**PERFORMANCE REPORT FOR FEDERAL AID GRANT F-63-R, SEGMENT 1**

**2010**

# MARINE AND ESTUARINE FINFISH ECOLOGICAL AND HABITAT INVESTIGATIONS

Maryland Department of Natural Resources
Fisheries Service
Tawes State Office Building B-2
Annapolis, Maryland 21401

This grant was funded by the State of Maryland Fisheries Management and Protection Fund
and
Federal Aid in Sport Fish Restoration Acts (Dingell-Johnson/Wallop-Breaux)

**Approval**

**Gina Hunt, Director**
**Legislation, Regulation, Ecosystem Management and Environmental Assessment Division**
**Maryland Fisheries Service**
**Department of Natural Resources**

**James H. Uphoff, Jr.**
**Fisheries Ecosytem Program**
**Legislation, Regulation, Ecosystem Management and Environmental Assessment Division**
**Maryland Fisheries Service**
**Department of Natural Resources**

**Acknowledgements**

The Maryland Department of Natural Resources (MDDNR) would like to thank the Mattawoman Watershed Society and Arlington Echo Education Center (Steve Barry and staff) for their volunteer sampling efforts. Mattawoman Creek volunteers consisted of Bonnie Bick, Kevin Grimes, Edward Joell, Yvonne Irvin, Sherry Hession, Debi Krahling, Julie Simpson, Katherin Adkins, Jacob Elmslie, Jim Long, Ken Hastings, Bob Boxwell, Roy Parker, Frank Cowherd, and Stan and Barbara Stepura. Tom Parham, Bill Romano, Mark Price, Lee Karrh and Brian Smith of MDDNR's Tidewater Ecosystem Assessment are thanked for assistance with water quality and submerged aquatic vegetation (SAV) information. Jim Thompson, Rick Morin, Marek Topolski, Nancy Butowski, Tony Jarzynski, and Butch Webb of MDDNR's Maryland Fisheries Service are thanked for assistance with sampling. The GIS skills of Marek Topolski have been invaluable in preparing tax map data.

**Project Staff**

Jim Uphoff
Margaret McGinty
Rudy Lukacovic
Bob Sadzinski
Bruce Pyle
James Mowrer
Sarah Bornhoeft

**Report Organization**

This report consists of summaries of activities for Jobs 1 – 3 under this grant. All pages are numbered sequentially; there are no separate page numbering systems for each Job. Job 1 activities are reported in separate numbered sections (Sections 1-4). Tables in Job 1 are numbered as section number – table number (1-1, 2-1, 2-2, etc). Figures are numbered in the same fashion. Jobs 2 and 3 are less complex and do not require sections.

**Errata from the 2009 Report**

Activities for 2009 were reported in the F-61-R-5 document under Project 3, Job 1. An analysis under the Summer Seining and Trawling section was in error. Under Analysis of Long-Term Data, Mattawoman Creek a regression analysis of annual mean ln-transformed catch of all species + 1 (ln N) was in fact an analysis of annual ln total catch. Effort varied little over the years, so the resulting trend was largely correct. A corrected version of Project 3, Job 1 for 2009 is available upon request.

**Job 1: Development of habitat-based reference points for recreationally important Chesapeake Bay fishes of special concern: development targets and thresholds**

Jim Uphoff, Margaret McGinty, Rudy Lukacovic, Bruce Pyle, Marek Topolski, and

Sarah Bornhoeft.

## Executive Summary

*Tax Map Indicators of Development* - We used tax map based counts of structures in a watershed, standardized to hectares (C / ha), as our indicator of development for analyses in this report. Annual estimates of number of C / ha for watersheds sampled during 1998-2009 surveys for estuarine yellow perch larval presence-absence were compared to static estimates of impervious surface (IS) calculated by Towson University from 1999-2000 satellite imagery to gain insight on how consistently both indicators depicted status of development. The relationship of IS and C / ha was well described by a non-linear power function ($r^2 = 0.95$; $P < 0.0001$). Trends in residuals of this relationship were not evident in rural watersheds (5% IS or less). Positive and negative variation in residuals was evident in more developed watersheds, suggesting that differences in development status between IS or C / ha were more related to measurement differences than growth of watershed development. The level of development in one developed watershed (South River) may have been seriously underestimated by satellite imagery.

*Stream Ichthyoplankton* - A survey to identify herring, white perch, and yellow perch (hereafter "anadromous fish") stream spawning habitat (indicated by presence of eggs, larvae, or adults) in southern Maryland was conducted during 1971. During 2008-2010, stream sites in Mattawoman Creek where anadromous fish spawning was documented in 1971 were sampled for eggs and larvae by citizen volunteers. Anadromous fish spawning data from a 1989-1991 survey of Mattawoman Creek were available as well. Piscataway Creek anadromous fish spawning sites were also sampled by volunteers during 2008 and 2009 and these data were contrasted with Mattawoman Creek.

Anadromous fish spawning was detected at Mattawoman Creek's mainstem stations in 2010 and the diminished distribution detected during 2009 was not repeated. Reappearance of spawning in 2010 supported the hypothesis that 2009 spawning was subject to an episodic loss due to application of road salt after an early March snowstorm.

In general, little change in anadromous fish stream spawning in Mattawoman Creek was indicated between surveys conducted in 1971 and 1989-1991. However, by 2008-2010 diminished spawning distributions that supported the hypothesis of chronic habitat loss were evident for all three species groups. Herring spawning was reduced from 6 sites in Mattawoman Creek in 1971 to 2-4 during 2008-2010. White perch stream spawning was detected at 1-2 sites in 1971 and 1989-1991, and 0-1 site during 2008-2010. Yellow perch stream spawning was detected at the most downstream stream site during every survey between 1971 and 2010, except 2009.

The 1971 spawning survey in Mattawoman Creek was conducted in a watershed with relatively little development (0.16 C / ha) and herring and white perch spawning was widespread. Development in Piscataway Creek in 1971 (0.47 C / ha) was similar to the level in Mattawoman Creek during 1989-1991 (0.41-0.45 C / ha) and anadromous fish spawning was widespread in both creeks. Based on the relationship of IS to C / ha developed for yellow perch larval presence-absence watersheds, current Mattawoman Creek watershed IS was near 11% at C / ha equal to 0.86 and is projected to grow to 22% IS (C / ha greater than 2.3), far greater than Piscataway Creek currently (C / ha = 1.4). Using the absence of anadromous fish spawning in Piscataway Creek as an indicator, stream spawning will disappear from Mattawoman Creek at projected levels of development at build-out.

USGS Flow gauges were located on Mattawoman Creek and Piscataway Creek and we used the annual median flow (M) as an indicator of flow magnitude and annual flow coefficient of variation (CV) as an indicator of flow variability. Both M and CV were divided by annual precipitation (P) and plotted against C / ha. At a threshold of about 0.7 C / ha ($\approx$ 9.5% IS), the response of M / P and CV / P to C / ha changed from a rural to a suburban watershed pattern. The near complete loss of stream spawning sites for anadromous fish in Piscataway Creek reflected increased flow magnitude and variability that followed large increases in development. Mattawoman Creek still supports anadromous fish stream spawning at a lesser level of development, but its hydrology appears to have shifted from that of a rural watershed to a suburban one. Changes in conductivity, hydrology, and anadromous fish stream spawning in Piscataway and Mattawoman creeks agreed with general findings elsewhere that (1) habitat quality in fluvial and tidal streams declined with IS and (2) streams and tidal creeks in watersheds with greater than 10% IS were degraded.

*Estuarine Yellow Perch Larval Sampling* - Yellow perch larval presence-absence sampling during 2010 was conducted in the upper tidal reaches of the Nanticoke, Northeast, Elk, and Severn rivers and Mattawoman, Nanjemoy, and Piscataway creeks during early spring. Annual $L_p$ (proportion of tows with yellow perch larvae during a standard time period and where larvae would be expected) provides an economically collected measure of the product of egg production and egg through early postlarval survival. During 2010, we sampled gut contents of yellow perch larvae to investigate whether feeding success and diet composition (1) influenced $L_p$ and (2) reflected the level of development indicated by counts of structures per hectare (C / ha) from tax maps.

A total of 332 larval guts were examined. Copepods were the most prevalent food item and were found in 55-100% of guts sampled in the five systems. Cladocerans were found in 2-22% of guts. The percentage of guts without food ranged from 0 to 19. Associations of the proportion of guts with copepods with other variables suggested that this class of zooplankton played a large role in yellow perch larval dynamics in the fresh-tidal systems sampled during 2010. Logistic regression indicated that the odds of yellow perch larval feeding successfully were negatively influenced by C / ha ($P < 0.0001$) and positively influenced by larval length ($P = 0.0008$). Predictive ability of the model was modest; 60% of larval fullness ranks were successfully classified and 35% were classified incorrectly.

Regression analyses indicated that C / ha was negatively related to $L_p$ and $L_p$ was, on average, higher in fresh-tidal subestuaries than in brackish subestuaries. The range of C / ha values available for analysis was greater in brackish subestuaries (0.07-2.74) than fresh-tidal (0.09-1.43). Predicted $L_p$ over the observed ranges of C / ha would decline from 0.50 to 0.13 in brackish subestuaries and from 0.84 to 0.66 in fresh-tidal subestuaries. These analyses indicated that watershed development negatively influenced survival of yellow perch larvae. First-feeding success may be an important factor influencing larval yellow perch survival that is negatively influenced by development.

*Estuarine Fish Community Sampling* - We evaluated nursery and adult habitat of recreationally important finfish in fresh-tidal, oligohaline, and mesohaline subestuaries of Chesapeake Bay during 2010. We sampled 10 Chesapeake Bay subestuaries in 2010.

We found that DO target and threshold criteria (5 mg/L and 3 mg/L, respectively) could be used for mesohaline bottom waters to evaluate habitat stress in a subestuary due to development, but they did not provide a great deal of insight for tidal-fresh and oligohaline subestuaries.

Correlations of mean bottom DO, SAV acreage, median chlorophyll a, and C / ha in Mattawoman Creek during 1989-2010 were strong and indicated that dynamics of these parameters could be inter-related. Increases in SAV were followed by falling water column chlorophyll a concentrations and bottom DO, although bottom DO remained largely at and above the target level. High DO during 1990-1996 (when SAV acreage was low) represented supersaturated conditions and, in combination with high chlorophyll a, indicated that algae blooms were prevalent. Comparisons of DO measurements at a continuous monitor located in a dense SAV bed to target and threshold criteria suggested SAV in Mattawoman Creek may be associated with DO deficits in shallow water. Proportions of fish in a community classification (resident-nonresident, spawning guild, and feeding strategy) changed in Mattawoman Creek after 2002. The proportions of trawl samples with resident and nonresident species in Mattawoman Creek were high during 1989-2001 and declined afterward. Proportions of trawl samples with freshwater and marine spawners varied considerably, but did not exhibit a definite decline; however, anadromous and estuarine spawners consistently exhibited lower proportions after 2001. Planktivores and carnivores were less frequent after 2001, but it was difficult to judge whether proportions of trawl samples in Mattawoman Creek with benthivores had changed.

We did not detect obvious indications of decline in bottom DO or the fish community in Tred Avon River during 2006-2010 due to development.

We examined subsamples of adult fish from all subestuaries for anomalies during 2010. White perch was the only target species sampled enough for estimates of proportions with anomalies that were statistically different from 0. The low frequency of anomalies we observed indicated very large and impractical sample sizes would need to be drawn from each subestuary for precise estimates of proportions of white perch with anomalies.

## Job 1 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 1 was to develop 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 2010 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 activities are reported as separate sections in Job 1. These efforts were collectively aimed at defining the impact of impervious surface on target fish species populations and habitats. Sampling and synthesis of information in 2010 emphasized fresh-tidal systems. Previous activities have formulated target and limit ISRPs for brackish subestuaries based on Chesapeake Bay dissolved oxygen (DO) criteria, and associations and relationships of percent of watershed in impervious surface (IS), summer DO, and presence of target species (Uphoff et al. in press).

## Section 1 - Tax Map Indicators of Development

### Introduction

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 and existing structures. The primary purpose of these 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 meet our requirements for a standardized, readily updated, and accessible data base (Uphoff et al. 2010). Based on comparisons of 2000 tax map indicators and Towson IS estimates for 1999-2000, both counts of structures per or square footage of structure footprints per unit area had strong relationships described by a nonlinear power function (Uphoff et al. 2010).

## Methods

Two indicators of development were estimated from tax map data, a count of structures and total square footage of structure footprints. For any given tax year, the count of structures and total structure footprint square footage estimates for each watershed studied required multiple geoprocessing tools.

Most files were managed and geoprocessed in ArcGIS 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 of interest were extracted from a statewide shapefile, provided by MD DNR, which was modified to exclude all estuarine waters of each watershed. Each watershed's geometry was then recalculated.

All tax data were organized by county. Since watersheds straddle political boundaries, one statewide tax map was created for each year of available tax data, and then subdivided into watersheds. A small portion of parcels in each year of tax map data had no coordinates and were omitted. Inconsistencies in the projection and year structures were built of 1998 and 1997 tax maps prevented their use.

ArcGIS geoprocessing models were developed using Model Builder 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 modified MD 8-digit watershed boundary file to create watershed tax maps. These watershed tax maps were queried for all parcels having a structure built from 1700 to the tax data year and foundation square feet greater than zero. A large portion of parcels did not have any record of foundation square feet or year built for structures. All square feet and number of structure calculations are likely underestimates. Consistent undercounts should not present a problem since we are interested in the trend and not absolute magnitude.

Time series of tax map data were constructed for 1950 – 2009. The 1999 data set was used to construct all historic annual data. Annual estimates of number of structures (C) per hectare or C / ha for watersheds sampled during 1998-2009 surveys for estuarine yellow perch larval presence-absence (Table 1-1) were compared to static estimates of IS used by Uphoff et al. (2010) to gain insight on how consistently both indicators depicted status of development. We used impervious and watershed area 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; D. Sides, Towson University, personal communication). We estimated IS for each watershed as (IA / TA) • 100; where IA is impervious surface area estimated in the watershed and TA is the estimate of total area of the watershed A non-linear power function that minimized the sums of squared residuals (under an assumption that they were normally distributed) was estimated with Proc NLIN in SAS (Gauss-Newton Algorithm; Freund and Littell 2006)) as

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

where I = C / ha and a and b are estimated coefficients. An approximate $r^2$ was used to describe overall fit. Of particular interest was the pattern of residuals with time. We plotted residuals against year minus 2000 to determine if systematic changes in residuals occurred due to continuous growth in development.

## Results and Discussion

Four 1950-2009 time-series of structure counts per hectare (C / ha) and structure area / hectare (A / ha) were plotted to see if they depicted similar trends (Figure 1-1). These plots revealed a "jump" in A / ha beginning in 1999 that was not evident in C / ha and a substantial deviation in both estimates during 2007 in three of four watersheds. We chose to use C / ha as our indicator of development for analyses in this report, but eliminated C / ha estimates, such as those for 2007, that exhibited large deviations from preceding and following years (Figure 1-1).

The relationship of IS and C / ha was well described by the equation

$$IS = 0.020*I^{1.58} \; (r^2 = 0.95; P < 0.0001; \text{Figure 1-2});$$

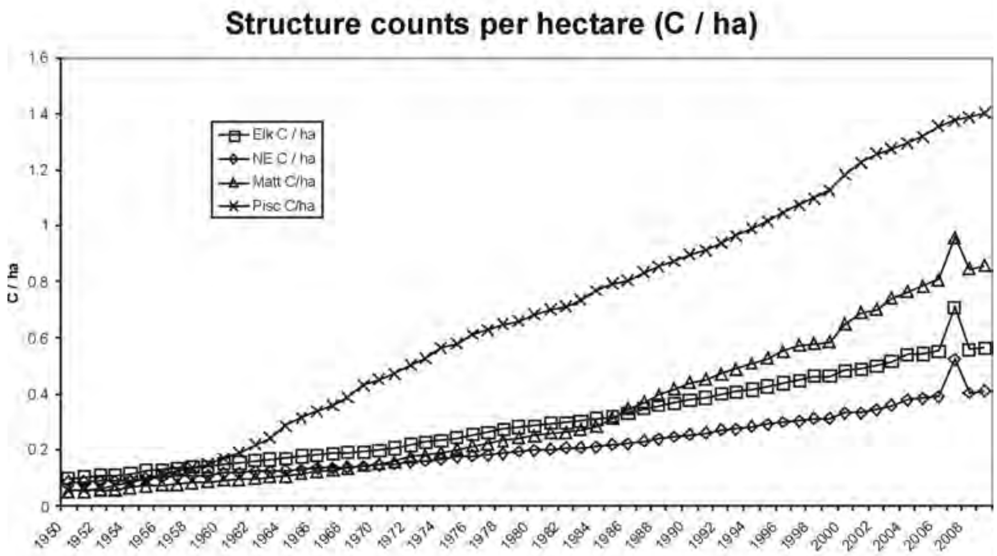
SE's of coefficients a and b were 0.008 and 0.14, respectively. Systematically increasing residuals were not evident in rural watersheds (5% IS or less). However, positive and negative variation was evident in more developed watersheds, suggesting that differences in development status between IS or C / ha were more related to measurement differences than growth of watershed development. Small residuals at time equal to -2 to 4 years were artifacts of exclusively rural watersheds represented in those years (Figure 1-2).

The level of development in one developed watershed (South River) may have been seriously underestimated. Estimated IS in South River during 2000 was 10.9% but C / ha indicated it may have been much higher (≈ 16-17% IS).

Table 1-1. Data used for comparison of static impervious surface estimates (IS, percent) and time-varying counts of structures per hectare (C / ha). Year is the year a tributary was sampled.

| Year | Subestuary | IS % | C / ha |
|---|---|---|---|
| 1998 | Choptank | 3.04 | 0.10 |
| 1999 | Choptank | 3.04 | 0.10 |
| 2000 | Choptank | 3.04 | 0.10 |
| 2001 | Choptank | 3.04 | 0.10 |
| 2002 | Choptank | 3.04 | 0.11 |
| 2003 | Choptank | 3.04 | 0.11 |
| 2004 | Nanticoke | 1.98 | 0.09 |
| 2004 | Choptank | 3.04 | 0.12 |
| 2004 | Severn | 19.46 | 2.09 |
| 2005 | Nanticoke | 1.98 | 0.14 |
| 2005 | Severn | 19.46 | 2.15 |
| 2006 | Nanticoke | 1.98 | 0.10 |
| 2006 | Corsica | 4.13 | 0.21 |
| 2006 | Bush | 11.29 | 0.68 |
| 2006 | Severn | 19.46 | 2.17 |
| 2007 | Nanticoke | 1.98 | 0.13 |
| 2007 | Langford | 3.1 | 0.07 |
| 2007 | Corsica | 4.13 | 0.22 |
| 2007 | Bush | 11.29 | 0.69 |
| 2007 | Severn | 19.46 | 2.21 |
| 2008 | Nanticoke | 1.98 | 0.11 |
| 2008 | Mattawoman | 8.99 | 0.87 |
| 2008 | South | 10.94 | 1.61 |
| 2008 | Bush | 11.29 | 0.70 |
| 2008 | Piscataway | 16.51 | 1.41 |
| 2008 | Severn | 19.46 | |
| 2009 | Nanjemoy | 0.09 | 0.09 |
| 2009 | Nanticoke | 1.98 | 0.14 |
| 2009 | Mattawoman | 8.99 | 0.88 |
| 2009 | Bush | 11.29 | 0.72 |
| 2009 | Piscataway | 16.51 | 1.43 |
| 2009 | Severn | 19.46 | 2.25 |
| 2009 | Magothy | 20.2 | 2.73 |

Figure 1-1. Time-series of tax map based indicators of development for Elk River, Northeast (NE) River, Mattawoman Creek (Matt), and Piscataway Creek (Pisc).



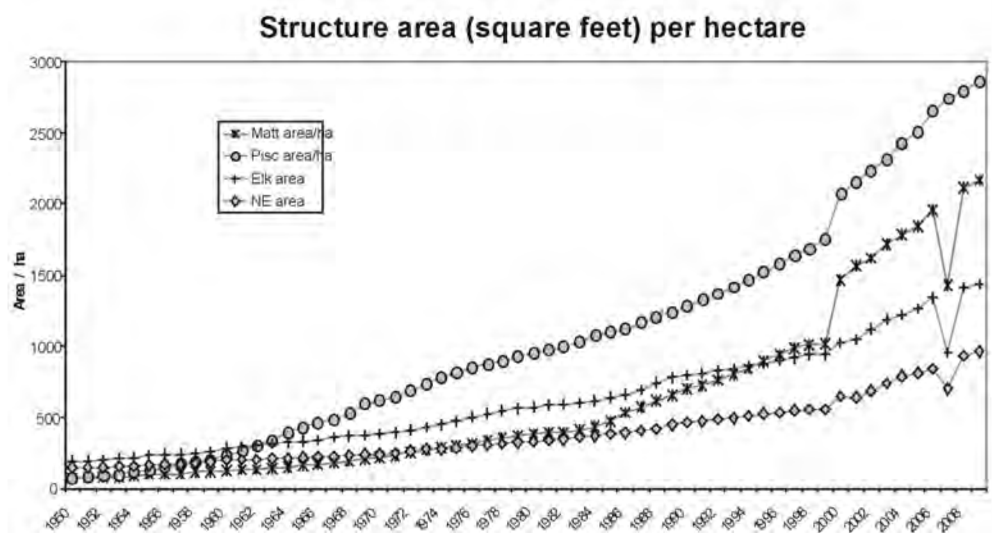
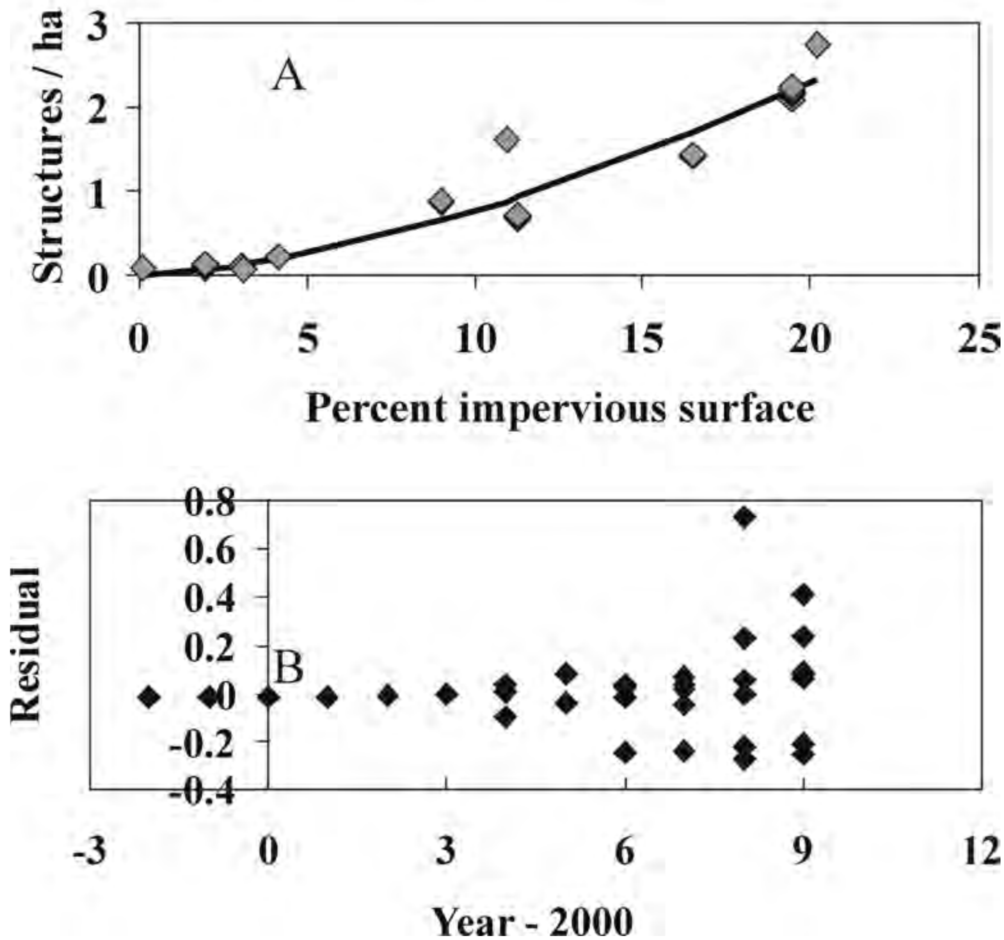



Figure 1-2 . (A) Relationship of static impervious surface estimates (2000) to time-specific (1998-2009) estimates of structure count per hectare.
(B) Residuals plotted against years from 2000.



## Section 2 - Stream Ichthyoplankton Sampling

### Introduction

A survey to identify anadromous spawning habitat in Maryland was conducted during 1970-1986 and these data were used to develop statewide maps detailing spawning habitat (O'Dell et al. 1970; 1975; 1980; Mowrer and McGinty 2002). Recreating these surveys provides an opportunity to explore whether spawning habitat has declined in response to urbanization.

During 2008-2010, stream sites in Mattawoman Creek (Figure 2-1) were sampled for eggs and larvae of herring, white perch, and yellow perch (hereafter "anadromous fish") by citizen volunteers coordinated by program biologists. Piscataway Creek was also sampled by volunteers during 2008 and 2009 (Figure 2-1) and these data were contrasted with Mattawoman Creek. Methods of O'Dell et al. (1975) were used to collected ichthyoplankton and sites that historically supported at least one of the three anadromous species were sampled.

Stream spawning of anadromous fish largely ceased in Piscataway, Swan, and Broad creeks, and Oxon Run between 1971 and 2008-2009 (Uphoff et al. 2010). Little change in anadromous fish stream spawning in Mattawoman Creek was indicated between 1971 and 1989-1991; however, by 2008-2009 some spawning site losses were evident for all three anadromous fish groups. A particularly severe decline in stream spawning was detected in Mattawoman Creek in 2009. Monitoring in 2010 evaluated whether spawning site loss was a drastic, chronic response to urbanization or an acute response to road salt application just prior to spawning season. A chronic loss would be indicated by continued low site use or complete site loss, while reoccupation of sites would support an acute response in 2009 (Uphoff et al. 2010).

