 range reported by O'Dell (1975), but were 2-3 times higher than the 1971 minimum. Most mainstem stream conductivity measurements in Mattawoman Creek during 2008 fell slightly above the range reported for March-April 1991 by Hall et al. (1992; 61-114 µmho / cm), but measurements were often well above this range during 2009. Conductivities fell into the 1991 range by late April 2008 and were slightly during the same time frame for 2009 (Figures 7-10).

The trend in median conductivity with distance from the mouth of Mattawoman Creek during 1970-1989 (hereafter, "historic" measurements) was best described by a quadratic regression ($R^2 = 0.37$, $P < 0.001$; Figure 11). Median conductivities were elevated nearest the mouth of the creek (≈ 190 µmho / cm at RKM 5), fell steadily to approximately 80 µmho / cm between RKMs 18 and 27, and then increased to 120-160 µmho / cm in the vicinity of Waldorf. Conductivity measurements were as variable at the upstream station nearest Waldorf (RKM 35) during 1970-1989 as they were near the mouth of the creek where salinity intrusion from the Potomac River was possible (Figure 11).

Conductivity measurements during 2008-2009 monitoring indicated that the impact of urbanization had spread throughout the non-tidal portion of Mattawoman Creek. Conductivities were elevated beyond predicted medians during both years (particularly in 2009) and increased with upstream distance from the confluence of the stream and estuary (Figure 11). Mean conductivities measured at the Sweden Point Marina (RKM 4.7) were similar to historic values, higher than non-tidal medians in 2008, and lower than non-tidal medians in 2009.

Under pristine conditions, rainfall and snowmelt should dilute streamwater and lower conductivity (State Water Resources Control Board 2004). However, elevated conductivity, related primarily to increased chloride concentrations, has emerged as an indicator of impervious surfaces and urbanization (Wenner et al. 2003; Kaushal 2005; Morgan et al. 2007). In many areas, chloride concentrations in urban streams have increased (Kaushal *et al.* 2005) and specific conductance is both a good indicator of chloride levels and watershed urbanization (Morgan et al. 2007). Most inorganic acids, bases, and salts are relatively good conductors, while organic compounds that do not dissociate in aqueous solution conduct current poorly (APHA 1979). Wenner et al. (2003) concluded that routinely measured conductivity was a good way to assess the impact of urban pollution in streams in the Georgia (USA) piedmont.

In addition to conductivity serving as an indicator of multiple effects on habitat related to urbanization leading to chronic and permanent degradation, two additional hypotheses can be proposed for temporary loss of spawning sites in Mattawoman Creek in 2009. These hypotheses are directly related to road salt use after a 140 mm (or 5.5 inches, approximately) snowfall during the first week of March that drastically elevated conductivity.

For the first hypothesis, eggs and larvae may have died in direct response to sudden changes in salinity and potentially toxic amounts of associated contaminants and additives. Use of salt as a deicer could lead to both “shock loads” of salt that may be acutely toxic to freshwater biota and elevated chloride baselines (increased average concentrations) that have been associated with decreased fish and benthic diversity (Kaushal 2005; Wheeler et al. 2005; Morgan et al. 2007). Rapid salinity increases can result in osmotic stress and lower survival since higher salinity represents osmotic cost for fish eggs and larvae (Research Council of Norway 2009). Commonly used anti-clumping agents (ferro- and ferricyanide) mixed in with the road salt are not thought to be directly toxic, but are of concern because they can break down into toxic cyanide under exposure to ultraviolet light. The degree of breakdown into cyanide in nature is unclear, but these compounds have been implicated in fish kills (Burdick and Lipschuetz 1950; Pablo et al. 1996; Transportation Research Board 2007).

A Transportation Review Board (1991) review of salt use policies 20 years ago indicated that Maryland had been applying some of the highest loads per mile in the US. However, the state has recently indicated that a possible change to a low molecular-weight carbohydrate product (Ice B'Gone; www.seaco.com) as a road de-icer is under consideration.

Concerning the second hypothesis, changing stream chemistry may have caused disorientation that disrupted upstream migration of anadromous fish. Elevated conductivity and a trend of increasing values with distance would be indicative of changes in the chemical composition of Mattawoman Creek, especially during 2009. These changes from prevailing historic conditions could prevent anadromous fish from recognizing and ascending spawning areas. Alewife and blueback herring are thought to home to natal rivers to spawn (ASMFC 2009; ASMFC 2009b), while yellow and white perch populations are generally tributary-specific (Setzler-Hamilton 1991; Yellow Perch Workgroup 2002). Physiological details of spawning migrations are not well described for these target species, but homing migration in anadromous American shad and salmon has been attributed to chemical composition, smell, and pH of natal streams (Royce-Malmgren and Watson 1987; Dittman and Quinn 1996; Carruth et al. 2002;

Leggett 2004). Conductivity is related to total dissolved solids in water (Cole 1975) and it was markedly higher during the beginning of the 2009 spawning season than reported ranges in 1971 (O'Dell et al. 1975), 1989-1991 (Hall et al. 1992), and 2008 (Table 4) or historic medians estimated from monitoring data.

Continued stream monitoring in Mattawoman Creek may provide insight into whether spawning site loss between 2008 and 2009 was a chronic response to urbanization or an acute response to road salt. A chronic loss would be indicated by continued low site use or complete site loss, while reoccupation of sites would support an acute response.

Elevated conductivity baselines associated with urbanization were indicated by several phenomena. First, conductivities at mainstem sites were higher than those from unnamed tributaries that were more remote from road networks. Second, most Mattawoman Creek measurements during 2008-2009 did not fall within the conductivity range measured during the same period in 1991. Third, average conductivity during the sampling periods was greater in the more urbanized Piscataway Creek than Mattawoman Creek. Fourth, the conductivity gradient for non-tidal stream waters has changed from declining with distance from the confluence with the estuary during 1970-1989 to increasing with distance during 2008-2009. Finally, median conductivities during 2008-2009 were generally higher than those measured during 1970-1989.

Low site occupation could also have reflected low population sizes; however, species surveyed during 2008-2009 were not at similar relative stock levels. Stock assessments have identified that many populations of river herring (alewife and blueback herring) along the Atlantic coast including those in Maryland are in decline or are at depressed stable levels (ASMFC 2009; 2009b; Limburg and Waldman 2009; Jarzynski and Sadzinski 2009). However, white perch abundance has been at relatively high levels throughout the Maryland portion of the

Chesapeake Bay (Piavis and Webb 2009), while yellow perch abundance has varied from moderate to high for systems where assessments were conducted (Piavis 2009).

Volunteer-based sampling of Piscataway and Mattawoman creeks in 2008-2009 used only stream drift nets, while O'Dell et al. (1975) and Hall et al. (1992) determined spawning activity with ichthyoplankton nets and adult wire traps. Tabular summaries of egg, larval, and adult catches in Hall et al. (1992) allowed for a comparison of how conclusions of site use in Mattawoman Creek might have varied in 1991 with and without adult wire trap sampling. Sites estimated when eggs or larvae were present in one or more samples were identical to those when adults present in wire traps were included with the ichthyoplankton data (Hall et al. 1992). Similar results were obtained from the Bush River during 2006 at sites where ichthyoplankton drift nets and wire traps were used; adults were captured by traps at one site and eggs/larvae at nine sites with ichthyoplankton nets (Uphoff et al. 2007). Wire traps set in the Bush River during 2007 did not indicate different results than ichthyoplankton sampling for herring and yellow perch, but white perch adults were observed in two trap samples and not in plankton drift nets (Uphoff et al. 2008). These comparisons of trap and ichthyoplankton sampling indicated it was unlikely that an absence of adult wire trap sampling would impact interpretation of 2008-2009 spawning sites.

Absence of detectable stream spawning does not necessarily indicate an absence of spawning in the estuarine portion of these systems. Estuarine yellow perch presence-absence results for Mattawoman and Piscataway creeks did not indicate that lack of detectable stream spawning of this species in 2009 corresponded to their elimination from these subestuaries. Although the proportion of standard estuarine plankton tows (see following section) was lower in Piscataway Creek than in Mattawoman Creek (Figure 13), yellow perch larvae were present in both. Yellow perch larvae were highly abundant in the upstream tidal regions of these two subestuaries and much less abundant downstream. This would indicate that spawning occurred primarily in the upper tidal creek reaches and that large numbers of larvae were not drifting or swimming in from the Potomac River. Similar results have been noted in the Bush River, where stream spawning of yellow perch has largely ceased while estuarine spawning activity was high (McGinty et al. 2009). Yellow perch do not appear to be dependent on non-tidal stream spawning, but their use may confer benefit to the population through expanded spawning habitat diversity. Stream spawning is also very important to yellow perch anglers since it provides access for shore fisherman and most recreational harvest probably occurs during spawning season (Yellow Perch Workgroup 2002). The effect of lost stream spawning on the other anadromous species may be different as both blueback and alewife herring ascend streams much further than yellow or white perch.

ESTUARINE YELLOW PERCH LARVAL PRESENCE-ABSENCE SAMPLING

Introduction

Yellow perch larval presence-absence sampling during 2009 was conducted in the upper tidal reaches of the Nanticoke, Bush, Magothy, and Severn rivers and Mattawoman, Nanjemoy, and Piscataway creeks during late March through April (Figure 12). Annual L_p (proportion of tows with yellow perch larvae during a standard time period and where larvae would be expected) provides an easily collected measure of the product of egg production and egg through early postlarval survival. Yellow perch larvae can be readily identified in the field because they are larger and more developed than *Morone* larvae that could be confused with them (Lippson and Moran 1974).

Methods

A conical plankton net towed from a boat to collect yellow perch larvae at 10 sites (7 in Piscataway Creek) per system on 2-3 days each week in the upper portion of the estuaries sampled (Figure 12). Nets were 0.5-m in diameter, 1.0-m long, and constructed of 0.5 mm mesh. The nets were towed for two minutes at approximately 2.8 km per hour. Larval sampling occurred during late March through late April to early May, 2009.

Sites in all rivers except the Nanticoke were sampled with little spacing between tows because larval nurseries areas or the systems themselves were small. Piscataway Creek was only large enough for 7 stations and up to 3 upstream sites could not be sampled at very low tides. Extent of the area to be sampled was determined from bounds of larval presence in surveys conducted during the 1970s and 1980s (O'Dell 1987).

The Nanticoke River was divided into 18, 1.61-km (1-mile) segments that spanned the striped bass spawning ground where historic surveys were conducted (Uphoff 1997; Uphoff et al. 2005). The striped bass spawning area on the mainstem Nanticoke River was divided into upriver, mid-river, and lower river subareas, each containing 5-6 segments and Marshyhope Creek, a tributary, which contained 2 additional segments (Uphoff 1997). Maps detailing segment locations can be found in Uphoff (1997). Ten distinct segments were sampled with a single tow once a trip. Sample trips were made two times per week. Sampling segments were selected randomly in proportion to subarea size. Nanticoke River sampling was piggybacked onto multispecies sampling conducted by the ISSA Project (Project 2, Job 1).

Each sample was emptied into a glass jar and checked for larvae. If a jar contained enough detritus to obscure examination, it was emptied into a pan with a dark background and observed through a magnifying lens. Detritus was moved with a probe or forceps to free larvae for observation. If detritus loads or wave action prevented thorough examination, samples were preserved and brought back to the lab for sorting.

The proportion of tows with yellow perch larvae (L_p) was determined annually for dates spanning the first catch through the last date that larvae were consistently present. Uphoff et al. (2005) reviewed presence-absence of yellow perch larvae in past Choptank and Nanticoke river collections and found that starting dates during the first or early in the second week of April were typical and end dates occurred during the last week of April through the first week of May. Sampling during 2009 began during the last week of March and ended after larvae were absent (or nearly so) for two consecutive sampling rounds. In years where larvae disappeared quickly, sampling rounds into the third week of April were included in analysis even if larvae were not collected. Confidence intervals (95%) were constructed using the normal distribution to approximate the binomial distribution (Ott 1977; Uphoff 1997).

Yellow perch larval presence-absence during 2009 was compared to a record of L_p developed from collections in the tidal Nanticoke (1965-1971 and 2004-2008) and Choptank rivers (1986-1990 and 1998-2003), Mattawoman Creek (1990 and 2008), Severn River (2004-2008), Bush River (2006-2008), Corsica River (2006-2007), Langford Creek (2007), South River (2008), and Piscataway Creek (2008).

Trained volunteers from the Arlington Echo Outdoor Education Center conducted Severn River collections and volunteers from Anita Leight Estuarine Research Center conducted Bush River collections based on the sampling design described above. These volunteers had been instructed by project biologists on collection techniques and larval identification.

Historic collections in the Choptank and Nanticoke rivers targeted striped bass eggs and larvae (Uphoff 1997), but yellow perch were also common (J. Uphoff, MD DNR, personal observation). Larval presence-absence was calculated from data sheets (reflecting lab sorting) through 1990. After 1998, L_p in the Choptank River was determined directly in the field and recorded on data sheets (P. Piavis, MD DNR, personal communication). All tows were made for two minutes. Standard 0.5 m diameter nets were used in the Nanticoke River during 1965-1971 (1.0 * 0.5 mm mesh) and after 1998 in the Choptank River (0.5 mm mesh). Trawls with 0.5 m nets (0.5 mm mesh) mounted in the cod-end were used in the Choptank River between 1986-1990 (Uphoff et al. 2005). Survey designs for the Choptank and Nanticoke rivers are described in Uphoff (1997).

Choptank River and Nanticoke River collections made prior to 1991 were considered an historic reference and their mean L_p (0.66) was used as an estimate of central tendency. Nine of 11 reference estimates of L_p fell between 0.4-0.8 and this was used as the range of the "typical" minimum and maximum. The 95% CI's of L_p of rivers sampled during 2009 were compared to the mean and "typical" range of historic values. Risk of L_p during 2009 falling below a criterion indicating potential poor reproduction was estimated as one minus the cumulative proportion (expressed as a percentage) of the L_p distribution function equaling or exceeding the "typical" minimum (0.4). This general technique of judging relative status of L_p was patterned after a similar application for striped bass eggs (Uphoff 1997).

Associations of mean salinity, IS, and L_p were tested with correlation analysis. Mean salinity of dates and sites used to calculate L_p were estimated for each system sampled during 2009. Past data with salinity measurements were available for Choptank River collections from 1998, 2000, and 2001; Nanticoke River between 2006-2008; Severn River between 2004-2008;

Bush and Corsica rivers between 2006-2008, Langford Creek for 2007, and South River, Mattawoman Creek, and Piscataway Creek in 2008

Linear regression was used to further test whether L_p between 1998-2009 was influenced by IS and salinity. High salinities have been implicated in contributing to low L_p (Uphoff et al. 2005; 2007). The association of mean salinity and IS can be significant and as strong or stronger than those of IS or salinity with L_p (see Results). Ricker (1975) warned against using well correlated variables in multiple regressions, so separate regressions of IS against L_p were developed for fresh-tidal (< 2‰) and brackish tributaries ($\geq$ 2‰) to minimize confounding salinity with IS. Data from additional systems were included in the linear regressions by classifying systems as fresh-tidal or brackish. The Choptank River (1998-2004: IS = 3.0%), Nanticoke River (2004-2009; IS = 2.0%), Severn River (2004-2009; IS = 19.5%), , Corsica River (2006-2007; IS = 4.1%), Langford Creek (2007; IS = 3.1%), South River (2008; IS = 10.9%), Nanjemoy Creek (2009; IS = 0.9%), and Magothy River (2009; IS = 20.2%) were classified as brackish systems. The Bush River (2006-2008; IS = 11.3%), Mattawoman Creek (2008-2009; IS = 9.0%), and Piscataway Creek (2008-2009; IS = 16.5%) were classified as fresh-tidal. Residuals were inspected for non-normality and need for additional terms.

Results and Discussion

Proportions of tows with larval yellow perch in brackish systems with high IS, Severn River (L_p = 0.15, SD = 0.05, N = 60; 19.5 % IS) and Magothy River (L_p = 0.17, SD = 0.08, N = 24; 20.2 % IS), during 2009 were significantly lower than the historic reference range of L_p (Figure 13) based on 95% confidence interval overlap. Confidence intervals of L_p in Piscataway Creek (L_p = 0.39, SD = 0.08, N = 33; 16.5% IS), and the Nanticoke River (L_p = 0.41, SD = 0.07, N = 46; 2.0 % IS) overlapped the lower bound of the historic reference range. Mattawoman

Creek (L_p = 0.92, SD = 0.04, N = 60; 9.0% IS) fell above the historic reference upper limit, while Nanjemoy Creek (L_p = 0.83, SD = 0.05, N = 60; 0.9% IS) and Bush River (L_p = 0.86, SD = 0.08, N = 33; 11.3% IS) overlapped the upper reference level (Figure 13).

Risk of falling below the "typical" historic minimum of L_p = 0.4 during 2009 was near 100% in high IS brackish systems (Magothy and Severn rivers). Moderate risk was present in the high IS fresh-tidal Piscataway Creek and the low IS Nanticoke River (45% and 37%, respectively). Risk of being below the historic minimum was near zero in Mattawoman and Nanjemoy creeks and the Bush River

Brackish systems with small watersheds and high IS (South, Severn, and Magothy rivers) have exhibited a persistent depression in $L_{p,}$ below the reference minimum, while remaining systems have exhibited extensive variation (Figure 14). Interpretation of L_p in recent years has been based on comparisons with previous collections from rural systems (Choptank and Nanticoke) located on the Eastern Shore. These reference rivers have larger watersheds and more extensive regions of fresh-tidal water than some brackish tributaries sampled. However, L_p estimates from tributaries other than the Nanticoke or Choptank rivers (and excluding high IS brackish systems) during 2006-2009 have fallen within or above the historic reference range and the range that the reference rivers exhibited after the1965-1990 reference period (Figure 14).

Mean salinity was negatively associated with L_p (r = -0.45, P < 0.02). The association of IS and L_p (r =-0.36, P < 0.07) was marginal. Correlation analysis indicated a significant association between IS and mean salinity as well (r = 0.52, P < 0.006).

Linear regressions of L_p against IS by salinity category were significant (P < 0.05). The relationship of L_p and IS in fresh-tidal tributaries was described by the equation:

$L_p = (-0.052 \cdot IS) + 1.31$ (r^2 = 0.51, P = 0.048, N = 8; Figure A-4);

where IS = impervious surface percentage. Standard errors for the IS and intercept were 0.021 and 0.26, respectively. In brackish systems, the relationship of L_p and IS was described by the equation:

$$L_p = (-0.018 \bullet \text{IS}) + 0.55 \ (r^2 = 0.35, P = 0.002, N = 25; \text{Figure A-4}).$$

Standard errors for the slope and intercept were 0.005 and 0.05, respectively.

Residuals of both regressions appeared normally distributed with a mean very near zero and inspection of plots of residuals against predicted L_p did not indicate a need for additional terms.

These regressions indicated IS was negatively related to L_p, but the relationships were different in fresh-tidal and brackish systems. On average, L_p would be higher in fresh-tidal systems until high levels of IS (≈ 20%) were reached (Figure 15). No estimates of L_p from fresh-tidal systems with low IS (5% or less) are available; however, predicted L_p approaches 1.0 at the lowest estimate of IS (9%). The fresh-tidal relationship suggests an asymptotic relationship with an IS threshold of approximately 10%; L_p would remain high and steady (on average) below the threshold (since L_p cannot be higher than 1) and then decline rapidly beyond it. The dichotomous nature of the distribution of IS in brackish systems (a large, variable cluster of points at < 5% IS, a tightly grouped cluster of low values at 20% IS, and one low point at 11% IS) makes detection of a threshold difficult (Figure 15). Both relationships converge just beyond 20% IS at low L_p (< 0.2) when the fresh-tidal relationship was projected. This convergence may represent the lowest level of L_p likely to be observed for systems where yellow perch have not been extirpated.

The frequency distribution of L_p values since 1965 in areas other than high IS brackish systems (Severn, South, and Magothy rivers) exhibits a bimodal distribution (Figure 16). Values of L_p range from 0.19 to 1.0 and modes of L_p appear at 0.5 and 0.9, with a nadir at 0.7 (Figure 16). Qualitatively, L_p is either good or bad. Low L_p such as that consistently exhibited in the Severn, South, and Magothy rivers is rare in the other systems studied and occurs less than 10% of the time. Modes were not composed exclusively of fresh-tidal or brackish systems. Assuming catchability does not change greatly from year to year, egg production and egg through larval survival would need to be high to produce strong L_p, but only one needs to be low to result in low L_p.

L_p is not a measure of year-class success. Significant processes may exist that limit year-class success after larvae become too large to be sampled effectively by plankton nets. If survival of each life stage is independent of the other, a log-normal distribution of L_p might be expected (Hilborn and Walters 1992), i.e., high estimates of L_p would be uncommon and would represent the upper tail of the distribution. The bimodal frequency distribution of L_p suggests a lack of independence of processes influencing L_p. Year-class success of yellow perch has been reliably measured in the Head-of-Bay region by the Maryland Juvenile Striped Bass Survey (Yellow Perch Workgroup 2002; Durell and Weedon 2010) and the frequency distribution of these indices (1966-2009) can be described by a log-normal distribution (J. Uphoff, unpublished analysis). Given the caveat that the Head-of-Bay and the regions where L_p has been estimated are different, the log-normal frequency distribution of Head-of-Bay YOY and bimodal L_p distribution indicate that additional independent and important periods of larval survival occur at larval stages beyond those sampled effectively by 0.5 m nets used to estimate L_p.

SUMMER ESTUARINE SEINING AND TRAWLING

Methods

Impervious surface (IS) was estimated from Towson University interpretation of Landsat, 30-meter pixel resolution satellite imagery (Eastern Shore of Chesapeake Bay in 1999 and western shore in 2001) for each watershed (Barnes et al. 2002; See Indicators of Land-Use section). General land-use for all watersheds (i.e., percent urban, forest, etc.; all non-water acreages) was based on MDP data (http://www.dnr.state.md.us/watersheds/surf/)). Urban land-use consisted of low through high-density residential and industrial designations. Water surface area, in acres, was estimated with the planimeter function on MDMerlin satellite photographs and maps (www.mdmerlin.net). Shorelines were traced five times for each water body and an average acreage was calculated. The lower limit of each water body was arbitrarily determined by drawing a straight line between the lowest downriver points on opposite shores.

Ten watersheds were sampled in 2009, three in the upper Bay, three in mid-Bay and four in the Potomac drainage (Figure 17; Table 9). Tidal-fresh tributaries (median salinity < 2‰; Table 9) sampled in 2009 included Mattawoman Creek, Piscataway Creek, Bush River, Gunpowder River and Northeast River (Figure 17). IS was estimated to cover approximately 1-16.5% of these watersheds. Nanjemoy Creek (0.9% IS) and Middle River (39% IS) were originally selected as fresh-tidal tributaries, but 2009 was abnormally dry through approximately mid-year (http://www.drought.gov/portal/server.pt/community/drought.gov/202/area_drought_information?mode=2&state=MD) and salinities were elevated. The Corsica River (4.1% IS), Tred Avon River (5.6% IS), and Wicomcio River (4.3%) were considered brackish (> 5‰) tributaries.

Four evenly spaced haul seine and bottom trawl sample sites were located in the upper two-thirds of each tributary (Figures 18-27). Sites were not located near the tributary mouth to reduce influence of the mainstem Bay or Potomac River waters on water quality measurements.

Bi-weekly sampling occurred from July through September with each site being sampled once per visit. All sites on one river were sampled on the same day. Sites were numbered from upstream (site 1) to downstream. The crew leader flipped a coin each day to determine whether to start upstream or downstream. This coin-flip somewhat randomized potential effects of location and time of day on catches and dissolved oxygen concentrations. However, sites located in the middle would likely not be influenced by the random start location as much as sites on the extremes because of the bus-route nature of the sampling design. If certain sites needed to be sampled on a given tide then the crew leader deviated from the sample route to accommodate this need. Trawl sites were generally in the channel, adjacent to seine sites. At some sites, seine hauls could not be made because of permanent obstructions, thick SAV beds, or lack of beaches. The latitude and longitude of the trawl sites was taken in the middle of the trawl area, while seine latitude and longitude were taken at the exact seining location.

Water quality parameters were recorded at all sites. Temperature (ºC), DO (mg/L), conductivity (µmho), salinity (‰) and pH were recorded for the surface, middle and bottom of the water column at the trawl sites and at the surface of the seine site. While a suite of water quality parameters were measured, DO was considered the estuarine habitat indicator for IS effects. Mid-depth measurements were omitted at shallow sites with less than 1.0 m difference between surface and bottom. Secchi depth was measured to the nearest 0.1 m at each trawl site. Weather, tide state (flood, ebb, high or low slack), date and start time were recorded for all sites.

Trawls and seines were used to sample fish. Target species were striped bass, yellow perch, white perch, alewife, blueback herring, American shad, spot, Atlantic croaker, and Atlantic menhaden. Gear specifications and techniques were selected to be compatible with other Fisheries Service surveys.

A 4.9 m semi-balloon otter trawl was used to sample fish in the mid-channel bottom habitat. The trawl was constructed of treated nylon mesh netting measuring 38.1 mm stretch in the body and 33 mm stretch mesh in the codend, with an untreated 12 mm stretch knotless mesh liner. The headrope was equipped with floats and the footrope was equipped with a 3.2 mm chain. The net was 0.61 m long by 0.30 m high with the trawl doors attached to a 6.1 m bridle leading to a 24.4 m towrope. Trawling was in the same direction as the tide. The trawl was set up tide to pass the site halfway through the tow thus allowing the same general area to be sampled regardless of tide direction. A single tow was made for six minutes at 3.2 km/hr (2.0 miles/hr) per site on each visit. Upon completion, the contents of the trawl were emptied into a tub for processing.

An untreated 30.5 m • 1.2 m bagless knotted 6.4 mm stretch mesh beach seine, the standard gear for Chesapeake Bay inshore fish surveys (Durell and Weedon 2010), was used to sample inshore habitat. The float-line was rigged with 38.1 mm • 66 mm floats spaced at 0.61 m (24 inch) intervals and the lead-line rigged with 57 gm (2 ounce) lead weights spaced evenly at 0.55 m (18 inch) intervals. One end of the seine was held on shore, while the other was stretched perpendicular to shore as far as depth permitted and then pulled with the tide in a quarter-arc. The open end of the net was moved towards shore once the net was stretched to its maximum. When both ends of the net were on shore, the net was retrieved by hand in a diminishing arc until the net was entirely pursed. The section of the net containing the fish was then placed in a washtub for processing. The distance the net was stretched from shore, maximum depth of the seine haul, primary and secondary bottom type, and percent of seine area containing aquatic vegetation were recorded.