Elevated conductivity in non-tidal Mattawoman and Piscataway creeks indicated that urbanization had impacted both spawning streams (Uphoff et al. 2010). Average conductivity was greater in more urbanized Piscataway Creek than Mattawoman Creek (Uphoff et al.2010). Increases in conductivity are strongly associated with urbanization and altered streamflow characteristics that result from urbanization (Wang and Yin 1997; Paul and Meyer 2001; Wenner et al. 2003; Morgan et al. 2007; Carlisle et al. 2010).

Increases in IS decrease groundwater infiltration and increase surface runoff (Paul and Meyer 2001). In general, peak discharges from floods increase and baseflow decreases with urbanization (Paul and Meyer 2001). Carlisle et al. (2010) determined that altered flow was a primary predictor of biological integrity in streams across the United States. Time-series of stream flow data from USGS gauging stations exist for Piscataway (1966-2008) and Mattawoman creeks (1950-1972 and 2001-2008) and we compared these time-series to increases in development indicated by tax map indicators of impervious surface (counts of structures per hectare or C / ha; Uphoff et al. 2010). We anticipated that these time-series might allow us to pinpoint a development threshold for altered flow conditions.

### Methods

In 2010, ichthyoplankton samples were collected from 7 stations in Mattawoman Creek during March-May by citizen volunteers. These volunteers were trained and their collection activities were monitored by program 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 one additional site (based on volunteer interest) were sampled in 2010 (Figure 2-2; Table 2-1). Piscataway Creek stations sampled during 2008-2009 are depicted in Figure 2-3.

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 stream drift net configuration and techniques were the same as those used by O'Dell et al. (1975). 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 for five minutes with the opening facing upstream. 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 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. Preservative was not added by volunteers because of safety and liability concerns. Water temperature (°C), conductivity (µmho/cm) and dissolved oxygen (DO, 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 later verification, if necessary.

Presence of white perch, yellow perch and herring eggs and-or larvae at each station in 2010 was compared to past surveys to determine which sites still supported spawning. O'Dell et al. (1975) summarized spawning activity as the presence of any species group egg, larva, or adult (latter from wire trap sampling) at a site and we used this criterion (spawning detected at a site or not) to evaluate 2008-2010 surveys. Raw data for 1971 were not available to formulate other metrics.

The proportion of samples at stations MC1-MC4 in Mattawoman Creek (Figure 2-2) where herring eggs and-or larvae were present was calculated for each year during 2008-2010. Confidence intervals (95%) were estimated using the normal distribution approximation of the binomial distribution (Ott 1977). Herring was the only species group represented throughout mainstem stations MC1-MC4 and adequate sample sizes existed for estimation of binomial confidence intervals using the normal distribution approximation.

Four Mattawoman Creek mainstem stations sampled in 1971 by O'Dell et al. (1975) were sampled by Hall et al. (1992) during 1989-1991 for water quality and ichthyoplankton. Comparisons of site occupation by the species groups and water quality were made among the current study (2008-2010), 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 level of development indicated by C / ha (see Tax Map Indicators of Development section) in both watersheds.

Conductivity measurements collected for each date and stream site during 2008-2010 surveys were plotted and mainstem measurements were summarized for each year. Unnamed tributaries were excluded from calculation of summary statistics to capture conditions in the largest portion of habitat. Conductivity distributions in both streams and years were compared to breakpoint conductivity (<171 µS / cm) needed for a "good" fish index of biotic integrity (FIBI) 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 and Piscataway creeks by O'Dell (1975) and Hall et al. (1992). The frequency distribution of conductivity measurements at Mattawoman Creek's mainstem stations during 2008-2010 was contrasted with the frequency distribution of conductivity for samples where herring were present.

A water quality database maintained by DNR's Tidewater Ecosystem Assessment (TEA) Division (S. Garrison, MD DNR TEA, personal communication) provided historic conductivity measurements for Mattawoman Creek between 1970 and 1989. These historic measurements, along with those collected in 2008-2010, were used to examine changes in conductivity over time. Monitoring was irregular for many of the historic stations and Table 2-2 summarizes site location, month sampled, total measurements at a site, and what years were sampled. Historic stations and those sampled in 2008-2010 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 estuary's mouth to the city of Waldorf (Route 301 crossing), the major urban influence on the watershed (Figure 2-4).

Historic monthly median conductivities at each site and their trend were plotted and 2008- 2010 spawning season median conductivities from each non-tidal site were added to these plots. Median conductivity from the 2010 larval yellow perch survey was plotted at the approximate center of the area covered by this survey as well. Estuarine conductivities were sampled by continuous monitors located at Sweden Point Marina and Indianhead (M. Trice, MD DNR TEA, personal communication; site information available at http://mddnr.chesapeakebay.net/eyesonthebay/index.cfm ). These results were summarized as means for March 2008 and April 2008, 2009, and 2010 and plotted.

USGS Flow gauges were located on Mattawoman Creek (USGS station 01658000, ≈ 9 m downstream of Old Woman's Run, near Pomonkey, MD) and Piscataway Creek (USGS station 01653600, ≈ 22 m downstream of the Route 223 bridge, at Piscataway, MD). We used the annual median flow (cfs) as an indicator of flow magnitude and annual flow coefficient of variation ([mean / SE] * 100) as an indicator of flow variability. Median annual flow (M) and flow coefficient of variation (CV) were divided by annual precipitation (P; inches) at Reagan National Airport in Washington DC (http://www.erh.noaa.gov/lwx/climate/dca/dcaprecip.txt) and plotted against C / ha. Division by annual precipitation standardized flow metrics to the only input of water under natural conditions, although variation in flow would occur because of differences in delivery and watershed conditions. As watersheds urbanize, additional inputs may appear from interbasin transfer, and make their way into groundwater as septic drainage, water and sewage pipe leaks, and irrigation (Paul and Meyer 2001), but we assumed these inputs would be negligible compared to shifts from groundwater infiltration to surface runoff due to IS. We anticipated that changes indicative of lower baseflows and-or higher flood peaks would appear first in the Piscataway Creek since this watershed developed at a much more rapid pace. We could not develop specific hypotheses about how flow would change since Carlisle et al. (2010) found that minimum flows of streams were most commonly altered (diminished or inflated) by human influence (which was not specified), but maximum flows could be in many cases altered also (usually diminished).

We also explored the relationship of M / P with CV / P to determine if changes were indicated. First, scatter plots were examined to determine if different regimes within the time-series were indicated and if differences were indicated between the two creeks. If time periods were indicated, regression with indicator variables for each creek (Piscataway = 0 and Mattawoman = 1) was applied to each time period (Freund and Littell 2006). This approach tested for a common slope between the creeks and different intercepts (Freund and Littell 2006).

**Results and Discussion**

White perch, yellow perch, and herring spawning were detected at Mattawoman Creek's mainstem stations in 2010 and the diminished distribution of 2009 was not repeated (Table 2-4). Reappearance of spawning in 2010 supported the hypothesis that 2009 spawning was subject to a particularly severe episodic loss due to application of road salt after an early March snowstorm. Herring spawning was detected at all four mainstem stations during 2010, but not at two unnamed tributaries where it was detected in 1971 and one unnamed tributary where it was detected in 2008. The proportion of mainstem samples containing herring eggs and-or larvae were 0.15 (SD = 0.06) in 2008, 0.08 (SD = 0.04) in 2009, and 0.39 (SD = 0.07) in 2010. White and yellow perch spawning returned to the most downstream station (MC1). Station MC1 is the only stream station where yellow perch spawning has been detected in surveys conducted since 1971. White perch spawning had been detected upstream at stations MC2 and MC3 in the past (Table 2-4).

In general, little change in anadromous fish stream spawning in Mattawoman Creek was indicated between 1971 and 1989-1991 (Table 2-4). Presence of spawning at these sites was consistently detected. However, by 2008-2010 diminished spawning distributions that supported the hypothesis of chronic habitat loss were evident for all three species groups. Herring spawning was reduced from 6 sites in Mattawoman Creek in 1971 to 2-4 during 2008-2010. White perch stream spawning was detected at 1-2 sites in 1971 and 1989-1991, and 0-1 site during 2008-2010. Yellow perch stream spawning was detected at the most downstream stream site during every survey between 1971 and 2010, except 2009 (Table 2-4).

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. Piscataway Creek is closer to Washington, DC, than

Mattawoman Creek. Both watersheds started at approximately the same level of development in 1950, 0.05 C / ha (Figure 2-5). Development accelerated in Piscataway Creek's watershed in the 1960s and reached 0.68 C / ha in the mid-1980s. Development in Mattawoman Creek was slower and reached about 0.25 C / ha in the mid-1980s. The pace of development remained largely unchanged in Piscataway Creek's watershed and1.4 C/ ha was reached in 2009. The rate of development increased in Mattawoman Creek after the late 1980s and reached 0.86 C / ha in 2010 (Figure 2-5).

The spawning survey by O'Dell et al.(1975) in Mattawoman Creek during 1971 was conducted in a watershed with relatively little development (0.16 C / ha) when herring and white perch spawning was widespread (Table 2-4). Development in Piscataway Creek in 1971 (0.47 C / ha) was similar to the level in Mattawoman Creek during 1989-1991 (0.41-0.45 C / ha) and anadromous fish spawning was widespread in both creeks (Tables 2-4 and 2-5).

United States Army Corps of Engineers (USACOE) projections of 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). Based on the relationship of IS to C / ha developed for yellow perch larval presence-absence watersheds, current Mattawoman Creek watershed IS was near 11% at C / ha equal to 0.86; growth to 22% IS was equivalent to C / ha greater than 2.3, far greater than Piscataway Creek currently (C / ha = 1.4). Using status of anadromous fish spawning in Piscataway Creek as an indicator, stream spawning will disappear from Mattawoman Creek at projected levels of development at build-out.

Stream spawning of anadromous fish has largely ceased in Piscataway Creek, a watershed both smaller and closer to Washington, DC, than Mattawoman Creek (Uphoff et al. 2010). 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).

Conductivity levels for 2008 and 2009 were elevated in Piscataway Creek when compared to Mattawoman Creek during 2008-2010 (Table 2-5). Summary statistics indicated highly variable distributions by system and year (Table 2-5).

Based on comparisons with the 171 µmho / cm critical value for the 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 (Table 2-5). Mattawoman creek did not display values higher than the FIBI threshold during the 2008 spawning survey, but 63% of the measurements were in excess of the FIBI conductivity criterion in 2009, and 16% in 2010 (Table 2-5). Although not directly related to egg and larval survival, FIBI criterion provides a benchmark for good or bad conditions for fish diversity in Maryland streams (Morgan et al. 2007).

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 during 1971. 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 (Table B-5). Mattawoman Creek conductivities during 2008 and 2010 fell within the range reported for the 1971 O'Dell survey, but mainstem measurements during March 2009 exceeded the reported maximum. The ranges reported in O'Dell et al. (1975) for both creeks may have included both stream and estuarine samples

Frequency distributions of 2008-2010 Mattawoman Creek conductivity measurements where herring were present mirrored the "bell" of all measurements taken (100-200 µmho / cm), with one occurrence within the "tail" of higher values (out to 600 µmho / cm; Figure 2-6). Specifically, 96% of the measurements where herring were present fell between 112 and 182 µmho / cm. Conductivities within this range represent 74% of all measurements in 2008, 42% in 2009, and 93% in 2010. These percentages align with the proportion of samples with herring eggs and-or larvae (described above).

Plots of conductivity in Mattawoman Creek by year and site indicated lower and more stable measurements in unnamed tributaries (Figures 2-7 to 2-9). The unnamed tributaries were generally more isolated from roads. Conductivities in unnamed tributaries usually remained in the boundaries of those observed by Hall et al. (1992) during 1989-1991 in the mainstem (61-114 µmho / cm).

Conductivities in Mattawoman Creek's mainstem stations during March and April, 2008, were elevated above the 1989-1991 maximum, but fell within this range at the end of April to the beginning of May (Figure 2-7). During 2009, conductivity was highly elevated in early March following application of road salt in response to a significant, preceding snowfall (Figure 2-8). Conductivity measurements in 2009 then steadily declined for nearly a month before leveling off slightly above the 1989-1991 maximum (Figure B-8). Conductivities during the 2010 survey were steady and nearly always above the 1989-1991 maximum (Figure 2-9).

Conductivities at mainstem stations (MC2 to MC4) above the confluence of Mattawoman Creek's stream and estuary (MC 1) were elevated beyond predicted historic medians during 2008-2010 (particularly in 2009) and increased with upstream distance away from the confluence of the stream and estuary and toward Waldorf (Figure 2-10). The trend in median conductivity with distance from the mouth of Mattawoman Creek during 1970-1989 (hereafter, "historic" measurements) was U-shaped (Uphoff et al. 2010). During 1970-1989, predicted median conductivities were elevated nearest the confluence of Mattawoman Creek's estuary and Potomac River (≈ 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 (RKM 35). Conductivity medians were as variable at the upstream station nearest Waldorf during 1970-1989 as they were near the mouth of the creek where salinity intrusion from the Potomac River was possible (Figure 2-10).

During 1966-1979 when C / ha was less than 0.68 (≈ 9% IS), M / P in Piscataway Creek was typically above 0.4 (overall, M / P varied from near 0 to ≈ 2; Figure 2-11). Once C / ha exceeded 0.68, values of M / P below 0.4 greatly increased (from 1 in 15 years to 8 in 29 years). In general, M / P in Piscataway Creek shifted to lower values once C / ha exceeded 0.68; 80% of M / P values were above 0.6 during 1966-1979 and 54% during 1980-2008. The decrease in M / P values above 0.6 and the increase in M / P values below 0.4 supports a hypothesis of lowered baseflow with increased IS in Piscataway Creek.

Estimates of M / P in Mattawoman Creek during 2001-2008 represented values at C / ha greater than 0.68 and 1950-1972 represented C / ha far lower than those estimated for Piscataway Creek (Figure 2-11). Mattawoman Creek's time-series at C / ha greater than 0.68 was limited. However, the first 7 years of M / P for Piscataway Creek after C / ha exceeded 0.68 had nearly the same distribution of values that Mattawoman Creek exhibited since 2001:2 below M / P = 0.4 for both creeks; 4 below 0.6 in Mattawoman Creek and 5 for Piscataway Creek; and 3 above 0.6 in Mattawoman Creek and 2 above in Piscataway Creek.

Overall, CV / P ranged between 2 and 11 and two regimes of CV / P in Piscataway Creek were suggested from the plot with C / ha (Figure 2-12). During 1966-1981, C / ha increased from 0.34 to 0.71 ($\approx$ 6% to 10% IS), and CV / P increased as well. A linear regression of CV / P and C / ha for this segment was significant ($r^2 = 0.36$, $P = 0.014$). Once C / ha exceeded 0.71, spread in CV / P increased and the trend disappeared. Values of CV / P below 3.8 greatly increased (from 0 in 15 years to 8 in 29 years) and 2 values exceeded the maximum observed during 1966-1981. Observations of CV / P for C / ha between 0.34 and 0.68 do not exist for Mattawoman Creek, so we cannot determine if the patterns are similar in the two creeks (Figure 2-12).

Scatter plots of M / P against CV / P for Mattawoman and Piscataway creeks indicated that different relationships existed for early (1950-1980) and late portions (1981-2008) of the time-series that corresponded to development less than 10% IS and greater than 10% IS respectively. Regression models with indicator variables for each creek were applied to the early and late time-series. The regression for the early period was not significant ($R^2 = 0.04$, $P = 0.46$; Figure 2-13), but was for the late period ($R^2 = 0.59$, $P < 0.001$ ; Figure 2-14). Differences between creeks (intercepts) were not significant in either model. During 1981-2008 (IS > 10%), M / P was negatively related to CV / P, i.e. as magnitude of annual flow increased, it became less variable. A reduced model for the late period (M / P versus CV /P without creek indicators) was significant ($R^2 = 0.56$, $P < 0.001$ ; Figure 2-13). This analysis indicated that Mattawoman Creek has shifted into a hydrological regime associated with a suburban landscape.

The near complete loss of stream spawning sites for anadromous fish in Piscataway Creek reflected increased flow magnitude and variability that followed large increases in development. Mattawoman Creek still supports anadromous fish stream spawning at a lesser level of development, but its hydrology appears to have shifted from that of a rural watershed to a suburban one. Alewife spawn in sluggish water flows, while blueback herring spawning occurs in sluggish to swift flows (Pardue 1983). Spawning substrates include gravel, sand, and detritus (Pardue 1983). Urbanization affects both discharge and sediment supply of streams (Paul and Meyer 2001) that, in turn, could affect location, substrate composition, and success of spawning.

In response to urbanization, streams in the Southeastern U.S. exhibit increased peak flows and variability, while minimum and bankfull flows decrease (Poff et al. 2006). As watershed undergo a construction phase, erosion of exposed soils increases sediment yield by $10^2$–$10^4$ over forested catchments with most export occurring during a few large episodic floods. Increased sediment supply leads to an aggradation phase as sediment fills the channel. Flooding associated with aggradation may attenuate increased flows by from IS by storing water in the flood plain, temporarily mitigating urban effects. After construction, sediment supply diminishes while bankfull flows increase due to increased IS. This leads to a second phase with increased channel erosion from more frequent bankfull flows. Absolute distance between pool-riffle units increases and stream meanders change to braided or straighter, channelized patterns. Urbanization decreases sediment diversity, decreasing both fine sediment and gravel, while increasing sand due to altered supply and stream velocity (Paul and Meyer 2001). Large woody debris decrease in urban stream channels and retention of organic matter (detritus) lessens (Paul and Meyer 2001; Poff et al. 2006).

Estimated loads of sediment in Mattawoman Creek were elevated in comparison to those for the agricultural Choptank River watershed and provide supporting evidence for IS-related changes in hydrology in Mattawoman Creek. Maryland DNR's Tidal Ecosystem Assessment (TEA) Division has compared the total suspended sediment loads predicted by USGS for Mattawoman Creek to a site located on the less developed, agricultural watershed of the Choptank River near Greensboro, MD (W. Romano, MD DNR TEA personal communication). Annual loads in kilograms per year were available for the Choptank River site for 1981 through 2009. Estimates of annual average sediment load during 2001-2009 were 250 MT / year and 410 MT / year for the Choptank River and Mattawoman Creek sites, respectively. Area above the gauge site for Mattawoman Creek (14,193 ha) was less than half that of the area above the Choptank River site (29,267 ha) and it appears that sediment loads for Mattawoman Creek greatly exceed those of a much larger watershed that is heavily farmed (W. Romano, MD DNR TEA, personal communication). Agriculture does not induce as great a change in hydrology as urbanization (Poff et al. 2006).

Changes in conductivity, hydrology, and anadromous fish stream spawning in Piscataway and Mattawoman creeks agreed with general findings elsewhere that (1) habitat quality in fluvial and tidal streams declined with IS and (2) streams and tidal creeks in watersheds with greater than 10% IS were degraded (Arnold and Gibbons 1996; Cappiella and Brown 2001; Beach 2002; Holland et al. 2004; NRC 2009).

Site occupation could also have reflected low population sizes; however, species surveyed during 2008-2010 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 2008-2010 used only stream drift nets, while O'Dell et al. (1975) and Hall et al. (1992) determined spawning activity with ichthyoplankton nets and wire traps (for adults). Tabular summaries of egg, larval, and adult catches in Hall et al. (1992) allowed for a comparison of how 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 surveys in Mattawoman and Piscataway creeks did not indicate that lack of detectable stream spawning corresponded to their elimination from these subestuaries. Yellow perch larvae were present in upper reaches of both subestuaries (see Estuarine Yellow Perch Larval Presence-Absence Sampling section). 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 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).

Table 2-1. Summary of sites, dates, and anadromous fish sample sizes (N) in Mattawoman and Piscataway creeks during 2008-2010.

| 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 |
| Mattawoman | 2010 | 7 | 7-Mar | 15-May | 11 | 75 |

Table 2-2. Summary of historic conductivity sampling used 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 | | | | | |

Table 2-3. Presence-absence of herring (blueback herring and alewife) and white perch stream spawning in Mattawoman Creek during 1971 and 2008-2010. 0 = site sampled, but spawning not detected; 1 = site sampled, spawning detected; and blank indicates no sample. Station locations are identified on Figure B-4.

| STATION | 1971 | 1989 | 1990 | 1991 | 2008 | 2009 | 2010 |
|---|---|---|---|---|---|---|---|
| | | | Herring | | | | |
| MC1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| MC2 | 1 | 1 | 1 | 1 | 0 | 0 | 1 |
| MC3 | 1 | | | 1 | 1 | 1 | 1 |
| MC4 | 1 | | | 1 | 0 | 0 | 1 |
| MUT3 | 1 | | | | 0 | 0 | 0 |
| MUT4 | | | | | | | 0 |
| MUT5 | 1 | | | | 1 | 0 | 0 |
| | | | White Perch | | | | |
| MC1 | 1 | 1 | 1 | 1 | 1 | 0 | 1 |
| MC2 | 0 | 0 | 1 | 0 | 0 | 0 | 0 |
| MC3 | 1 | | | 0 | 0 | 0 | 0 |
| | | | Yellow Perch | | | | |
| MC1 | 1 | 1 | 1 | 1 | 1 | 0 | 1 |

Table 2-4. 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 B-3.

| | 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 2-5. Summary statistics of conductivity (µmho / cm) for mainstem stations in Piscatatway and Mattawoman creeks during 2008-2010. Count > 171 = count of conductivity meaurements greater than threshold for a "good" fish index of biotic integrity (Morgan et al. 2007). Unnamed tributaries were excluded from analysis. Tinkers Creek was included with mainstem stations in Piscataway Creek.

| Creek | Piscataway | Piscataway | Mattawoman | Mattawoman | Mattawoman |
|---|---|---|---|---|---|
| Year | 2008 | 2009 | 2008 | 2009 | 2010 |
| Mean | 218.4 | 305.4 | 120.1 | 244.5 | 153.7 |
| Standard Error | 7.4 | 19.4 | 3.8 | 19.2 | 38.0 |
| Median | 210.4 | 260.6 | 124.6 | 211 | 152.3 |
| Kurtosis | -0.38 | 1.85 | 2.1 | 1.41 | 1.3 |
| Skewness | 0.75 | 1.32 | -1.41 | 1.37 | 0.03 |
| Range | 138 | 641 | 102 | 495 | 111 |
| Minimum | 163 | 97 | 47 | 115 | 99 |
| Maximum | 301 | 737 | 148.2 | 610 | 210 |
| Count | 29 | 50 | 39 | 40 | 43 |
| Count > 171 | 28 | 46 | 0 | 25 | 7 |

Table 2-6. ANOVA tables and regression parameter estimates for regressions of M / P versus CV / P for early (1950-1980) and late (1981-2008) regimes in Mattawoman (system = 1) and Piscataway (system = 0) creeks.

| *Early regime* | *df* | *SS* | *MS* | *F* | *Significance F* | $R^2$ |
|---|---|---|---|---|---|---|
| Regression | 2 | 2.483027743 | 1.241514 | 0.787612 | 0.462826885 | 0.04 |
| Residual | 35 | 55.17058277 | 1.576302 | | | |
| Total | 37 | 57.65361051 | | | | |

| *Early regime* | *Coefficients* | *Standard Error* | *t Stat* | *P-value* | *Lower 95%* | *Upper 95%* |
|---|---|---|---|---|---|---|
| Intercept | 5.55 | 0.66 | 8.40 | 6.41E-10 | 4.21 | 6.90 |
| M / P | -1.05 | 0.84 | -1.25 | 0.218957 | -2.76 | 0.65 |
| System | -0.10 | 0.43 | -0.24 | 0.80875 | -0.98 | 0.77 |

| *Late regime* | *df* | *SS* | *MS* | *F* | *Significance F* | $R^2$ |
|---|---|---|---|---|---|---|
| Regression | 2 | 73.21037284 | 36.60519 | 23.56596 | 4.39227E-07 | 0.59 |
| Residual | 33 | 51.2591621 | 1.553308 | | | |
| Total | 35 | 124.4695349 | | | | |

| *Late regime* | *Coefficients* | *Standard Error* | *t Stat* | *P-value* | *Lower 95%* | *Upper 95%* |
|---|---|---|---|---|---|---|
| Intercept | 8.08 | 0.5 | 15.50 | 1.03E-16 | 7.02 | 9.14 |
| M / P | -5.49 | 0.82 | -6.72 | 1.15E-07 | -7.15 | -3.83 |
| System | 0.74 | 0.50 | 1.48 | 0.14827 | -0.28 | 1.76 |

Figure 2-1. Watersheds sampled for stream spawning anadromous fish eggs and larvae in 2008-2010.

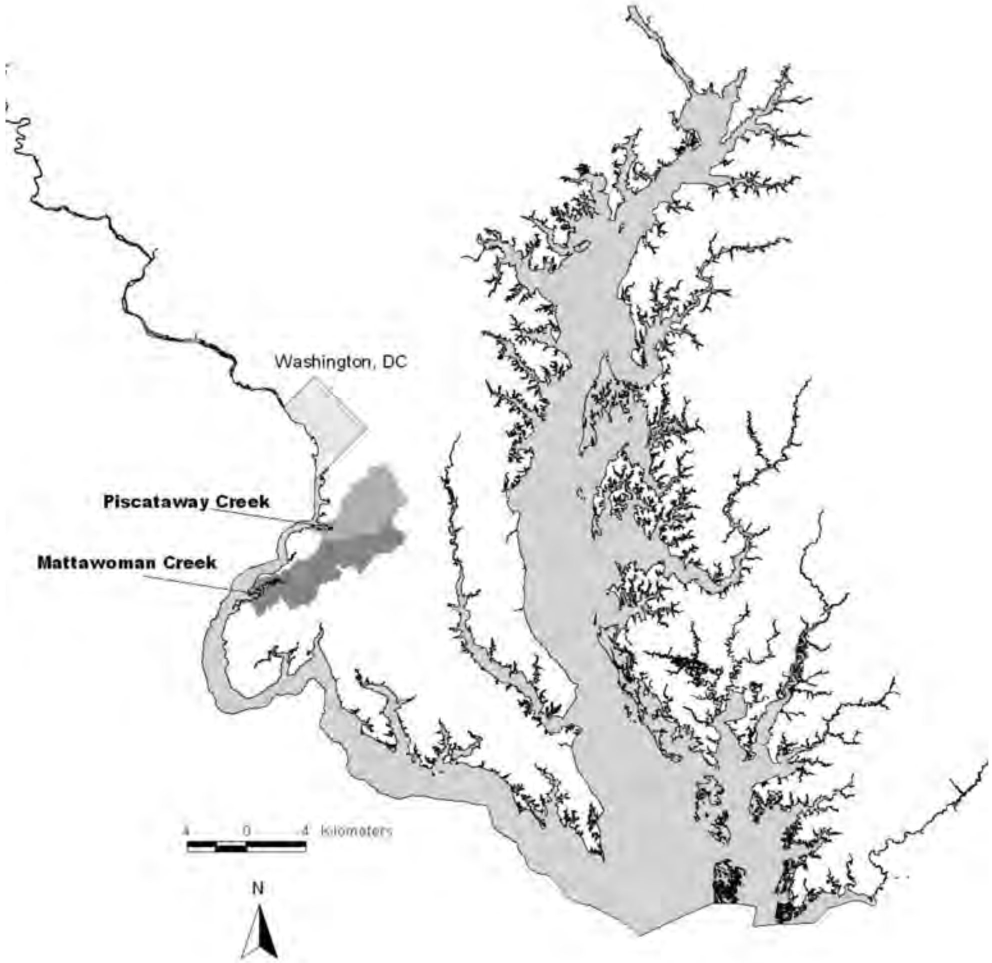


Figure 2-2. Mattawoman Creek historic and 2008-2010 sampling stations.

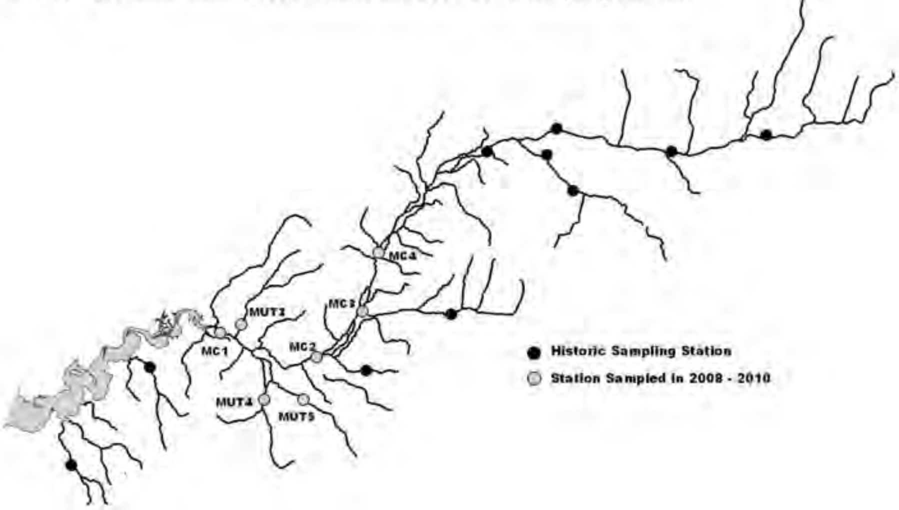



Figure 2-3. Piscataway Creek historic and 2008-2009 sampling stations.

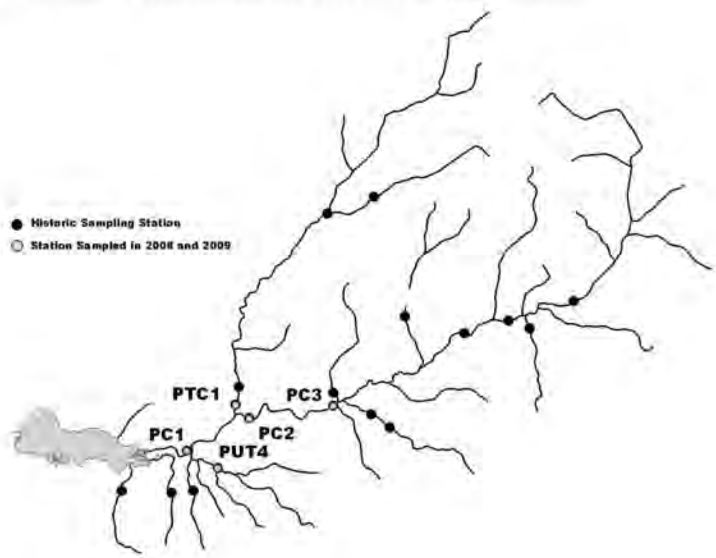


Figure 2-4. Mattawoman Creek mainstem stations with conductivity measurements used in analysis of historic trends (1970-1989). Mainstem stream ichthyoplankton stations where anadromous spawning was present during 2008-2010 are indicated (MC1, MC2, MC3, and MC4). Kilometers (KM) from the mouth of the creek are indicated.

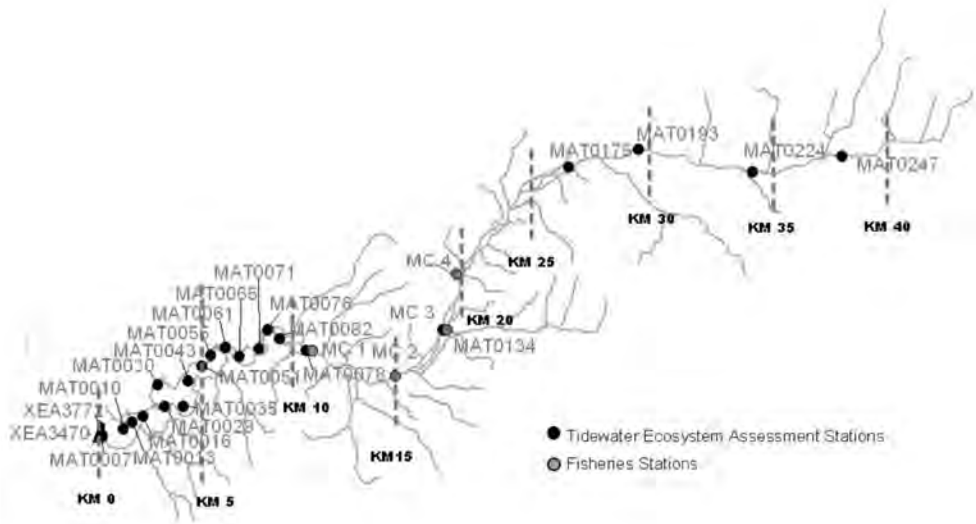


Figure 2-5. Trends in counts of structures per hectare (C / ha) since 1950 in Piscataway Creek and Mattawoman Creek watersheds. Large symbols indicate years when stream ichthyoplankton was sampled.

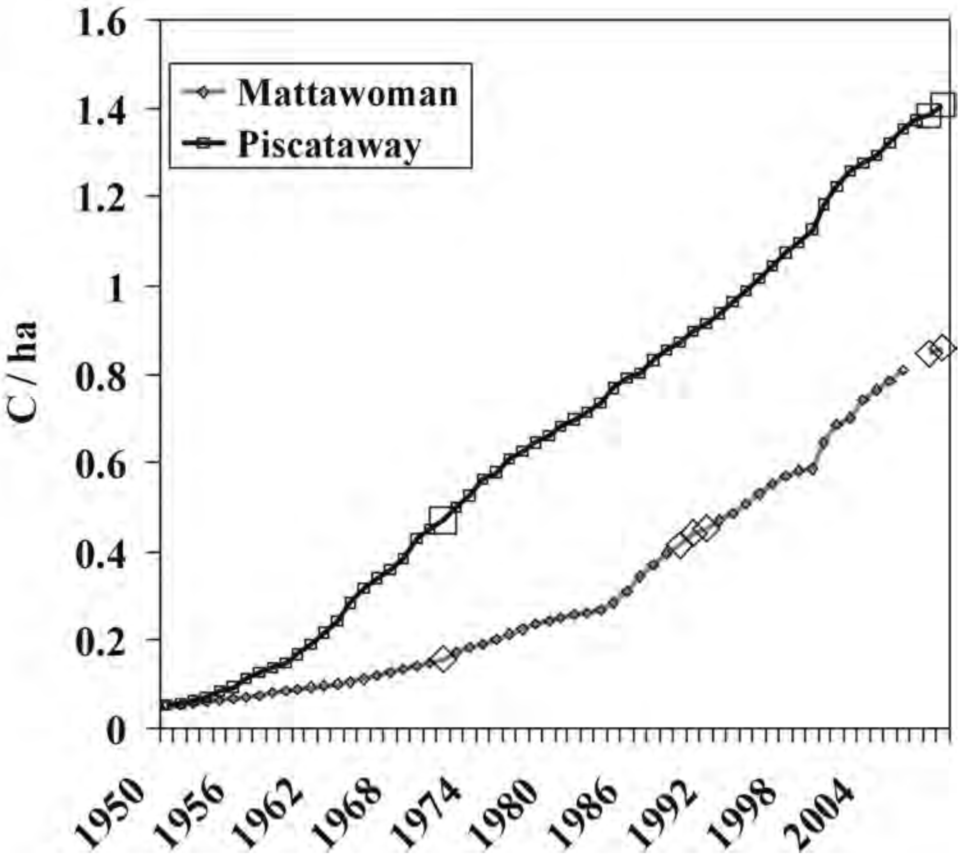


Figure 2-6. Frequency distribuitions of all conductivity measurements and measurements when herring were present in Mattawoman Creek during anadromous fish spawning surveys, 2008-2010.

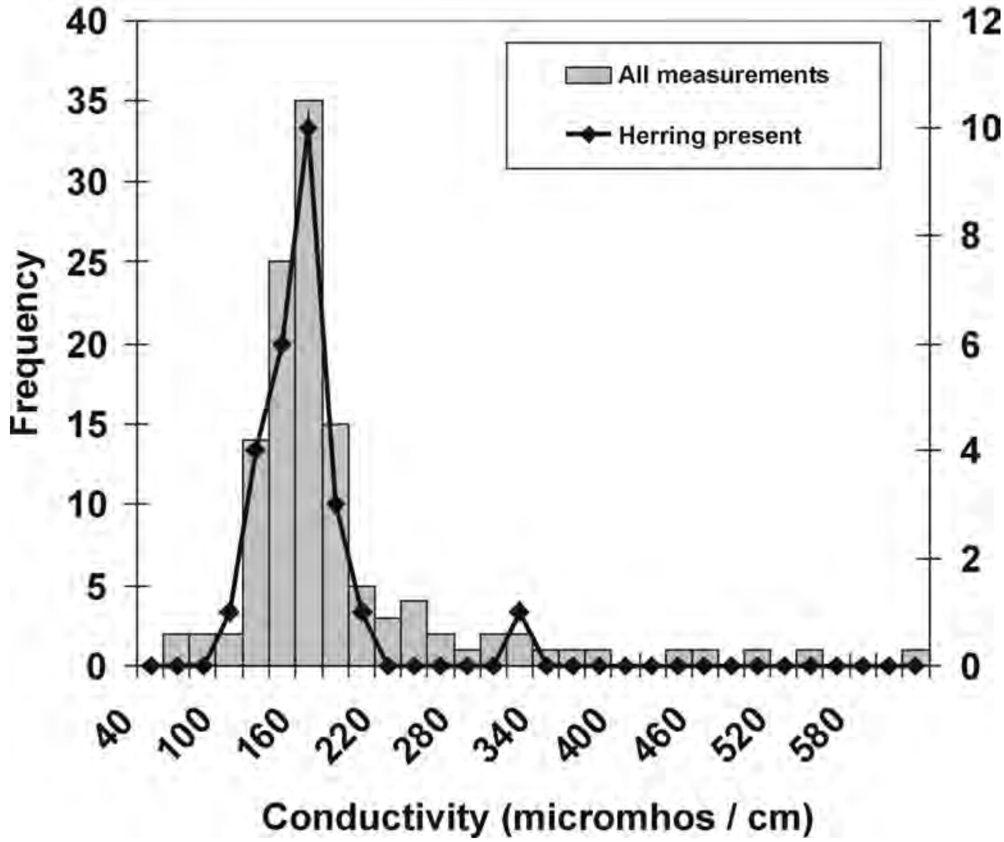


Figure 2-7. Conductivity during the 2008 anadromous fish stream spawning survey in Mattawoman Creek for mainstem stations (open symbols) and tributaries (filled symbols). Lines represent the minimum and maximum conductivities reported at MC2 and MC4 during March and April, 1991 (Hall et al. 1992).

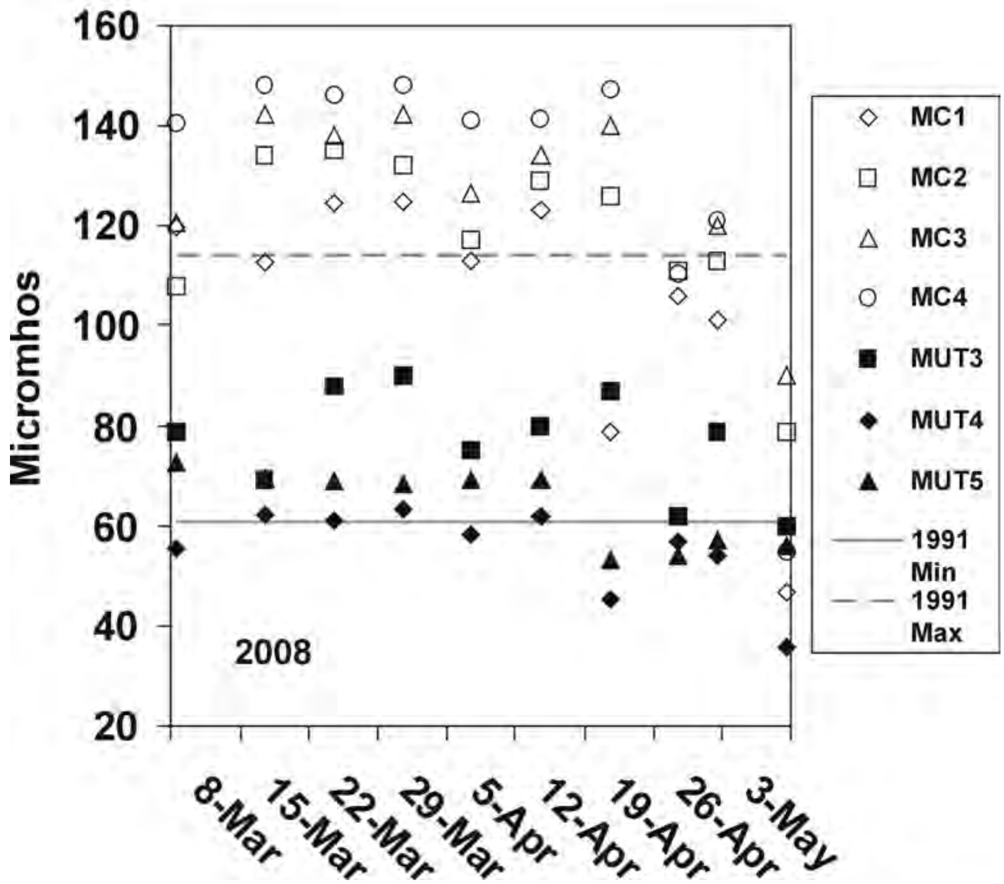


Figure 2-8. Conductivity during the 2009 anadromous fish stream spawning survey in Mattawoman Creek for mainstem stations (open symbols) and tributaries (filled symbols). Lines represent the minimum and maximum conductivities reported at MC2 and MC4 during March and April, 1991 (Hall et al. 1992).

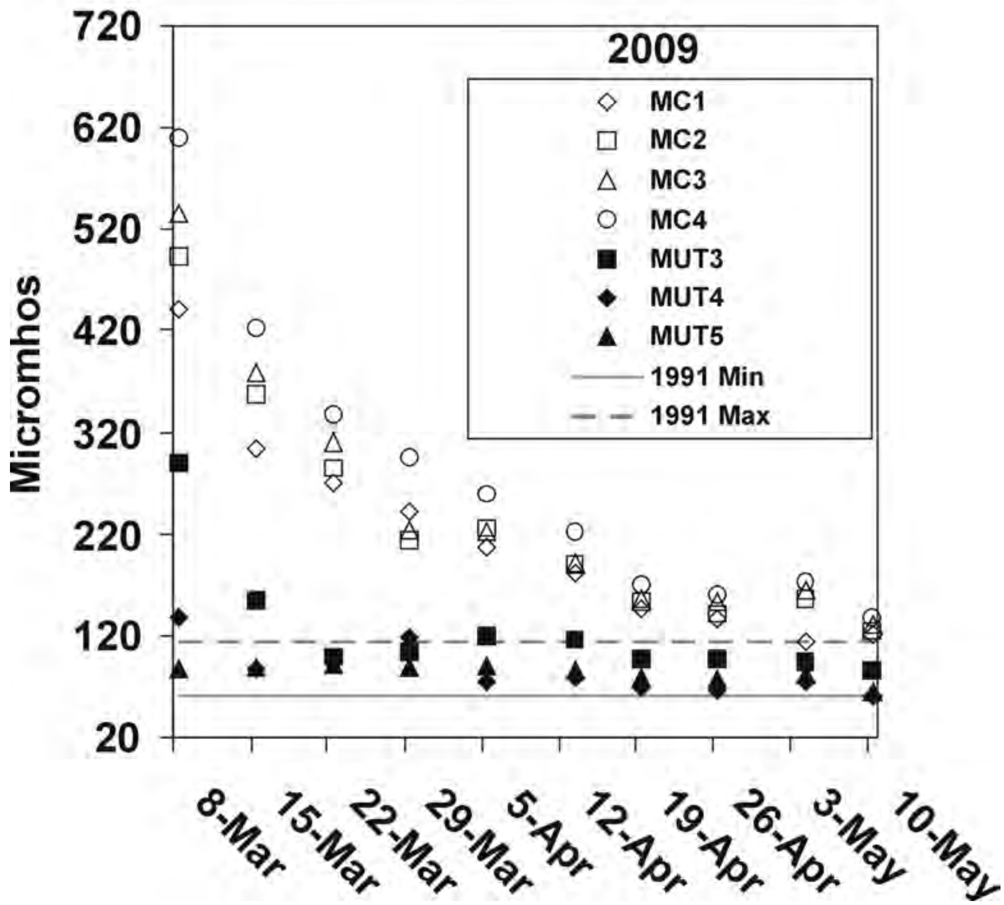


Figure 2-9. Conductivity during the 2010 anadromous fish stream spawning survey in Mattawoman Creek for mainstem stations (open symbols) and tributaries (filled symbols). Lines represent the minimum and maximum conductivities reported at MC2 and MC4 during March and April, 1991 (Hall et al. 1992).

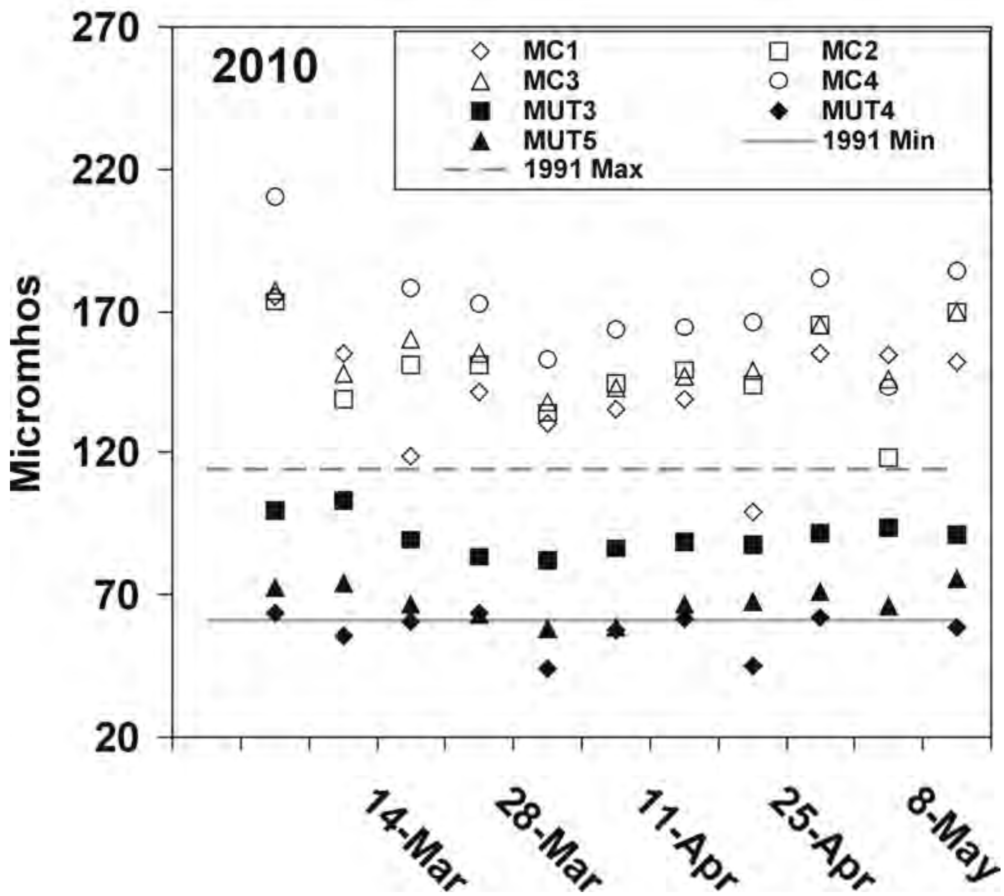


Figure 2-10. Historical (1970-1989; see Table B-2) monthly median conductivity measurements in Mattawoman Creek (between the mouth and Waldorf,) plotted against distance from the mouth of the creek. Tidal (open squares) and non-tidal stations (open triangles) are designated. Predicted historic station medians are indicated by the solid line and dotted lines indicate 95% CIs. Measurements from 2008 -2010 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.

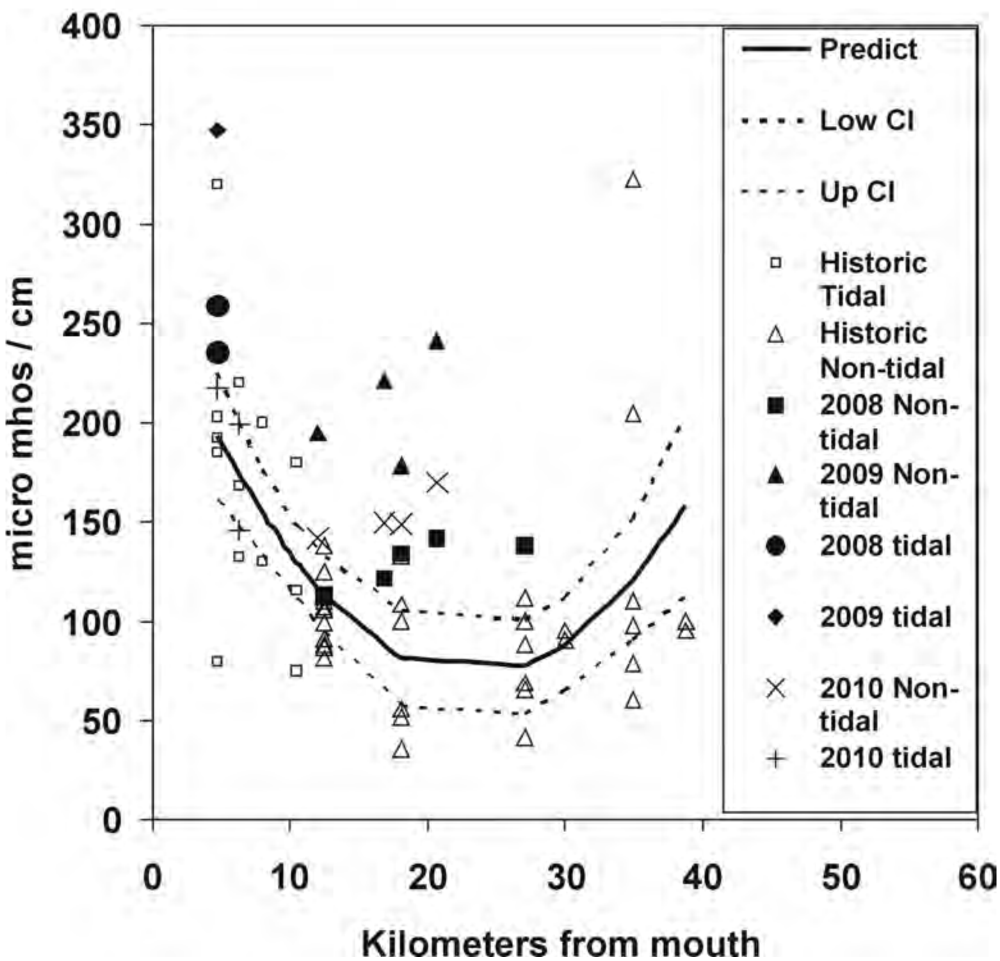


Figure 2-11. Median annual flow (cfs) / annual precipitation(in) at Reagan National Airport (Washington DC) plotted against C / ha for Piscataway and Mattawoman creeks. Dotted line emphasizes drop in median flow beyond lower limit exhibited in Piscataway Creek during 1966-1979.