All fish captured were identified to species and counted. Striped bass and yellow perch were separated into juveniles and adults. White perch were separated into three categories (juvenile, small, and harvestable size) based on size. The small white perch category consisted of age 1+ white perch smaller than 200 mm. White perch greater than or equal to 200 mm were considered to be of harvestable size and all captured were measured to the nearest millimeter.

Water quality data were compared to fish habitat criteria (Table 10) and reported as deviations from a target or limit (McGinty et al. 2006). Dissolved oxygen and temperature measurements were examined by watershed to determine habitat suitability for the target species. Percent of measurements that did not meet these requirements (violations) were calculated by river.

Presence-absence of targeted finfish species and life stages was used to examine changes in populations of various species, because it was robust to errors and biases in sampling, and reduced statistical concerns regarding contagious distributions and high frequency of zeros; (Green 1979; Mangel and Smith 1990; Uphoff 1997). Presence-absence was calculated as the proportion of samples containing a target species and life stage for species separated into juveniles and adults. Confidence intervals (95%) were estimated by using the normal distribution to approximate the binomial probability distribution (Ott 1977). This approximation can be used when the sample size is greater than or equal to 5 divided by the smaller of the proportion of positive or zero tows (Ott 1977). Interpreting absence can pose interpretation problems (Green 1979) and sampling and analyses were generally designed to confine presence-absence to areas and times where species and life stages in question had been documented.

Relative abundance of all finfish combined was summarized as catch per unit effort (CPUE). General summaries of total catches were based on an arithmetic mean, but means of $\log_{10}$-transformed catches were used in some analyses. Typically, natural logarithms are used on ecological data to induce normality and reduce variability (Green 1979). The $\log_{10}$ transformation can be similarly applied and is easier to convert into a numeric scale on inspection (i.e, 2 = 10^2 or 100; 3 = 10^3 or 1,000). Species diversity was summarized as number of species captured (richness; Kwak and Peterson 2007). General comparisons among watersheds sampled during 2009 and exploratory analyses of hypotheses have been conducted that examined the role of development on the target species and fish communities for several established time-series. Details of these analyses are described in the sections that follow.

Results and Discussion

2009 Water Quality

Water quality data were examined to determine if habitat requirements were met for target species (Table 11). The Bush and Northeast rivers were the only rivers where temperature exceeded the criteria of 31°C (1.2%, Table 11). Among the tidal-fresh rivers three systems (Northeast River, and Mattawoman and Piscataway creeks) did not have DO violations (below the 5.0 mg/L living resources criterion; USEPA 2003; McGinty et al. 2009) for all habitats and depths. The Bush, Gunpowder and Northeast rivers had a very low percentage of DO violations with none greater than 5.6% (Table 11). In contrast, all brackish (mesohaline) tributaries had violations of the 5.0 m/L criteria, and all but Tred Avon River had violations of 3.0 mg/L.

Nanjemoy Creek, the least developed brackish system surveyed, had the lowest level of DO violations (5.6%). The Corsica River had the greatest percentage of violations for both the 5.0 and 3.0 mg/L criteria. The Wicomico River had the second highest violation for both criteria (60.0% - 5.0 mg/L, 30.0% - 3.0 mg/L) (Table 11). Middle River, the most heavily developed sub-estuary, had frequencies of DO violations that were similar to less developed Tred Avon River and far less than Wicomico and Corsica rivers (Table 11).

Generally, tidal fresh subestuaries experienced few DO criteria violations than mesohaline subestuaries. Uphoff et al. (2009) reported frequent violations of DO criteria in mesohaline habitats associated with suburban landscapes. Salinity is a major source of differences in water density that impedes mixing and promotes stratification which influences oxygen depletion (Reid and Wood 1976; Eby and Crowder 2002; Kemp et al. 2005). Stratification of these mesohaline habitats has the potential to reduce flushing rates and contribute to lower oxygen concentrations because the exchange between oxygen poor and oxygen rich water is limited (Kemp et al, 2005). In tidal-fresh habitats, there is limited stratification (temperature related density differences) of the water column, so mixing is more likely. This does not mean these regions are immune to impacts of urbanization, and other habitat stress indicators associated with development in fresh-tidal systems need to be developed.

2009 Fish Sampling

A total of 90,075 fish (trawl and seine) were captured representing 55 species in 2009. Of these species, 8 comprised 90% of the catch. These species, in descending order, included white perch, bay anchovy, gizzard shad, blueback herring, Atlantic menhaden, spottail shiner, Atlantic silverside, and pumpkinseed. Only three of these species, white perch, Atlantic menhaden, and blueback herring were target species.

Seining was conducted in all systems except Mattawoman and Piscataway creeks because of thick SAV beds. Seining in Middle River ceased after the first month of sampling because SAV had extensively populated the sampling areas. Seining at station 4 in the Gunpowder River was also discontinued after the first round of sampling for the same reason. A total of 32,377 fish representing 47 species were captured in the seine. Nine species comprised 90% of the catch. They were, in descending order, white perch, gizzard shad, blueback herring, Atlantic menhaden, Atlantic silverside, spottail shiner, pumpkinseed and striped killifish. The greatest number of species in the seine was observed in the Gunpowder River, while CPUE was greatest in the Bush River (Table 12).

Trawl sampling was conducted in all systems (Table 13). A total of 57,698 fish were captured, representing 46 species. Three species comprised 90% of the total trawl catch; white perch, bay anchovy, and pumpkinseed. The number of species was highest in the Gunpowder River while CPUE was greatest in Nanjemoy Creek (Table 13).

Proportion of positive tows was calculated by river for all target species in trawls and seines (Table 14). White perch were the most prevalent species captured in both gears in all watersheds. The only exception was in Mattawoman Creek where juvenile striped bass were present more frequently than white perch juveniles or adults.

White perch percent presence (Wp or proportion of trawls with white perch present) in 2009, examined by river for trawls only, was high in seven systems and low in three (Table 15). The systems with high Wp had a mix of IS estimates, ranging from 0.9-39.1%, and were fresh-tidal to brackish. The low Wp systems had low to near threshold IS, 4.3-9.0% and consisted of two brackish and one fresh-tidal subestuary. Low Wp in the brackish Wicomico and Tred Avon rivers reflected low abundance of juveniles, while both adults and juveniles were poorly represented in fresh-tidal Mattawoman Creek. Low juvenile Wp in Wicomico and Tred Avon rivers would not be unusual because of their high salinities and low to modest year-class success in their main spawning rivers in 2009 (Durrell and Weedon 2010; Uphoff et al. 2009). Changes in Wp for both juveniles and adults in Mattawoman Creek (2009 Wp = 0.33 and 0.46 for juveniles and adults, respectively) represent a major change from past distributions (Wp = 0.88-1.0 during 2003-2007 for juveniles and adults). Tributaries upstream (Piscataway Creek) and downstream (Nanjemoy Creek) of Mattawoman Creek did not exhibit low Wp (Table 14).

EXAMINATION OF LONG-TERM DATA

Mattawoman Creek

Mattawoman Creek has been sampled continuously since 1989 (Carmichael et al. 1992). Until 2003, sampling was conducted monthly during July-September. Seining and trawling was conducted at five stations spaced evenly along the subestuary. Water quality measurements were taken at surface, mid-water and bottom depths in the trawl area using a Hydrolab (Carmichael et al. 1992). Trawl specifications changed in 2003. Those used during 1989-2002 were smaller (10 foot headrope and smaller mesh; Carmichael et al. 1992) than the 16 foot headrope trawl employed since 2003. The 10 foot trawl was towed for five minutes and the 16 foot trawl was towed for six minutes in the channel with the tide. Both gears were used in 2009 in Mattawoman Creek with the tow durations described above to analyze how this gear change may have affected habitat evaluation. Unfortunately, most of the 2009 small trawl samples did not catch any fish and species specific adjustments were not possible. However, comparisons of the small trawl catch of all species of fish and species richness in 2009 could be made with historic (1989-2002) samples. The last seven years of data from the large trawl were also evaluated.

A decline in number of species collected was noted with both gear types (Figure 28). Mean number of species collected in the small trawl during 1989-2002 was 28.7. In 2009, only 11 species were observed in the small trawl even though bimonthly sampling nearly doubled the effort employed annually during 1989-2002. Species richness estimates are positively influenced by sample size (Kwak and Anderson 2007). Thirteen species were identified in the large trawl in 2009 - seven less than 2008 (Figure 28). Sampling effort was biweekly for this entire time-series.

Mean number of species captured in small trawls was calculated by station for the historic period (1989-2002) and compared to richness in the small trawl by station for 2009 (Table 16). Species richness declined at all stations: Station 1 by half; Station 2 by one species; no catch at Station 3 (from a mean of 8.5 species); and Station 4 declined by nearly one third (Table 16).

Changes in richness in the small trawls were also examined by month (Table 16). Little change in richness was indicated in July, 2009. August had the most drastic decline in richness, going from an average of 10.5 species during 1989-2002 to 1 in 2009. Richness recovered somewhat by September, 2009 (Table 16)

Mean $\log_{10}$-transformed catch of all species + 1 ($\log_{10}$ N) declined for both trawls (Figure 28). Examination of $\log_{10}$ N at each station indicated that declines began upstream and progressed downstream over time (Figure 29). Small trawl $\log_{10}$ N at Stations 1 and 2 had begun to decline in the early 2000s and 2002 was not visually different than 2009. Station 3 small trawl $\log_{10}$ N did not noticeably decline until 2002, but the decline between 2002 and 2009 was more pronounced. Station 4, nearest the junction with the Potomac River, underwent the least decline. Large trawl $\log_{10}$ N (2003-2009) had declined considerably at Stations 1-3 and may have declined to a lesser extent at Station 4 (Figure 29).

Potomac River seining data (Durrell and Weedon 2010) were examined to determine if these declining trends were unique to Mattawoman Creek or were more widespread. Species richness, abundance, and presence of dominant species over the last 20 years at four seining sites (representing nearshore habitat) on the upper Potomac River (below and above Mattawoman Creek) were examined (Figure 30). These nearshore fish community samples were then compared to Mattawoman trawl data from channel habitat. We assumed that nearshore community changes could occur if changes observed in Mattawoman Creek were occurring on a larger scale (ie. Potomac River). Species richness fluctuated in the seining data over time at each station (Figure 31). However, the Indianhead station (just outside of Mattawoman Creek) did decline from 14 species in 2007 to 10 species in 2008 and 2009. This represents two species less than the lowest count (1990; Figure 31), but is difficult to judge whether this decline was different from natural variation. Like species richness, $\log_{10}$ N fluctuated but did not change significantly at any of the four stations sampled (figure 31). None of the seven species comprising 90% of the catch changed in terms of presence-absence when all stations were examined collectively (Figure 32). These seining data did not support the hypothesis of a more widespread decline in community richness or abundance in the upper tidal Potomac River. Therefore, declines observed in Mattawoman Creek over the twenty year record were unique to Mattawoman Creek.

Number of species (S) collected annually and $\log_{10}$ N were used as dependent variables to investigate their relationship with development in the Mattawoman Creek watershed during

1989-2009. These dependent variables were chosen because they were basic, easily understood, and robust indicators of fish diversity and abundance (Kwak and Peterson 2007). Log_{10} N was not impacted by large amounts of zero catches as most single species indicators were.

Plots of the S and log_{10} N time-series indicated that both were stable (with some variation) into the early to mid-2000s (Figure 28). A large drop in log_{10} N in the 10 ft trawl occurred in 2002 and log_{10} N was even lower by 2009 when the gear was used along with the 16 ft trawl. A change to a 16 ft trawl in 2003 was made and the time-series plot suggested that S and log_{10} N had increased with the gear change, but both declined substantially by 2009. Surveys during 1989-2002 using the 10 ft trawl were conducted monthly, while surveys using a 16 ft trawl occurred twice a month as did the concurrent 10ft trawl survey in 2009. Number of species collected, particularly the collection of uncommon species, was very likely affected by sample size and size of gear employed (Kwak and Peterson 2007). Size of gear would affect log_{10} N, but the number of samples would likely affect estimation of variability much more than average total catch. In general, changes in S and log_{10} N suggested a negative threshold was crossed in 2002.

Linear regressions with indicator variables and slope shift coefficients (Freund and Littel 2000) were used to analyze S and log_{10} N for threshold responses to counts of structures built in the watershed (C). Structure counts were not available for 2009 and 1989-2008 data were analyzed (Table 17). Number of structures was considered an index of IS (see *Indicators of Land Use* section). Both gear (G) and years where a threshold (Y) was crossed or not crossed were coded as binary variables. Years where a 10 ft trawl was used were coded as 0 (1989-2002) and years where a 16 ft trawl was used (2003-2008) were coded as 1. Based on the beginning of a decline in log_{10} N (Figure 28), 2002 was designated as the year threshold effects began; years during 1989-2001 were coded 0 and years during 2002-2008 were coded as 1. A slope shift coefficient was estimated to detect the threshold effect of C on S and $\log_{10}$ N. The slope shift coefficient was estimated by including a variable equal to the product of C multiplied by Y (Freund and Littel 2000; Table 17). The equation for the multiple regression was

$$S \text{ or } \log_{10} N = a \bullet H + b \bullet G + c \bullet Y + d \bullet (C \bullet Y) + I;$$

where a, b, c, and d are coefficients and I is the intercept. If the slope shift coefficient (d) was significantly different ($P < 0.05$) from zero, the analysis would be considered complete (Freund and Littel 2000). The coefficient for the lower order terms (single terms with no interaction) would not be evaluated in the presence of higher order terms (Freund and Littel 2000). Residuals were examined for normality and trends with time or predicted S and $\log_{10}$ N.

Regressions for S ($R^2 = 0.78$) or $\log_{10}$ N ($R^2 = 0.72$) were highly significant ($P < 0.0005$; Tables 18 and 19). Importantly, the time by structure terms, d•(C•Y), which tested for change in slopes following the crossing of a development threshold in 2002, were significant for both S ($P = 0.05$; Table 18) and $\log_{10}$ N ($P = 0.001$; Table 19). Trends in residuals with time or with predicted S or $\log_{10}$ N were not indicated. Residuals of the $\log_{10}$ N regression appeared normally distributed. Residuals of the S regression were somewhat positively skewed with a positive secondary mode and it was difficult to judge whether these residuals were normally distributed or not.

While structure counts steadily increased from 10,943 to 21,290 between 1989-2008, both models described little or no effect of development until a threshold of approximately 18,000 structures was reached (Figure 33). Development beyond this threshold was followed by declines of S and $\log_{10}$ N (Figure 33).

We have some concern that these regression models of structures versus S or $\log_{10}$ N may have been overfitted (too many terms for the amount of observations; Babyak 2004). Overfitted models will fail to replicate in future samples. As a rule of thumb, a minimum of 10-15 observations per predictor will generally allow for good estimates from multiple regression models (Babyak 2004). The models utilized had 20 observations and 4 variables, or five observations per variable. Gear changes required an additional variable and, unfortunately, the gear change is nearly concurrent with the threshold year which may result in confounding the estimates. These problems do not preclude usefulness of these regressions, but this note of caution is necessary (Babyak 2004). Adjusted R^2's provide some indication of how overoptimistic the estimated relationships may be by accounting for the number of variables in calculating model fit (Freund and Littel 2000; Babyak 2004). Adjusted R^2's were 0.72 and 0.65 for S and $\log_{10}$ N, respectively, indicating fit would be nearly as good. The addition of 2009 structure data for future analysis may aid interpretation of whether overfitting is a problem since it will allow for inclusion of a year where both type of trawls were used. Collecting more data is a strategy for overcoming overfitting (Babyak 2004) and sampling with both trawls in this system will take place next year.

In the *Indicators of Land Use* section, an equation was developed to convert structures per acre to an estimate of "new" Towson IS which was subsequently applied to estimated IS associated with the threshold response in the Mattawoman Creek watershed. The equation describing the relationship of IS to structure count per area (C), $IS = 0.0071C^{1.65}$, can be solved for IS. The level of IS corresponding to the 2002 structures per acre threshold, (18,456 structures / 56771.5 acres or 0.324) was predicted by this equation to be 10.2% IS. This estimate is close to the 10% threshold level of IS developed from brackish subestuaries (Uphoff et al. 2009). Impervious surface was estimated from the equation above to occupy 11.1% of the Mattawoman Creek watershed in 2008.

Mattawoman Creek water quality data collected during fish sampling were also examined. Annual distribution of DO was examined to determine if oxygen dynamics changed over the twenty-year record (Figure 34). Prior to 2006, there was just one DO measurement (in 2001) violating the 5.0 mg/L criterion. In 2006, 16.7% of DO measurements were less than the 5.0 mg/L criterion and 4.2% were less than the 3.0 mg/L criteria. This was the only year the 3.0 mg/L criterion was violated. In 2007, 5.0 mg/L was violated 16.7% of the time and 4.5% of the time in 2008. There were no violations of these criteria in 2009. By and large, DO levels recorded in the daytime monitoring of channel conditions have been acceptable and do not indicate extensive depletion observed in brackish western shore tributaries such as the South and Severn rivers (Uphoff et al. 2005; 2009). However, these changes could indicate significant shifts in ecological processes that are concurrent with changes in the finfish community.

To further evaluate habitat conditions in Mattawoman Creek, 2009 continuous monitoring data from DNR's Resource Assessment Service monitoring station at the Sweden Point Marina was examined (http://mddnr.chesapeakebay.net/newmontech/contmon/eotb_results_graphs.cfm?station=mattawoman). This site was located near-shore in a dense SAV bed and continuous DO measurements from this site indicated frequent violations of the 5.0 mg/L criteria (Table 20). The most frequent violations were observed during August where the 5.0 mg/L criterion was violated 42% of the time (Table 18). Violations of the 3.0 mg/L criterion also increased over time with the greatest percentage of violations occurring in August of 2009 (Table 20). Declining DO at this continuous monitoring site may also be attributable to dense SAV beds in the area. The invasive, *Hydrilla verticillata*, appears to be the dominant species in Mattawoman Creek (McGinty, personal observation). Miranda et al. (2000) observed localized hypoxia in dense SAV beds in a reservoir. Caraco and Cole (2002) reported that beds of nonnative SAV (water chestnut *Trapa natans*) in the Hudson River were more likely to contribute to localized hypoxia than beds dominated by native species. Given these results, it is possible that the dense vegetation in Mattawoman Creek contributes to localized hypoxia. Despite documenting localized hypoxic conditions in SAV beds, Miranda et al. (2000) did not observe declines in fish densities, suggesting that these hypoxic microhabitats may exist without having a significant impact on fish densities.

Tidal-fresh systems have been more resilient in terms of DO responses to IS than brackish systems described by Uphoff et al. (2009). Lack of salinity-driven stratification, coupled with phosphorus (P) reductions may explain the different DO dynamics in tidal-fresh systems (Kemp et al. 2005). Limitation of P in the Potomac River point sources was followed by decreased algal biomass, reduced organic loading, higher DO, increased water clarity and recolonization of shoals with submerged aquatic vegetation (SAV; Kemp et al. 2005). Recent DNR water quality monitoring of the mid-Potomac River region indicates phosphorus and chlorophyll a concentrations are "good", with concentrations of phosphorus and chlorophyll a declining between 1995 and 2006 (http://www.dnr.state.md.us/bay/tribstrat/mid_pot/mp_status_trends.html).

DNR water quality monitoring stations in Mattawoman Creek indicate similar changes in P, DO, water clarity, and SAV as described for the tidal-fresh mainstem Potomac River. In Mattawoman Creek, chlorophyll a has been steady and in the "good" range at the upper station and "fair" and declining at the lower station. Total P was "good" at both stations and declining (http://www.dnr.state.md.us/bay/tribstrat/low_pot/lp_statu_trends.html). These declines in phosphorus with attendant declines in chlorophyll a are likely contributing to improved water clarity and increased SAV growth in Mattawoman Creek. SAV coverage in Mattawoman Creek increased from 96 acres in 1989 to approximately 800 acres during 2005-2008 (http://web.vims.edu/bio/sav/SegmentAreaChart.htm). These SAV affect biogeochemical processes by enhancing deposition of suspended particles, thereby increasing water clarity, benthic photosynthesis, and nutrient assimilation (Kemp et al. 2005).

Nonlinear ecological feedback may yield poorer conditions than those expected at low levels of P (Kemp et al. 2005) and recent increases in DO violations may indicate Mattawoman Creek has undergone a negative change even though P trends have been favorable. Over the past two decades, the number of structures built in the watershed nearly doubled and attendant infrastructure (roads, sewers, schools, shopping centers, etc) would have increased concurrently. Multiple stressors besides nutrients (detrimental flow conditions, sediment, contaminants, invasive species, and elevated water temperature) are associated with development and IS (NRC 2009). Fish community richness and abundance has drastically declined recently and recent DO trends may be an additional signal of a negative habitat shift. Changes in the fish community may not be linked directly to changes in DO and these data may be symptoms of factors not captured directly by these indicators. Though it is not conclusive that increased urbanization has caused these declines, there is considerable literature that implicates development as a factor degrading Mattawoman Creek's estuarine fish habitat (Beach 2002; Capiella and Brown, 2001; Holland et al. 2004; Uphoff et al. 2005; Uphoff et al. 2009).

An alternate hypothesis of more widespread changes was not supported by other Potomac River monitoring (MD DNR seine survey and water quality monitoring) nor do comparisons with other systems sampled in 2009 support this hypothesis. Mattawoman Creek's species richness and CPUE rank last in comparison with other watersheds monitored in 2009.

Mattawoman Creek was characterized in the early 1990s as “near to the ideal conditions as can be found in the northern Chesapeake Bay, perhaps unattainable in the other systems, and should be protected from overdevelopment.” (Carmichael et al. 1992). Mattawoman Creek watershed sits within a large portion of the growth district of Charles County (Charles County Government, 2006) and, as development increased beyond this watershed’s threshold, substantial declines in the fish community followed. By 2009, the creek has become seriously degraded as fish habitat. Planned levels of development in Mattawoman Creek’s Watershed to 22% IS should be reconsidered in light of the extent of declines detected in the fish community at current IS (11%). Without effective mitigation and restoration, further increases in impervious surface will result in irreversible ecological changes.

Corsica River

The Corsica River watershed was selected as a targeted watershed by MDDNR in 2005 to demonstrate the effectiveness of restoration practices (Rettig and Rochez 2009). This watershed is predominately in agriculture and much of the restoration focus has centered on reducing nutrient loads. Extensive monitoring is being conducted to track changes in both habitat and biota. The tidal fish community has been monitored since 2003 as part of this project.

Evaluation of water quality data show that the river has had violations of the 3.0 mg/L and 5.0 mg/L criteria each year since 2003 (Figure 35). Though the percentage of violations changed from year to year, they appear to have varied without trend. The temperature criterion of 31°C was exceeded in two years (2005 and 2006; Figure 36).

Species richness in the Corsica River remained fairly steady and rose slightly in the seine samples collected in 2009 (Figure 37). CPUE initially declined in the trawl samples and then recovered, while those for the seine showed a slight decline the first three years but stabilized thereafter (Table 21).

At this point, there is no indication that the Corsica River is either exhibiting improvements or declines in habitat quality based on water quality and fish assemblages. At present, the community appears to reflect what is expected of a low IS (4.1%) mesohaline habitat in the Chesapeake Bay. McGinty et al (2009) compared Corsica River to Langford Creek (IS = 3.1%), a similar sized watershed across the Chester River from the Corsica and found that the fish communities were similar in richness and abundance.

Wicomico River

The Wicomico River, a tributary to the Potomac River, was monitored annually from 1989 to 2003. It was considered a reference tributary for other mesohaline tributaries because of its rural watershed (Carmichael et al. 1992). The Wicomico was revisited in 2008 and 2009 by the ISSA Alosine Investigation (Project 2, Job 1), and the data were evaluated to determine the status of the habitat and fish community. The Wicomico watershed boundaries lie within two Maryland counties; Charles and St Mary's. According to the U.S. Census Bureau (2009), both counties experienced significant growth between 2000 and 2008. Charles County population grew by 16.8% and St. Mary's County by 17.8%. Since the mean travel time to work is between 30 and 40 minutes, this growth is probably spill over from Washington, DC. Growth projections provided by the Maryland State Archives suggest both counties will continue to grow, with population increasing by another 25.9% in Charles County and 28.1% in St. Mary's County by 2020 While growth will be directed within approved growth districts that are generally outside of the Wicomico River watershed in both counties, variances can be approved to develop outside of the growth envelope (St. Mary's County Planning Commission, 2003). Increased road density to accommodate growing transportation needs may impact the watershed. Because strong growth has occurred in the county since 2000, the Wicomico River Estuary was revisited to determine if the fish community and supporting habitat had changed in response to the population increase.

From 1989 to 2002, five equally spaced stations were sampled monthly in the Wicomico River. Water quality was recorded at these stations and DO dynamics were evaluated. Historically, bottom DO in the Wicomico River declined from upstream to downstream. Table 22 presents proportion of concentrations below the 5.0 and 3.0 mg/L living resources criteria (U.S. EPA 2003) and the mean and range of values observed over the 1989 to 2002 time frame. These represent three samples annually over thirteen years of sampling. There were numerous DO violations of both the 5.0 and 3.0 mg/L criteria. The greatest number of violations was observed near the mouth of the river and fewest in the two upstream stations (Table 22) during 1989-2002. Minimum bottom DO also declined with distance from the mouth of the river, suggesting the source of low DO was from mainstem Potomac waters. In 2003, sampling effort increased from one to two samples a month and the number of sites decreased to four sites per river. In the Wicomico River, sampling at station 5, the station nearest the confluence with the Potomac River, was discontinued while the four remaining stations were sampled in 2003, 2008, and 2009. Data from 2003 followed the pattern where DO improved in the upriver direction (Table 23). However, during 2008 and 2009, upstream stations were in violation of the DO criteria most of the time, representing a significant change from the prior decade (Table 24 and 25). This changed pattern in DO is similar to that observed in suburban mesohaline tributaries by Uphoff et al. (2009) - bottom DO was lowest in the shallow uppermost tidal region and improved downstream. It is possible that the Wicomico River is showing signs of stress in response to changes in the watershed as indicated by the low DO measurements in upriver sites. Consequently, these early signs of degradation may warrant additional investigation into identifying the stressor.