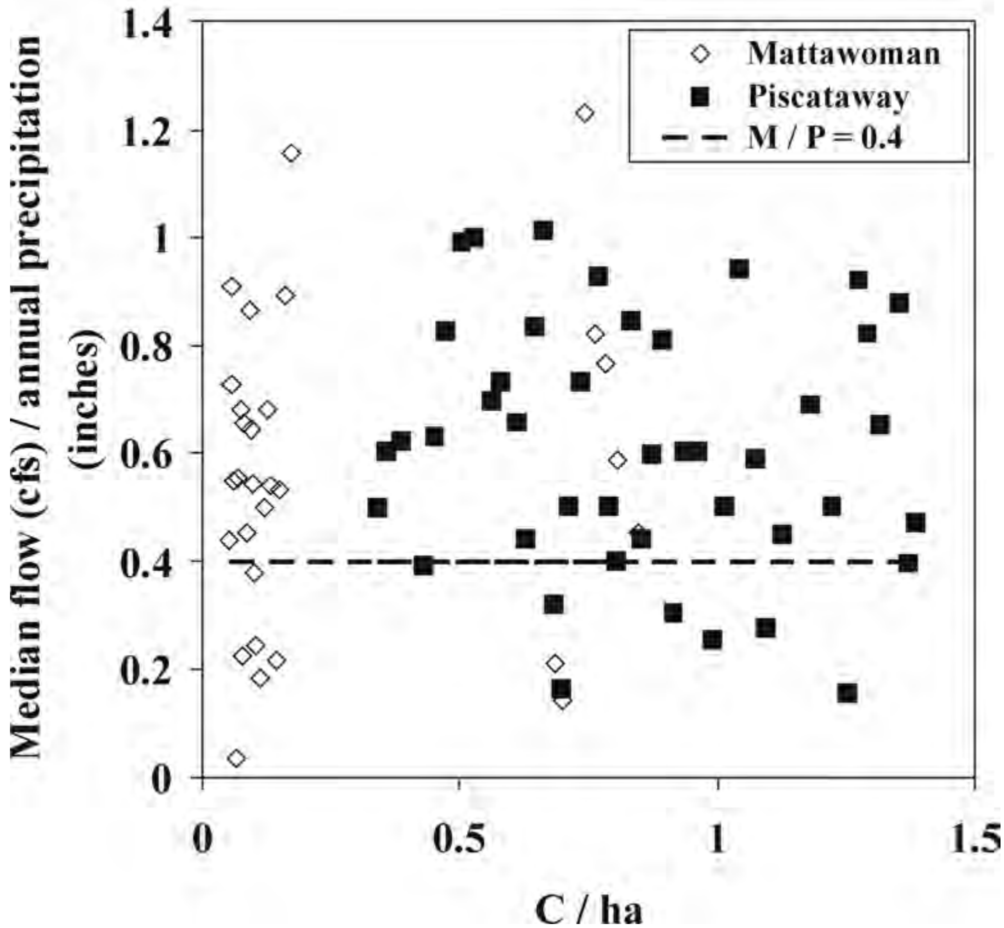


Figure 2-12. Annual coefficient of variation (CV) of flow (cfs) / annual precipitation (inches) plotted against C / ha in Piscataway (1966-2008) and Mattawoman creeks(1950-1972 and 2001-2008). Flow data are from USGS guaging stations and precipitation was measured at National Airport (Washington DC). Line indicates the trend of flow CV during 1966-1982 in Piscataway Creek.

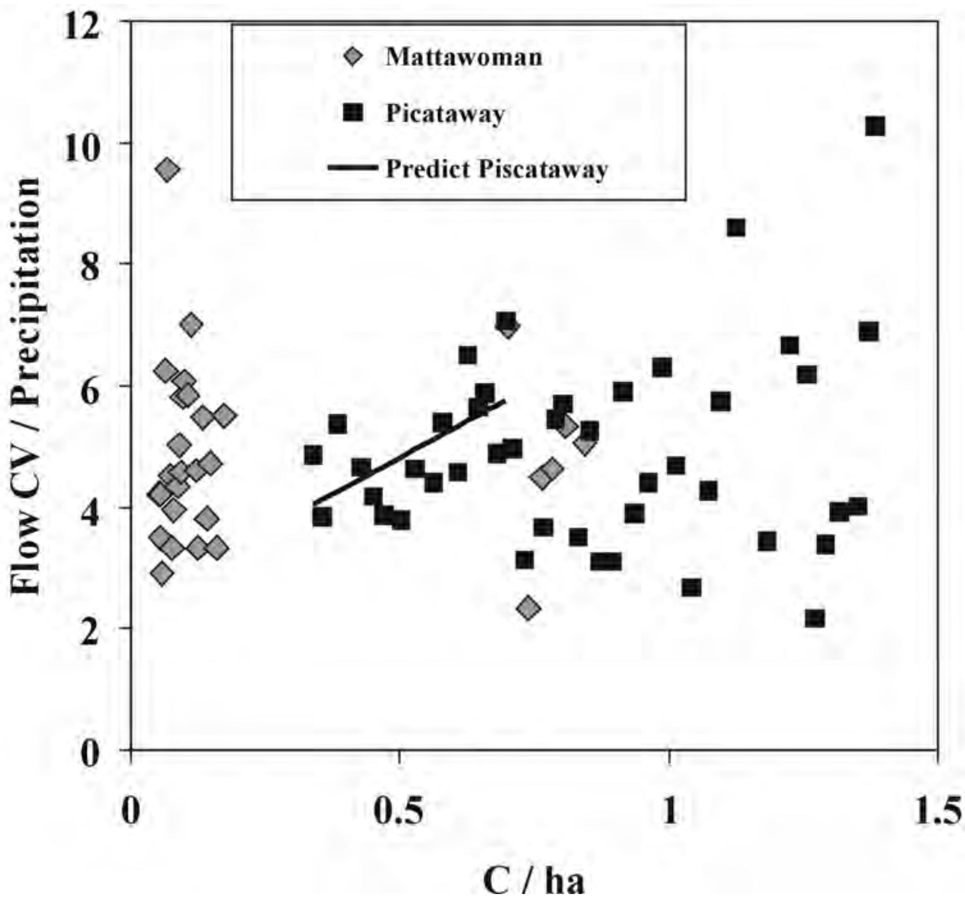


Figure 2-13. Plot of M / P (median annual flow in cfs / annual precipitation in inches) against CV / P (coefficient of variation of annual flow / precipitation) in Piscataway Creek (1966-1980) and Mattawoman Creek (1950-1972). This time period corresponds to impervious surface less than 10%.

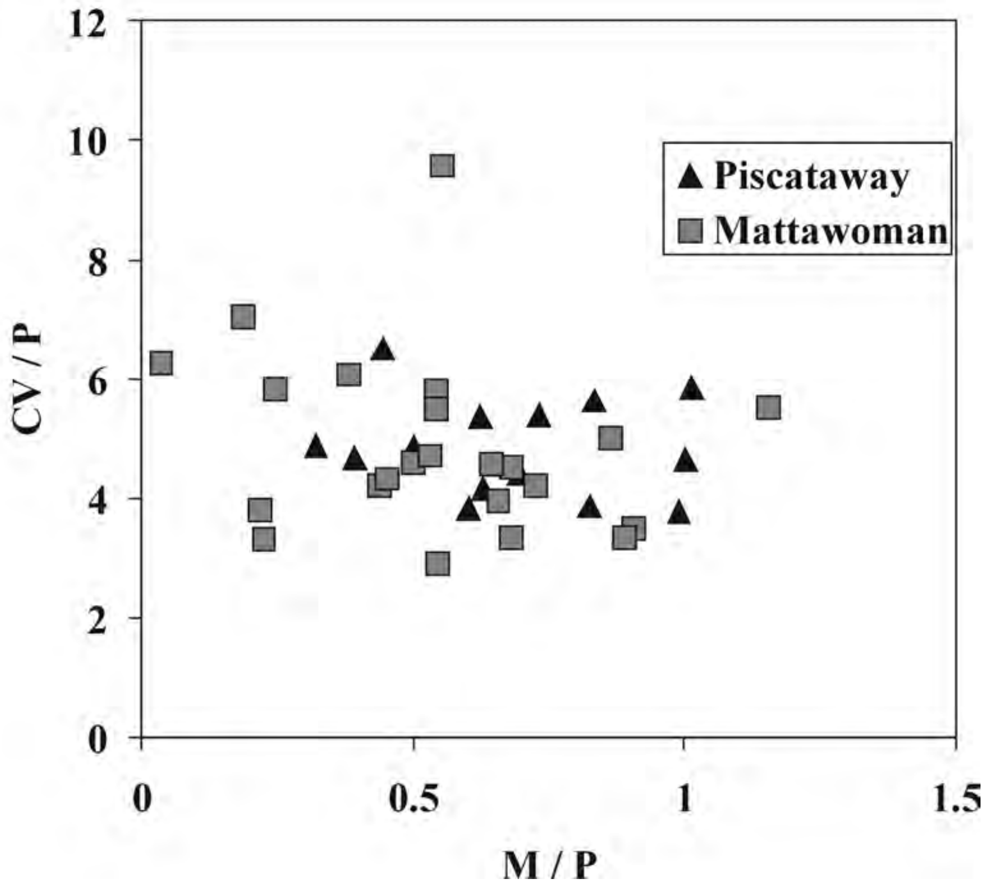
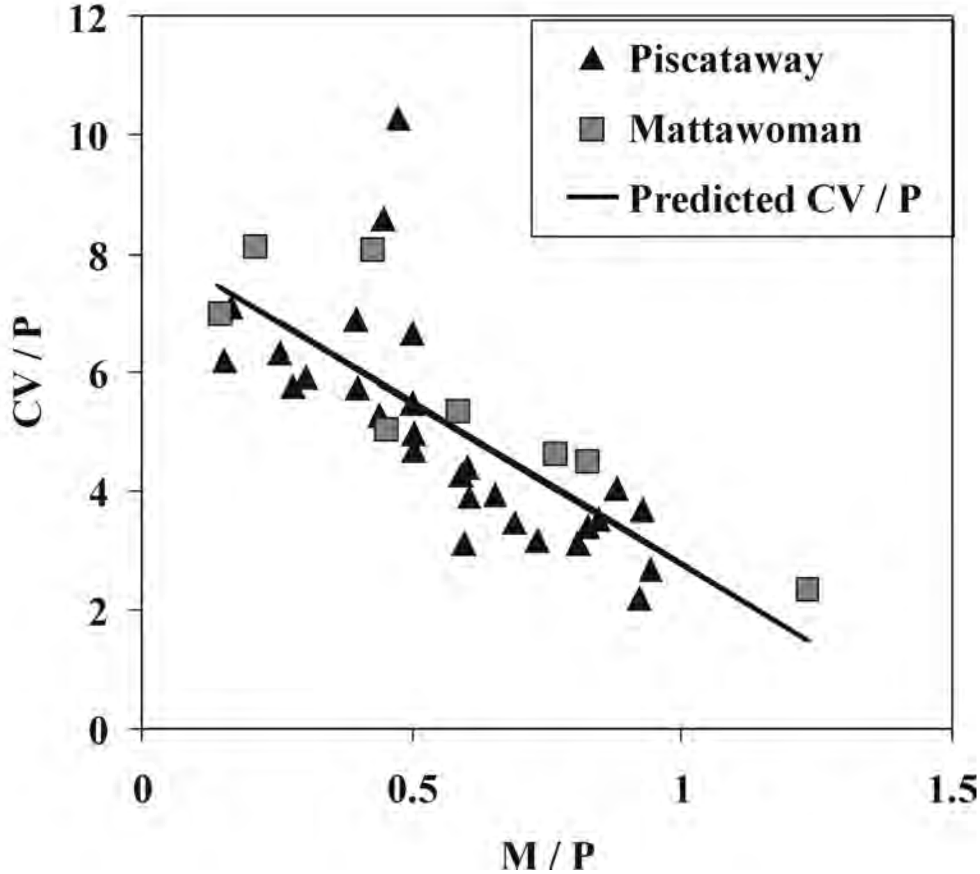


Figure 2-14. Relationship of M / P (median annual flow in cfs / annual precipitation in inches) against CV / P (coefficient of variation of annual flow / precipitation) in Piscataway Creek (1981-2008) and Mattawoman Creek (2001-2008). This time period corresponds to impervious surface greater than 10%. Predicted line is from a regression without indicator variables for the two creeks.



## Section 3 - Estuarine Yellow Perch Presence-Absence Sampling

### Introduction

Yellow perch larval presence-absence sampling during 2010 was conducted in the upper tidal reaches of the Nanticoke, Northeast, Elk, and Severn rivers and Mattawoman, Nanjemoy, and Piscataway creeks during late March through April (Figure 17). Annual $L_p$ (proportion of tows with yellow perch larvae during a standard time period and where larvae would be expected) provides an economically collected measure of the product of egg production and egg through early postlarval survival. Yellow perch larvae can be readily identified because they are larger and more developed than *Morone* larvae that could be confused with them (Lippson and Moran 1974).

During 2010, we sampled gut contents of yellow perch larvae to investigate whether feeding success and diet composition (1) influenced $L_p$ and (2) reflected the level of development indicated by counts of structures per hectare (C / ha) from tax maps. Shortage of appropriate food has been frequently hypothesized to cause high mortality of fish larvae (Martin et al. 1985; Heath1992.).

### Methods

Conical plankton nets were towed from boats in Chesapeake Bay in upper portions of subestuaries to collect yellow perch larvae. Nets were 0.5-m in diameter, 1.0-m long, and constructed of 0.5 mm mesh. Nets were towed for two minutes at approximately 2.8 km per hour.

Ten sites were sampled in Nanjemoy Creek, Mattawoman Creek, Severn River, Elk River and Nanticoke River; seven sites in Piscataway Creek; and five sites in Northeast River (Figure 3-1). Elk and Northeast rivers were sampled once a week and all other subestuaries were sampled twice per week.

Larval sampling occurred during late March through mid-to-late April, 2010. Boundaries of areas to be sampled were determined from yellow perch larval presence in estuarine surveys conducted during the 1970s and 1980s (O'Dell 1987). Sites in all subestuaries (except the Nanticoke River) were sampled with little spacing between tows because their larval nurseries were small. Three upstream sites in Piscataway Creek could not be sampled at very low tides.

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 5X magnifying lens. Detritus was moved with a probe or forceps to free larvae for observation. If detritus loads, wave action, or collector uncertainty prevented positive identification, samples were preserved and brought back to the lab for sorting.

Nanjemoy, Piscataway, and Mattawoman creeks were sampled by Program personnel. Nanticoke, Elk, and Northeast rivers were voluntarily sampled by other Maryland Fisheries Service projects without charge to this grant. Trained volunteers from the Arlington Echo Outdoor Education Center conducted Severn River collections. These volunteers had been instructed by project biologists on collection techniques and larval identification. Nanticoke River data were collected but not included for analysis because a data sheet was unavailable to confirm an unusual pattern found in the spreadsheet provided. Miss-communication resulted in half the number of stations being sampled in Northeast River (i.e., 10 stations were requested, but 5 were sampled).

We collected a composite sample of larvae from several sites of each subestuary during sample trips during April 6 – 14. Larvae were subsampled for gut contents from each sample. These larvae represented first-feeding postlarvae, larvae that have absorbed their yolk and begun active feeding (Hardy 1978; Rogers and Westin 1981). Larvae were measured to the nearest mm. Gut fullness was judged visually and assigned a rank: 0 = empty; 1 = up to ¼ full; 2 = up to ½ full; 3 = up to ¾ full; and 4 = full. Major food items were classified as copepods, cladocerans, or other and the presence (coded 1) or absence (coded 0) of each group was noted.

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. Confidence intervals (95%) were constructed using the normal distribution to approximate the binomial distribution (Ott 1977; Uphoff 1997).

In general, sampling to determine $L_p$ begins during the last days of March or first days of April and ends after larvae are 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. This sampling schedule has been maintained for tributaries sampled by program personnel since 2006. Sampling by other Fisheries Service projects and volunteers sometimes did not adhere as strictly to this schedule.

During 2010, sampling began on March 31 in Piscataway, Mattawoman and Nanjemoy creeks, and they were sampled through April 23; samples through April 15 were used to estimate $L_p$. Sampling began on April 6 in the Northeast and Elk rivers, ended on May 12, and samples through April 29 were used to estimate $L_p$. Severn River collections were made on April 8, 13, and 15; all of these samples were used to estimate $L_p$.

Yellow perch larval presence-absence during 2010 was compared to a record of $L_p$ developed from past collections (Table 3-1). 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. Estimates of $L_p$ during the reference period ranged from 0.33 to 1.0. 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 2010 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).

Historic collections in the Choptank and Nanticoke rivers targeted striped bass eggs and larvae (Uphoff 1997), but yellow perch were also common (Uphoff 1991). 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 week of April or early in the second week were typical and end dates occurred during the last week of April through the first week of May. 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 during 1986-1990 (Uphoff et al. 2005). Survey designs for the Choptank and Nanticoke rivers were described in Uphoff (1997).

Estimates of C / ha (1998-2009) were used as estimators of development for analysis with $L_p$ (Table 3-1). Generally whole watershed estimates were used with the following exceptions: Nanticoke and Choptank river watersheds were truncated at the lower boundaries of their striped bass spawning areas and Elk River was confined to the subwatersheds designating the "upper Elk River" (Elk River proper above the C and D Canal). Estimates of C / ha were not available for 2010 and estimates for 2009 were substituted.

The mean of feeding success rank was calculated for each subestuary sampled in 2010 as was mean total length (TL in mm) of larvae. The proportion of guts without food (P0) was estimated for each system, as was the proportion of larvae with copepods ($P_{cope}$), cladocerans ($P_{clad}$), or other ($P_{othr}$) food items. The latter three proportions were not additive. Associations of C / ha, mean feeding success, mean TL, prevalence of food items, and $L_p$ were tested with correlation analysis. Number of observations was low (N = 5) and we considered correlations at $P < 0.20$ of interest in this exploratory analysis.

We used logistic regression to determine if C / ha and TL influenced odds of feeding ranks (0-4) being attained (SAS 1995; Wright 1998). The logistic regression modeled cumulative probabilities and assumed a common slope was associated with the predictor variables (SAS 1995). Intercepts of this model described cumulative odds related to fullness = 0, i.e., intercept 1 related odds of attaining fullness = 1 to fullness = 0, intercept 2 related attaining fullness = 2 or 1 to fullness = 0, etc (SAS 1995). Only main effects were considered. Analysis was conducted with Proc Logistic in SAS (SAS 1995). Level of significance was set at $P \leq 0.05$.

Uphoff et al. (2010) determined that significant ($P \leq 0.05$) negative linear relationships existed for IS and $L_p$, but these relationships were different for fresh-tidal (< 2‰) and brackish tributaries (≥ 2‰). We updated this linear regression analysis, but tested whether $L_p$ was influenced by C / ha for these two salinity categories. Two regression approaches were applied to data from 1998-2010 (Table 3-1): (1) two separate linear regressions of C / ha against $L_p$ estimated for brackish and fresh-tidal and (2) one multiple regression of C / ha and salinity against $L_p$ that assumed slopes were equal for two subestuary salinity categories, but intercepts were different (Freund and Littell 2006). In the latter analysis, salinity was modeled with an indicator variable, where 0 indicated fresh-tidal and 1 indicated brackish. High salinity has been implicated in contributing to low $L_p$ and the association of mean salinity and IS can be significant and strong (Uphoff et al. 2010). Ricker (1975) warned against using well correlated variables in multiple regressions, so categorizing salinity for multiple or separate regressions of C / ha against $L_p$ minimized confounding salinity with IS. Level of significance was set at $P \leq 0.05$. Residuals were inspected for trends, non-normality and need for additional terms. Nanjemoy Creek was positioned in a region of Potomac River between strictly fresh-tidal and brackish subestuaries and it was difficult to classify it exactly. We explored the sensitivity of Nanjemoy Creek's classification by running separate regressions with it classified as fresh-tidal or brackish and by excluding it from analyses.

## Results and Discussion

Based on 95% CI overlap, estimated $L_p$ in Severn River during 2010 ($L_p$ = 0.03, SD = 0.03, N = 30) was significantly lower than the historic reference range (Figure 3-2). Confidence intervals of $L_p$ in Piscataway Creek ($L_p$ = 0.54, SD = 0.08, N = 35), Mattawoman Creek ($L_p$ = 0.82, SD = 0.05, N = 50), Northeast River ($L_p$ = 0.68, SD = 0.09, N = 25), and Elk River ($L_p$ = 0.75, SD = 0.07, N = 36) overlapped the historic reference range. Nanjemoy Creek ($L_p$ = 0.96, SD = 0.03, N = 50) fell above the historic reference range (Figure 3-2).

Risk of falling below the "typical" historic minimum of $L_p$ = 0.4 during 2010 was near 100% in brackish Severn River where C / ha was 2.25 in 2009. Low risk (3%) was present at 1.43 C / ha in fresh-tidal Piscataway Creek during 2010. Risk of being below the historic minimum was near zero in remaining systems (C / ha 0.09-0.88).

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 3-3). 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 2006-2010 have fallen within or above the historic reference range and the range that the reference rivers exhibited after the1965-1990 reference period (Figure 3-3).

A total of 332 larval guts were examined. Copepods were the most prevalent food item and were found in 55-100% of guts sampled in the five systems (Table 3-2). Cladocerans were found in 2-22% of guts. The "other" food item category represented in a high fraction of guts in Piscataway Creek (53%) and 9-30% of guts in remaining systems. The percentage of guts without food ranged from 0 to 19%, while mean fullness rank ranged between 1.85 and 2.88 (Table 3-2).

Strong negative associations between C / ha and $P_{cope}$ (r = -.083) or mean fullness (r = -0.87) were evident (Table 3-3). Importance of copepods was indicated by strong negative associations of $P_{cope}$ with $P_{zero}$ (r = -0.79) and $P_{othr}$ (r = -0.84) and a strong positive correlation (r = 0.91) with mean fullness. Strong associations with mean length of larvae were not evident, with the exception of a negative association with $P_{clad}$. Estimates of $L_p$ were strongly and positively associated with $P_{cope}$ (r = 0.88) and negatively associated with $P_{zero}$ (r = -0.74) and $P_{othr}$ (r = -0.84; Table 3-3). Strong associations of $P_{cope}$ with other variables suggested that this class of zooplankton played a large role in yellow perch larval dynamics in the fresh-tidal systems sampled during 2010.

Logistic regression indicated that the odds of yellow perch larval feeding successfully were negatively influenced by C / ha ($P$ < 0.0001) and positively influenced by larval length (P = 0.0008; Table 3-4). Predictive ability of the model was modest; 60% of larval fullness ranks were successfully classified and 35% were classified incorrectly. Modest predictive ability may reflect the difficulty of assigning one rank to guts that could be interpreted as falling into an adjacent category and the possibility that other important factors that affect feeding success were not accounted for. Lack of significance of some intercepts (Table 3-4) suggested that pooling of feeding categories 3 and 4 into category 2 or additional samples might improve precision. Interpretation of intercepts was not the main purpose of this analysis and the logistic regression was not refined further.

Regression analyses indicated that C / ha was negatively related to $L_p$ and $L_p$ was, on average, higher in fresh-tidal subestuaries than in brackish subestuaries (Figure 3-4). The two regression approaches (separate regressions for fresh and brackish or one multiple regression with salinity as an indicator variable) provided similar outcomes (Table 3-5). Coefficients for C / ha were negative and nearly the same for the multiple regression and the linear regression for brackish subestuaries. The mean coefficients for C / ha estimated for fresh-tidal were steeper than the others but were not as precisely estimated and, based on 95% CI overlap, not different from those estimated from multiple regression or for brackish subestuaries alone (Table 3-5; Figure 3-4).

Classification of Nanjemoy Creek as fresh-tidal or brackish had no effect on the outcome of the multiple regression approach and removing it had a minor effect on parameter estimates (Table 3-5). Regressions of $L_p$ and C / ha in fresh-tidal tributaries were most impacted by classification or exclusion of Nanjemoy Creek and only the model with Nanjemoy Creek classified as fresh-tidal was significant. Results of $L_p$ and C / ha in brackish tributaries were largely unchanged with the classification or exclusion of Nanjemoy Creek (Table 3-5).

Overall, the multiple regression approach offered a better fit and inspection of residuals provided little indication of bias by assuming a constant slope over most of the subestuaries. The range of C / ha values available for analysis was greater in brackish subestuaries (0.07-2.74) than fresh-tidal (0.09-1.43). Predicted $L_p$ over the observed ranges of C / ha would decline from 0.50 to 0.13 in brackish subestuaries and from 0.84 to 0.66 in fresh-tidal subestuaries (Figure 3-4). A plot of residuals against C / ha indicate that fresh-tidal Piscataway Creek (C / ha $\approx$ 1.4) may not conform to a model of linear changes with development. Residuals for the three Piscataway Creek points were always negative, while other watersheds sampled in multiple years had both positive and negative residuals. Detection of different intercepts for fresh-tidal and brackish subestuaries indicated that historic reference period estimates of $L_p$ should only be applied to interpreting $L_p$ in brackish subestuaries since they were derived solely from them. It may be possible to develop separate reference levels of $L_p$ for brackish and fresh-tidal subestuaries from regression intercepts.

The proportion of tows with yellow perch larvae is not a measure of year-class success and we interpret it as an index integrating egg production, egg hatching success, and survival of first-feeding larvae. Characterization of larval survival normally is derived from count data that requires labor-intensive bench work. Estimates of $L_p$ were largely derived in the field and only the gut analysis required laboratory analysis. Increasingly tight budgets necessitate development of less costly indicators of larval survival in order to pursue habitat-based fisheries management.