Fish data for the same time period were examined to determine what effect these habitat changes were having on the fish community. Species richness remained similar in the seine samples, and increased for those in the trawl (Figures 38 and 39). However, a larger trawl was introduced and substituted for a smaller trawl when the study shifted focus in 2003. The seine methodology remained the same and no increase in species richness was detected for this habitat. However, seine sampling has not proven to be sensitive to changes in target species presence-absence in brackish tributaries (Uphoff et al. 2009). It was assumed that increased richness in the trawl samples was related to increasing the gear size, tow time, and sampling frequency.

Proportion of white perch collected in the seine increased slightly from a high of 0.8 during the period prior to 2002 to 1.0 in 2008 and 2009. The increase in white perch presence was more pronounced in the trawl, likely due to the change to larger gear.

In previous studies, systems undergoing change associated with development as they happened have not been observed and the inferences presented have been based on spatial differences in IS levels and not a time-series from a single watershed. However, the time-series data from the Wicomico River may be indicating declines in water quality that could be associated with the watershed crossing a threshold (tipping point) related to development. Monitoring of water quality should, therefore, be bolstered to provide better resolution of these changes.. The Wicomico River was once identified as a reference system in the Bay and, like Mattawoman Creek, it may be at an early stage of degradation. If so, it could become an ideal watershed for restrained growth, and application and evaluation of restoration and mitigation measures.

SUMMARY

1) Tax map derived development indices are the best source for standardized, readily updated, and accessible development indicators in Maryland. Counts of structures per acre and square footage of structures per acre had a strong relationship with "new" Towson IS estimates for 2000 and predictions of IS developed from these indices are well within the "play" experienced when using other data sources to estimate IS.
2) Little change in anadromous fish stream spawning in Mattawoman Creek was indicated between 1971 and 1989-1991; however, by 2008-2009 spawning site losses were evident for all three species groups. Stream spawning of anadromous fish nearly ceased in Piscataway, Swan, and Broad creeks, and Oxon Run between 1971 and 2008-2009. The most current urban cover estimate for Mattawoman Creek is similar to Piscataway Creek in 1973 and current Piscataway Creek urban cover is similar to that projected for Mattawoman Creek's development district. If planned development proceeds in Mattawoman Creek's watershed, anadromous fish stream spawning is expected to cease.
3) Elevated conductivity in non-tidal Mattawoman and Piscataway creeks indicated that urbanization has impacted both spawning streams. Average conductivity was greater in more urbanized Piscataway Creek than Mattawoman Creek. Mattawoman Creek's conductivity gradient in the non-tidal mainstem changed from declining to increasing with distance from the estuary between 1991 and 2008-2009.

4) Regression analyses (multiple watersheds and years) indicated IS was negatively related to an index of yellow perch egg-larval survival (L_p, the proportion of standard estuarine plankton tows with larvae), but the relationships were different in fresh-tidal and brackish systems. On average, L_p would be higher in fresh-tidal systems until high levels of IS (≈ 20%) were reached

5) Generally, tidal fresh subestuaries experienced few DO criteria violations than mesohaline subestuaries. A total of 90,075 fish (trawl and seine) were captured representing 55 species in ten subestuaries sampled during 2009. Of these species, 8 comprised 90% of the catch, but only three (white perch, Atlantic menhaden, and blueback herring) were target species. White perch have been the most consistently captured species and is an ideal target species for examining habitat impacts because of they are ubiquitous, effectively captured in both seines and trawls as adults and juveniles, have similar habitat requirements as other target anadromous species, and are recreationally important panfish.

6) Mattawoman Creek's summer trawl sampling species richness and relative abundance ranked last in comparison with other watersheds monitored in 2009, including brackish tributaries with very high IS. It was the most highly ranked system in the early 1990s.

7) Mattawoman Creek fish community has declined over the last two decades in spite of the achievement of meeting Chesapeake Bay habitat goals related to water clarity, dissolved oxygen, nutrients and SAV.

8) Counts of structures in Mattawoman Creek's watershed steadily increased from about 11,000 to 21,000 during 1989-2008. Regression models described little or no effect of development on number of species collected or catch of all species until a threshold of

about 18,000 structures was reached in 2002. Development beyond this threshold was followed by declines. The number of structures per acre threshold corresponds to 10% IS.

9) Planned levels of development in Charles County's portion of Mattawoman Creek Watershed should be reconsidered in light of the extent of declines detected in the fish community at current levels of IS. Mitigation and restoration must be considered to offset damage already exhibited.

10) There is no indication that the Corsica River is experiencing changes in habitat quality based on water quality and fish assemblages.

11) A decline in Wicomico River dissolved oxygen could indicate a development threshold (tipping point) was crossed. Greater monitoring effort should be expended here to clarify whether changes have occurred.

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Table 1. Percent of county parcels in the 2000 tax maps without coordinates.

County	Percent Parcels Without x,y coordinates
Allegheny	3.9
Anne Arundel	0.9
Baltimore City	1.8
Baltimore	2.2
Calvert	1.1
Caroline	0.4
Carroll	1.4
Cecil	1.2
Charles	1.6
Dorchester	0.7
Frederick	3.8
Garret	1.6
Harford	1.3
Howard	1.2
Kent	1.1
Montgomery	0.7
Prince George	0.8
Queen Anne	3.2
Somerset	0.2
St. Mary’s	1.7
Talbot	1.2
Washington	2.4
Wicomico	0.6
Worcester	1.4

Table 2. Percent of parcels in the 2000 watershed tax maps that did not have foundation square feet or structure year built data.

Watershed	Percent Zero Square Feet	Percent Zero Year Built
Bohemia River	40	40
Breton Bay	78	7
Bush River	20	20
Corsica River	78	7
Gunpowder River	16	16
Langford Creek	31	31
Magothy River	11	12
Mattawoman Creek	15	16
Middle River/Browns Creek	19	19
Miles River	78	7
Nanjemoy Creek	33	33
Northeast River	28	26
Piscataway Creek	13	13
Severn River	15	19
South River	17	19
St. Clements Bay	79	7
Tred Avon River	78	7
West River/Rhode River	26	27
Wicomico River/Gilbert Swamp/Zekiah Swamp	31	35
Wye River	78	7

Table 3. Estimates of impervious surface (IS) and data used to develop development indices based on Maryland tax maps. Count / area = count of structures per watershed acre. Square ft / acre = square footage of structures per watershed acre.

Watershed	Acres	Structure Count	Structure Square ft	IS	Count / acre	Square ft / acre
Nanjemoy Creek	45461	1460	2461976	0.9	0.03	54.2
Bohemia River	26395	1081	2091164	1.2	0.04	79.2
Langford Creek	23087	610	1170650	3.1	0.03	50.7
Wye River	49321	1640	4216329	3.4	0.03	85.5
Miles River	26707	2507	5851713	3.4	0.09	219.1
Corsica River	23065	1277	3450678	4.1	0.06	149.6
Wicomico River	141378	16521	34089324	4.3	0.12	241.1
Northeast River	39280	5743	11620433	4.4	0.15	295.8
Gunpowder River	533122	5908	9375949	4.4	0.01	17.6
St Clements Bay	28554	2203	3931610	4.4	0.08	137.7
West River Rhode River	15616	3476	6325844	5	0.22	405.1
Breton Bay	33889	3408	8969424	5.3	0.1	264.7
Mattawoman Creek	56772	16228	37764636	9	0.29	665.2
South River	33994	16986	38036360	10.9	0.5	1118.9
Bush River	31677	7613	24321156	11.3	0.24	767.8
Piscataway Creek	39236	21261	37149837	16.5	0.54	946.8
Severn River	39760	34382	75886550	19.5	0.86	1908.6
Magothy River	19565	23803	45611641	20.2	1.22	2331.3
Middle River	2744	8202	12329893	39.1	2.99	4493.7

Table 4. Summary of sites and dates, and sample sizes for anadromous fish egg and larvae sampling by volunteers in Mattawoman and Piscataway Creeks during 2008-2009.

System	Year	Number sites	1st date	Last date	Number visits	N
Piscataway	2008	5	17-Mar	4-May	8	39
Piscataway	2009	6	9-Mar	14-May	11	60
Mattawoman	2008	9	8-Mar	9-May	10	90
Mattawoman	2009	9	8-Mar	11-May	10	70

Table 5. Summary of historic conductivity sampling summarized to examine historic conditions in Mattawoman Creek. RKM = site location in river km from mouth; months – months when samples were drawn; N = sum of samples for all years. Type designates sites as tidal (T) or non-tidal (N).

RKM	1	1.8	2.4	2.8	3.9	4.8	6.3	8	10.5	12.4	18.1	27	30	34.9	38.8
Months	4 to 9	5 to 10	5,7,9	1 to 12	5,7,9	4 to 9	5,7,9	7,9	5,7.9	1 to 12	4 to 9	4 to 9	8,9	4 to 9	8,9
N	21	28	3	246	3	19	4	2	3	218	8	9	2	9	2
Type	T	T	T	T	T	T	T	T	T	N	N	N	N	N	N
	Years sampled														
1970									70			70	70	70	70
1971	71	71	71	71	71	71	71	71	71	71					
1974	74			74		74				74	74	74		74	
1975										75					
1976										76					
1977										77					
1978										78					
1979										79					
1980										80					
1981										81					
1982										82					
1983										83					
1984				84						84					
1985		85		85						85					
1986				86						86					
1987				87						87					
1988				88						88					
1989				89						89					
2008															
2009															

Table 6. Presence-absence of herring (blueback herring and alewife) and white perch stream spawning in Mattawoman Creek during 1971 and 2008-2009. 0 = site sampled, but spawning not detected; 1 = site sampled, spawning detected; and blank indicates no sample. Station locations are identified on Figure 4.

STATION	1971	1989	1990	1991	2008	2009
Herring						
MC1	1	1	1	1	1	1
MC2	1	1	1	1	0	0
MC3	1			1	1	1
MC4	1			1	0	0
MUT3	1				0	0
MUT5	1				1	0
White Perch						
MC1	1	1	1	1	1	0
MC2	0	0	1	0	0	0
MC3	1			0	0	0
Yellow Perch						
MC1	1	1	1	1	1	0

Table 7. Presence-absence of herring (blueback herring and alewife), white perch, and yellow perch stream spawning in Piscataway Creek during 1971, 1989-1991, and 2008-2009. 0 = site sampled, but spawning not detected; 1 = site sampled, spawning detected; and blank indicates no sample. Station locations are identified on Figure 5.

	Year		
STATION	1971	2008	2009
Herring			
PC1	1	0	0
PC2	1	0	1
PC3	1	0	0
PTC4	1	0	0
PUT4	1		0
White Perch			
PC1	1	0	0
PC2	1	0	0

Table 8. Summary statistics of conductivity (µmho / cm) for mainstem stations in Piscatatway and Mattawoman creeks during 2008-2009. Unnamed tributaries were excluded from analysis. Tinkers Creek was included with mainstem stations in Piscataway Creek.

Creek	Piscataway	Piscataway	Mattawoman	Mattawoman
Year	2008	2009	2008	2009
Mean	218.4	305.4	120.1	244.5
Standard Error	7.4	19.4	3.8	19.2
Median	210.4	260.6	124.6	211
Kurtosis	-0.38	1.85	2.1	1.41
Skewness	0.75	1.32	-1.41	1.37
Range	138	641	102	495
Minimum	163	97	47	115
Maximum	301	737	148.2	610
Count	29	50	39	40
Count > 171	28	46	0	25

Table 9. Characterization of watersheds monitored during July-October, 2009. Area = Mid refers to mid-Chesapeake Bay; Potomac indicates sub-estuary located on the tidal Potomac River; and Upper indicates upper Chesapeake Bay. Median salinity is based on 2009 measurements. IS = impervious surface estimates from Towson University based on 1999-2000 satellite imagery. Other land-uses are based on 1994 MDP estimates. Figure refers to map that has station locations and land-use distribution in a watershed.

Area	Watershed	Median Salinity	IS (%)	Total acres	Water acres	% Urban	% Forest	% Agriculture	% Wetland	Figure
Mid	Corsica R.	8.6	4.1	23,924	1,256	6	28	65	1	18
Mid	Middle R.	6.0	39.1	6,759	2,132	62	29	6	3	19
Mid	Tred Avon R.	10.6	7.5	23,518	4,338	22	38	39	>1	20
Potomac	Mattawoman Cr.	0.2	9.0	60,300	1,848	22	63	14	1	21
Potomac	Nanjemoy Cr.	6.0	0.9	46,604	2,345	6	74	16	4	22
Potomac	Piscataway Cr.	0.2	16.5	43,579	858	34	49	16	1	23
Potomac	Wicomico R.	11.2	4.3	49,364	1,398	7	51	37	4	24
Upper	Bush R.	0.4	11.3	36,964	7,966	24	48	22	6	25
Upper	Gunpowder R.	1.4	4.4	43,466	10,013	35	36	24	5	26
Upper	Northeast	0.1	4.4	40,377	3,884	6	36	65	1	27

Table 10. Water temperature and dissovled oxygen requirements for juvenile (J) and adult (A) target species.

Water Quality Criteria Requirements	Striped Bass	Yellow Perch	White Perch	Alewife	Blueback Herring	American Shad	Spot	Atlantic Croaker	Atlantic Menhaden
TEMPERATURE (^{o}C)	14.0-26.0 J	19.0 -24.0 J	15.2 - 31.0 J	17.0 - 23.0 J	11.5 - 28.0 J	15.6 - 23.90 J	6.0 - 25.0 J	17.5 - 28.2 J	16.9 - 28.2 J
	20.0 – 22.0 A Preferred	12.0 – 22.0 A	21.5 – 22.8 A preferred	16.0 – 22.0 A	8.0-22.8 A	8.0-30.0 A	12.0 - 24.0 A	14.9 - 31.4 A	6.0 - 25.0 A
DISSOLVED OXYGEN (mg/l)	>5.0 J, A	minimum of 5.0 J A	minimum of 5.0 – 7.0 J/A	minimum of 3.6 J A	minimum of 3.6 J	4.0 – 5.0 J A	2 - >5.0 J A		> 4.5 J, A
				> 5.0 preferred	> 5.0 preferred	>5.0 preferred	>5.0 preferred		

Table 11. Percentage of time overall habitat conditions (all depths in the channel and near shore) did not support the highest maximum temperature, threshold and target D.O. and the lowest maximum salinity for the target species during July-September, 2009 and percentage of time bottom dissolved oxygen in the channel was below 5.0 mg/L and 3.0 mg/L.

Salinity Calssification	Watershed	Percentage Impervious	Temperature > 31°C	DO < 5.0 mg/L	Bottom DO < 5.0 mg/L	BottomDO < 3.0 mg/L
Fresh-tidal	Bush River	11.3	2.4	2.4	5.6	0.0
Fresh-tidal	Gunpowder River	4.4	0.0	2.3	0.0	0.0
Fresh-tidal	Mattawoman Creek	9.0	0.0	0.0	0.0	0.0
Fresh-tidal	Northeast	4.4	2.1	2.1	4.2	0.0
Fresh-tidal	Piscataway	16.5	0.0	0.0	0.0	0.0
Mesohaline	Corsica	4.1	0.0	45.7	65.6	43.7
Mesohaline	Tred Avon River	7.5	0.0	8.3	12.5	0.0
Mesohaline	Middle River	39.1	0.0	18.5	18.2	4.5
Mesohaline	Nanjemoy	0.9	0.0	5.6	5.6	5.6
Mesohaline	Wicomico	4.3	0.0	34.5	60.0	30.0

Table 12. Seine catch statistics and impervious cover by river for 2009.

River	Number of Samples	Number of Species	Species Comprising 90% of Catch	Percent Impervious	Total Catch	Number of Fish per Seine
Bush	24	31	gizzard shad white perch juvenile white perch adult spottail shiner pumpkinseed blueback herring channel catfish	11.29	9781	407.5
Corsica	20	24	white perch juvenile striped killifish white perch adult pumpkinseed striped bass Atlantic silverside spottail shiner mummichog alewife channel catfish banded killifish yellow perch juvenile striped anchovy	4.13	2257	112.8
Gunpowder	19	37	white perch juvenile spottail shiner gizzard shad Atlantic menhaden white perch adult banded killifish Atlantic silverside Bay anchovy pumpkinseed channel catfish	4.38	5026	264.5
Mattawoman	1	6	bluegill	8.99	67	67.0
Middle	5	18	white perch juvenile banded killifish pumpkinseed white perch adult Atlantic silverside inland silverside	39.12	1009	201.8
Nanjemoy	18	31	white perch juvenile white perch adult Atlantic menhaden Atlantic silverside Bay anchovy	0.94	3441	191.2

Table 12 (continued). Seine catch statistics and impervious cover by river for 2009.

Northeast	24	28	gizzard shad blueback herring white perch juvenile white perch adult Atlantic menhaden	4.35	7261	302.5
Piscataway	0			16.51		
Tred Avon	24	23	Atlantic silverside Atlantic menhaden striped killifish striped bass white perch adult	7.45	3535	147.3
Wicomico	32	20	Atlantic silverside white perch adult striped bass juvenile striped killifish mummichog	4.29	3620	113.1

Table 13. Trawl (16 ft headrope) catch statistics and impervious cover by river for 2009.
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River	Number of Samples	Number of Species	Species Comprising 90% of Catch	Percent Impervious	Total Catch	Number of Fish per Trawl
Bush	18	19	white perch juvenile white perch adult bay anchovy gizzard shad	11.29	6237	346.5
Corsica	32	15	white perch adult white perch juvenile bay anchovy	4.13	8582	268.2
Gunpowder	24	23	white perch juvenile bay anchovy white perch adult gizzard shad	4.38	8022	334.3
Mattawoman	24	13	white perch juvenile white perch adult bluegill striped bass juvenile	8.99	427	17.8
Middle	24	17	white perch juvenile white perch adult bay anchovy	39.12	7493	312.2
Nanjemoy	18	17	white perch juvenile bay anchovy white perch adult	0.94	10033	557.4
Northeast	24	18	white perch adult white perch juvenile bay anchovy	4.35	5911	246.3
Piscataway	18	20	white perch juvenile spottail shiner white perch adult pumpkinseed	16.51	3590	199.4
Tred Avon	24	16	bay anchovy blue crab striped bass juvenile weakfish white perch adult	7.45	2158	89.9
Wicomico	32	20	bay anchovy white perch adult spot striped bass juvenile hogchoker Atlantic silverside	4.29	2211	69.1

Table 14. Proportion (pt = trawl, ps = seine) of positive tows and standard deviation (sd) for target species by river and gear for 2009.

	Bush		Gunpowder		Mattawoman		Middle		Nanjemoy		Northeast		Piscataway		Tred Avon	
Species in the Trawl	p_t	sd	p_t	sd	p_t	sd	p_t	sd	p_t	sd	p_t	sd	p_t	sd	p_t	sd
Alewife	0.11	0.07	0.00	0.00	0.00	0.00	0.00	0.00	0.06	0.05	0.17	0.08	0.00	0.00	0.00	0.00
Blueback	0.17	0.09	0.04	0.04	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.17	0.09	0.00	0.00
Atlantic menhaden	0.06	0.05	0.04	0.04	0.00	0.00	0.08	0.06	0.08	0.06	0.25	0.09	0.00	0.00	0.00	0.00
American shad	0.00	0.00	0.00	0.00	0.05	0.05	0.00	0.00	0.11	0.07	0.00	0.00	0.00	0.00	0.00	0.00
Atlantic croaker	0.00	0.00	0.00	0.00	0.00	0.00	0.04	0.04	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Spot	0.00	0.00	0.00	0.00	0.00	0.00	0.08	0.06	0.39	0.11	0.00	0.00	0.00	0.00	0.00	0.00
Striped bass (adult)	0.00	0.00	0.04	0.04	0.00	0.00	0.04	0.04	0.06	0.05	0.08	0.06	0.00	0.00	0.04	0.04
Striped bass (juvenile)	0.11	0.07	0.33	0.10	0.62	0.11	0.54	0.10	0.72	0.11	0.17	0.08	0.06	0.05	0.83	0.08
White perch (adult)	0.89	0.07	0.92	0.06	0.52	0.11	0.96	0.04	1.00	0.00	0.96	0.04	0.78	0.10	0.63	0.10
White perch (juvenile)	1.00	0.00	0.96	0.04	0.52	0.11	1.00	0.00	0.94	0.05	1.00	0.00	1.00	0.00	0.00	0.00
Yellow perch (adult)	0.33	0.11	0.08	0.06	0.05	0.05	0.00	0.00	0.00	0.00	0.08	0.06	0.11	0.07	0.00	0.00
Yellow perch (juvenile)	0.17	0.09	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.06	0.05	0.00	0.00

	Bush		Gunpowder		Middle		Nanjemoy		Northeast		Tred Avon	
Species in the Seine	p_s	sd	p_s	sd	p_s	sd	p_s	sd	p_s	sd	p_s	sd
Alewife	29.00	0.09	0.32	0.11	0.00	0.00	0.00		0.11	0.07	0.33	0.10
Blueback	0.33	0.10	0.26	0.10	0.00	0.00	0.44	0.12	0.63	0.10	0.04	0.04
Atlantic menhaden	0.25	0.09	0.47	0.11	0.00	0.00	0.44	0.12	0.29	0.09	0.17	0.08
American shad	0.00	0.00	0.05	0.05	0.00	0.00	0.11	0.07	0.33	0.10	0.00	0.00
Atlantic croaker	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Spot	0.00	0.00	0.16	0.08	0.00	0.00	0.50	0.12	0.00	0.00	0.29	0.09
Striped bass (adult)	0.25	0.09	0.05	0.05	0.00	0.00	0.06	0.05	0.17	0.08	0.04	0.04
Striped bass (juvenile)	0.67	0.10	0.47	0.11	0.60	0.22	0.72	0.11	0.42	0.10	0.83	0.08
White perch (adult)	0.83	0.08	0.84	0.08	0.60	0.22	0.94	0.05	0.79	0.08	0.67	0.10
White perch (juvenile)	1.00	0.00	1.00	0.00	1.00	0.00	0.94	0.05	0.79	0.08	0.21	0.08
Yellow perch (adult)	0.17	0.08	0.05	0.05	0.40	0.22	0.06	0.05	0.08	0.06	0.00	0.00
Yellow perch (juvenile)	0.46	0.10	0.16	0.08	0.40	0.22	0.00	0.00	0.29	0.09	0.00	0.00

Table 15. Proportion of trawl samples withjuvenile and adult white perch during 2009.

RIVER	Proportion of white perch juveniles	Proportion white perch adults	% Impervious
BUSH	1.00	0.89	11.3
CORSICA	1.00	0.97	4.1
GUNPOWDER	0.96	0.92	4.4
MATTAWOMAN	0.33	0.46	9.0
MIDDLE	1.00	0.96	39.1
NANJEMOY	0.94	1.00	0.9
NORTH	1.00	0.96	4.4
PISCATAWAY	1.00	0.78	7.5
TRED AVON	0.00	0.63	7.5
WICOMICO	0.22	0.66	4.3

Table 16. Comparisons of mean species richness (count of species) collected by 10 ft trawl during 1989-2002 and 2009. Comparisons were made by station and month. Collections in 2009 represent approximately twice the level of effort as annual collections during 1989-2002.

Comparison	1989-2002 mean richness	2009 richness
Station		
Station 1	10.3	5
Station 2	8.1	7
Station 3	8.5	0
Station 4	8.2	3
Month		
July	10.1	9
August	10.5	1
September	7.7	4

Table 17. Summary of data and abbreviations used in the multiple regression to describe threshold effects of Mattawoman Creek Watershed development on annual (July-early October) number of species or mean log10 trawl catch (+1).

Year	Structures	Gear	Time	Time*house	Number Species	Log_{10} catch
Abbreviation	H	G	Y	H*Y	S	Log_{10} N
1989	10,943	0	0	0	15	3.02
1990	11,584	0	0	0	19	2.94
1991	11,966	0	0	0	14	3.14
1992	12,388	0	0	0	14	2.62
1993	12,791	0	0	0	13	2.96
1994	13,319	0	0	0	17	2.76
1995	13,906	0	0	0	8	3.19
1996	14,470	0	0	0	14	3.02
1997	15,135	0	0	0	11	2.86
1998	15,869	0	0	0	11	3.07
1999	16,564	0	0	0	15	3.14
2000	17,193	0	0	0	11	2.93
2001	17,863	0	0	0	14	2.9
2002	18,456	0	1	18,456	14	2.29
2003	18,988	1	1	18,988	24	3.34
2004	19,475	1	1	19,475	25	3.43
2005	19,931	1	1	19,931	26	3.35
2006	20,486	1	1	20,486	19	2.97
2007	20,968	1	1	20,968	19	2.93
2008	21,290	1	1	21,290	18	2.59

Table 18. ANOVA tables and coefficient estimates for the regression model investigating threshold effects of development on number of species encountered annually during 1989-2008 monitoring of Mattawoman Creek's estuary. Model R^2 = 0.77.

ANOVA for number of species

	df	*SS*	*MS*	*F*
Regression	4	346.7733852	86.69335	12.98108
Residual	15	100.1766148	6.678441	
Total	19	446.95		

	Coefficients	*Standard Error*	*t Stat*	*P-value*
Intercept	20.70765	4.76659	4.34	0.0006
Structures	-0.00050654	0.00033296	-1.52	0.1490
Gear	66.40383	27.18364	2.44	0.0274
Time	2.64112	3.04051	0.87	0.3987
Time*Structures	-0.00286	0.00135	-2.12	0.0508

Table 19. ANOVA tables and coefficient estimates for the regression model investigating threshold effects of development on annual mean $\log_{10}$–transformed catch (+1) of all fish during 1989-2008 monitoring of Mattawoman Creek's estuary. Model R^2 = 0.72.