Assuming catchability does not change greatly from year to year, egg production and egg through postlarval survival would need to be high to produce strong $L_p$, but only one factor needs to be low to result in lower $L_p$. Qualitative patterns of survival, derived by estimating $L_p$ in the first and second halves of the sampling period, may provide insight on what stages are experiencing relatively high or low mortality. A comparison of first and second half $L_p$ for 2010 samples (Figure 3-5) suggests three patterns: (1) little negative or positive difference between halves (Nanjemoy Creek and Elk River), (2) large negative differences in the second half (Mattawoman Creek, Piscataway Creek, and Northeast River), and (3) little evidence of yellow perch larvae at all (Severn River). The first pattern suggests both good hatching success of eggs and survival of larvae. The second suggests hatching was successful, but subsequent survival of larvae was lower than in pattern 1. The third pattern suggests hatching success was poor and-or egg production was low. In the case of Severn River (and by inference other suburban western shore tributaries in the region), this pattern likely reflects poor hatching success of eggs due to adverse habitat conditions (Uphoff et al. 2005). However, declining year-class success in the Head-of –Bay region (Piavis 2009) would lead to less migrants to Severn River and diminish egg production as well (Uphoff et al. 2005). As time permits, we will continue to explore past data to see if these patterns have consistently appeared in the past. If these interpretations prove reasonable, this type of analysis may provide cost-effective judgments of larval survival that can be related to habitat conditions.

These analyses indicated that watershed development negatively influenced survival of yellow perch larvae. Diminished first-feeding success may be an important mechanism influenced by development that reduces survival. The importance of adequate zooplankton supply and factors influencing zooplankton dynamics have been established for survival of Chesapeake Bay striped bass and American shad larvae (Hoffman et al. 2007; Fabrizio and Martino 2009). Yellow perch larvae share habitat with other anadromous fish larvae in larger tributaries, but little has been published on dynamics and feeding ecology of larval yellow perch in Chesapeake Bay (Uphoff 1991). Zooplankton supply (cladocerans and copedpods) for first-feeding yellow perch larvae has been identified as an influence on yellow year-class success in southwest Lake Michigan (Dettmers et al. 2003).

Years of high spring discharge favor anadromous fish recruitment in Chesapeake Bay (Hoffman et al. 2007; Fabrizio and Martino 2009) and may represent episodic “hot moments” for hydrologic transport of accumulated organic matter (OM) from watersheds (McClain et al. 2003). High flows provide a large subsidy of OM from the watershed to the estuary that fuels higher zooplankton production (Hoffman et al. 2007). Stable isotope signatures of York River, VA, American shad larvae and zooplankton indicated that terrestrial OM largely supported one of its most successful year-classes. Lesser year-classes of Amercian shad on the York River were associated with low flows, OM largely based on phytoplankton, and lesser zooplankton production (Hoffman et al. 2007).

The York River watershed, with large riparian marshes and forest, is largely intact relative to other Chesapeake Bay tributaries (Hoffman et al. 2007). Uphoff et al. (in press) found that the percentage of Maryland’s Chesapeake Bay subestuary watersheds in wetlands declined hyperbolically as IS increased, so this source of OM diminishes with development. Urbanization affects the quality and quantity of OM in streams (Paul and Meyer 2001). Riparian zones and floodplains that are sources of OM become disconnected from stream channels by stormwater management in suburban and urban watersheds (Craig et al. 2008; Kaushal et al. 2008; Brush 2009; NRC 2009). Small headwater streams in the Gunpowder and Patapsco rivers watersheds (tributaries of Chesapeake Bay in Maryland) were highly vulnerable to burial into culverts and pipes, or were simply paved over (Elmore and Kaushal 2008). Streams were more completely buried on Maryland's coastal plain (where our watersheds are located) than in upland areas (Elmore and Kaushal 2008). Decay of leaves occurred much faster in urban streams, apparently due to greater fragmentation of leaves from higher stormflow rather than biological activity (Paul and Meyer 2001). Alteration of flowpaths associated with urbanization affect the timing and delivery of carbon (as OM) to streams (McClain et al. 2003). Organic matter was transported further and was retained less in urban streams (Paul and Meyer 2001).

Changes in quality, quantity, and timing of OM delivered to subestuaries due to stream alteration and wetland loss associated with urbanization could act to decrease zooplankton production or alter timing of spring blooms important for feeding success and survival of anadromous fish larvae. Differences in yellow perch larval feeding success and survival with watershed development suggested from our investigation of Chesapeake Bay tributaries supports further testing of this hypothesis.

Table 3-1. Estimates of proportion of tows with yellow perch larvae ($L_p$) during 1998-2010 and data used for regression with counts of structures per hectare (C / ha). Salinity class 0 = tidal-fresh ($\leq$ 2.0 ‰) and 1 = brackish (> 2.0 ‰). Year is the year a subestuary was sampled.

| Year | Subestuary | $L_p$ | Counts / ha | Salinity class |
|---|---|---|---|---|
| 1998 | Choptank | 0.60 | 0.10 | 1 |
| 1999 | Choptank | 0.76 | 0.10 | 1 |
| 2000 | Choptank | 0.25 | 0.10 | 1 |
| 2001 | Choptank | 0.21 | 0.10 | 1 |
| 2002 | Choptank | 0.38 | 0.11 | 1 |
| 2003 | Choptank | 0.52 | 0.11 | 1 |
| 2004 | Nanticoke | 0.49 | 0.09 | 1 |
| 2004 | Choptank | 0.41 | 0.12 | 1 |
| 2004 | Severn | 0.29 | 2.09 | 1 |
| 2005 | Nanticoke | 0.67 | 0.14 | 1 |
| 2005 | Severn | 0.33 | 2.15 | 1 |
| 2006 | Nanticoke | 0.35 | 0.10 | 1 |
| 2006 | Corsica | 0.47 | 0.21 | 1 |
| 2006 | Bush | 0.79 | 0.68 | 0 |
| 2006 | Severn | 0.27 | 2.17 | 1 |
| 2007 | Langford | 0.83 | 0.07 | 1 |
| 2007 | Nanticoke | 0.55 | 0.13 | 1 |
| 2007 | Corsica | 0.83 | 0.22 | 1 |
| 2007 | Bush | 0.92 | 0.69 | 0 |
| 2007 | Severn | 0.3 | 2.21 | 1 |
| 2008 | Nanticoke | 0.19 | 0.11 | 1 |
| 2008 | Mattawoman | 0.66 | 0.87 | 0 |
| 2008 | South | 0.14 | 1.61 | 1 |
| 2008 | Bush | 0.49 | 0.70 | 0 |
| 2008 | Piscataway | 0.47 | 1.41 | 0 |
| 2008 | Severn | 0.08 | 2.74 | 1 |
| 2009 | Magothy | 0.17 | 2.73 | 1 |
| 2009 | Severn | 0.15 | 2.25 | 1 |
| 2009 | Nanticoke | 0.41 | 0.14 | 1 |
| 2009 | Mattawoman | 0.92 | 0.88 | 0 |
| 2009 | Piscataway | 0.39 | 1.43 | 0 |
| 2009 | Nanjemoy | 0.83 | 0.09 | 1 |
| 2009 | Bush | 0.86 | 0.72 | 0 |

Table 3-2. Summary of estimates used in correlation analysis of yellow perch larval feeding success. C / ha = counts of structures per acre. P 0 = proportion of guts without food. P Cladocera = proportion of guts with cladocerans. P Copepod = proportion of guts with copedpods. P other = proportion of guts with “other” food items. Mean TL = mean TL of larvae in mm. Mean fullness = average feeding rank of larvae. $L_p$ = proportion of tows with yellow perch larvae.

| Tributary | C / ha | P 0 | P Cladocera | P Copepod | P Other | Mean TL | Mean fullness | $L_p$ |
|---|---|---|---|---|---|---|---|---|
| Nanjemoy Cr. | 0.09 | 0 | 0.10 | 1.00 | 0.15 | 9.1 | 2.88 | 0.96 |
| Elk R. | 0.56 | 0.05 | 0.02 | 0.95 | 0.13 | 11.1 | 2.75 | 0.75 |
| Northeast R. | 0.41 | 0.19 | 0.22 | 0.72 | 0.30 | 8.4 | 2.34 | 0.68 |
| Mattawoman Cr. | 0.88 | 0.09 | 0.15 | 0.78 | 0.09 | 9.2 | 2.00 | 0.82 |
| Piscataway Cr. | 1.43 | 0.13 | 0 | 0.55 | 0.53 | 9.4 | 1.85 | 0.54 |

Table 3-3. Correlation matrix of C / ha, food item presence, mean TL of yellow perch larvae, and mean fullness rank. Abbreviations and labels are defined in Table 2. $r$ = correlation coefficient and $P$ = level of significance.

| | Statistic | C / ha | P zero | P Cladocera | P Copepod | P other | Mean TL | Mean fullness |
|---|---|---|---|---|---|---|---|---|
| P Zero | $r$ | 0.41 | | | | | | |
| | $P$ | 0.49 | | | | | | |
| P Cladocera | $r$ | -0.49 | 0.43 | | | | | |
| | $P$ | 0.40 | 0.48 | | | | | |
| P Copepod | $r$ | -0.83 | -0.79 | 0.06 | | | | |
| | $P$ | 0.08 | 0.11 | 0.93 | | | | |
| P other | $r$ | 0.65 | 0.57 | -0.31 | -0.84 | | | |
| | $P$ | 0.23 | 0.32 | 0.62 | 0.07 | | | |
| Mean TL | $r$ | 0.09 | -0.51 | -0.74 | 0.38 | -0.26 | | |
| | $P$ | 0.88 | 0.38 | 0.16 | 0.53 | 0.67 | | |
| Mean fullness | $r$ | -0.87 | -0.65 | 0.02 | 0.91 | -0.57 | 0.34 | |
| | $P$ | 0.05 | 0.23 | 0.98 | 0.03 | 0.31 | 0.58 | |
| $L_p$ | $r$ | -0.78 | -0.74 | 0.30 | 0.88 | -0.84 | -0.01 | 0.68 |
| | $P$ | 0.12 | 0.15 | 0.63 | 0.05 | 0.08 | 0.99 | 0.21 |

Table 3-4. Summary of results of the logistic regression of yellow perch larval gut fullness rank against counts of structures per hectare ( C / ha) and larval length (mm) from SAS Proc Logistic.

| Response Profile | | |
|---|---|---|
| **Ordered Value** | **Fullness** | **Total Frequency** |
| **1** | 4 | 98 |
| **2** | 3 | 74 |
| **3** | 2 | 57 |
| **4** | 1 | 74 |
| **5** | 0 | 29 |

Probabilities modeled are cumulated over the lower Ordered Values.

**Model Convergence Status**

Convergence criterion (GCONV=1E-8) satisfied.

**Score Test for the Proportional Odds Assumption**

| Chi-Square | DF | Pr > ChiSq |
|---|---|---|
| 1.9609 | 6 | 0.9233 |

| Model Fit Statistics | | |
|---|---|---|
| **Criterion** | **Intercept Only** | **Intercept and Covariates** |
| **AIC** | 1033.742 | 1007.978 |
| **SC** | 1048.962 | 1030.809 |
| **-2 Log L** | 1025.742 | 995.978 |

Table 3-4. (continued)

| Test | Chi-Square | DF | Pr > ChiSq |
|---|---|---|---|
| **Likelihood Ratio** | 29.7637 | 2 | <.0001 |
| **Score** | 29.9812 | 2 | <.0001 |
| **Wald** | 28.0826 | 2 | <.0001 |

**Analysis of Maximum Likelihood Estimates**

| Parameter | | DF | Estimate | Standard Error | Wald Chi-Square | Pr > ChiSq |
|---|---|---|---|---|---|---|
| **Intercept** | **4** | 1 | -2.3593 | 0.6569 | 12.9016 | 0.0003 |
| **Intercept** | **3** | 1 | -1.3523 | 0.6481 | 4.3537 | 0.0369 |
| **Intercept** | **2** | 1 | -0.5665 | 0.6449 | 0.7718 | 0.3797 |
| **Intercept** | **1** | 1 | 1.0501 | 0.6576 | 2.5502 | 0.1103 |
| **Length** | | 1 | 0.2179 | 0.0648 | 11.3101 | 0.0008 |
| **C_ha** | | 1 | -1.0370 | 0.2443 | 18.0138 | <.0001 |

**Odds Ratio Estimates**

| Effect | Point Estimate | 95% Wald Confidence Limits | |
|---|---|---|---|
| **Length** | 1.244 | 1.095 | 1.412 |
| **C_ha** | 0.355 | 0.220 | 0.572 |

**Association of Predicted Probabilities and Observed Responses**

| | | | |
|---|---|---|---|
| **Percent Concordant** | 59.5 | **Somers' D** | 0.249 |
| **Percent Discordant** | 34.6 | **Gamma** | 0.265 |
| **Percent Tied** | 6.0 | **Tau-a** | 0.194 |

Table 3-5. Sensitivity of regression $r^2$, parameter means and SE to treatment of Nanjemoy Creek for regressions used to analyze the relationship of proportion of positive tows (Lp; dependent variable) to development (tax map counts of structures per hectare (C / ha; independent variable). Model = combined includes salinity as an independent categorical variable and Nanjemoy Creek as fresh-tidal (0 < 2‰ and 1 ≥2‰); Model = fresh is a regression for fresh-tidal subestuaries only and Nanjemoy Creek as fresh-tidal; and Model = brackish is a regression of brackish subestuaries only and Nanjemoy Creek as brackish.

| Coefficients | Estimate | Fresh | Brackish | Removed |
|---|---|---|---|---|
| | | Model = combined; $R^2 = 0.61$, $P < 0.0001$, N = 39 | | |
| Intercept | Mean | 0.85 | 0.85 | 0.84 |
| | SE | 0.05 | 0.05 | 0.06 |
| C / ha | Mean | -0.15 | -0.15 | -0.14 |
| | SE | 0.03 | 0.03 | 0.03 |
| Salinity | Mean | -0.34 | -0.34 | -0.33 |
| | SE | 0.06 | 0.06 | 0.06 |
| | | Model = fresh; $r^2 = 0.31$, $P = 0.038$, N = 14 | | |
| Intercept | Mean | 0.92 | 0.94 | 0.92 |
| | SE | 0.10 | 0.17 | 0.10 |
| C / ha | Mean | -0.22 | -0.23 | -0.22 |
| | SE | 0.09 | 0.15 | 0.09 |
| | | Model = brackish; $r^2 = 0.41$, $P = 0.0003$, N = 27 | | |
| Intercept | Mean | 0.51 | 0.56 | 0.56 |
| | SE | 0.05 | 0.05 | 0.05 |
| C / ha | Mean | -0.14 | -0.16 | -0.16 |
| | SE | 0.03 | 0.04 | 0.04 |

Figure 3-1. Sampling areas and stations for the 2010 yellow perch larval presence absence study.

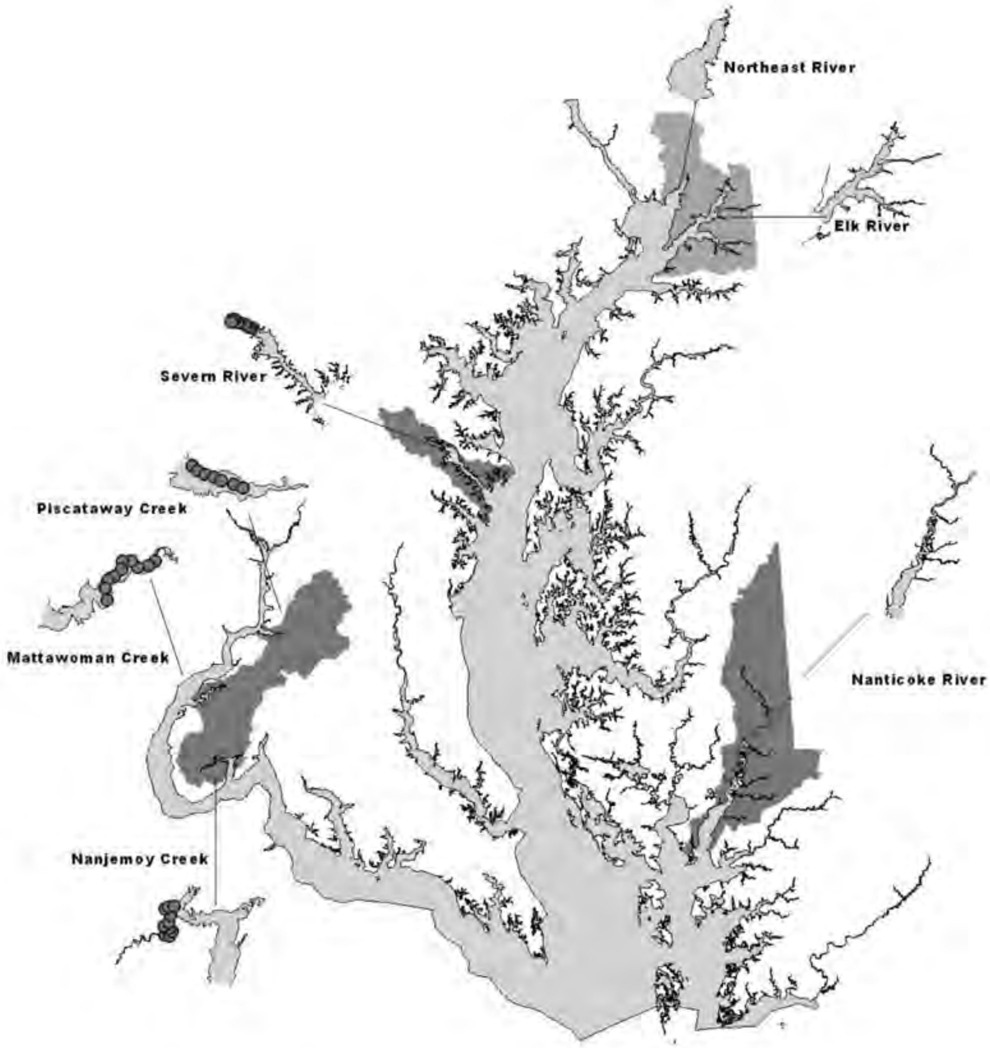


Figure 3-2. Proportion of tows with larval yellow perch and its 95% confidence interval in systems studied during 2009. Mean of brackish tributaries indicated by diamond and fresh-tidal mean indicated by dash. High and low points of "Historic" data indicate spread of 9 of 11 points and midpoint is the mean of historic period.

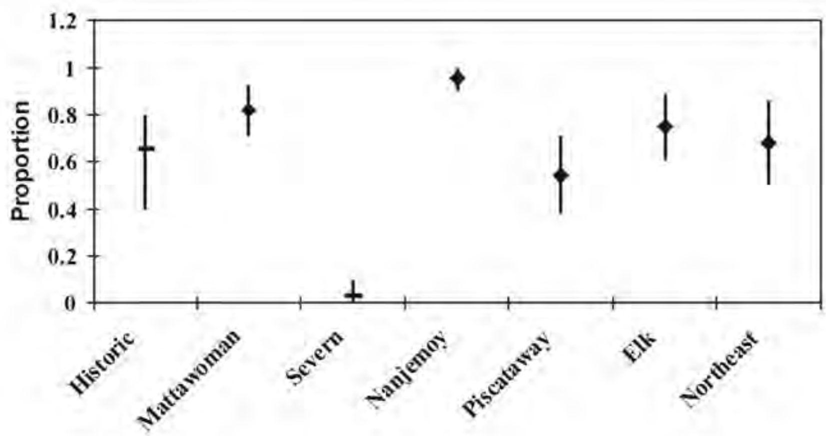



Figure 3-3. Proportion of tows with yellow perch larvae, by river, during 1965-2009. Dotted lines indicates reference system (Nanticoke and Choptank rivers) and period (prior to 1991) "typical" range..

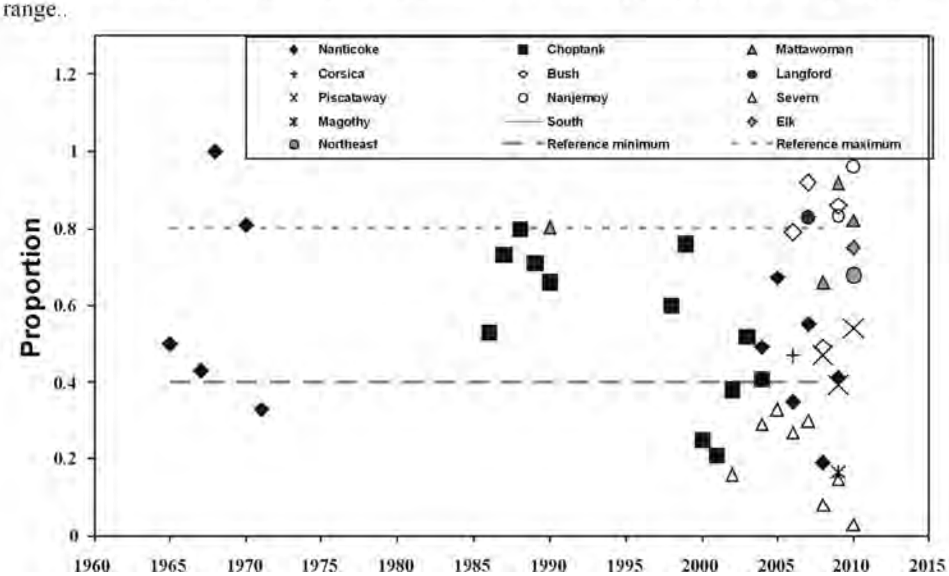


Figure 3-4. Estimated relationship of watershed counts of structures per hectare versus estuarine yellow perch larval presence-absence in towed nets for fresh-tidal and brackish tributaries, 1998-2010.

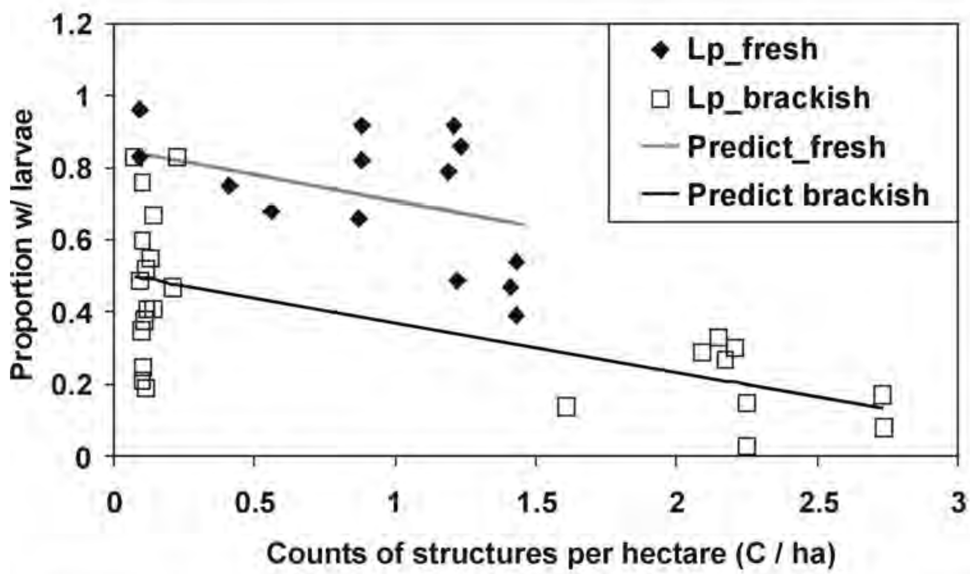
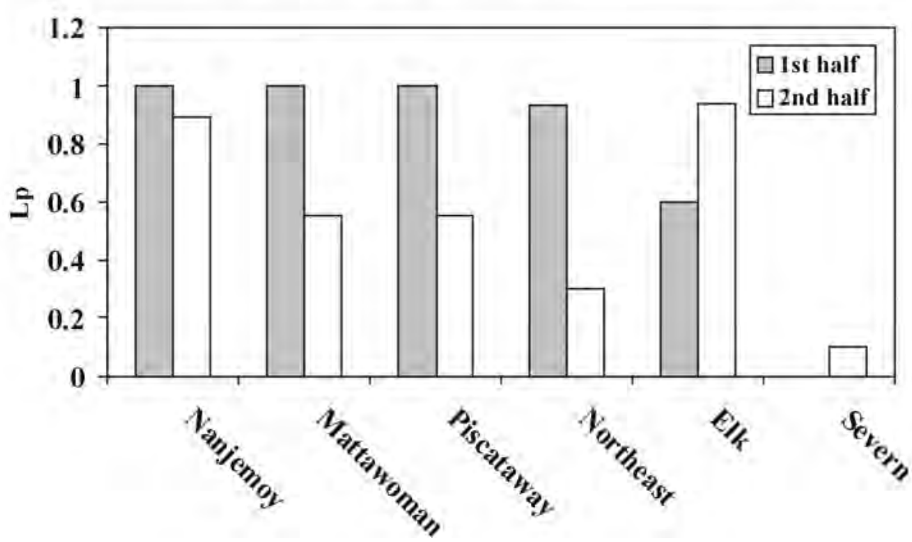



Figure 3-5. Estimates of proportion of plankton tows with yellow perch larvae (Lp) in the first and second halves of the sampling periods during 2010.



## Section 4 - Estuarine Fish Community Sampling

### Introduction

We continued to evaluate nursery and adult habitat for recreationally important finfish in fresh-tidal, oligohaline, and mesohaline subestuaries of Chesapeake Bay during 2010. We have emphasized monitoring and analysis of habitat data from fresh-tidal and low salinity subestuaries since 2006.

A variety of studies have documented deterioration of non-tidal freshwater aquatic habitat as IS occupied more than 10% of watershed area (Wheeler et al. 2005; NRC 2009). Uphoff et al. (in press) estimated target and limit ISRPs for brackish (mesohaline) Chesapeake Bay subestuaries based on Chesapeake Bay DO criteria, and associations and relationships of percent of watershed in IS, summer DO, and presence of recreationally important finfish in bottom waters of nine brackish Chesapeake Bay subestuaries. Watersheds at a target of 5.5% IS or less (rural watershed) maintained mean bottom DO above 3.0 mg/L (threshold DO), but mean DO was only occasionally at or above 5 mg/L (target DO). Mean DO seldom exceeded 3.0 mg/L above 10% IS (suburban threshold; Uphoff et al. in press).