ANOVA for mean $\log_{10}$ transformed catch (+1)

	df	*SS*	*MS*	*F*
Regression	4	1.014	0.253	9.69
Residual	15	0.392	0.0261	
Total	19	1.406		

	Coefficients	*Standard Error*	*t Stat*	*P-value*
Intercept	2.875	0.298	9.64	8.07E-08
Structures	6.36E-06	2.083E-05	0.30	0.764497
Gear	7.752	1.701	4.55	0.000378
Time	-0.701	0.190	-3.68	0.002194
Time*structures	-0.00034	8.424E-05	-4.08	0.000968

Table 20. Percentage of dissolved oxygen concentrations below the 5.0and 3.0 mg/L criteria. Data are from Tidewater Ecosystem Assessment's Continuous Monitoring data base, provided by Bill Romano.

Dissolved Oxygen less than 5.0 mg/L (%)						
Month	2004	2005	2006	2007	2008	2009
3		0	0	0	0	
4	0	0	0	0	0.28	0
5	0	0	0	0	1.18	5.58
6	0.03	0	9.72	0	3.58	28.4
7	1.48	0.44	4.94	0.37	1.75	11.2
8	2.15	39.8	4.6	14.78	7.29	42.52
9	0.24	21.67	7.78	17.17	2.09	5.24
10	0	12.34	0	9.18	0	0
Dissolved Oxygen less than 3.0 mg/L (%)						
Month	2004	2005	2006	2007	2008	2009
3		0	0	0	0	
4	0	0	0	0	0	0
5	0	0	0	0	0.07	0
6	0	0	2.67	0	0	2.36
7	0.27	0	0.13	0	0	0.88
8	0.74	7.09	0.03	0.84	0.15	16.15
9	0	2.26	0.49	0.49	0	0.08
10	0	3.39	0	0.11	0	0
11	0					

Table 21. Corsica River log $_{10}$ catch per effort by year and gear type.

Year	Trawl	Seine
2003	2.78	3.08
2004	2.43	2.83
2005	2.22	2.68
2006	2.42	2.17
2007	2.28	2.24
2008	2.19	2.36
2009	2.46	2.07

Table 22. Proportion of dissolved oxygen (DO) measurements below living resources criteria and mean, min and max in the Wicomico River, 1989-2002.

Station	Bottom DO < 5.0 mg/L	BottomDO < 3.0 mg/L	Mean DO	Minimum DO	Maximum DO
1	0.15	0.00	6.36	4.35	9.87
2	0.08	0.00	6.65	3.82	9.86
3	0.29	0.05	5.77	2.22	8.88
4	0.51	0.27	4.50	0.46	8.24

5	0.005	0.25	4.77	0.15	8.86

Table 23. Proportion of dissolved oxygen (DO) measurements below living resources criteria and mean, min and max in the Wicomico River, 2003.

Station	Bottom DO < 5.0 mg/L	BottomDO < 3.0 mg/L	Mean DO	Minimum DO	Maximum DO
1	0.25	0.00	6.4	4.8	8.4
2	0.25	0.00	5.875	4.9	8.4
3	0.00	0.00	6.975	5.9	9.6
4	0.50	0.25	5.05	1.4	8.7

Table 24. Proportion of dissolved oxygen (DO) measurements below living resources criteria and mean, min and max in the Wicomico River, 2008.

Station	Bottom DO < 5.0 mg/L	BottomDO < 3.0 mg/L	Mean DO	Minimum DO	Maximum DO
1	1.00	0.25	3.44	0.18	4.96
2	0.50	0.25	3.9325	0.06	5.97
3	0.75	0.25	3.825	1.49	6.47
4	0.75	0.50	2.77	0.13	6.22

Table 25. Proportion of dissolved oxygen (DO) measurements below living resources criteria and mean, min and max in the Wicomico River, 2009.

Station	Bottom DO < 5.0 mg/L	BottomDO < 3.0 mg/L	Mean DO	Minimum DO	Maximum DO
1	1.00	0.75	1.633333	0.05	4.63
2	0.50	0.25	4.4025	0.24	7.88
3	0.25	0	5.12	4.17	5.57
4	0.50	0	5.19	4.66	5.93

Figure 1. Watersheds selected for comparisons of tax map based development indicators and impervious surface estimates.

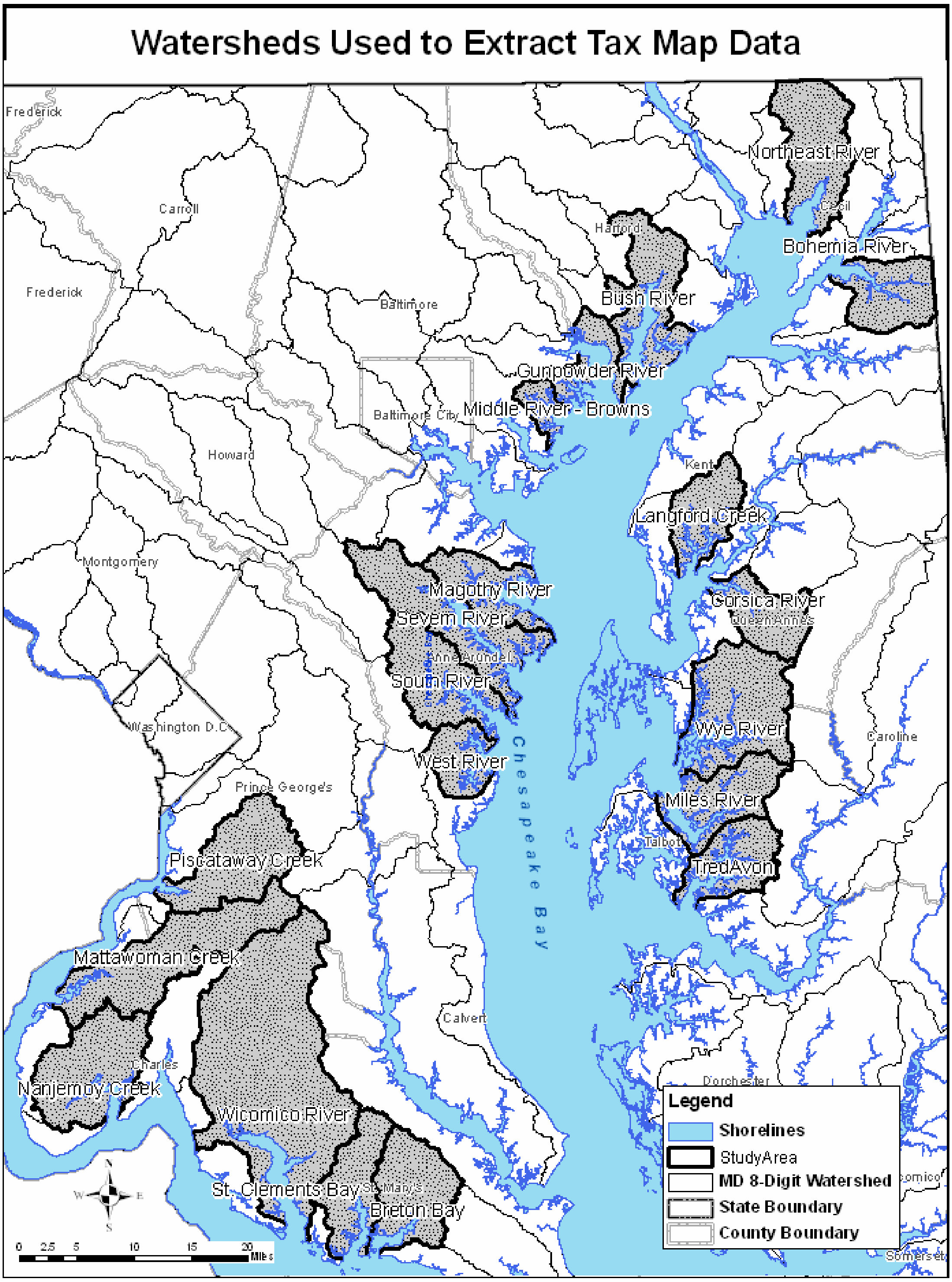

Figure 2. Relationships of percent impervious surface with (A) count of structures per watershed acre and (B) square footage of structures per watershed acre. Observed data are indicated by open symbols and lines represent predictions from a non-linear power function.

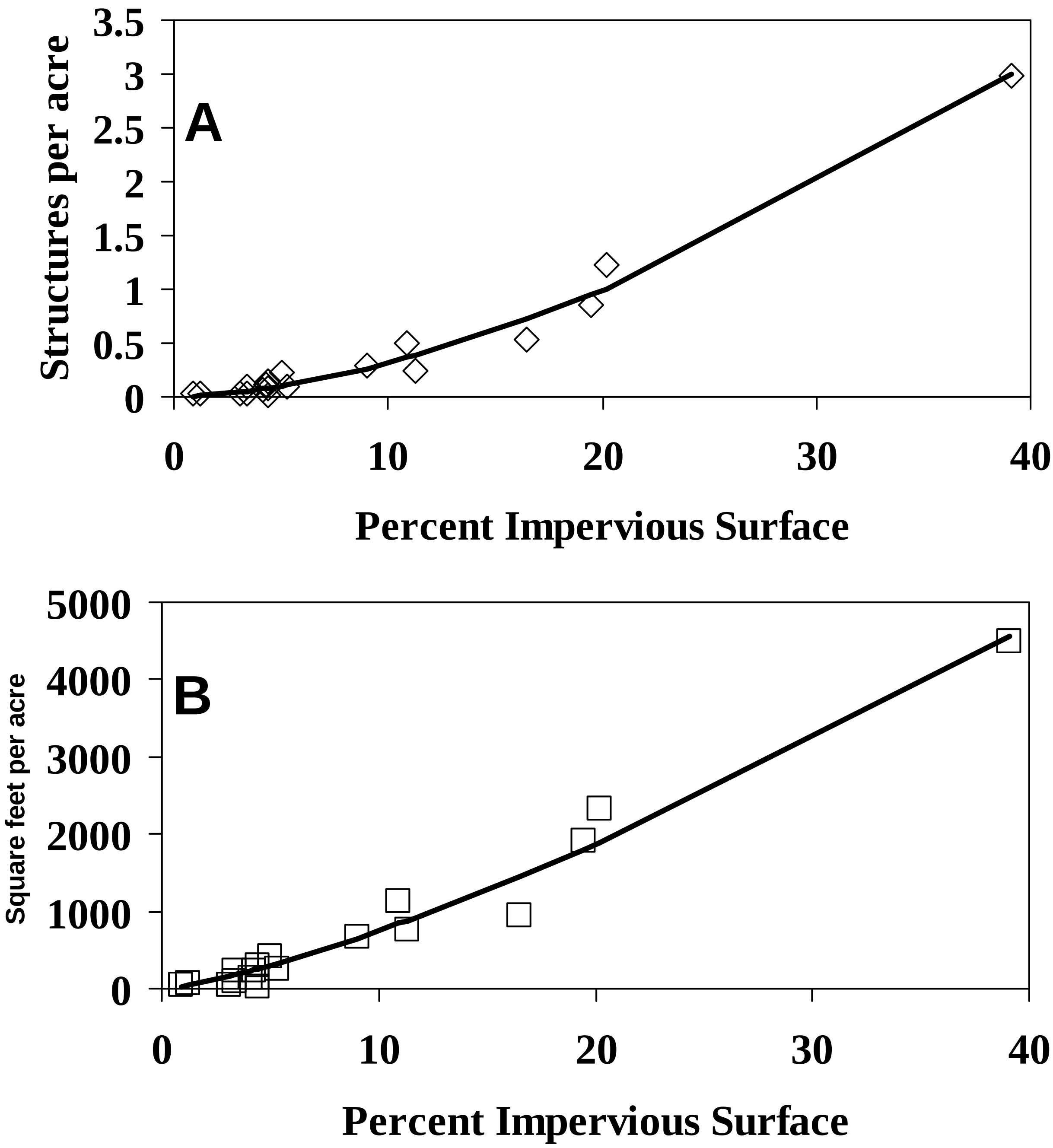

Figure 3.Watersheds sampled for stream spawning anadromous fish eggs and larvae in 2009.

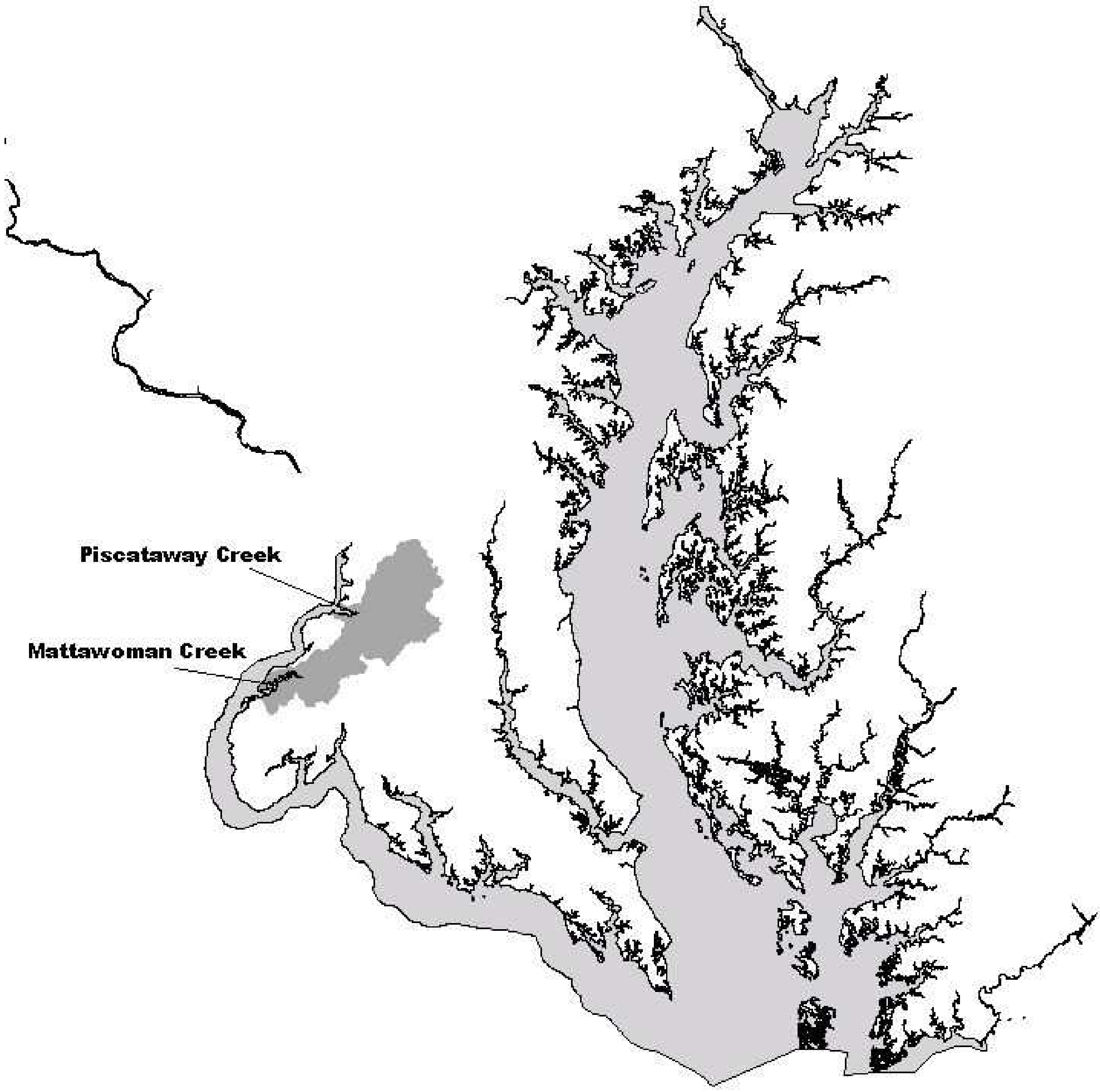

Figure 4. Mattawoman Creek historic and 2008-2009 sampling stations.

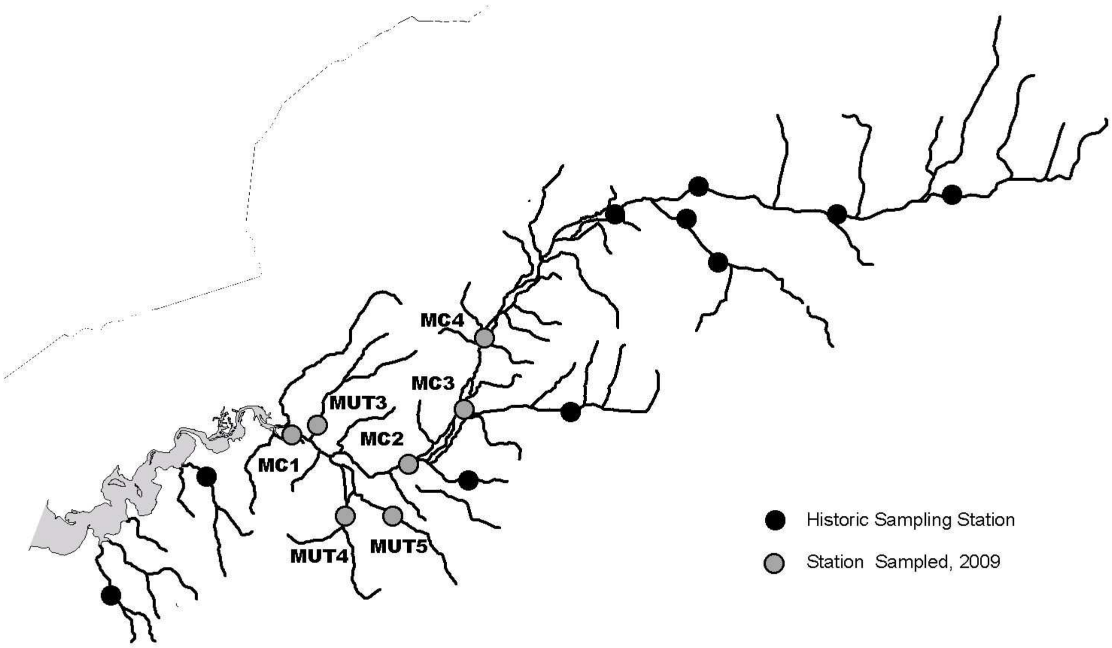

Figure 5. Piscataway Creek historic and 2008-2009 sampling stations.

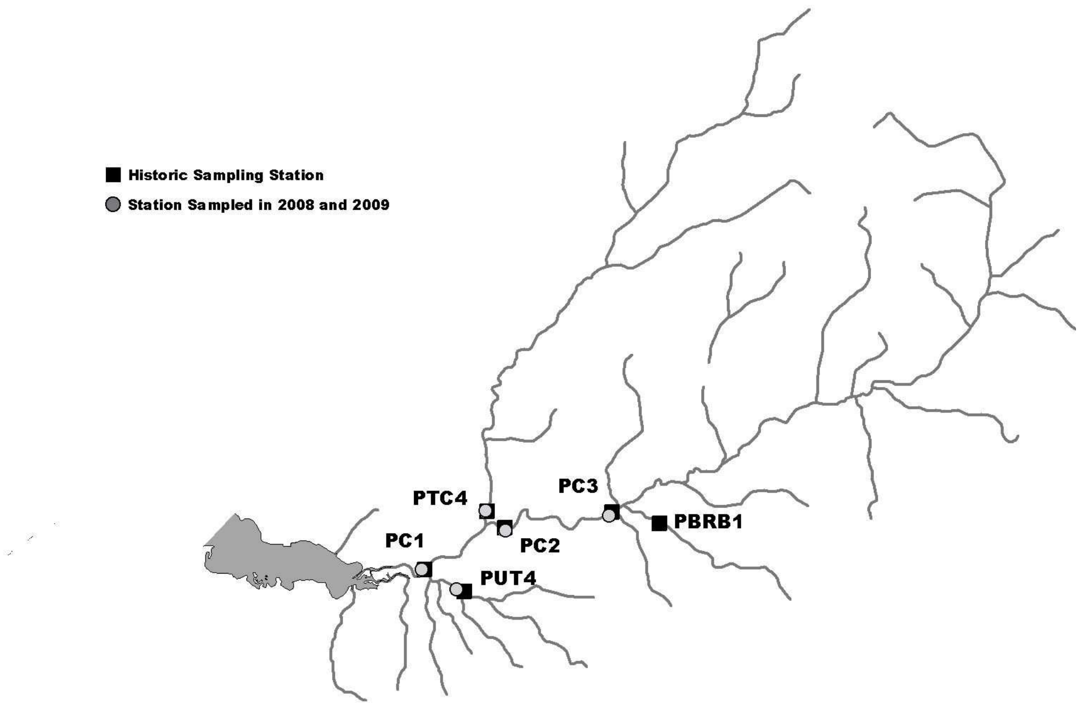

Figure 6. Mattawoman Creek stations with conductivity measurements used in analysis.

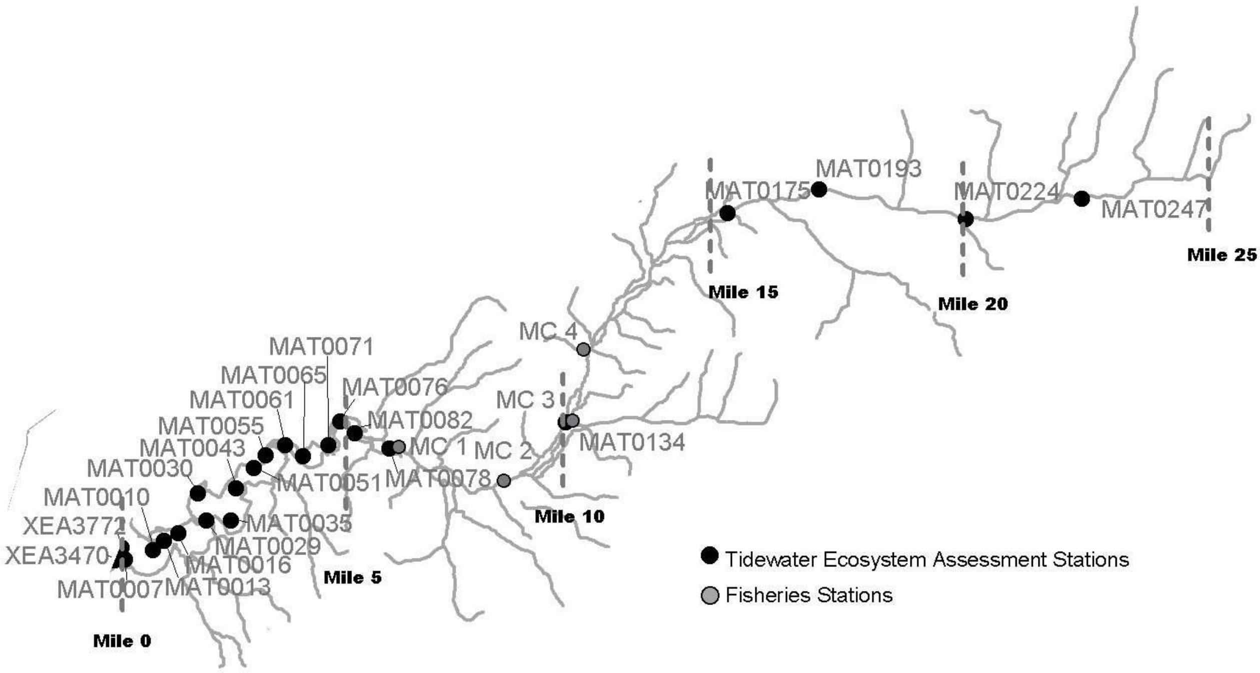

Figure 7. Conductivity during the 2008 anadromous fish stream spawning survey in Mattawoman Creek for mainstem stations (open symbols) and tributaies. Lines represent the minimum and maximum conductivities reported at MC2 and MC4 during March and April, 1991 (Hall et al. 1992). Stations labeled as MCx are mainstem stations, while stations labeled as MUTx are unnamed tributaries.

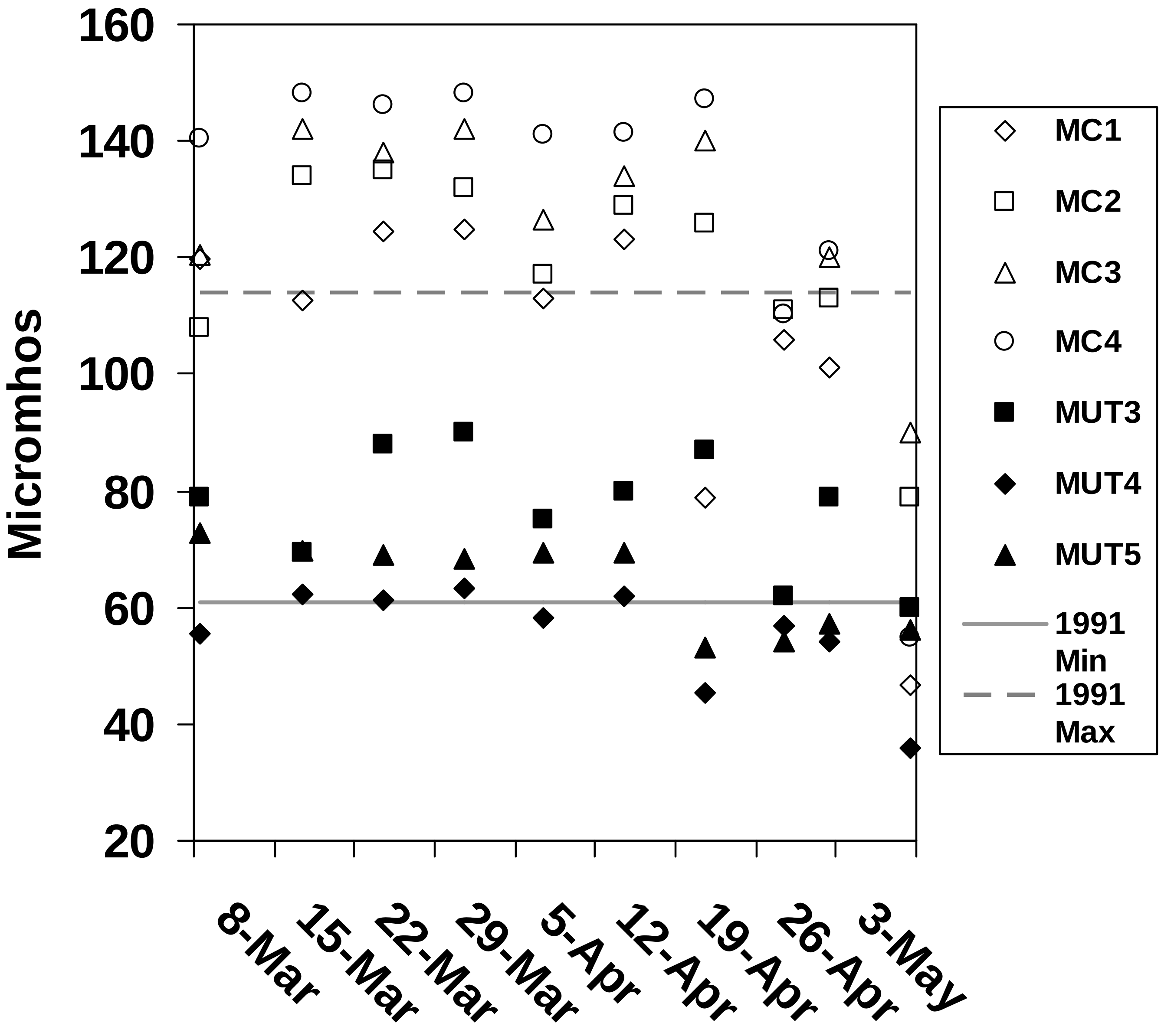

Figure 8. Conductivity during the 2009 anadromous fish stream spawning survey in Mattawoman Creek for mainstem stations (open symbols) and tributaies. Lines represent the minimum and maximum conductivities reported at MC2 and MC4 during March and April, 1991 (Hall et al. 1992). Stations labeled as MCx are mainstem stations, while stations labeled as MUTx are unnamed tributaries.