Impervious surface is used as an indicator of development by planning and zoning agencies because of compelling scientific evidence of its effect in freshwater systems and because it is a critical input variable in many water quality and quantity models (Arnold and Gibbons 1996; Cappiella and Brown 2001). Because of the strong relationship between tax map based indicators (C / ha) and IS, these measures can be used interchangeably to develop ISRPs. Chesapeake Bay watershed ISRPs would be useful for informing county and state growth planners, watershed-based citizen groups, and interstate finfish habitat managers. Defining the impact of IS on summer finfish habitat would give Maryland Fisheries Service managers a better understanding of how coastal development influences fish production and allow them to account for these effects in managing individual fisheries.

### Methods

We sampled eight tributaries in Chesapeake Bay in 2010 and two additional tributaries were sampled for us by Maryland Fisheries Service's Alosine Project (Figure 4-1). Table 4-1 summarizes regional location and estimates of IS, C / ha, non-water watershed area, tidal water surface area, and percent of each watershed in urban land, forest, agriculture, and wetlands. We used 1999-2000 IS estimates made by Towson University from Landsat, 30-meter pixel resolution satellite imagery for each watershed (see Section 1). We also compiled watershed-specific estimates of percent land cover in agriculture, forest, urban land, and wetlands during 1994 made by Maryland's Department of Planning to summarize basic land use (MD DNR 1999). Housing density estimates (C / ha) were estimated from Maryland Tax Data according to methodology described in Section 1 and were used as an indicator of recent development.

Tidal water surface area was estimated using 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.

Trawls sampled mid-channel habitat and seines sampled the shore zone. Target finfish were striped bass, yellow perch, white perch, alewife, blueback herring, American shad, spot, Atlantic croaker, and Atlantic menhaden. All target species were primarily age 0 fish with the exception of white perch. Gear specifications and techniques were selected to be compatible with other Fisheries Service surveys in Chesapeake Bay (Bonzek et al. 2007; Durell and Weedon 2011)

Three to four evenly spaced bottom trawl sample sites were located in the upper two-thirds of each tributary (depending on tributary size) and seine sites were located in the vicinity of the trawl sites when possible. Latitudes and longitudes of trawl sites were measured in the middle of the trawl paths and at the exact seining location. Seine sites could not always be located because of permanent obstructions, absence of beaches for landing the net, and thick SAV beds. Growth of SAV over a sampling season could result in abandonment of seining sites. Sample sites were not located near the subestuary mouth to reduce influence of the mainstem Bay or Potomac River waters on water quality measurements.

Each site was sampled once every other week during July-September (six visits per year). 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 DO. However, sites located in the middle would not be as influenced by the random start location as much as sites on the extremes because of the bus-route sampling design. Certain sites needed to be sampled on specific tide stages and sample routes were changed to meet these conditions.

Water quality parameters were recorded at all sites. Water temperature (ºC), dissolved oxygen (DO, mg/L), conductivity ( mho), salinity (ppt) 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. 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.

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 mm stretch in the body and 33 mm stretch mesh in the codend, with an untreated 12 mm stretch knotless mesh liner. The head rope was equipped with floats and the foot rope was equipped with a 3.2 mm chain. The net used 0.61 m long by 0.30 m high trawl doors attached to a 6.1 m bridle leading to a 24.4 m tow rope. The trawl was towed in the same direction as the tide. The trawl path was set up to pass the site halfway through the tow, 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. The contents of the trawl were emptied into a water-filled tub for processing.

An untreated 30.5 m • 1.2 m bagless beach seine made of knotted 6.4 mm stretch-mesh was used to sample inshore habitat. The float-line was rigged with 38.1 mm • 66 mm floats spaced at 0.61 m intervals and the lead-line rigged with 57 gm lead weights spaced evenly at 0.55 m 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 of water for processing. The distance the net was stretched from shore, maximum depth of the seine haul, primary and secondary bottom type, and quartile 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 and life stage. 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.

Salinity influences on distribution and abundance of fish are well documented (Allen 1982; Cyrus and Blaber 1992; Hopkins and Cech 2003). We examined mean salinity in the sample areas during 2010 to classify them according to salinity zone in order to assure comparisons among watersheds accounted for salinity differences. Tidal-fresh subestuaries sampled in 2010 included Mattawoman Creek, Piscataway Creek, Bush River, and Northeast River (Table 4-2; Figure 4.1). Structures per hectare in these watersheds ranged from 0.45 to 1.46 (Table 4-1). The Gunpowder and Middle rivers were classified as oligohaline; C / ha was 0.77 and 3.31, respectively (Table 4-1 and 4-2). The Corsica River, Nanjemoy Creek, Tred Avon River, and Wicomcio River were mesohaline and C / ha estimates were between 0.09 and 0.74 (Tables 4-1 and 4-2; Figure 4-1).

Dissolved oxygen data were compared to fish habitat criteria and reported as deviations from a target or limit (McGinty et al. 2006). We used 5 mg/L DO as a target and 3 mg/L as a threshold (Uphoff et al. in press). Concentrations of DO 5 mg/L or greater are considered desirable for many Chesapeake Bay living resources (Batiuk et al. 2009; Uphoff et al. in press). Chesapeake Bay DO criteria for deep-water fish and shellfish call for maintaining a 30 day mean of 3 mg/L during June 1 – September 30 in bottom waters (Batiuk et al. 2009; Uphoff et al. in press). In each subestuary, we examined the percentages of bottom DO that did not meet the target or threshold during 2010 sampling. The percentages of bottom DO measurements that met or fell below the 5 mg/L target ($V_{target}$) or fell at or below the 3 mg/L threshold ($V_{threshold}$) were estimated as $[(N_{target} / N_{total})\bullet 100]$ or $[(N_{threshold} / N_{total}) \bullet 100]$, respectively; where $N_{target}$ was the number of measurements meeting or falling below 5 mg/L, $N_{threshold}$ was the number of measurements falling at or below 3 mg/L, and $N_{total}$ was total sample size.

In an effort to identify other important water quality variables in tidal fresh areas, we examined pH in the tidal fresh and oligohaline waters. We applied the upper and lower pH criteria established in Virginia's tidal and nontidal waters (below 6.0 and above 9.0 are undesirable; State Water Quality Control Board 2010).

Catch data were summarized as arithmetic means for all species collected and as proportions of gear-specific samples containing a specific target species. Presence-absence 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). Proportion of samples with a target species $\boldsymbol{i}$ ($\boldsymbol{P_i}$) was calculated as $\boldsymbol{N_i}$ / $\boldsymbol{N_{total}}$ where $\boldsymbol{N_i}$ was the number samples containing target species $\boldsymbol{i}$, and $\boldsymbol{N_{total}}$ was total sample size. The SD of each proportion was estimated as

$$SD = [(P_i \cdot (1- P_i)) / N_{total}]^{0.5}$$

and used to construct 95% CIs for each target species life stage (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.

We used correlation analysis to explore associations of development and other factors on habitat conditions in tidal-fresh Mattawoman Creek during 1989-2010. The correlation matrix consisted of C / ha, SAV acreage, mean bottom DO, and annual median chlorophyll a in Mattawoman Creek. We estimated mean DO of bottom channel samples at the upper four stations (combined); five stations were sampled prior to 2003 (Carmichael et al. 1992) and the station closest to the mouth was eliminated from 1989-2002 data. There has been a significant increase in SAV in Mattawoman Creek as well and SAV acreage was included in the correlation matrix (L. Karrh MD DNR personal communication). Annual median chlorophyll a was estimated from Chesapeake Bay Program monitoring station MAT016, located in Mattawoman Creek near station 4 (nearest the mouth). Estimates of SAV acreage were not available for 2001. The C / ha estimate for 2009 was used for 2010 since 2010 was not available; the 2007 estimate of C/ha was not used (See Section 1).

Maryland DNR, Resource Assessment Service oversees a network of continuous monitoring stations throughout the Chesapeake Bay and a site located in Mattawoman Creek at Smallwood State Park (Sweden Point Marina) (http://mddnr.chesapeakebay.net/newmontech/contmon/eotb_results_graphs.cfm?station=mattawoman) has been operating since 2004 (near station 3). We calculated $V_{target}$ and $V_{threshold}$ by month and year with DO measurements made by the continuous monitor.

In 2009, we reported that shifts in Mattawoman Creek's fish community had occurred after 2002 (Uphoff et al. 2010). We evaluated 1989-2010 data from Mattawoman Creek to determine how fish community characteristics changed after 2002. We confined this analysis to samples collected by the 10 foot head rope trawl used during 1989-2002 and during 2009-2010; 10 foot and 16 foot head rope trawls have both been used in Mattawoman Creek since 2009 to help interpret data when either gear was used alone (Uphoff et al. 2010). We characterized different aspects of community composition using (1) the proportion of trawls with resident or nonresident fish, (2) the proportion of trawls with different spawning guilds (anadromous, freshwater, estuarine, and marine), and (3) proportion of trawls with fish in three feeding strategy categories (planktivore, carnivore, and benthivore). Table 4-3 lists the species and classifications that we assigned. Each time-series of community composition proportions was graphed to view changes.

We began sampling the Tred Avon River in 2006 after identifying the opportunity to track temporal changes within a mesohaline subestuary in response to development rather than use comparisons of different subestuaries as a proxy for changes over time. Development in the Tred Avon is occurring under more stringent stormwater requirements and there may be an opportunity to evaluate how well these stormwater measures protect habitat quality in the estuary when compared to other developed mesohaline subestuaries. Because Tred Avon River is a mesohaline tributary, we would expect these responses to manifest as deteriorating bottom DO and reduced presence of fish in bottom samples (Uphoff et al. in press). We examined percentage of violations of target and threshold oxygen values in bottom waters since 2006. We also examined $P_i$ estimated for the most frequently captured species in each gear. Species analyzed were those that occurred in 10% or more of all trawl samples.

The NOAA Integrated Assessment Program (see Job 3) requested that we subsample 30 adult fish from each sample for anomalies in the subestuaries both projects sampled during 2010. We expanded this examination to all subestuaries we sampled during 2010. Anomalies were recorded as reddening of fins or skins, ulcer, tumor, parasite, skeletal deformity or other. We calculated proportion of anomalies by species and gear for each subestuary. We eliminated the "other" category from estimates of proportion of anomalies, because it was likely that many of the "other" anomalies were from gear handling.

## Results and Discussion

During 2010, we found that mesohaline subestuaries had highest $V_{target}$ and $V_{threshold}$ estimates in bottom waters (up to 37.5% and 17.6%, respectively) and these estimates increased with C / ha (Table 4-4). Only one oligohaline and one fresh-tidal subestuary (Middle and Bush rivers, respectively) had non-zero estimates of $V_{target}$ (both near 13%); these two subestuaries had substantial levels of development (1.46-3.31 C/ha). Estimates of $V_{target}$ equaled zero for the other six oligohaline and fresh-tidal subestuaries, while C /ha varied considerably (0.45-1.43). All estimates of $V_{threshold}$ equaled zero for oligohaline and mesohaline subestuaries (Table 4-4). Estimates of $V_{target}$ and $V_{threshold}$ did not prove to be particularly sensitive indicators of development-related degradation in non-mesohaline areas.

Salinity's influence on DO was not unexpected because of its effect on DO saturation and depletion due to stratification (Kemp et al. 2005). Density stratification in these higher salinity subestuaries limits circulation and exchange of bottom waters with the upper water column. Stratification, combined with high nutrient loads and reduced nutrient processing associated with development, contributes to process that rob the system of DO (Uphoff et al. in press). Because stratification is less common in lower salinity subestuaries of the Bay, these subestuaries are not prone to bottom water DO depletion that is a feature of mesohaline tributaries.

None of the tributaries sampled had pH below 6.0; however, the Bush and Northeast rivers both had pH in excess of the upper criteria (12.2% and 7.0% of the time, respectively).

A total 124,583 fish comprised of 54 species (trawl and seine) were captured in 2010. Eight species comprised 90% of the catch. These species, in descending order of abundance, included white perch, spot, bay anchovy, gizzard shad, Atlantic menhaden, spottail shiner, pumpkinseed and Atlantic silverside. Only three of these species, white perch, spot, and Atlantic menhaden were target species.

Seining was not conducted in Mattawoman and Piscataway creeks because of extensive SAV beds along the shoreline. Seining in Middle River was sporadic because of high water and dense SAV. A total of 46,003 fish representing 44 species were captured seining. Ten species comprised 90% of the catch. They were, in descending order of abundance, white perch, gizzard shad, Atlantic menhaden, Atlantic silverside, pumpkinseed, spot, bay anchovy, spottail shiner, banded killifish and mummichog.

Only two tidal fresh areas, Bush and Northeast rivers, were consistently seined and species richness was similar (Table 4-5). Twenty-nine species were observed in the Bush River seine samples with six accounting for 90% of the catch. Twenty-eight species were observed in Northeast River seine samples and six accounted for 90% of the total catch. Catch per effort of all fish (CPE) was 456.8 in the Bush River and 331.7 in the Northeast River (Table 4-5).

Summary seine catch statistics of the two oligohaline rivers were also compared (Table 4-5). The Gunpowder River (C / ha = 0.774) had 29 species with seven comprising 90% of the total catch and a CPE of 397.1. The Middle River (C / ha = 3.31) had 22 species with seven comprising 90% of the catch and CPE of 202.9 (Table 4-5). There is a notable difference in species richness and CPE between the two rivers; however, we did not determine if the difference reflected land cover or sampling effort. Middle River has few suitable seining sites because much of its shoreline is bulkheaded. The few beaches available in Middle River were either too deep to sample with a seine or had dense SAV coverage.

Of the four mesohaline rivers sampled with seines, Wicomico River had the fewest species observed, 20; Tred Avon River and Corsica River both had 21; and Nanjemoy Creek, 24 (Table 4-5). Tred Avon River had 6 species responsible for 90% of the total seine catch and the other three rivers had 7 species representing this 90%. Catch per seine haul by river in ascending order was Wicomico (79.4), Corsica (136.4), Nanjemoy (142.5) and Tred Avon (219.5; Table 4-5).

A total of 78,580 fish were captured by trawling, representing 47 species (Table 4-7). Four species comprised 90% of the total catch for the trawl: white perch, spot, bay anchovy and spottail shiner (Table 4-6).

Richness and CPE measures differed among trawl samples in tidal-fresh rivers. Northeast River and Piscataway Creek had 21 species with three accounting for the majority of the catch (Table 4-6). Mattawoman Creek had 20 species, with five comprising 90% of the catch, and Bush had 16 species in the trawl with two dominating the catch. Catch per effort was 551.3 in Piscataway, 515.6 in Bush River, 419.8 in Northeast River, and 169.6 in Mattawoman Creek. Some of the differences in species may have reflected differences in number of samples that were taken in the subestuaries; detection of species is often positively affected by the number of samples (Kwak and Peterson 2007).

Two oligohaline subestuaries were sampled by trawl. Gunpowder River had 23 species with three comprising 90% of catch; CPE was 425.3. Middle River had 20 species with four comprising 90%; CPE was 342.1 (Table 4-6).

Total species in trawl samples ranged from 13 to 18 in mesohaline rivers and species comprising 90% of catch ranged between two and four (Table 4-6). Catch per effort was 169.7 in Wicomico River, 221.8 in Corsica River, 333.8 in Nanjemoy Creek and 412.2 in Tred Avon River (Table 4-6).

Mean bottom DO in Mattawoman Creek increased from about 8 mg / L in 1989 to levels in excess of 10 mg / L during 1990-1996 (Figure 4-2). Mean bottom DO then declined to 7-8 mg / L by 2007-2010. Estimates of C / ha increased from 0.41 to 0.86 during 1982-2010 and rate of growth in C / ha accelerated after 1984 (Figure 4-2). Coverage by SAV greatly increased during 1987-2008 (Figure 4-2). Mattawoman Creek has a Chesapeake Bay Program SAV coverage goal of 792 acres and SAV has reached approximately half of the goal (T. Parham, MD DNR, personal communication; http://archive.chesapeakebay.net/pubs/sav/08.pdf; Figure 4-2). Median annual chlorophyll a at MAT016 ranged from 15-40 μg/L during 1989-1999 and was often between 30 and 35 μg/L (Figure 4-3). Median annual chlorophyll a collapsed between 1999 and 2002 and remained at 5-10 μg/L after 2002 (Figure 4-3).

All correlations of Mattawoman Creek mean bottom DO, SAV acreage, median chlorophyll a, and C / ha were significant at ($P \leq 0.0018$; Table 4-7). Correlations were strong and indicated that dynamics of these parameters could be inter-related. Correlations of mean bottom DO in Mattawoman Creek with C / ha and SAV acreage during 1989-2010 were negative ($r = -0.81$ and $-0.83$, respectively) and mean bottom DO was positively correlated with chorophyll a ($r = 0.64$). Acreage of SAV was positively correlated with C / ha ($r = 0.92$) and negatively correlated with median chlorophyll a ($r = -0.88$; Table 4-7). Increases in SAV were followed by falling water column chlorophyll a concentrations and bottom DO, although bottom DO remained largely above the target level. High DO during 1990-1996 (when SAV acreage was low) represented supersaturated conditions and, in combination with high chlorophyll a, indicated that algae blooms were prevalent. The increase in SAV and decrease in bottom DO could be interpreted as an improvement in habitat conditions; however, Uphoff et al. (2010) documented substantial downward shifts in number of species and abundance of finfish in trawl samples from Mattawoman Creek since the early 2002.

Monthly estimates of both $V_{target}$ and $V_{threshold}$ at the Sweden Point Marina continuous monitor generally increased steadily between June and September and these monthly estimates usually, but not always, increased annually between 2004 and 2010 (Figures 4-7 and 4-8). In every year except 2010, $V_{target}$ would start in June at less than 10% (one exception near 30%) and finish in September at 0-20% (Figure 4-7); $V_{threshold}$ would start at less than 5% in June and end at 1-18% (Figure 4-8). In 2010, $V_{target}$ began in June, 2010, at about 1% and finished at over 80% (Figure 4-7); $V_{threshold}$ began at 0% and ended in excess of 60% (Figure 4-8). These data suggest SAV in Mattawoman Creek may be associated with DO deficits in shallow water. Our monitoring of channel waters and DO data from a second continuous monitor upstream at Indianhead (adjacent to the channel and not within a dense SAV bed) (http://mddnr.chesapeakebay.net/newmontech/contmon/current_results_fullyear_graph.cfm?param=DOC&station=indianhead&choose_date=19423&choose_range=7) did not detect depleted DO. We do not know how representative DO measurements in the SAV at Sweden Point is of conditions in all SAV beds in Mattawoman Creek.

Sweden Point Marina is the location of many largemouth bass releases and these DO deficits could increase the risk of losses. We have relayed these results to the Freshwater Fisheries Division, so they can address potential impacts to largemouth bass releases in the area.

It is possible that a dominant non-native SAV species in Mattawoman Creek, ***Hydrilla verticalla,*** could be contributing to DO deficits. Caraco and Cole (2002) reported lower DO in beds of nonnative canopy forming SAV ***Trapa natens*** when compared to native ***Vallisneria americana***. They reported DO in native beds never dropped below 5.0 mg/L; however, DO in nonnative beds was below 2.5 mg/L 40% of the time. High density of ***Trapa natens*** impaired light penetration into the water column and higher DO occurred in less dense beds (Caraco and Cole 2002). ***Hydrilla*** is a canopy forming non-native SAV species (Holm et al. 1997) that we hypothesize could be impacting fish habitat both positively and negatively in Mattawoman Creek. We have observed that Mattawoman Creek supports a thriving largemouth bass fishery that extensively fishes the outside portions of SAV beds. Increased water clarity, which is a goal of the Chesapeake Bay Program (see http://www.chesapeakebay.net/status_clarity.aspx?menuitem=19676), has been reported in areas where ***Hydrilla*** have become established (Langeland, 1986) and our Secchi readings in Mattawoman Creek have increased since 1989 (not shown). In addition to depleted DO conditions measured at Sweden Point, Simberloff et al. (1997) cited numerous deleterious effects from ***Hydrilla*** in Florida: blocked sunlight for native SAV, physico-chemical changes in lakes, shifts in zooplankton densities, and stunted growth of gamefish from reduced predator cropping. Uphoff et al. (2010) detected significant declines in number of fish species and total fish abundance in Mattawoman Creek since 2002 that coincided with crossing a C / ha threshold equivalent to about 10% IS, an upsurge in SAV, and a decline in chlorophyll a. In 2011, we hope to initiate transect DO sampling across grass beds in Mattawoman Creek to determine how extensive low DO is in its SAV beds.

Each of the fish community classifications (resident-nonresident, spawning guild, and feeding strategy) changed in Mattawoman Creek after 2002. Lowest levels of all three were observed in 2009 and there was some recovery in 2010. The proportions of trawl samples with resident and nonresident species in Mattawoman Creek were high during 1989-2001 and began to decline afterward (Figure 4-4). Proportions of trawl samples with freshwater and marine spawners varied considerably, but did not exhibit a definite decline (Figure 4-5). However, anadromous and estuarine spawners consistently exhibited lower proportions after 2001 (Figure 4-5). Planktivores and carnivores were less frequent after 2001, but it was difficult to judge whether proportions of trawl samples in Mattawoman Creek with benthivores had changed (Figure 4-6).

Estimates of $V_{target}$ in Tred Avon River during 2006-2010 ranged from 5-50% with little evidence of trend (Figure 4-8). Estimates of $V_{threshold}$ were 0% in 2006 and 2009, about 3% in 2007, and 9% in 2008 and 12% in 2010 (Figure 4-9). The two highest $V_{threshold}$ estimates have occurred more recently, but a year where $V_{threshold}$ equaled 0% fell between these years (Figure 4-9). Based on relationships of C / ha and IS developed in Section 1 and in Uphoff et al. (2010), IS in Tred Avon's watershed (0.74) is in the vicinity of a 10% IS threshold (C / ha $\approx$ 0.75) for mesohaline (brackish) subestuaries (Uphoff et al. in press). Subestuaries at 15% or more IS during 2003-2005 exhibited $V_{target}$ conditions about 86% of the time and $V_{threshold}$ conditions about 63% of the time; those at 5.5% IS or less ($\approx$ 0.3 C / ha) exhibited $V_{target}$ conditions about 58% of the time and $V_{threshold}$ conditions about 25% of the time (Uphoff et al. 2010). Dissolved oxygen conditions in bottom waters of Tred Avon River have remained in a range associated with rural Chesapeake Bay subestuaries since 2006. Systematic declines over time in $P_i$ of the most abundant species in trawl were not evident, but $P_i$ of white perch adults in 2010 was a third lower than all previous years (Figure 4-10).

We did not detect obvious indications of decline in bottom DO or the fish community in Tred Avon River due to development. We will continue to monitor this tributary to detect changes in habitat quality and fish community composition.

The most frequent categories of anomalies detected in seines and trawls combined were “reddening” (≈45-55% of fish examined) and “other” (≈30-50%), followed by lower frequencies (≈5-10%) of “ulcers” and “parasites”, and trace levels of “tumors” and “skeletal deformities” (Figure 4-11). Bush River (C / ha = 1.46), followed by Nanjemoy and Piscataway creeks (C / ha = 0.09 and 1.43, respectively) had the highest frequency of anomalies (“other” category omitted) summed over all species. These three systems represented the two most developed fresh-tidal subestuaries and the least developed mesohaline subestuary in the study. Only two species, brown bullhead (trawl only) and white perch (seine and trawl), exhibited proportions of anomalies (summed over all subestuaries) that were different from 0 based on 95% CI overlap (Table 4-8). White perch were the most prevalent species in both gear types and the most frequently evaluated species for anomalies; however, they exhibited a low level of anomalies in both gears. Brown bullhead had far higher highest frequency of anomalies in trawl samples than white perch (Table 4-8). White perch, as opposed to brown bullhead, are a widespread, recreationally important, and one of our target. However, the low frequency of anomalies we observed for white perch indicated very large (perhaps impractical) sample sizes would need to be drawn from each subestuary for precise estimates of proportions of white perch with anomalies. These are preliminary evaluations subject to further review and analysis, but anomaly data did not seem to provide additional insight on impacts of watershed development on fish habitat.