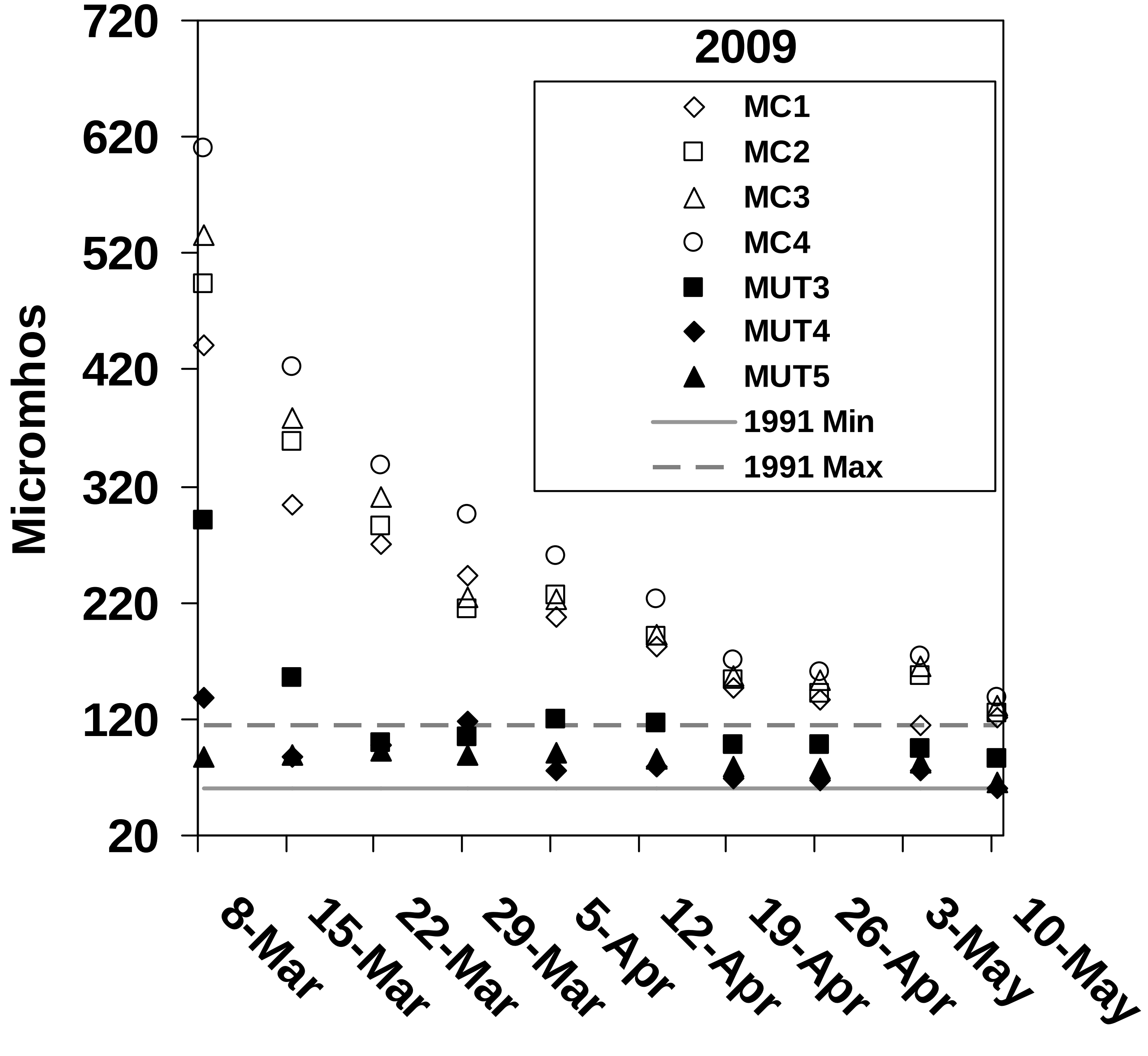

Figure 9. Conductivity during the 2008 anadromous fish stream spawning survey in Piscataway Creek for mainstem stations (open symbols) and tributaries. Stations PCx and PTC are mainstem stations, while PUT4 is a tributary.

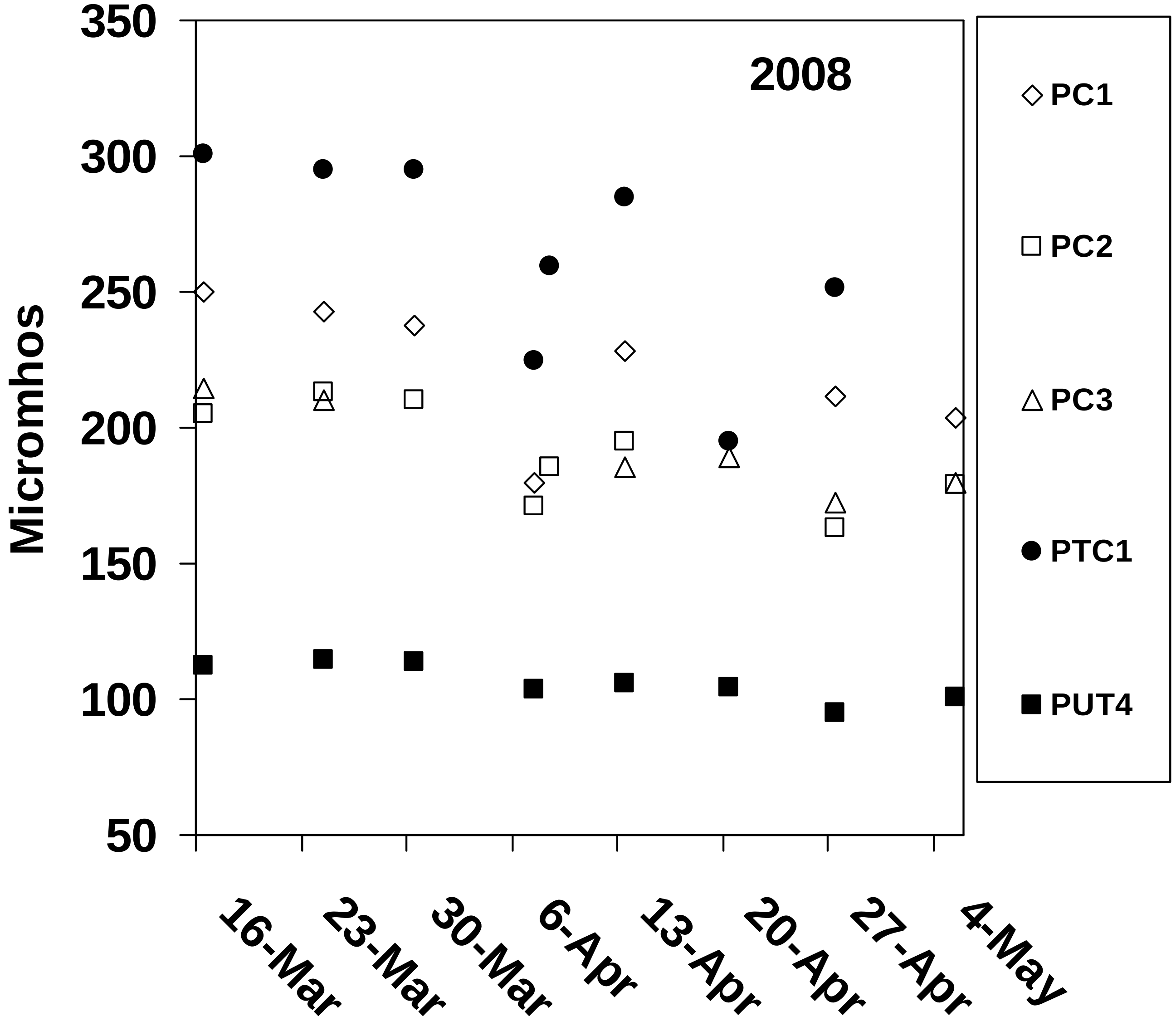

Figure 10. Conductivity during the 2009 anadromous fish stream spawning survey in Piscataway Creek for mainstem stations (open symbols) and tributaries. Stations PCx and PTC are mainstem stations, while PUT4 is a tributary.

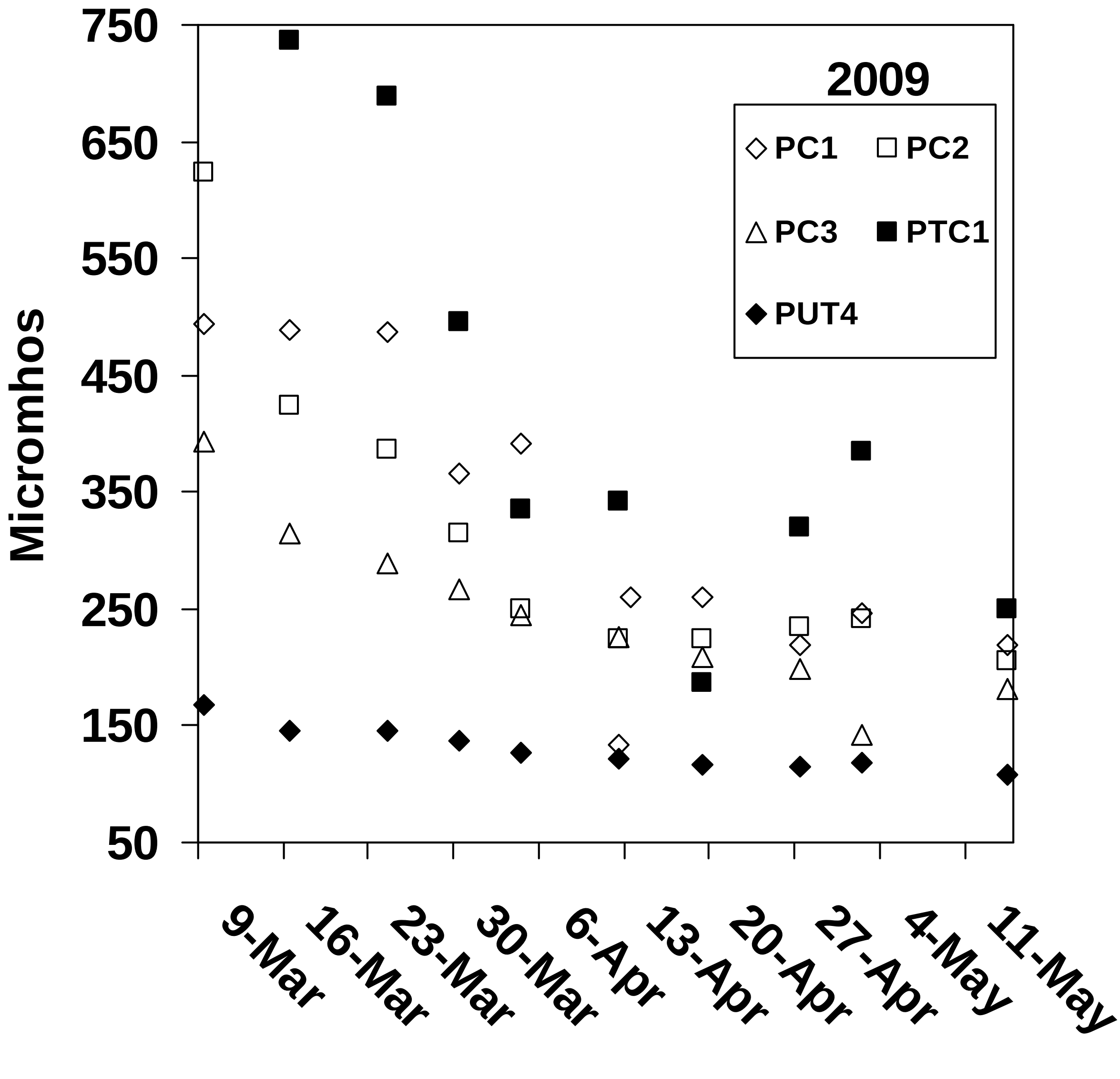

Figure 11. Historic (1970-1989; see Table 1) monthly median conductivity measurements in Mattawoman Creek (between the mouth and Waldorf,) plotted against distance from the mouth of the creek. Tidal (open squares) and non-tidal stations (open triangles) are designated. Predicted historic station medians are indicated by the line. Measurements from 2008 and 2009 stream spawning surveys and a continuous monitor at the Sweden Point Marina (March and April means) are superimposed on the plot and were not used to estimate the predicted line. The two stations furthest upstream are nearest Waldorf.

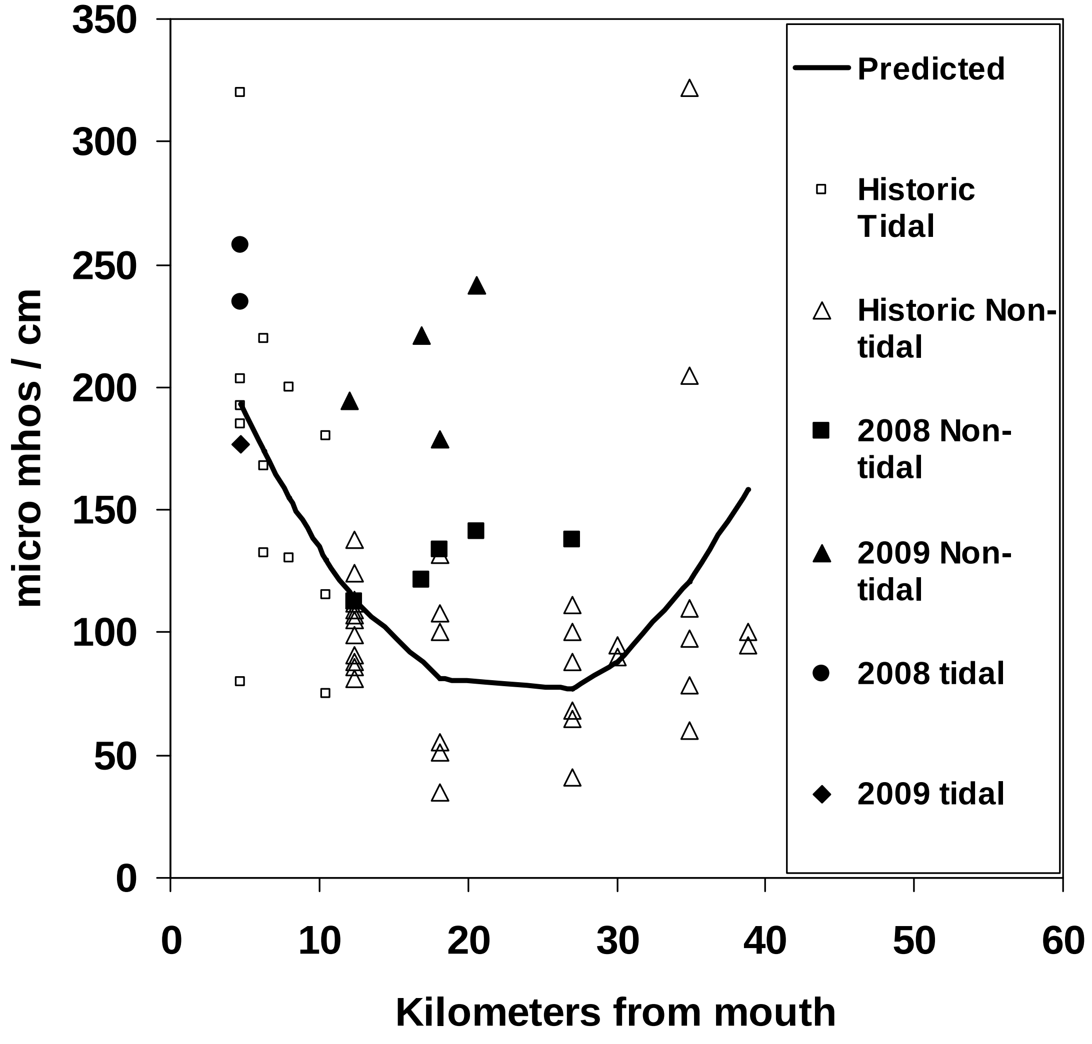

Figure 12. Sampling areas and stations for the spring yellow perch larval presence absence study.

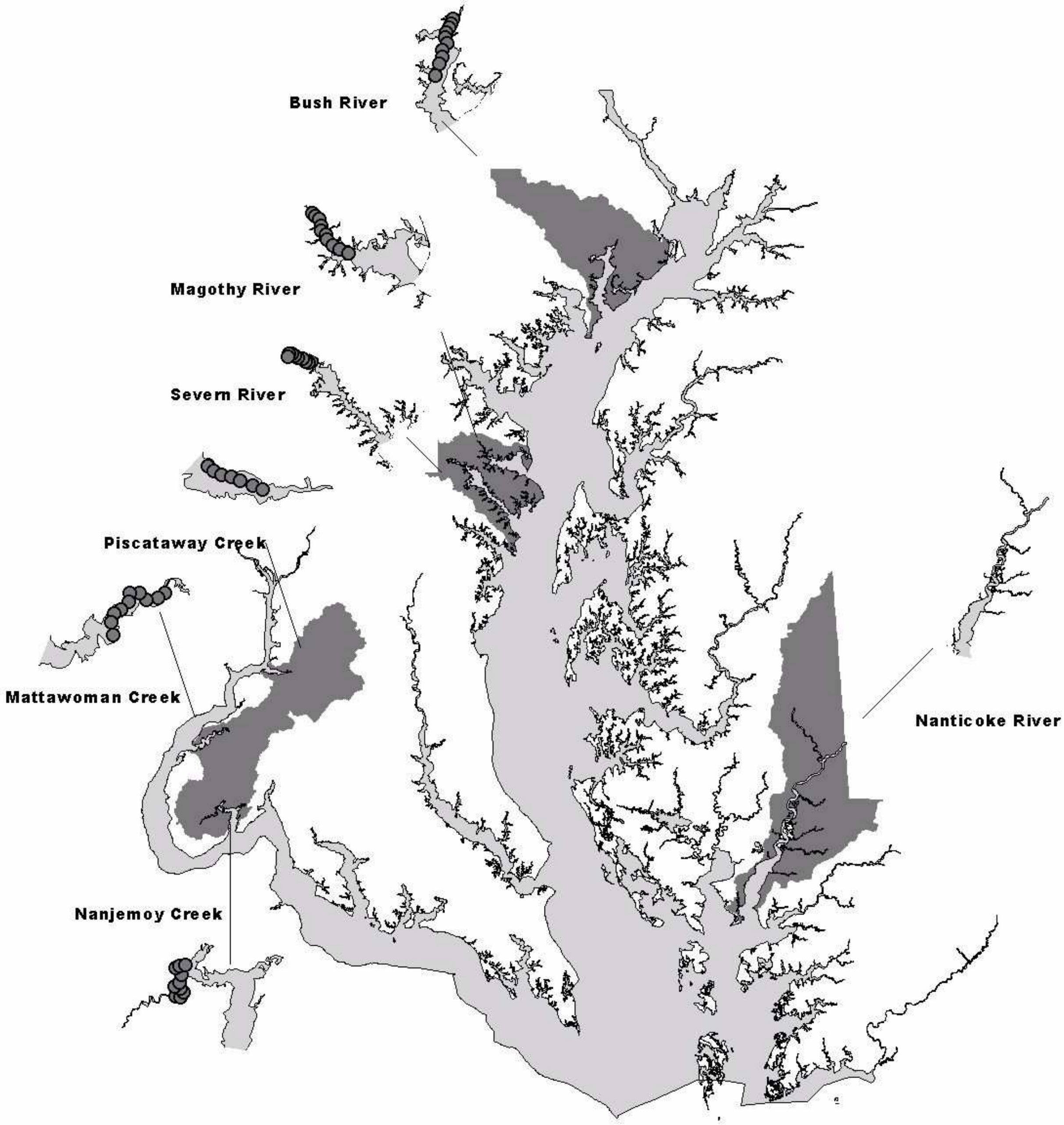

Figure 13. Proportion of tows with larval yellow perch and its 95% confidence interval in systems studied during 2009. Mean of brackish tributaries indicated by diamond and fresh-tidal mean indicated by dash. High and low points of “Historic” data indicate spread of 9 of 11 points and midpoint is the mean of historic period.

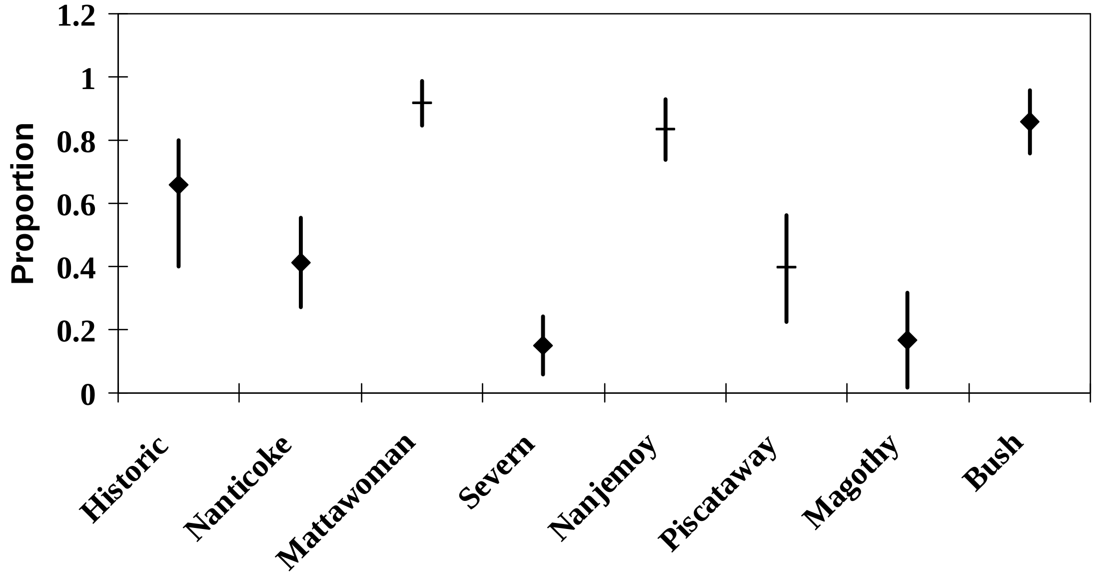

Figure 14. Proportion of tows with yellow perch larvae, by river, during 1965-2009. Dotted lines indicates reference system (Nanticoke and Choptank rivers) and period (prior to 1991) “typical” range..

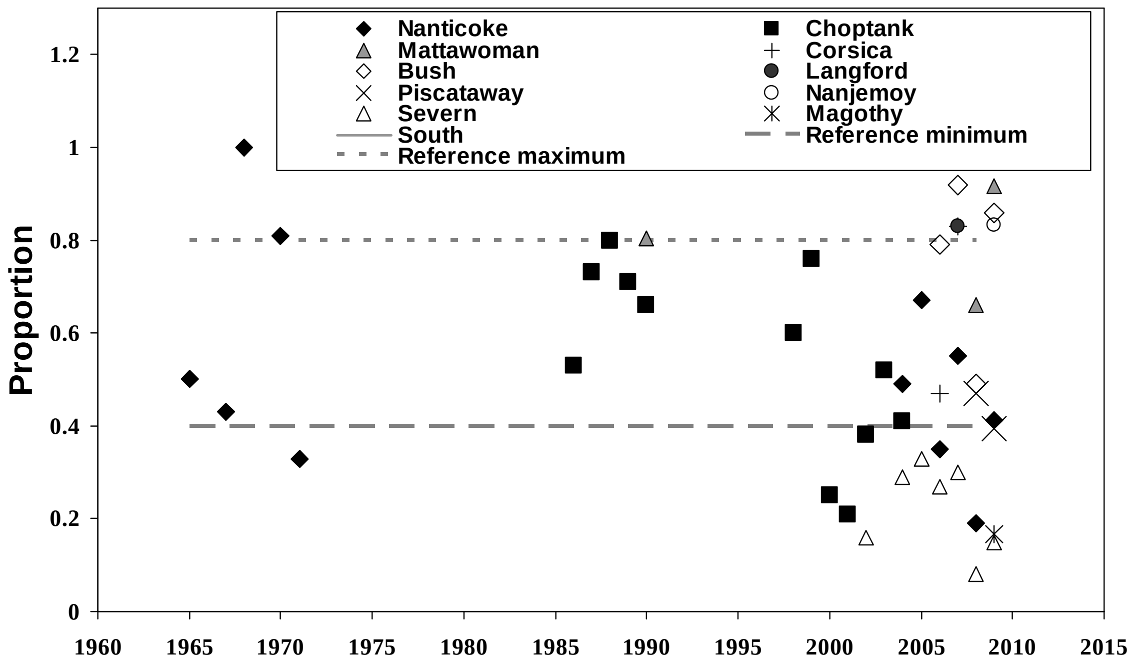

Figure 15. Impervious surface versus estuarine yellow perch larval presence-absence in towed nets 1998-2009. Salinity is treated as a categorical variable.