Table 4-1. Summary of land use for subestuaries monitored during 2010. IS estimates were made by Towson University for 1999-2000, C / ha was estimated from 2009 tax map data. Land use percentages were Maryland Department of Planning estimates for 1994.

| Region | Watershed | IS | C/ha | Total ha | Tidal water ha | Agriculture % | Forest % | Wetland % | Urban % |
|---|---|---|---|---|---|---|---|---|---|
| Mid-Bay | Corsica R. | 4.1 | 0.24 | 9,699 | 508 | 65.4 | 28.1 | 0.6 | 5.7 |
| Mid-Bay | Middle R. | 39.1 | 3.31 | 2,735 | 863 | 5.6 | 29.1 | 2.5 | 62.8 |
| Mid-Bay | Tred Avon R. | 7.5 | 0.74 | 9,517 | 1,756 | 39 | 38 | >1 | 22.0 |
| Potomac | Mattawoman Cr. | 9.0 | 0.88 | 24,403 | 748 | 13.8 | 62.6 | 0.9 | 22.5 |
| Potomac | Nanjemoy Cr. | 0.9 | 0.09 | 18,860 | 949 | 15.5 | 73.9 | 4.0 | 6.5 |
| Potomac | Piscataway Cr. | 16.5 | 1.43 | 17,636 | 347 | 16.3 | 48.4 | 0.2 | 33.9 |
| Potomac | Wicomico R. | 4.3 | 0.34 | 19,977 | 566 | 30.1 | 56.7 | 1.6 | 7.4 |
| Upper-Bay | Bush R. | 11.3 | 1.46 | 14,959 | 3,224 | 21.8 | 47.8 | 5.7 | 24.3 |
| Upper-Bay | Gunpowder R. | 4.4 | 0.77 | 17,590 | 4,052 | 23.7 | 36.2 | 5.2 | 34.5 |
| Upper-Bay | Northeast R. | 4.4 | 0.45 | 16,340 | 1,572 | 39.2 | 45.2 | 0.1 | 15.1 |

Table 4-2. Salinity classification and summary for subestuaries sampled in summer 2010.

| Area | Watershed | Salinity Classification | Mean Salinity | Minimum Salinity | Maximum Salinity |
|---|---|---|---|---|---|
| Mid-Bay | Corsica | Mesohaline | 7.5 | 4.4 | 9.7 |
| Mid-Bay | Tred Avon River | Mesohaline | 10.8 | 8.0 | 13.7 |
| Potomac | Nanjemoy | Mesohaline | 5.7 | 0.6 | 9.1 |
| Potomac | Wicomico | Mesohaline | 11.7 | 8.6 | 14.5 |
| Mid-Bay | Middle River | Oligohaline | 4.8 | 2.3 | 6.7 |
| Upper-Bay | Gunpowder River | Oligohaline | 2.1 | 0.6 | 4.9 |
| Potomac | Mattawoman Creek | Tidal Fresh | 0.9 | 0.5 | 1.3 |
| Potomac | Piscataway | Tidal Fresh | 0.1 | 0.1 | 0.2 |
| Upper-Bay | Bush River | Tidal Fresh | 1.3 | 0.1 | 3.6 |
| Upper-Bay | Northeast | Tidal Fresh | 0.1 | 0.1 | 0.6 |

Table 4-3. Spawning, trophic, and residency categories assigned fish species Mattawoman Creek.

| Species | Spawning Location | Trophic characterization | Residency |
|---|---|---|---|
| ALEWIFE | Anadromous | Planktivore | Nonresident |
| AMERICAN EEL | Marine | Benthivores | Nonresident |
| AMERICAN SHAD | Anadromous | Planktivore | Nonresident |
| ATLANTIC CROAKER | Marine | Benthivores | Nonresident |
| ATLANTIC MENHADEN | Marine | Planktivore | Nonresident |
| ATLANTIC NEEDLEFISH | Marine | Carnivores | Nonresident |
| ATLANTIC SILVERSIDE | Estuarine | Planktivore | Resident |
| BANDED KILLIFISH | Freshwater | Planktivore | Resident |
| BAY ANCHOVY | Estuarine | Planktivore | Resident |
| BLACK CRAPPIE | Freshwater | Carnivores | Resident |
| BLACKNOSE DACE | Freshwater | Planktivore | Resident |
| BLUE CATFISH | Freshwater | Benthivores | Nonresident |
| BLUEBACK HERRING | Anadromous | Planktivore | Nonresident |
| BLUEFISH | Marine | Carnivores | Nonresident |
| BLUEGILL | Freshwater | Planktivore | Resident |
| BLUESPOTTED SUNFISH | Freshwater | Planktivore | Resident |
| BROWN BULLHEAD | Freshwater | Benthivores | Resident |
| CARP | Freshwater | Benthivores | Resident |
| CARPIODES | Freshwater | Benthivores | Resident |
| CHAIN PICKEREL | Freshwater | Carnivores | Resident |
| CHANNEL CATFISH | Freshwater | Benthivores | Resident |
| CREEK CHUBSUCKER | Freshwater | Benthivores | Resident |
| GIZZARD SHAD | Freshwater | Planktivore | Resident |
| GOLDEN SHINER | Freshwater | Planktivore | Resident |
| GOLDFISH | Freshwater | Benthivores | Resident |
| HICKORY SHAD | Anadromous | Planktivore | Nonresident |
| HOGCHOKER | Estuarine | Benthivores | Resident |
| INLAND SILVERSIDE | Freshwater | Planktivore | Resident |
| LARGEMOUTH BASS | Freshwater | Carnivores | Resident |
| LONGNOSE GAR | Freshwater | Carnivores | Resident |
| MOSQUITOFISH | Freshwater | Planktivore | Resident |
| MUMMICHOG | Estuarine | Planktivore | Resident |
| NAKED GOBY | Estuarine | Benthivores | Resident |

Table 4-3 (continued). Spawning, trophic, and residency categories assigned fish species Mattawoman Creek.

| | | | |
|---|---|---|---|
| NORTHERN PIPEFISH | Estuarine | Planktivore | Resident |
| PUMPKINSEED | Freshwater | Planktivore | Resident |
| QUILLBACK | Freshwater | Benthivores | Resident |
| RAINWATER KILLIFISH | Estuarine | Planktivore | Resident |
| REDBREAST SUNFISH | Freshwater | Planktivore | Resident |
| ROUGH SILVERSIDE | Estuarine | Planktivore | Resident |
| SATINFIN SHINER | Freshwater | Planktivore | Resident |
| SHORTHEAD REDHORSE | Freshwater | Planktivore | Resident |
| SILVERY MINNOW | Freshwater | Planktivore | Resident |
| SMALLMOUTH BASS | Freshwater | Carnivores | Resident |
| SPOT | Marine | Benthivores | Nonresident |
| SPOTTAIL SHINER | Freshwater | Planktivore | Resident |
| STRIPED ANCHOVY | Marine | Planktivore | Resident |
| STRIPED BASS | Anadromous | Carnivores | Nonresident |
| STRIPED KILLIFISH | Estuarine | Planktivore | Resident |
| SUMMER FLOUNDER | Marine | Carnivores | Nonresident |
| TESSELLATED DARTER | Freshwater | Benthivores | Resident |
| THREADFIN SHAD | Freshwater | Planktivore | Nonresident |
| WHITE CATFISH | Freshwater | Benthivores | Resident |
| WHITE CRAPPIE | Freshwater | Carnivores | Resident |
| WHITE PERCH | Anadromous | Carnivores | Nonresident |
| WHITE SUCKER | Freshwater | Benthivores | Resident |
| YELLOW BULLHEAD | Freshwater | Benthivores | Resident |
| YELLOW PERCH | Freshwater | Carnivores | Resident |

Table 4-4. Salinity category, subestuary, level of development (C / ha), , and percentage of bottom DO meaurements in the channel that did not meet threshold (3 mg/L) and target DO criteria during July-September, 2010.

| Salinity Calssification | Subestuary | C/ha | Bottom DO < 5.0 mg/L | BottomDO < 3.0 mg/L |
|---|---|---|---|---|
| Mesohaline | Corsica River | 0.241 | 31.2 | 12.5 |
| Mesohaline | Tred Avon River | 0.736 | 37.5 | 12.5 |
| Mesohaline | Nanjemoy Creek | 0.091 | 5.6 | 0.0 |
| Mesohaline | Wicomico River | 0.335 | 29.4 | 17.6 |
| Oligohaline | Gunpowder River | 0.774 | 0.0 | 0.0 |
| Oligohaline | Middle River | 3.310 | 13.0 | 0.0 |
| Tidal Fresh | Bush River | 1.463 | 12.5 | 0.0 |
| Tidal Fresh | Mattawoman Creek | 0.883 | 0.0 | 0.0 |
| Tidal Fresh | Northeast River | 0.450 | 0.0 | 0.0 |
| Tidal Fresh | Piscataway Creek | 1.433 | 0.0 | 0.0 |

Table 4-5. Seine catch summary and structures per hectare (C / ha) by river in 2010.

| River | Number of Stations Sampled | Number of Samples | Number of Species | Species Comprising 90% of Catch | C / ha | Total Catch | Number of Fish per Seine |
|---|---|---|---|---|---|---|---|
| Bush | 4 | 24 | 29 | white perch juvenile<br>gizzard shad<br>white perch adult<br>bay anchovy<br>Atlantic silverside<br>spottail shiner<br>spot | 1.46 | 10964 | 456.8 |
| Corsica | 3 | 21 | 21 | white perch adult<br>Atlantic menhaden<br>Atlantic silverside<br>mummichog<br>striped killifish<br>spot<br>spottail shiner | 0.24 | 2865 | 136.4 |
| Gunpowder | 4 | 24 | 29 | gizzard shad<br>white perch juvenile<br>Atlantic menhaden<br>banded killifish<br>white perch adult<br>Atlantic silverside<br>spottail shiner<br>bay anchovy | 0.77 | 9531 | 397.1 |
| Middle | 3 | 12 | 22 | white perch juvenile<br>pumpkinseed<br>white perch adult<br>gizzard shad<br>banded killifish<br>Atlantic silverside<br>spot<br>inland silverside | 3.31 | 2435 | 202.9 |
| Nanjemoy | 3 | 18 | 24 | white perch juvenile<br>white perch adult<br>Atlantic silverside<br>gizzard shad<br>spot<br>mummichog<br>bay anchovy<br>Atlantic menhaden | 0.09 | 2565 | 142.5 |
| Northeast | 4 | 24 | 28 | white perch juvenile<br>gizzard shad<br>blueback herring<br>pumpkinseed<br>white perch adult | 0.45 | 7960 | 331.7 |

Table 4-5 (continued). Seine catch summary and structures per hectare (C / ha) by river in 2010.

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| | | | | bay anchovy<br>spottail shiner | | | |
| Tred Avon | 4 | 24 | 21 | Atlantic menhaden<br>spot<br>Atlantic silverside<br>mummichog<br>striped killifish<br>white perch adult | 0.74 | 5268 | 219.5 |
| Wicomico | 4 | 27 | 20 | Atlantic silverside<br>white perch adult<br>mummichog<br>spot<br>bay anchovy<br>striped killifish<br>gizzard shad<br>white perch juvenile | 0.34 | 2143 | 79.4 |

Table 4-6. Trawl catch summary and structures per hectare (C / ha) by river in 2010.

| River | Numer of Stations Sampled | Number of Samples | Number of Species | Species Comprising 90% of Catch | C / ha | Total Catch | Number of Fish per Trawl |
|---|---|---|---|---|---|---|---|
| Bush | 3 | 18 | 16 | white perch juvenile<br>white perch adult<br>spot | 1.46 | 9281 | 515.6 |
| Corsica | 4 | 28 | 15 | spot<br>white perch adult<br>bay anchovy<br>white perch juvenile | 0.24 | 6212 | 221.8 |
| Gunpowder | 4 | 24 | 23 | bay anchovy<br>white perch juvenile<br>spot<br>white perch adult | 0.77 | 10208 | 425.3 |
| Mattawoman | 4 | 24 | 20 | white perch juvenile<br>spottail shiner<br>white perch adult<br>spot<br>bluegill<br>tessellated darter | 0.88 | 4070 | 169.6 |
| Middle | 4 | 24 | 20 | white perch juvenile<br>bay anchovy<br>spot<br>white perch adult<br>pumpkinseed | 3.31 | 8211 | 342.1 |
| Nanjemoy | 3 | 18 | 18 | white perch juvenile<br>bay anchovy<br>spot<br>white perch adult<br>blueback herring | 0.09 | 6008 | 333.8 |
| Northeast | 4 | 23 | 21 | white perch juvenile<br>white perch adult<br>brown bullhead<br>bay anchovy | 0.45 | 9655 | 419.8 |
| Piscataway | 3 | 18 | 21 | white perch juvenile<br>spottail shiner<br>tessellated darter | 1.43 | 9924 | 551.3 |
| Tred Avon | 4 | 24 | 17 | spot<br>bay anchovy | 0.74 | 9893 | 412.2 |
| Wicomico | 4 | 28 | 13 | spot<br>bay anchovy<br>white perch adult | 0.34 | 4751 | 169.7 |

Table 4-7. Correlation matrix for acreage of SAV, C / ha, mean bottom DO, and median chlorphyll a in Mattawoman Creek during 1989-2010. Sample sizes (N) less than 21 indicate missing observations.

| Variable | Statistic | Median Chl a | Mean DO | C / ha |
|---|---|---|---|---|
| SAV | r | -0.88 | -0.83 | 0.92 |
| | P | <0.0001 | <0.0001 | <0.0001 |
| | N | 19 | 19 | 18 |
| C / ha | r | -0.84 | -0.81 | |
| | P | <0.0001 | <0.0001 | |
| | N | 20 | 20 | |
| Mean DO | r | 0.64 | | |
| | P | 0.0018 | | |
| | N | 21 | | |

Table 4-8. Proportions of fish with anomalies in the trawl or seine and their standard deviation. Anomolies classified as "other" were excluded because of they likely represented damage from sampling gear. Bolded proportions were different from 0 based on 95% CI overlap.

| Species | Method | N | Proportion | SD |
|---|---|---|---|---|
| BROWN BULLHEAD | Trawl | 189 | **0.106** | 0.022 |
| STRIPED BASS | Trawl | 18 | 0.056 | 0.054 |
| PUMPKINSEED | Trawl | 176 | 0.017 | 0.010 |
| BLUEGILL | Trawl | 91 | 0.033 | 0.019 |
| WHITE PERCH | Trawl | 2,513 | **0.021** | 0.003 |
| SPOTTAIL SHINER | Trawl | 83 | 0.012 | 0.012 |
| HOGCHOKER | Trawl | 123 | 0.008 | 0.008 |
| BROWN BULLHEAD | Seine | 10 | 0.200 | 0.248 |
| CHANNEL CATFISH | Seine | 10 | 0.200 | 0.248 |
| YELLOW PERCH | Seine | 19 | 0.158 | 0.164 |
| ALEWIFE | Seine | 7 | 0.143 | 0.259 |
| WHITE CATFISH | Seine | 24 | 0.083 | 0.111 |
| SILVERY MINNOW | Seine | 49 | 0.041 | 0.055 |
| PUMPKINSEED | Seine | 318 | 0.022 | 0.016 |
| GIZZARD SHAD | Seine | 332 | 0.027 | 0.018 |
| STRIPED KILLIFISH | Seine | 114 | 0.026 | 0.029 |
| MUMMICHOG | Seine | 103 | 0.019 | 0.027 |
| WHITE PERCH | Seine | 1,247 | **0.014** | 0.006 |
| BANDED KILLIFISH | Seine | 53 | 0.019 | 0.037 |

Figure 4-1. Tributaries sampled by seining and trawling during summer, 2010.

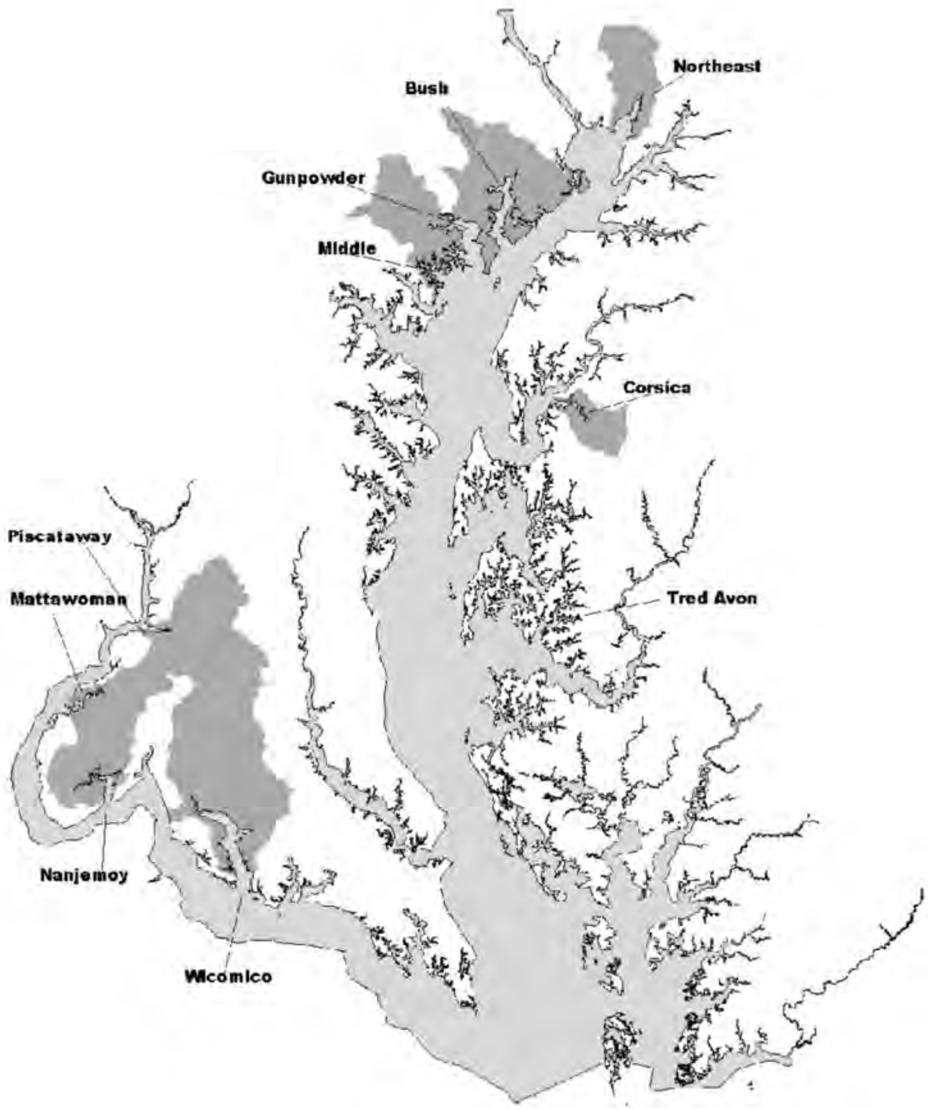


Figure 4-2. Trends in mean bottom DO, structures per hectare (housing density), and SAV acreage in Mattawoman Creek during 1989-2010.

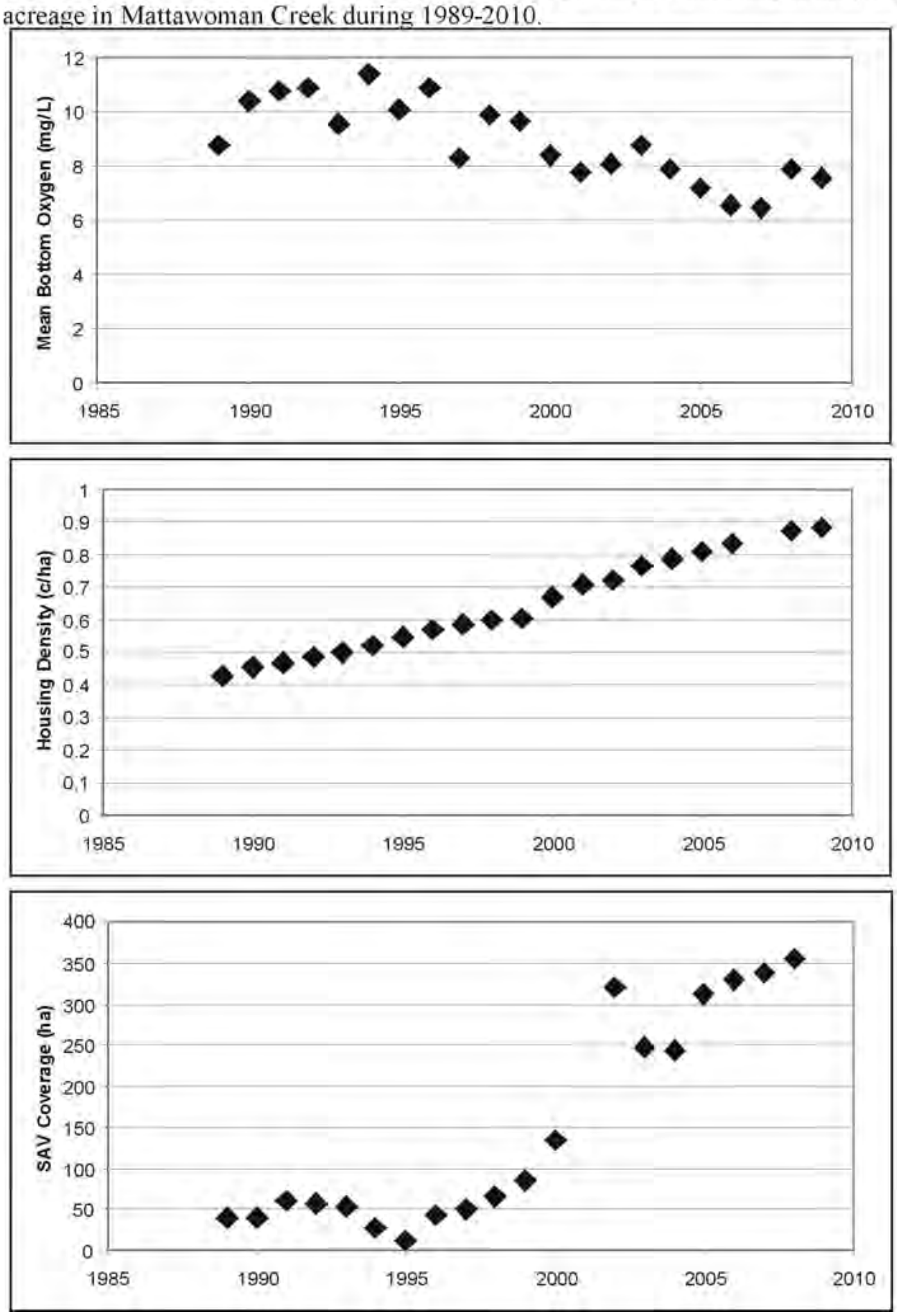


Figure 4-3. Trends in annual median Chlorophyll a in Mattawoman Creek during 1985-2010 at Chesapeake Bay Program monitoring station MAT106 (near the mouth).

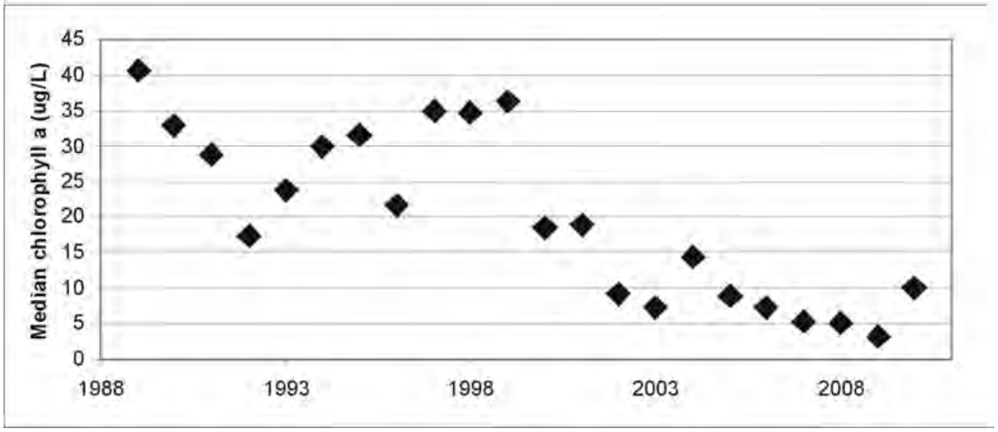


Figure 4-4 Proportion of positive trawls with resident or nonresident finfish based on 10 foot head rope trawl samples during 1989-1992 and 2009 and 2010.

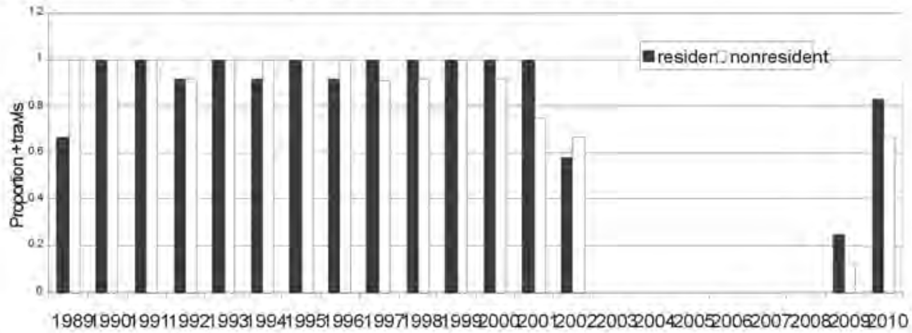



Figure 4-5. Proportion of positive trawls with finfish in a spawning guild based on 10 foot head rope trawl samples during 1989-1992 and 2009 and 2010.

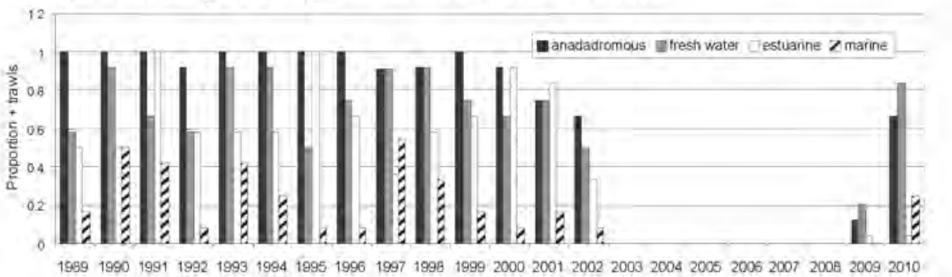



Figure 4-6. Proportion of positive trawls with finfish in a feeding guild based on 10 foot head rope trawl samples during 1989-1992 and 2009 and 2010.

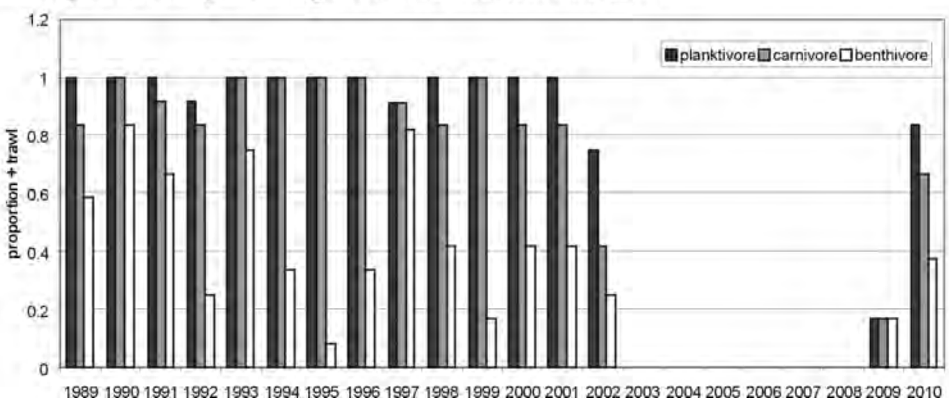


Figure 4-7. .Percentage of measurements of DO below the target (5 mg/L) at the Sweden Point continuous monitoring site located in a dense SAV bed.