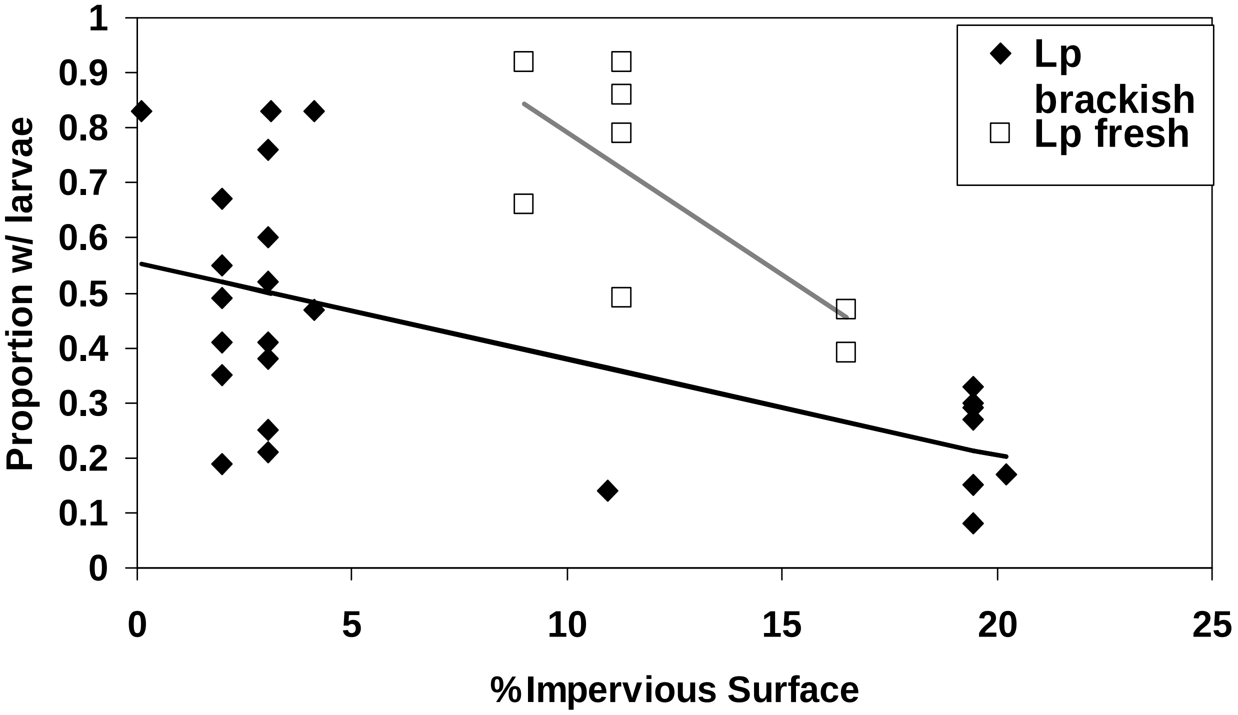

Figure 16. Number (N) of estimates of proportion of plankton tows with yellow perch larvae (Lp) falling within a category during 1965-2009. Severn, South, and Magothy rivers omitted due to suppression of Lp by factors related to impervious surface.

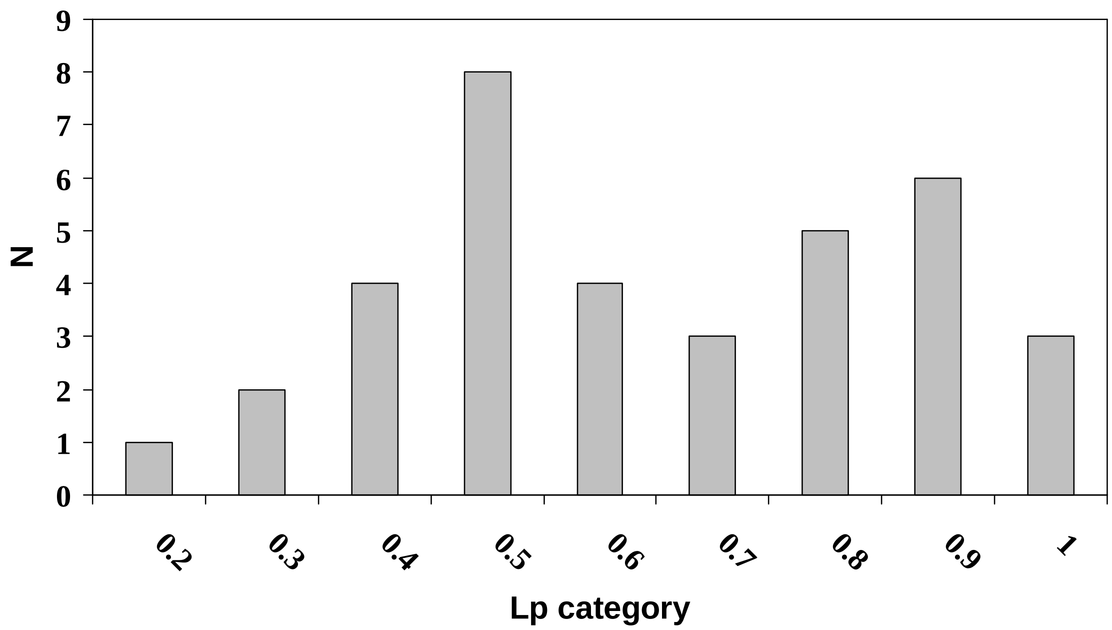

Figure 17. Rivers where seining and trawling was conducted in summer 2009. Watershed areas in Maryland indicated by dark gray shading.

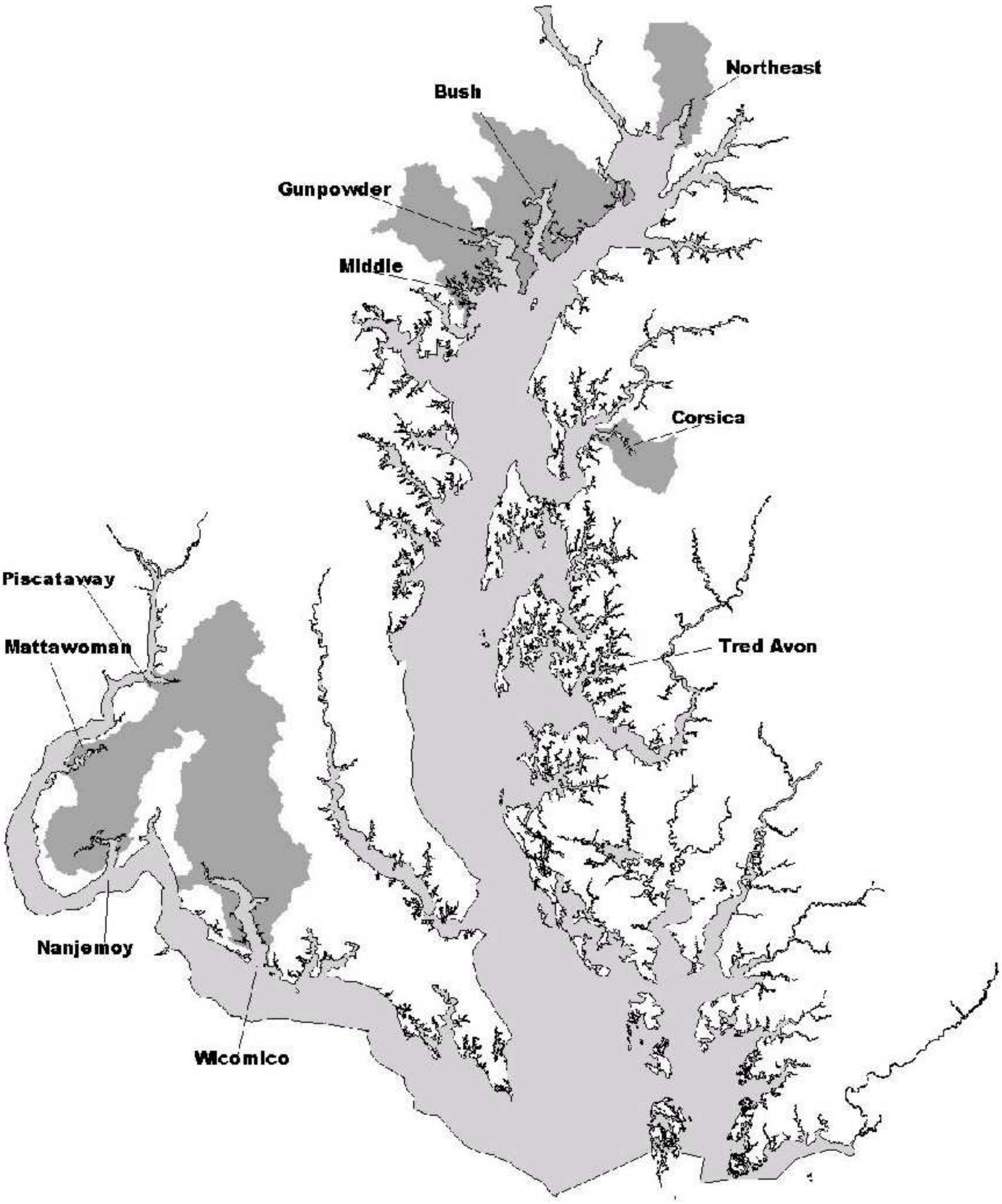

Figure 18. Land use and sampling stations in the Corsica River watershed.

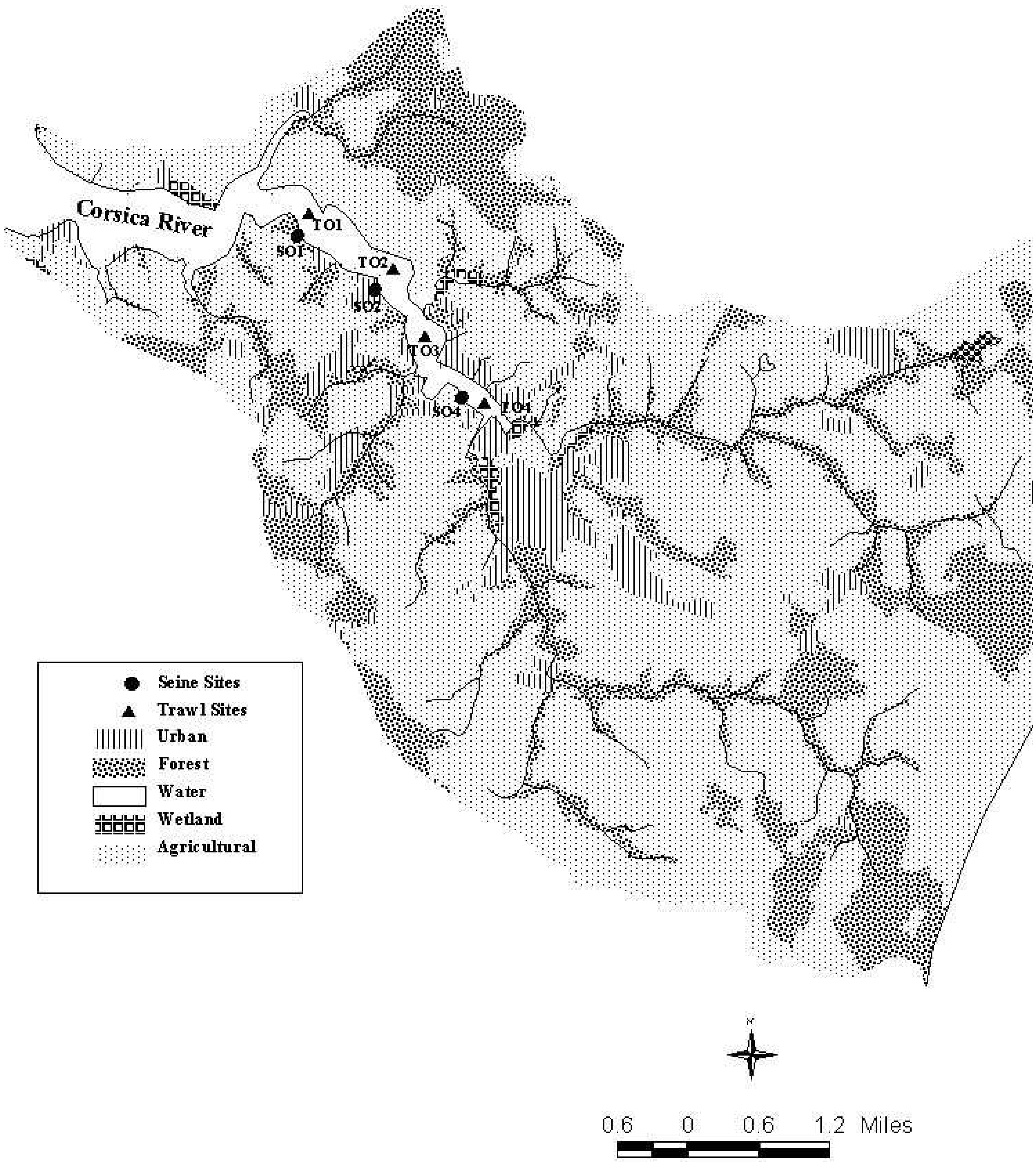

Figure 19. Land use and sampling stations in the Middle River watershed.

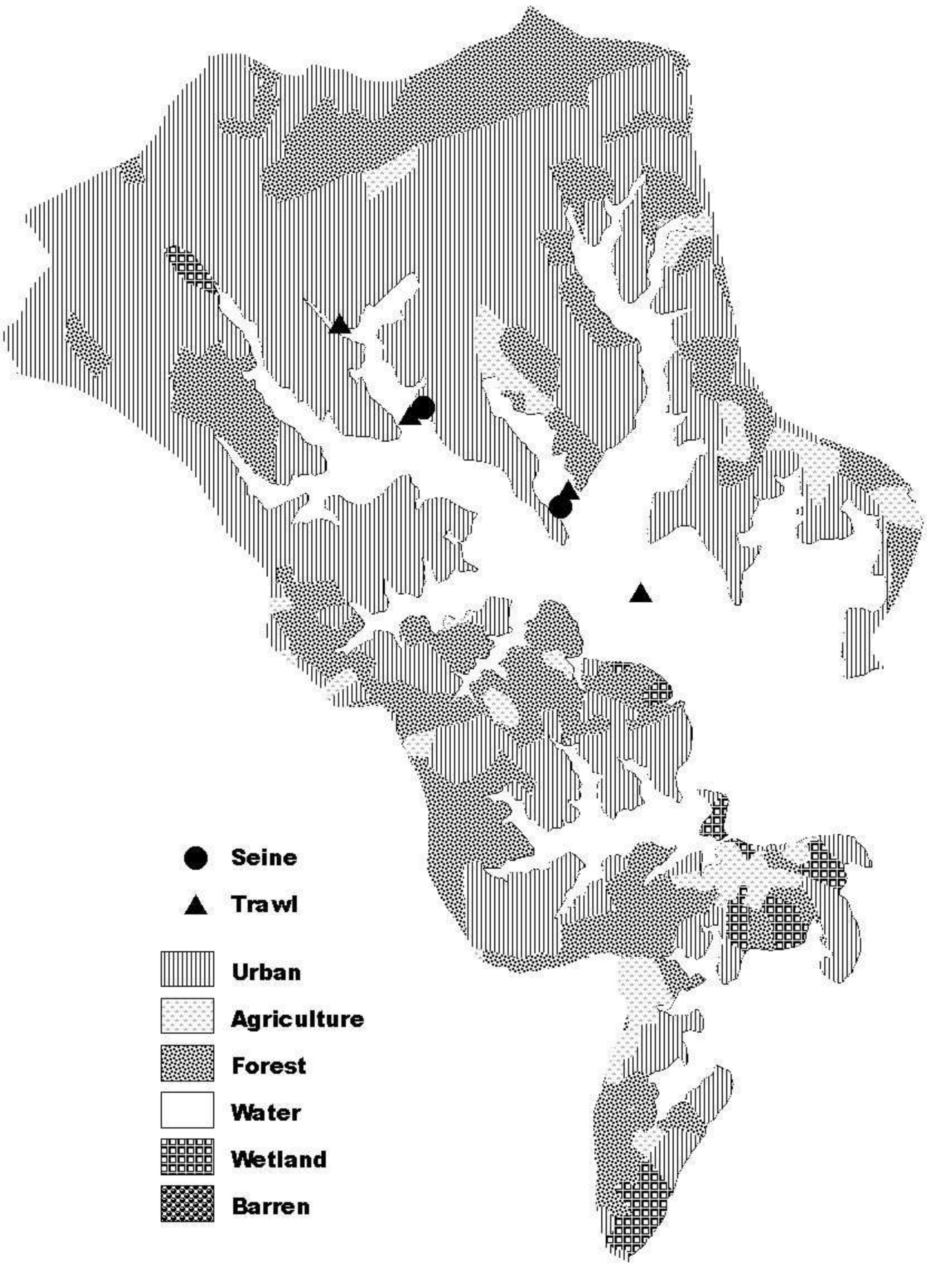

Figure 20. Land use and sampling stations in the Tred Avon watershed.

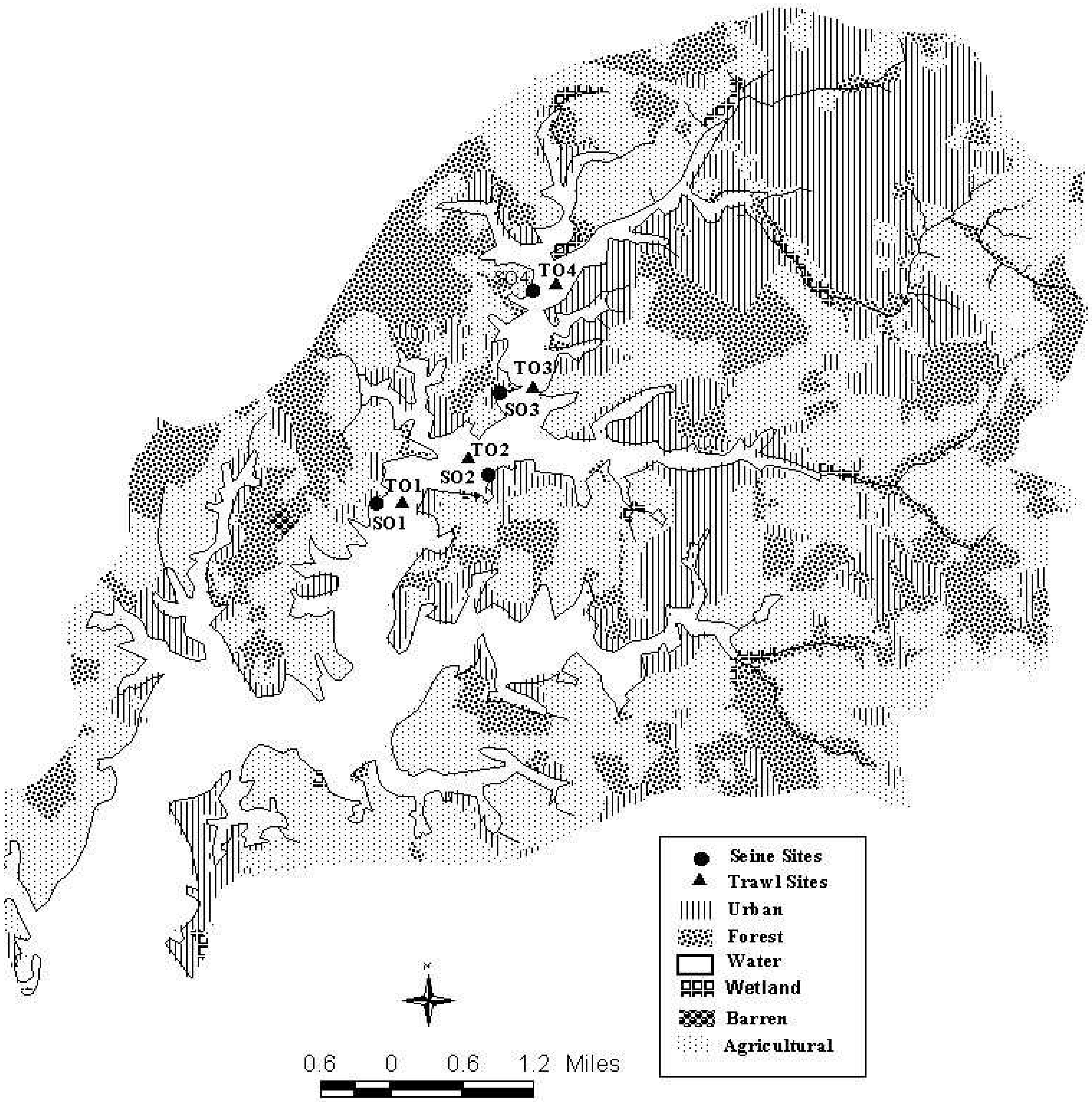

Figure 21. Land use and sampling stations in the Mattawoman Creek watershed.

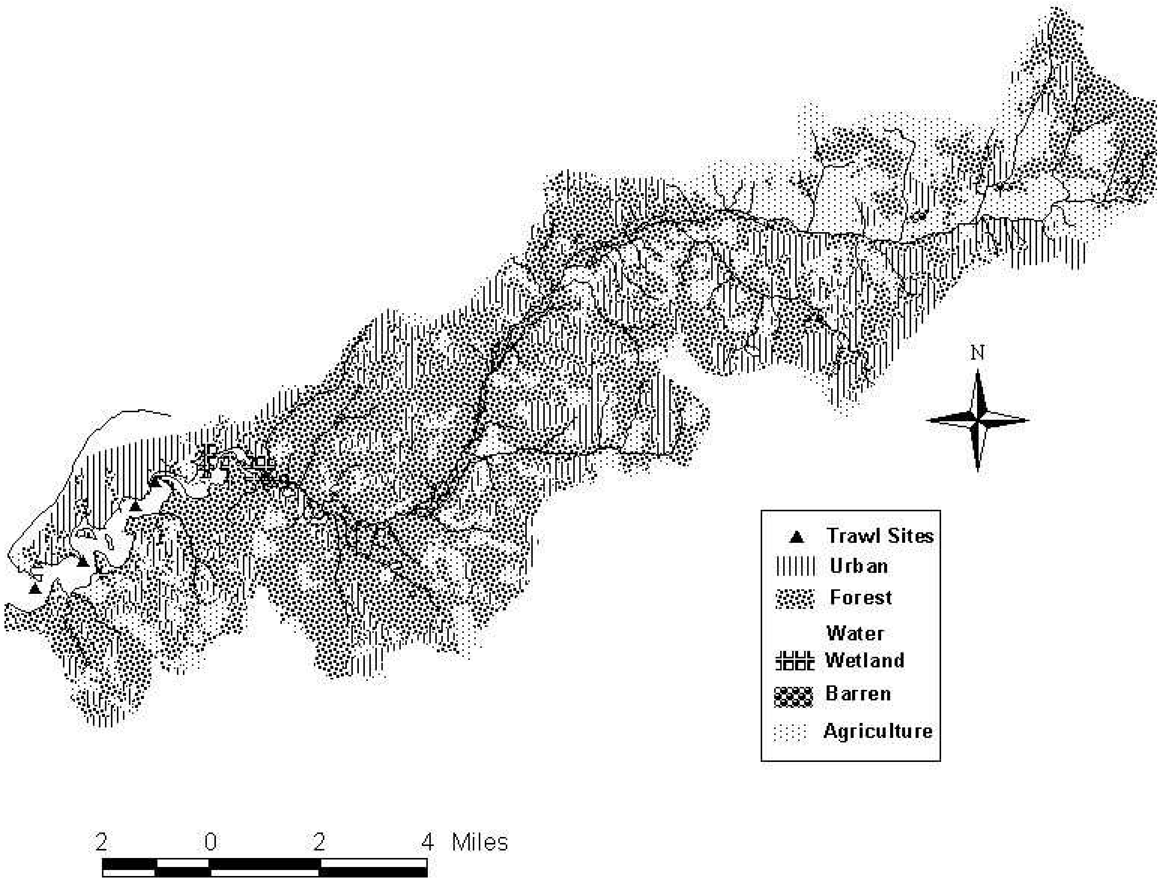

Figure 22. Land use and sampling stations in the Nanjemoy Creek watershed.

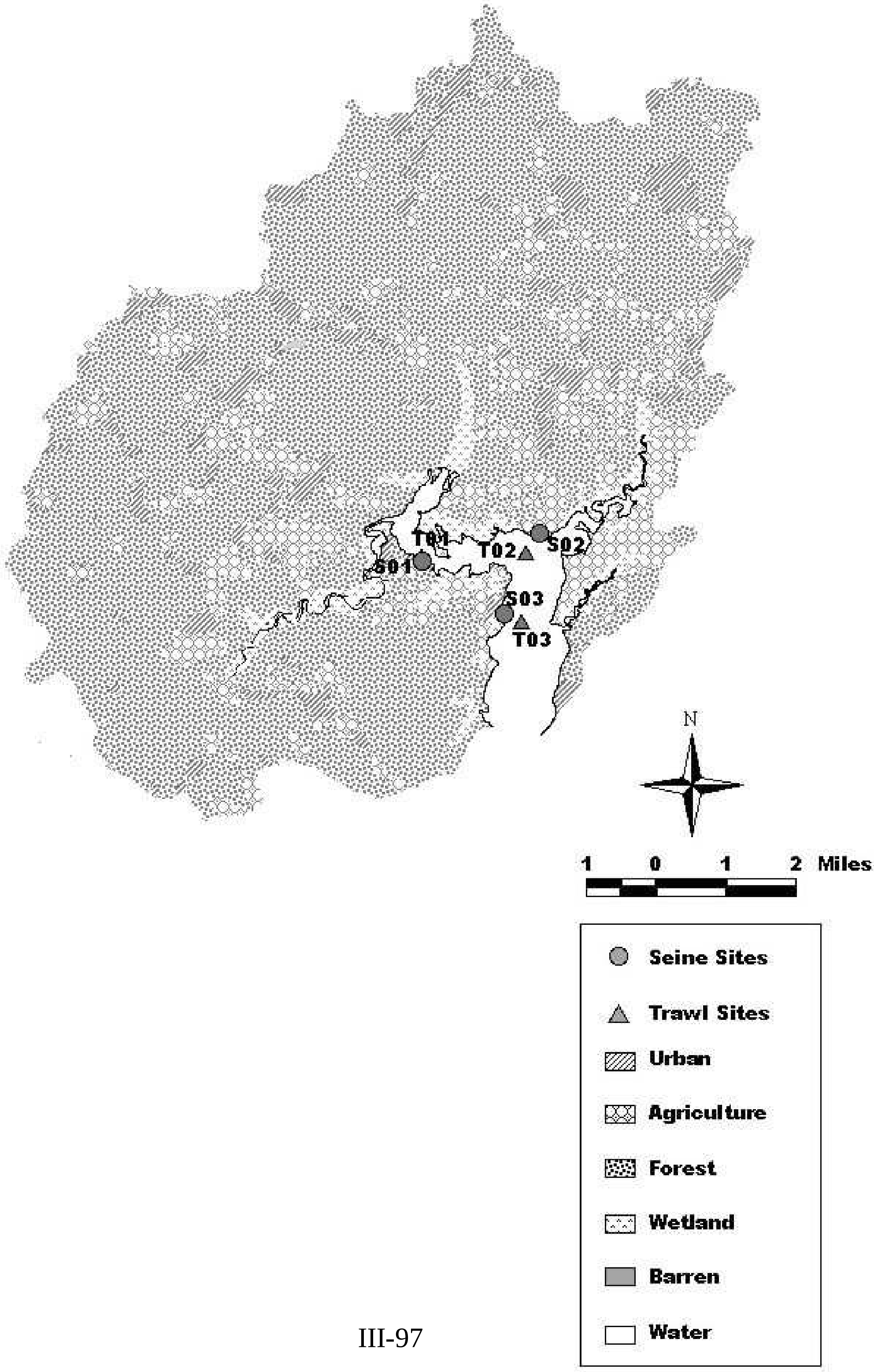

Figure 23. Land use and sampling stations in the Piscataway Creek watershed.

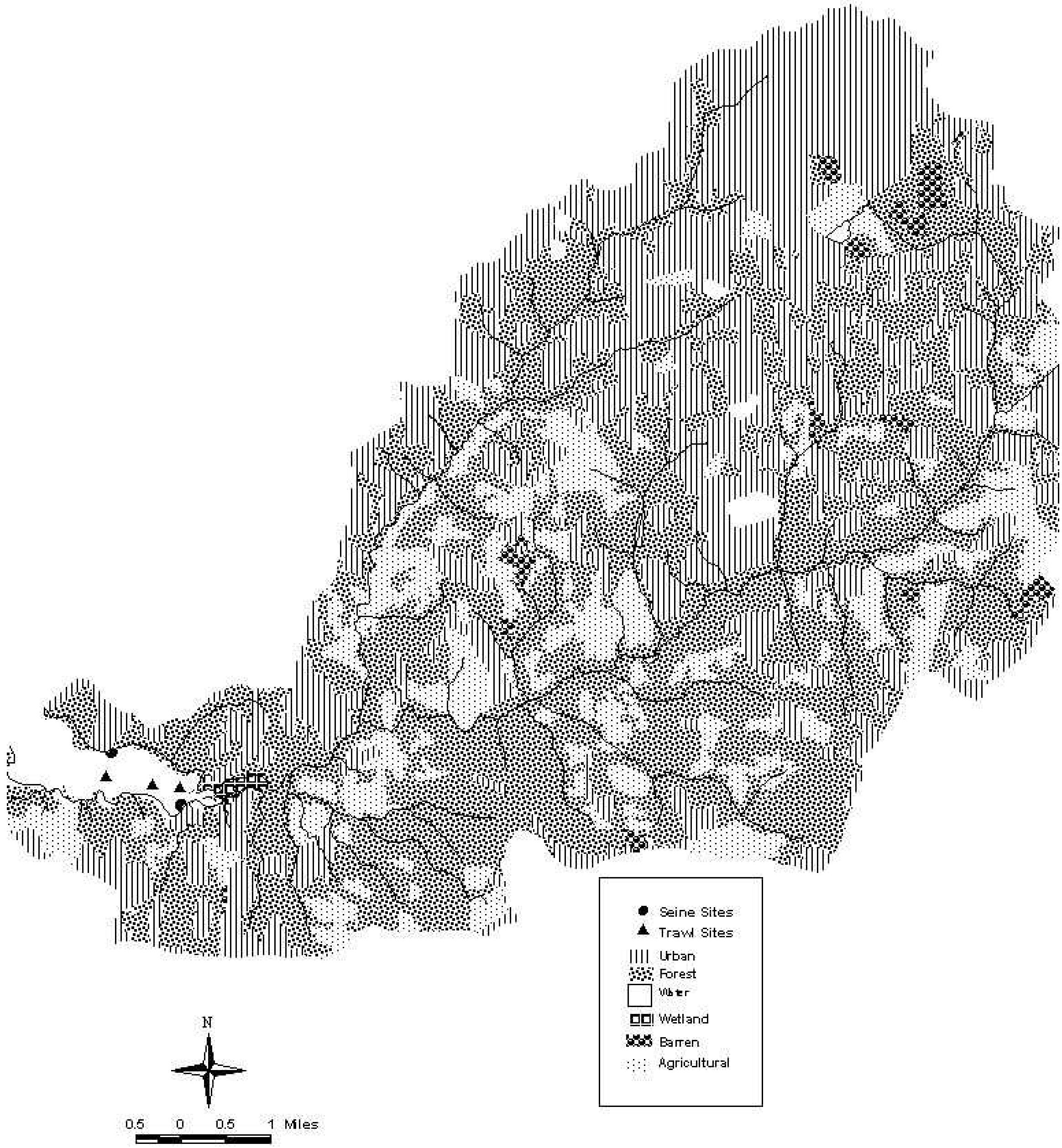

Figure 24. Land use and sampling stations in the Wicomico River watershed.

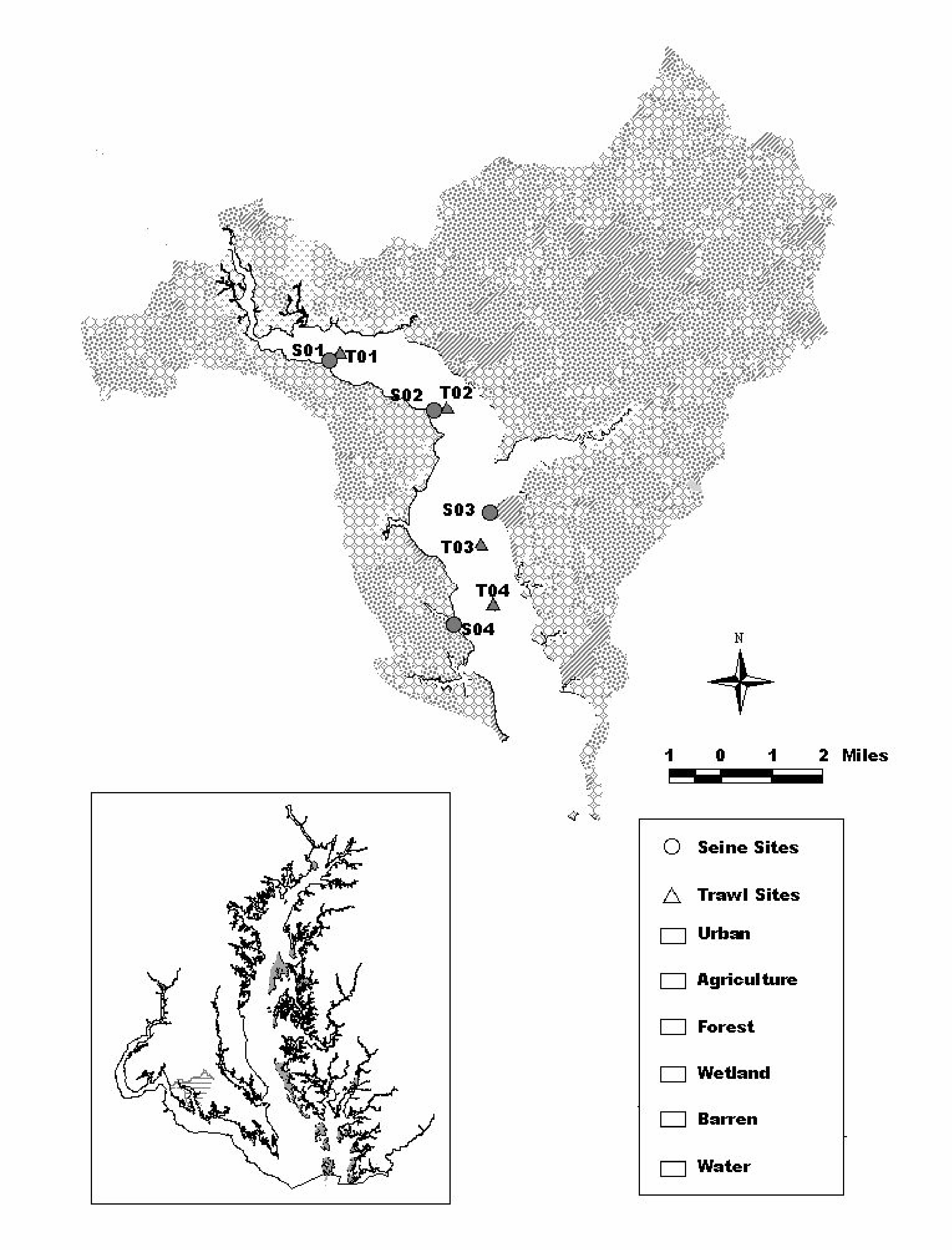

Figure 25. Land use and sampling stations n the Bush River watershed.

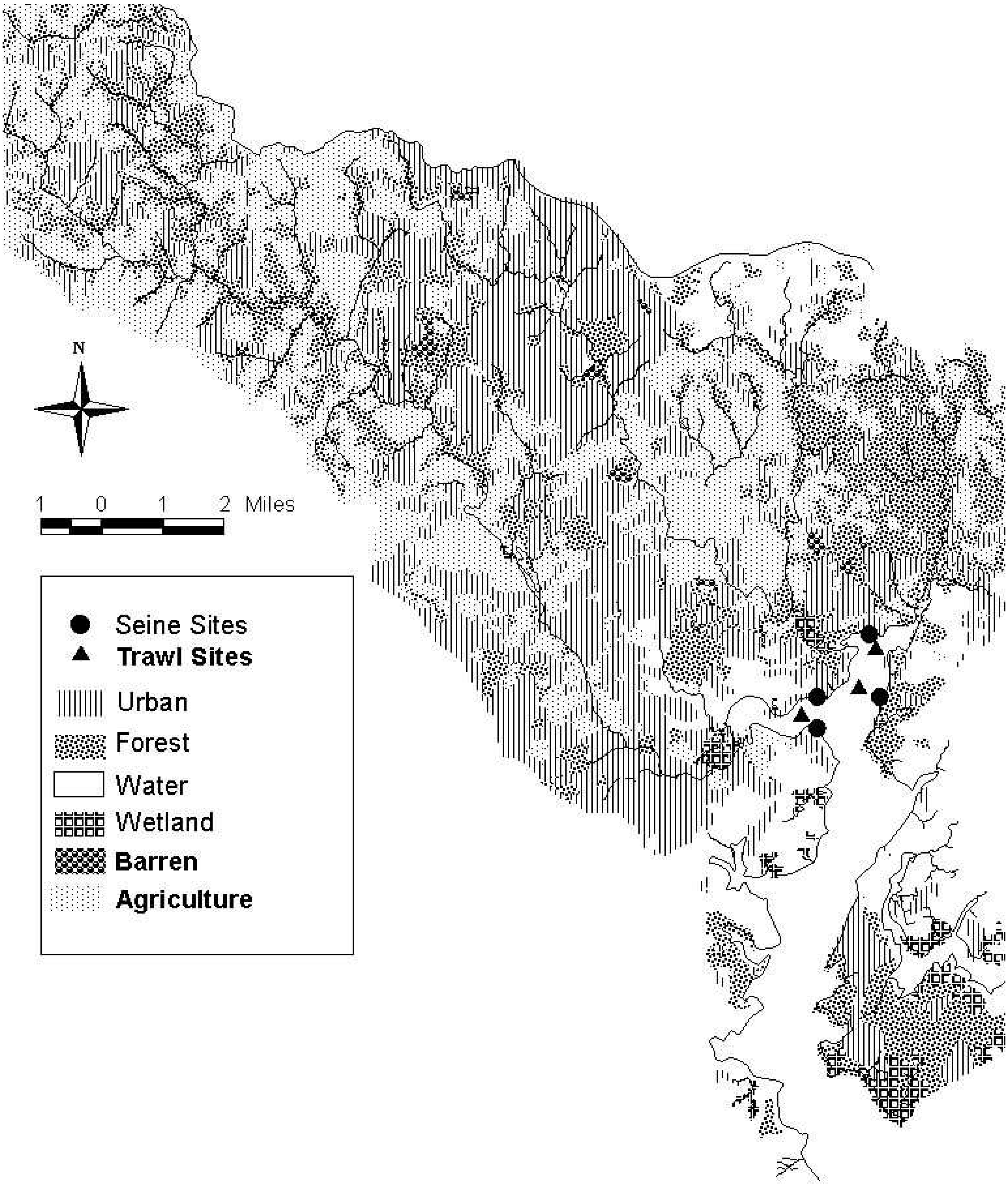

Figure 26. Land use and sampling stations in the Gunpowder River watershed.

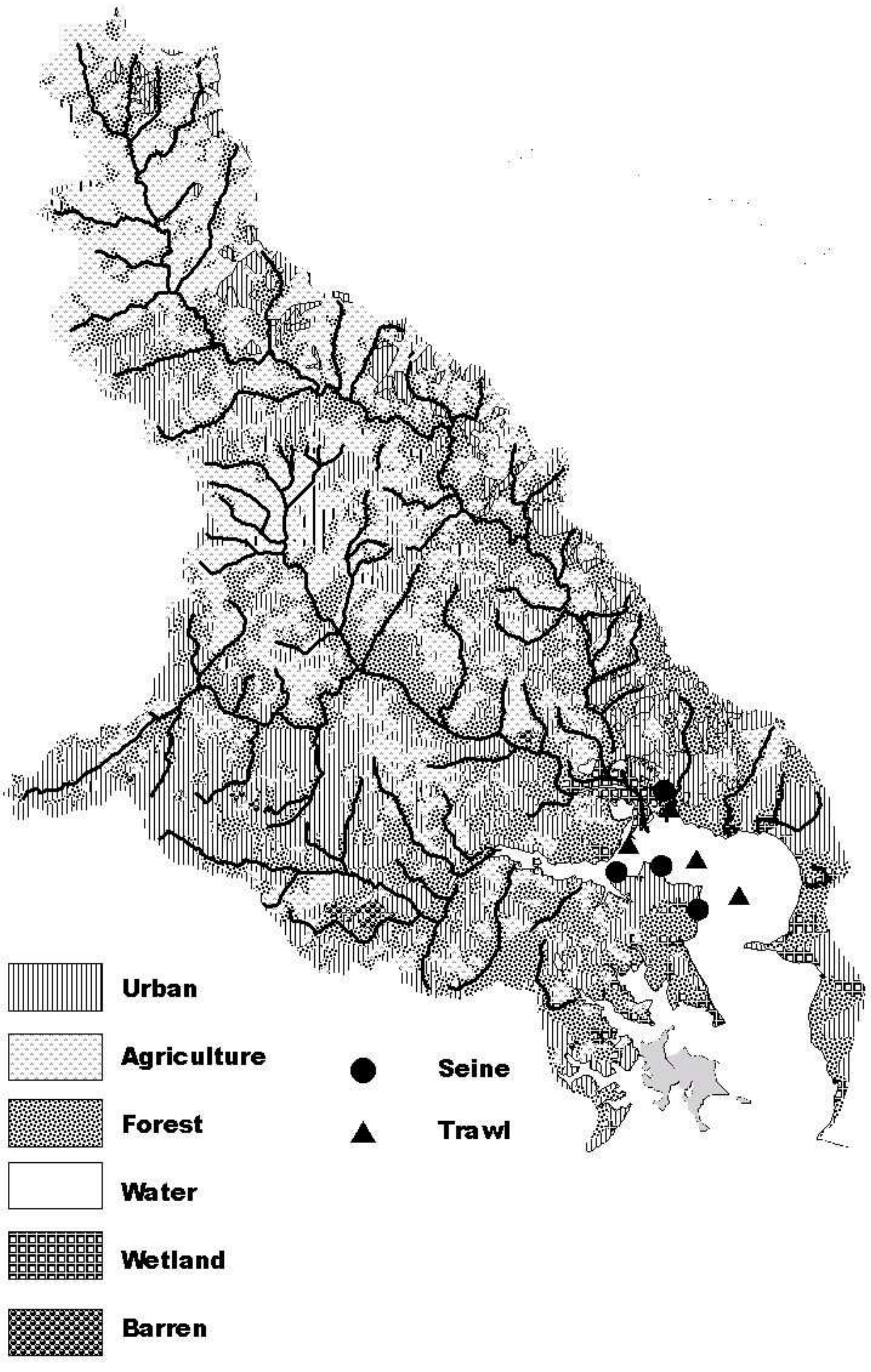

Figure 27. Land use and sampling stations in the Northeast River watershed.

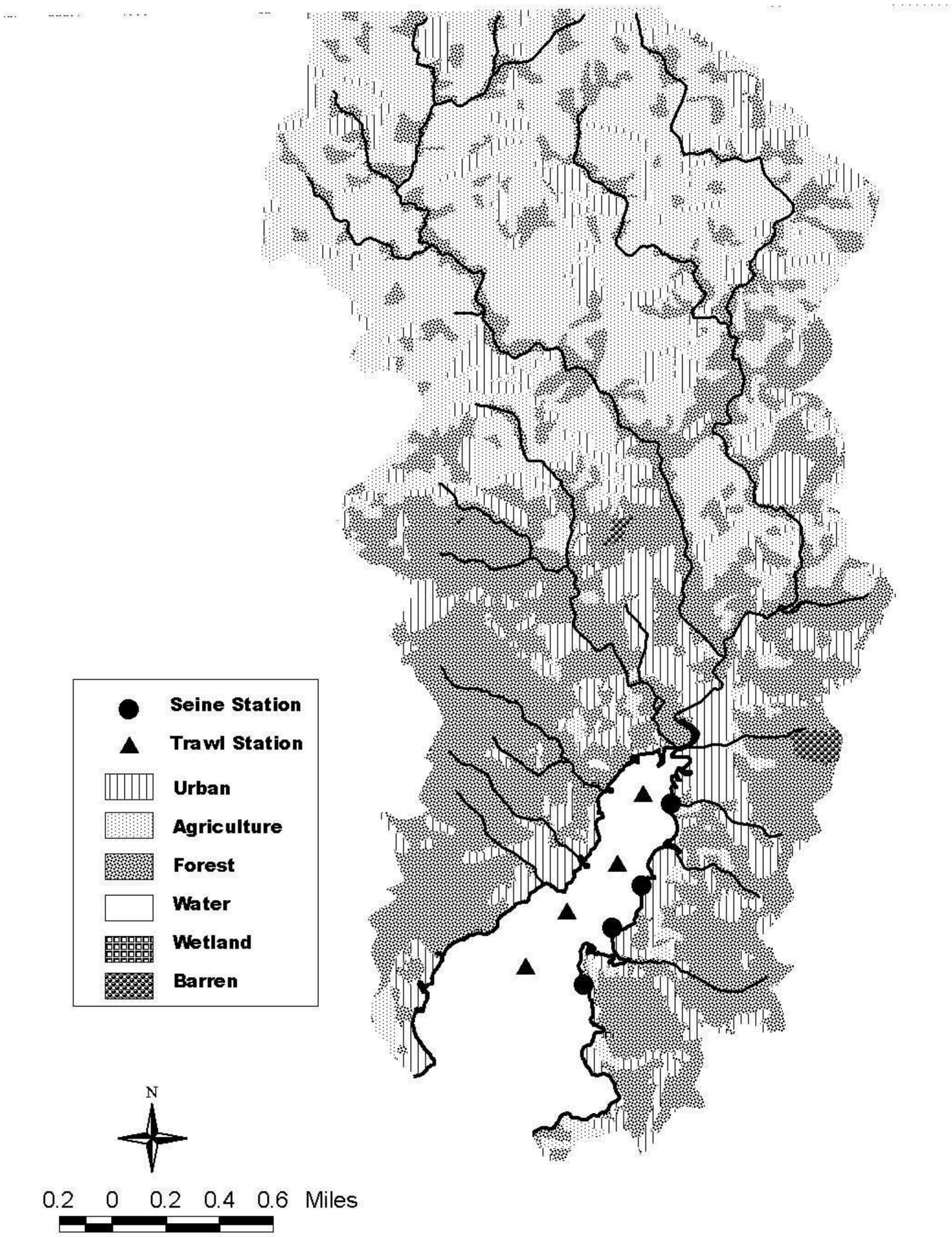

Figure 28. Trends in number of species annually captured (left Y-axis) and average $\log_{10}$ transformed catch of all species of fish (+1; right Y-axis) in Mattawoman Creek during 1989-2009. 10 ft = trawl with 10 foot headrope and 16 ft = trawl with 16 ft headrope.

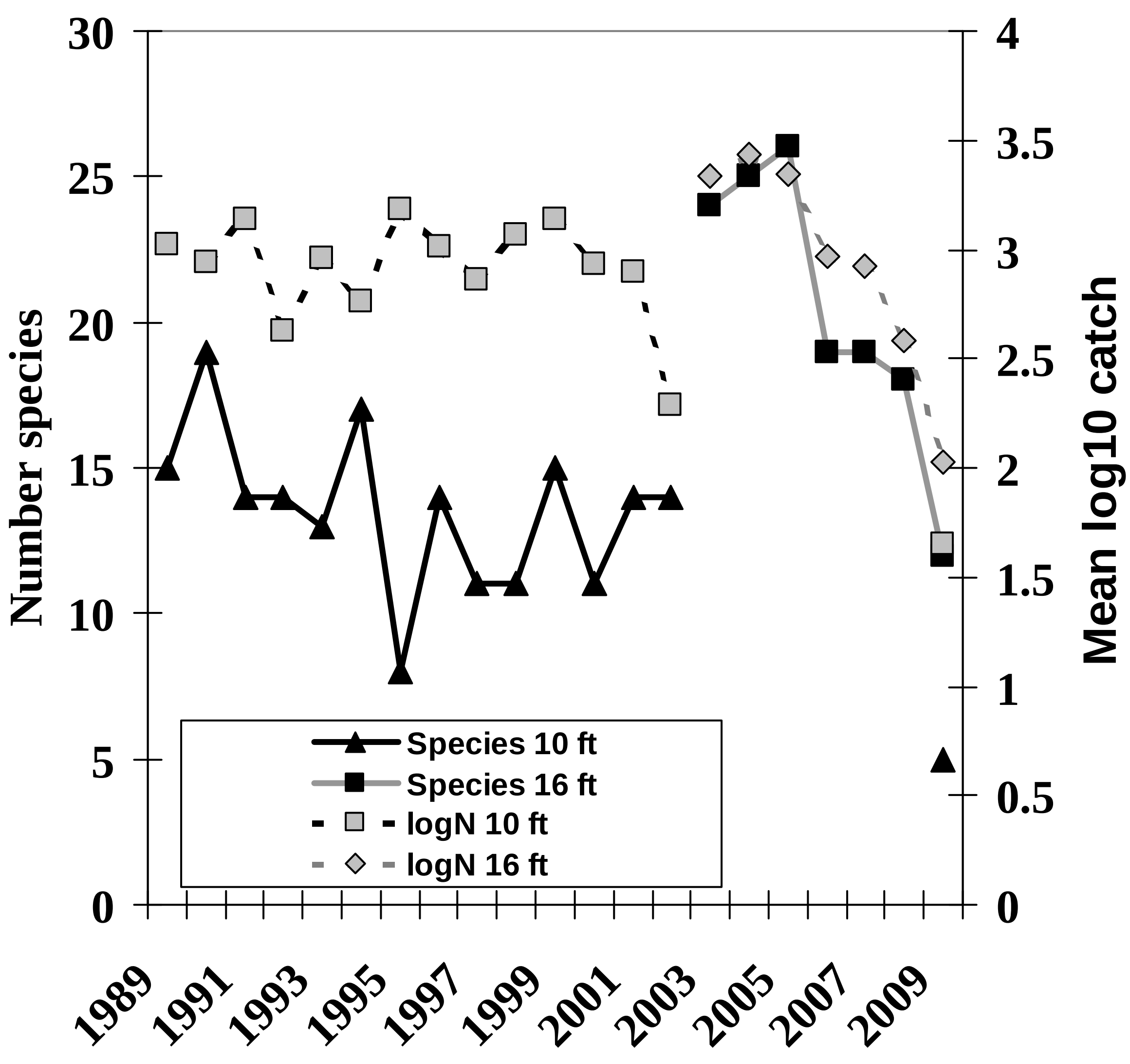

Figure 29. Log_{10} catch per effort by station and trawl type in Mattawoman Creek, 1989 to 2009; 10 ft and 16ft trawls were used at all stations.

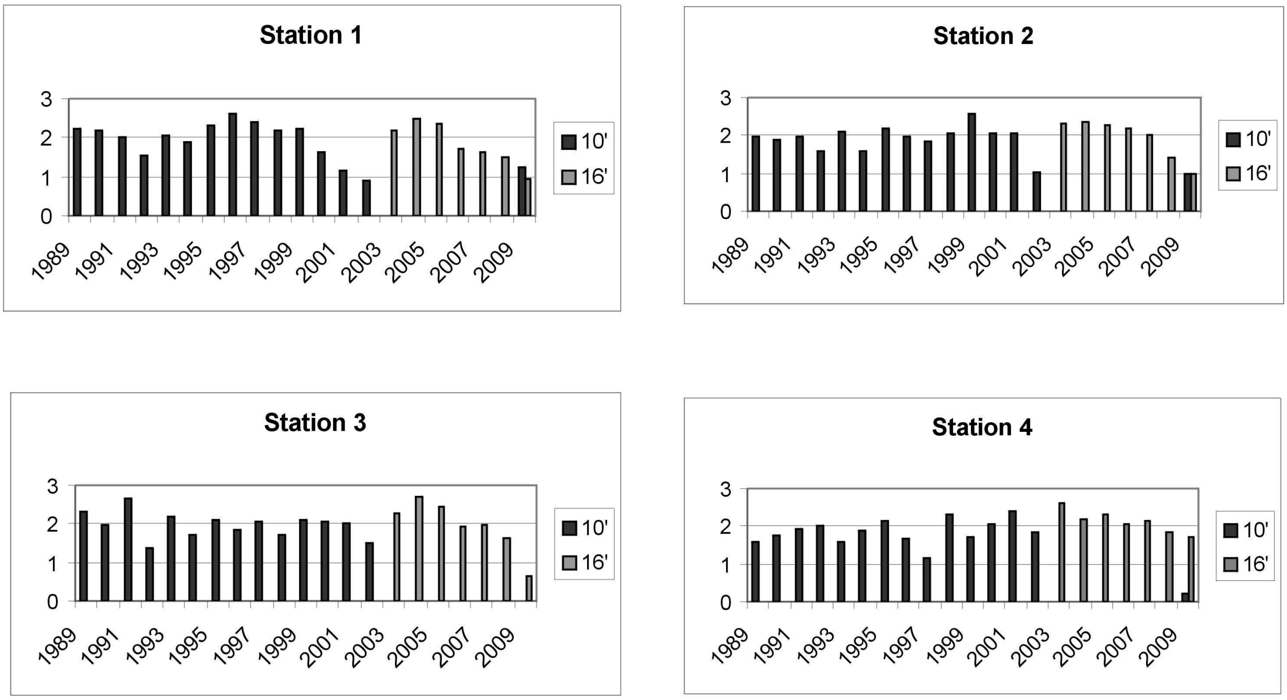

Figure 30. Striped bass sampling stations on the Upper Potomac River.

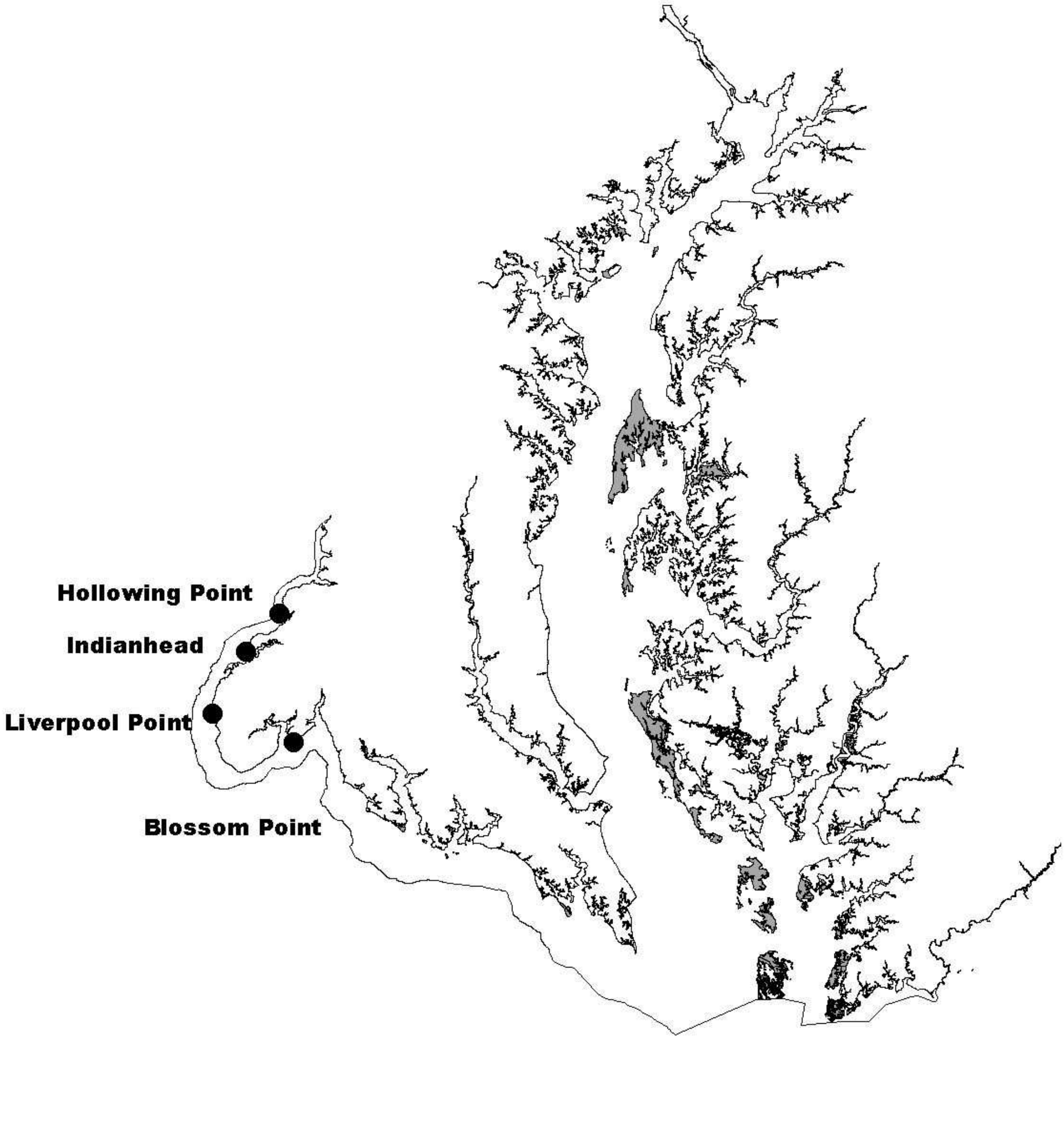

Figure 31. Species richness (number of species) by striped bass seining sites by year from 1989 to 2009. (Data provided by Eric Durell.)

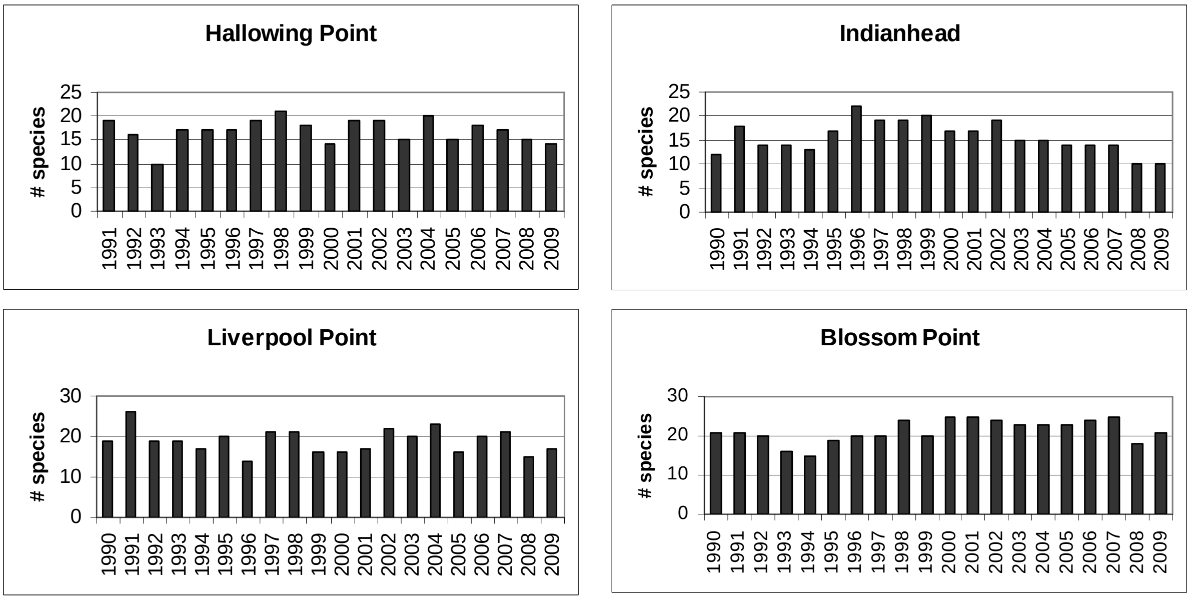

Figure 32. Species comprising 90% of the catch at striped bass seining sites from 1989 to 2009. (Data provided by Eric Durell.)

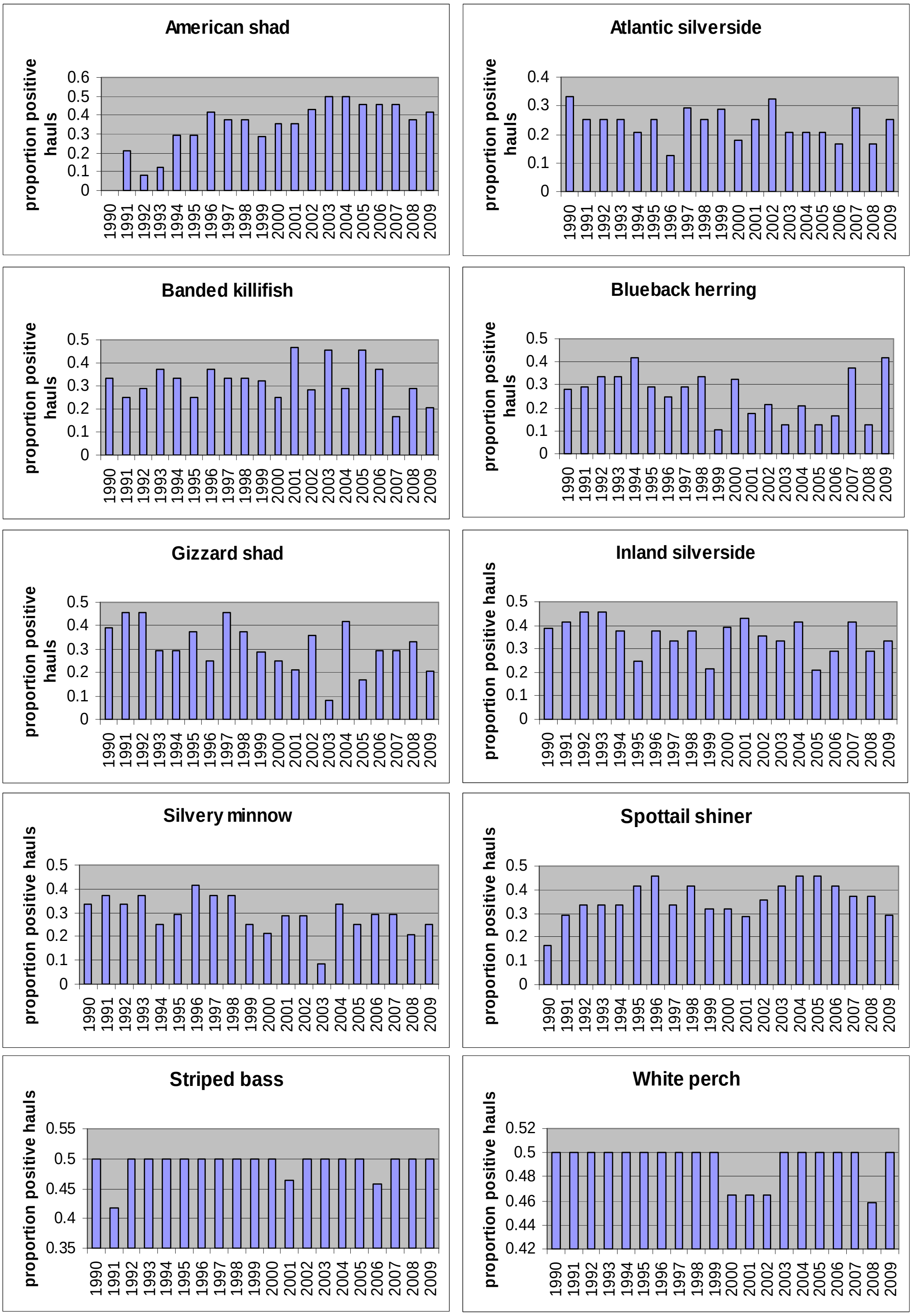

Figure 33. Observed and predicted number of species and mean log10-transformed catch (+1) plotted against number of structures built in Mattawoman Creek's watershed from 1989-2008. A 10 ft trawl (squares) was used to sample during 1989-2002 and a 16 ft trawl (diamonds) was used from 2003-2008. Species = number of species and P Species = predicted number of species. Log10 N = mean log10-transformed catch (+1). P Log10 N = predicted mean log10-transformed catch (+1).

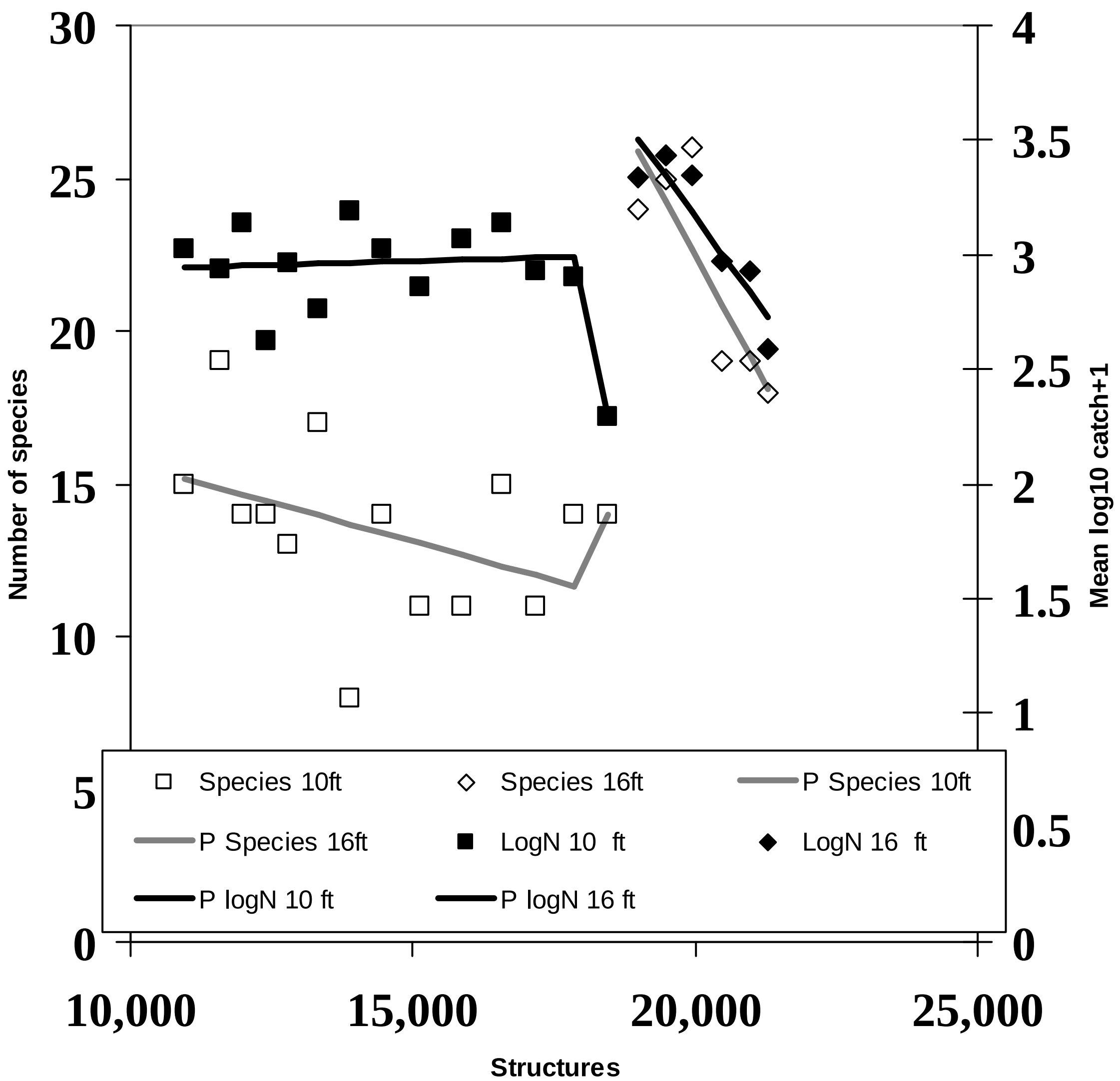

Figure 34. Box and whisker plot of bottom dissolved oxygen in Mattawoman Creek from 1989 to 2009. (Dark bar is the median, gray box represents the upper 75th percentile and the lower 25th percentile, black bars indicate the upper 95th and lower 5th percentiles, dark boxes indicate outliers.)

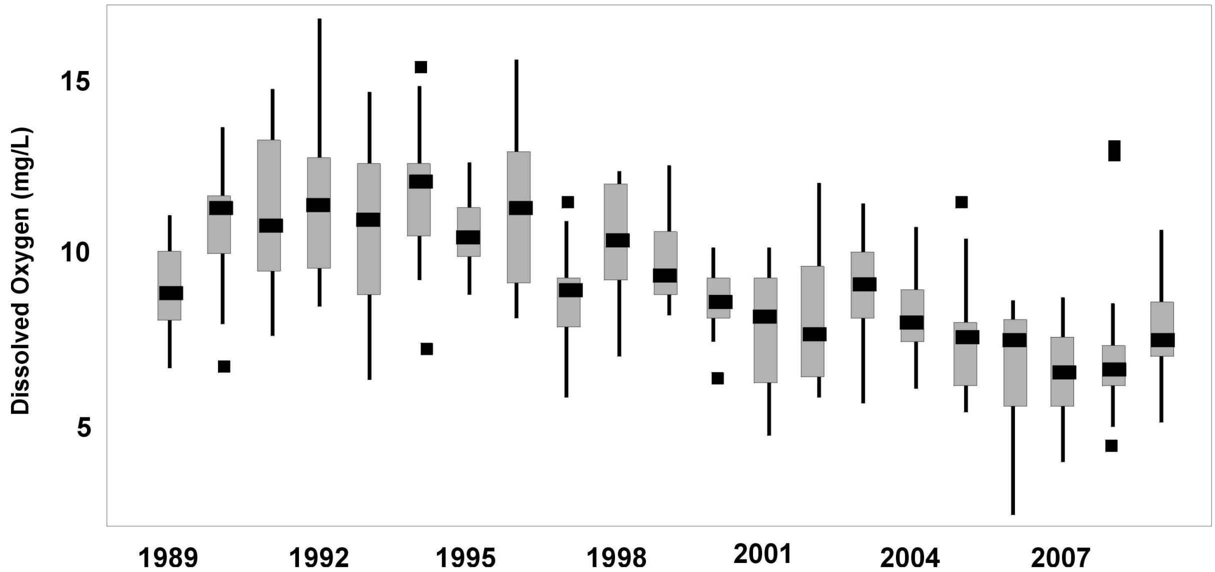

Figure 35. Proportion of violations of 3.0 and 5.0 mg/L criteria in the Corsica River.

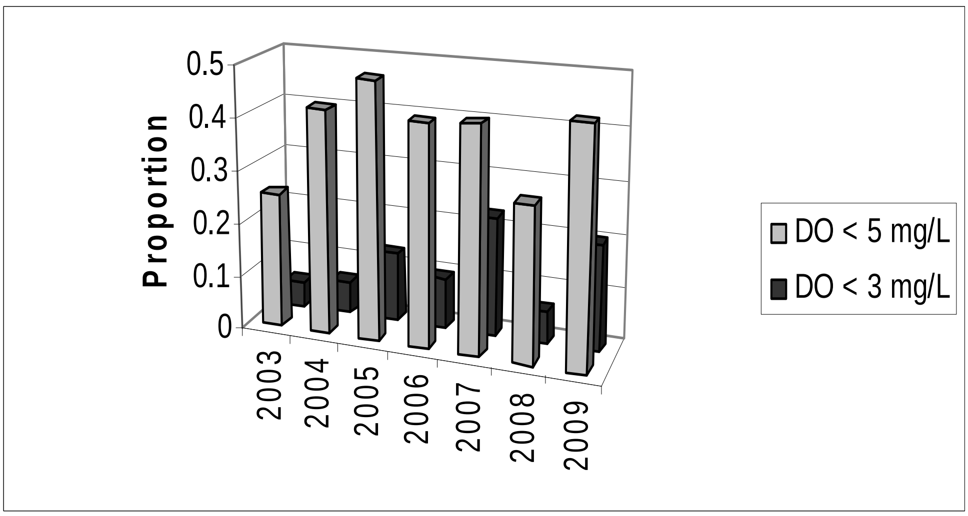

Figure 36. Proportion of temperature violations in Corsica River.

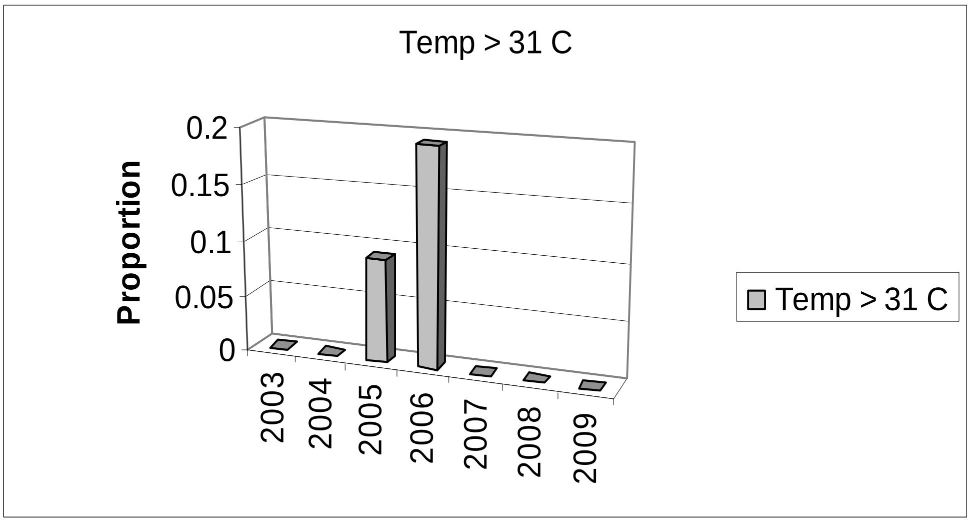

Figure 37. Number of species by year and gear type in the Corsica River.

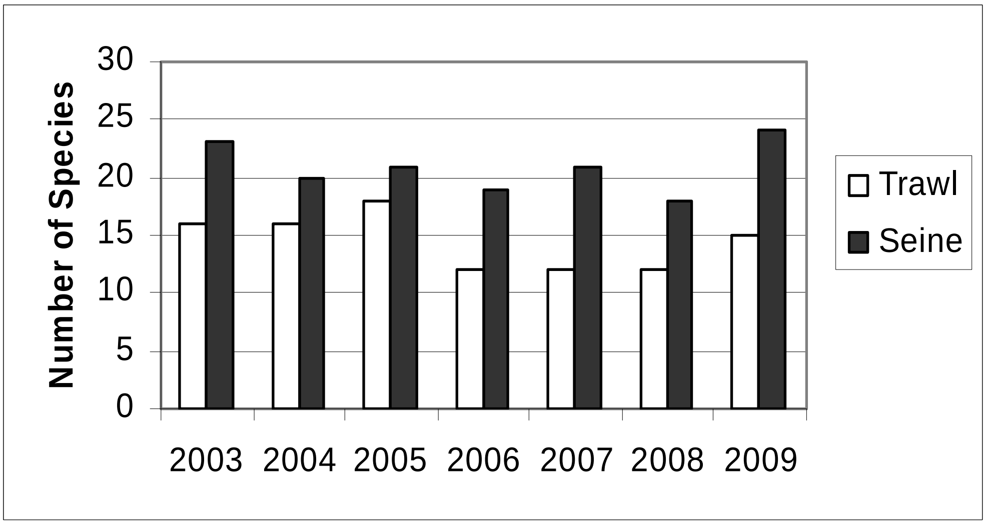

Figure 38. Number of species in the seine in Wicomico River, 1989-2009.

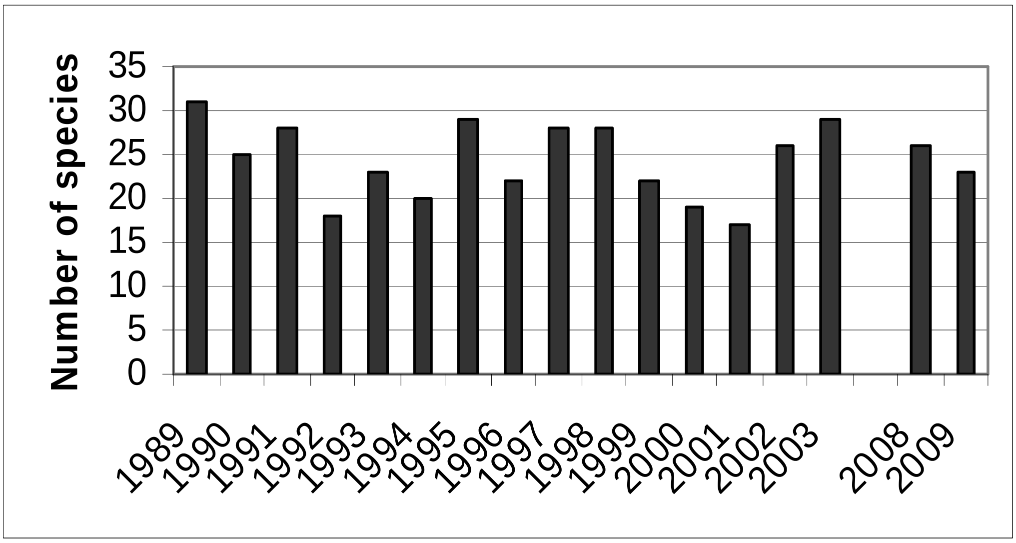

Figure 39. Number of species in the trawl in Wicomico River, 1989-2009. Note: We shifted from a small (10' trawl) to a large (16' trawl) in 2003.