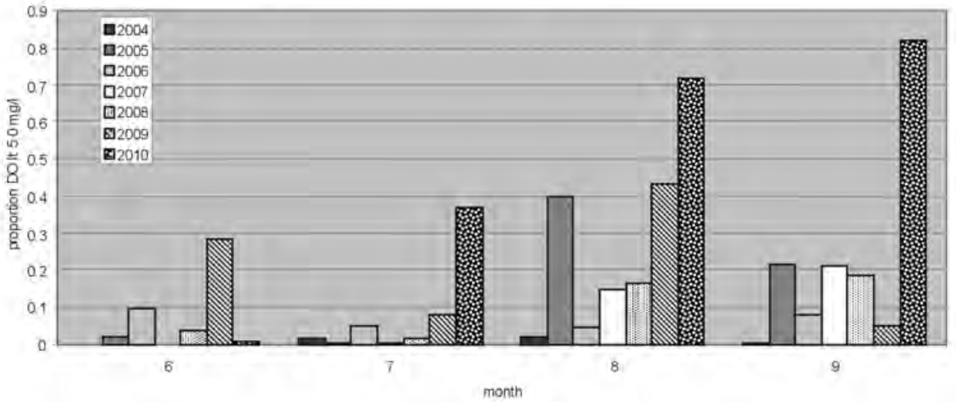



Figure 4-8. .Percentage of measurements of DO below the threshold (3 mg/L) at the Sweden Point continuous monitoring site located in a dense SAV bed.

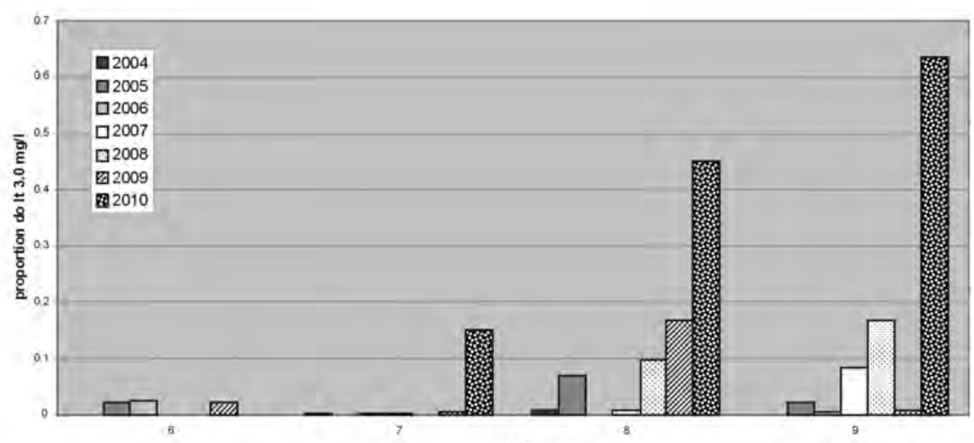


Figure 4-9. Proportion of bottom DO measurements falling below target (5 mg/L) and threshold (3 mg/L) levels in Tred Avon River during 2006-2010.

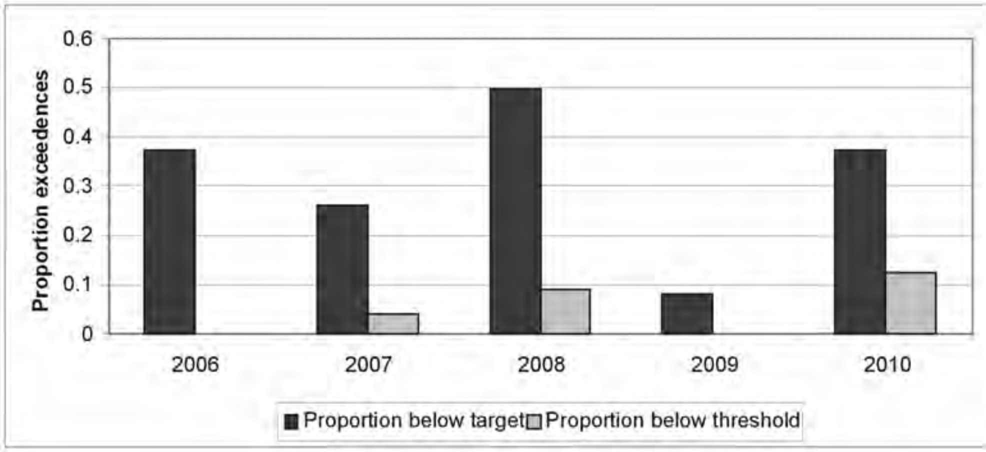



Figure 4-10. Proportion of trawls with each of the most frequently occurring species in Tred Avon River , 2006-2010.

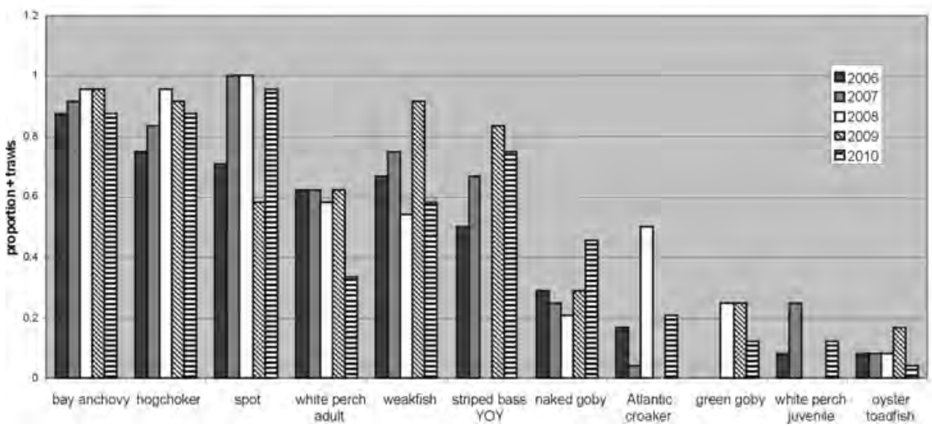
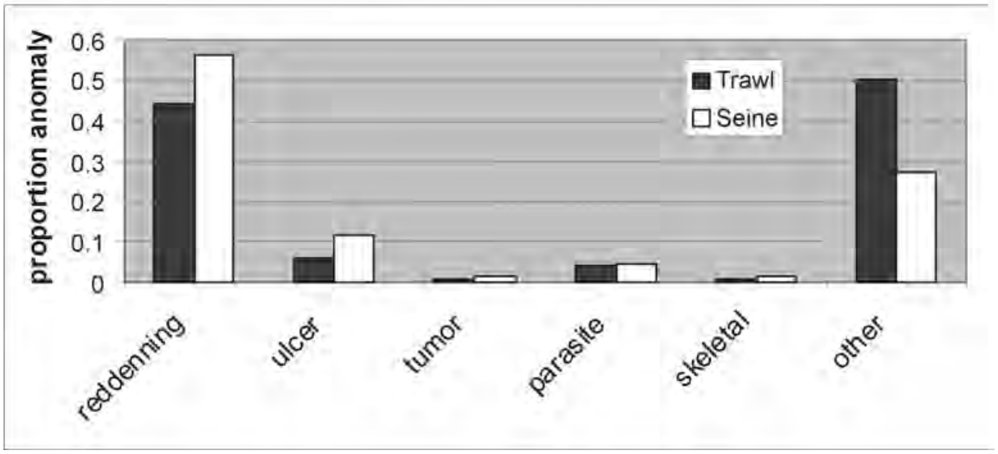


Figure 4-11. Proportion of anomalies by type in seine and trawls, 2010.



## References


Allen, L. 1982 Seasonal Abundance, Composition and Productivity of the littoral fish assemblage of the upper Newport Bay, California.1982. Fishery Bulletin: Vol 80, No. 4.

Arnold, C. L., and C. J. Gibbons. 1996. Impervious surface coverage: the emergence of a key environmental indicator. Journal of the American Planning Association 62:243-258.

ASMFC. 2009. Alewife. Available: http://www.asmfc.org/speciesDocuments/shad/alewifeHabitatFactsheet.pdf (December 2009).

ASMFC. 2009b. Blueback herring. Available: http://www.asmfc.org/speciesDocuments/shad/bluebackHabitatFactsheet.pdf (December 2009).

Barnes, K. B., J. M. Morgan III, M. C. Roberge, and Shannon Lowe Center for Geographic Information Sciences. 2002. Sprawl development: its patterns, consequences, and measurement. Towson University. Available: http://chesapeake.towson.edu/landscape/urbansprawl/download/Sprawl_white_paper.pdf (April 2008).

Batiuk, R. A., D. L. Breitburg, R. J. Diaz, T. M. Cronin, D. H. Secor, and G. Thursby. 2009. Derivation of habitat-specific dissolved oxygen criteria for Chesapeake Bay and its tidal tributaries. Journal of Experimental Marine Biology and Ecology 381:S204-S215.

Beach, D. 2002. Coastal sprawl: the effects of urban design on aquatic ecosystems in the United States. Pew Oceans Commission, Arlington, Virginia.

Beall, M. C. 2008. Response to Letter, dated June 27, 2005. Supporting information to the U. S. Army Corps of Engineers to accompany Charles County Planning & Growth/Cross County Connector?RD XING) 04-63344-19 application. Charles County Government, Planning and Growth Management, La Plata, Maryland.

Bonzek C., E. Houde, S. Giordano, R. Latour, T. Miller, and K. G. Sellner. 2007. Baywide and coordinated Chesapeake Bay fish stock monitoring. CRC Publication 07-163, Edgewater, MD, 70pp.

Brush, G. S. 2009. Historical land use, nitrogen, and coastal eutrophication: a paleoecological perspective. Estuaries and Coasts 32:18-28

Cappiella, K., and K. Brown. 2001. Impervious cover and land use in the Chesapeake Bay watershed. Center for Watershed Protection, Ellicott City, MD.

Caraco, N. R. and J. J. Cole. 2002. Contrasting impacts of a native and alien macrophyte on dissolved oxygen in a large river. Ecological Applications. 12:1496-1509.

Carlisle, D. M., D. M. Wolock, and M. R. Meador. 2010. Alteration of streamflow magnitudes and potential ecological consequences: a multiregional assessment. Frontiers in Ecology. Available: http://www.esajournals.org/doi/pdf/10.1890/100053 (January 2011).

Carmichael, J., M. Roberts, B. Richardson, and S. J. Jordan. 1992. Fish sampling in eight Chesapeake Bay tributaries. CBRM-HI-92-2, Maryland Department of Natural Resources, Annapolis.

Craig, L. S., and 12 coauthors. 2008. Stream restoration strategies for reducing river nitrogen loads. Frontiers in Ecology and the Environment, 6:529-538.

Cyrus, D.P. and Blaber, S.J.M. (1992) Turbidity and salinity in a tropical northern Australian estuary and their influence on fish distribution. Est. Coast. Shelf Sci. **35**: 545-563.

Dettmers, J. M., M. J. Raffenberg, and A. K. Weis. 2003. Exploring zooplankton changes in southern Lake Michigan: implications for yellow perch recruitment. Journal of Great Lakes Research 29:355-364.

Durell, E. Q., and C. Weedon. 2011. Striped bass seine survey juvenile index web page. Maryland Department of Natural Resources, Fisheries Service. Available: http://www.dnr.state.md.us/fisheries/juvindex/index.html (February 2011).

Elmore, A. J., and S.S. Kaushal. 2008. Disappearing headwaters: patterns of stream burial due to urbanization. Frontiers in Ecology 6:308-312.

ESRI. 2009. ArcView 9.3.1. Redlands, CA.

Fabrizio, M., and E. Martino. 2009. Striped bass species team background and issue briefs: early life history. Ecosystem Based Fisheries Management for Chesapeake Bay. http://www.mdsg.umd.edu/images/uploads/siteimages/Striped_Bass_Species_Team_Briefs.pdf (Available March, 2010).

Freund, R. J., and R. C. Littel. 2006. SAS system for regression, third edition. SAS Institute, Cary, NC.

Green, R. H. 1979. Sampling design and statistical methods for environmental biologists. John Wiley and Sons, New York.

Hall, L. W., S. A. Fischer, W. D. Killen, M. C. Ziegenfuss, R. D. Anderson, and R. J. Klauda. 1992. 1991 doser study in Maryland coastal plain: use of lime doser to mitigate stream acidification. Maryland Department of Natural Resources, CBRM-AD-93-6, Annapolis.

Hardy, J. D. 1978. Perca flavescens (Mitchill), Yellow perch. Development of Fishes of the Mid-Atlantic Bight: an Atlas of Egg, Larval and Juvenile Stages.Volume III. Aphredoderidae through Rachycentridae. U.S. Fish and Wildlife Service FWS/OBS-78/12.

Heath, M. R. 1992. Field investigations of the early life stages of marine fish. Pages 2-175 *in* J. H. S. Blaxter and A. J. Southward, editors. Advances in Marine Biology, Volume 28. Academic Press, New York.

Hoffman, J. C., D. A. Bronk, and J. E. Olney. 2007. Contribution of allochtonous carbon to American shad production in the Mattaponi River, Virginia, using stable isotopes. Estuaries and Coasts 30:1034-1048.

Holland, A. F., D. M. Sanger, C. P. Gawle, S. B. Lerberg, M. S. Santiago, G. H. M. Riekerk, L. E. Zimmerman, and G. I. Scott. 2004. Linkages between tidal creek ecosystems and the landscape and demographic attributes of their watersheds. Journal of Experimental Marine Biology and Ecology 298:151-178.

Holm, L., J. Doll, E. Holm, J. Pancho and J. Herberger. 1997. World Weeds: Natural Histories and Distribution. John Wiley and Sons, Inc. 605 Third Avenue, NY, NY.

Hopkins, T. E. and J. Cech. 1992. The Influence of Environmental Variables on the Distribution and Abundance of Three Elasmobranchs in Tomales Bay, California. Estuarine, Coastal and Shelf Science, Vol 35, Issue 6, 545-563.

Jarzynski, A., and R. Sadzinski. 2009. Stock assessment of adult and juvenile anadromous species in the Chesapeake Bay and select tributaries. Chesapeake Bay Finfish/Habitat Investigations 2008, Project 2. Maryland Department of Natural Resources, Annapolis, Maryland.

Kaushal, S. S., P. M. Groffman, P. M. Mayer, E. Striz, and A. J. Gold. 2008. Effects of stream restoration on denitrification in an urbanizing watershed. Ecological Applications 18:789-804.

Kemp, W. M., and 17 coauthors. 2005. Eutrophication of Chesapeake Bay: historical trends and ecological interactions. Marine Ecology Progress Series 303:1-29.

Kwak, T. J., and J. T. Peterson. 2007. Community indices, parameters, and comparisons. Pages 677-763 in C. S. Guy and M. L. Brown, editors. Analysis and interpretation of freshwater fisheries data. American Fisheries Society, Bethesda, Maryland.

Langeland, K.A. 1996. ***Hydrilla verticillata*** (L.F.) Royle (Hydrocharitaceae), "The Perfect Aquatic Weed". Castanea 61:293-304

Limburg, K.E. and R. E. Schmidt. 1990. Patterns of fish spawning in Hudson River tributaries: response to an urban gradient? Ecology 71:1238-1245.

Limburg and Waldman. 2009. Dramatic declines in north Atlantic diadromous fishes. BioScience 59: 955–965.

Lippson, A. J., and R. L. Moran. 1974. Manual for identification of early developmental stages of fishes of the Potomac River Estuary. Maryland Department of Natural Resources, PPSP-MP-13, Annapolis, Maryland.

Mangel, M. and P.E. Smith. 1990. Presence-absence sampling for fisheries management. Canadian Journal of Fisheries and Aquatic Science 47:1875-1887.

Martin, F. D., D. A. Wright, J. C. Means, and E. M. Setzler-Hamilton. 1985. Importance of food supply to nutritional state of larval striped bass in the Potomac River Estuary. Transactions of the American Fisheries Society 114:137-145.

MD DNR or Maryland Department of Natural Resources. 1999. Maryland's Surf Your Watershed. Available: http://www.dnr.state.md.us/watersheds/surf/ (March 2011).

Maryland Department of Planning. 2010. Welcome to MDP's Property Map and Data Products. Available http://planning.maryland.gov/OurProducts/PropertyMapProducts/PropertyMapProducts.shtml. (January 2010).

McClain, M. E. and eleven coauthors. 2003. Biogeochemical hot spots and hot moments at the interface of terrestrial and aquatic ecosystems. Ecosystems 6:301-312.

Miranda, L.E., M. P. Driscoll, and M. S. Allen. 2000. Transient physicochemical microhabitats facilitate fish survival in inhospitable aquatic plant stands. Freshwater Biology 44:617-628

McGinty, M. 2006. Larval Fish Sampling in the Bush River, 2006. Final Report to Chesapeake Bay National Estuarine Research Reserve. Maryland Department of Natural Resources. Annapolis, Maryland.

McGinty, M., J. Uphoff, R. Lukacovic, J. Mowrer, and B. Pyle. 2009. Development of habitat based reference points for Chesapeake Bay fishes of special concern: impervious surface as a test case. Chesapeake Bay Finfish/Habitat Investigations 2008, Project 3. Maryland Department of Natural Resources, Annapolis, Maryland.

Morgan, R. P., K. M. Kline, and S. F. Cushman. 2007. Relationships among nutrients, chloride and biological indices in urban Maryland streams. Urban Ecosystems 10:153-166.

Mowrer and McGinty 2002. Anadromous and estuarine finfish spawning locations in Maryland. Fisheries Service Technical Report Number 42. Maryland Department of Natural Resources, Annapolis.

National Research Council or NRC. 2009. Urban stormwater management in the United States. National Academies Press, Washington, D.C.

O'Dell, C. J., J. P. Gabor, J. P. Mowrer, K. Tutwiler, R. Klien, and F. Ryan. 1970. Stream improvement program for anadromous fish management. NMFS Completion Report AFC-3. Maryland Department of Game and Inland Fish, Annapolis.

O'Dell, C. J., J. Gabor, and R. Dintamin. 1975. Survey of anadromous fish spawning areas: Potomac River and upper Chesapeake Bay drainage. Completion Report, Project AFC-8, Maryland Department of Natural Resources, Annapolis.

O'Dell, C. J., J. Mowrer, and J. Gabor. 1980. Survey and inventory of anadromous fish spawning areas: Chester River and west Chesapeake Bay drainage. Completion Report, Project AFC-9, Maryland Department of Natural Resources, Annapolis.

O'Dell, C.J. 1987. Status of yellow perch (*Perca flavescens*) in Maryland, 1987: a situation paper on the biology, distribution, stocks, and fisheries of yellow perch with suggested study needs and management actions. Maryland Department of Natural Resources, Annapolis, Maryland.

Ott, L. 1977. An introduction to statistical methods and data analysis. Duxbury Press. North Scituate, Massachusetts

Pardue, G. B. 1983. Habitat suitability index models: alewife and blueback herring. U.S. Fish and Wildlife Service. Available: http://www.nwrc.usgs.gov/wdb/pub/hsi/hsi-058.pdf (January 2011).

Paul, M. J., and J. L. Meyer. 2001. Streams in the urban landscape. Annual Reviews in Ecology, Evolution, and Systematics 32:333-365.

Piavis, P.G. 1991. Yellow perch *Perca flavescens*. Pages 14.1 – 14.15 *in* S.L. Funderburk, S.J. Jordan, J.A. Mihursky, and D. Riley, editors. Habitat requirements for Chesapeake Bay living resources, 2nd edition. Chesapeake Bay Program, Living Resources Subcommittee, Annapolis, Maryland.

Piavis, P. G., and E. Webb. 2009. Population vital rates of resident finfish in selected tidal areas of Maryland's Chesapeake Bay. Chesapeake Bay Finfish/Habitat Investigations 2008, Project 1. Maryland Department of Natural Resources, Annapolis, Maryland.

Poff, N. L., B. P. Bledsoe, and C. O. Cuhaciyan. 2006. Hydrologic variation with land use across the contiguous United States: geomorphic and ecological consequences for stream ecosystems. Geomorphology 79:264-285.

Ricker, W. E. 1975. Computation and interpretation of biological statistics of fish populations.Fisheries Research Board of Canada Bulletin 191.

Rogers, B. A., and D. T. Westin. 1981. Laboratory studies on effects of temperature and delayed initial feeding on development of striped bass larvae.

SAS Institute. 1995. Logistic regression examples using the SAS System. Version 6, first edition. Cary, North Carolina.

Simberloff, D., D. C. Schmitz, and T. C. Brown (editors). 1997. Strangers in Paradise: Impact and Management of Nonindigenous Species in Florida. Island Press, Washington, D. C.

Sisenwine, M.P., and J. G. Shepherd. 1987. An alternative perspective on recruitment overfishing and biological reference points. Canadian Journal of Fisheries and Aquatic Sciences 44:913-918.

State Water Control Board, 2011. 9 VAC 25-260 Virginia Water Quality Standars. Statuatory Authority: : § 62.1-44.15 3a of the Code of Virginia.

Uphoff, J.H. 1991. Early life history and recruitment of yellow perch in the Choptank River, Maryland 1980-1985. Maryland Department of Natural Resources, Technical Memorandum CBRM-HI-91-1, Annapolis, Maryland.

Uphoff, J. H. 1997. Using egg presence-absence to derive probability based management criteria for upper Chesapeake Bay striped bass. North American Journal of Fisheries Management 17:663-676.

Uphoff, J., M. McGinty, B. Richardson, P. Piavis, H. Speir, and M.F. Topolski. 2005. Interim assessment of yellow perch *Perca flavescens* habitat and population dynamics in Severn River, a suburbanized Chesapeake Bay sub-estuary. Fisheries Tech. Rep. Series, Number 46. Maryland Department of Natural Resources, Fisheries Service, Stevensville, MD.

Uphoff, J., M. McGinty, R. Lukacovic, J. Mowrer, and B. Pyle. 2007. Development of habitat based reference points for Chesapeake Bay fishes of special concern: impervious surface as a test case. Chesapeake Bay Finfish/Habitat Investigations 2006, F-61-R-1, Project 3. Maryland Department of Natural Resources, Annapolis, Maryland.

Uphoff, J., M. McGinty, R. Lukacovic, J. Mowrer, and B. Pyle. 2008. Development of habitat based reference points for Chesapeake Bay fishes of special concern: impervious surface as a test case. Chesapeake Bay Finfish/Habitat Investigations 2007, Project 3. Maryland Department of Natural Resources, Annapolis, Maryland.

Uphoff, J., M. McGinty, R. Lukacovic, J. Mowrer, and B. Pyle. 2010. Development of habitat based reference points for Chesapeake Bay fishes of special concern: impervious surface as a test case. Chesapeake Bay Finfish/Habitat Investigations 2009, Project 3. Maryland Department of Natural Resources, Annapolis, Maryland.

Uphoff, J. H., M. McGinty, R. Lukacovic, J. Mowrer, and B.Pyle. In press. Impervious surface, summer dissolved oxygen, and fish distribution in Chesapeake subestuaries: linking watershed development, habitat conditions, and fisheries management. North American Journal of Fisheries Management.

U.S. Army Corps of Engineers. 2003. Mattawoman Creek Watershed Management Plan. Baltimore District, Maryland.

Wade, T. and S. Sommer (Eds.). 2006. A to Z GIS. Redlands, CA: ESRI Press.

Wang, X., and Z. Yin. 1997. Using GIS to assess the relationship between land use and water quality at a watershed level. Environmental International 23:103-114.

Wheeler, A. P., P. L. Angermeier, and A. E. Rosenberger. 2005. Impacts of new highways and subsequent landscape urbanization on stream habitat and biota. Reviews in Fisheries Science 13:141-164.

Wright, R. E., 1998. Logistic Regression. Pages 217-244 *in* L. G. Grimm and P. R.Yarnold, editors. Reading and Understanding Multivariate Statistics. American Psychological Association, Washington, D.C.

Yellow perch workgroup. 2002. Maryland tidewater yellow perch fishery management plan. Maryland Department of Natural Resources, Annapolis, Maryland.

**Job 2: Environmental Review Support for Estuarine and Marine Habitat**

Bob Sadzinski

## Introduction

Environmental review and planning represents the “frontline” of habitat management. The direct link between land-use, ecological condition of downstream receiving water and environmental review provides the opportunity to mitigate the impacts of land-based projects on aquatic resources through the permitting process.

The Task Force for Fishery Management recognized that Maryland Department of Natural Resources’ (DNR’s) Environmental Review (ER) Program was critically understaffed (Task Force on Fisheries Management 2008). An Integrated ER Team was created by assigning personnel from various units throughout DNR to address this critical staffing shortfall. Fisheries Service has provided one reviewer and an advisor who provides additional expertise to project review topics as well as guidance in setting ER policy for the Department. The activities of these positions are funded through this federal aid grant: ER activities were entirely funded under Job 2, while advisory and support activities were also covered under Jobs 1 and 3.

The ER unit has been charged by the Secretary of Natural Resources with both conducting routine reviews and taking a lead role in proactively using habitat criteria in project review activities. Routine reviews may be streamlined by developing habitat criteria for triage, such as impervious surface reference points and greater application of GIS technology.

The purpose of environmental review is to work proactively with partners (other DNR agencies, Maryland’s Department of Environment and Department of Planning, local governments, and federal agencies) to protect key habitats and ecosystem functions and limit environmental impacts while making better natural resource data available to agencies at the state, county and local levels. Environmental review must identify the natural resources potentially impacted, assess the extent of the impacts on resources, review for regulatory requirements, and as applicable, identify and attempt conflict resolutions. The review agency is responsible for providing comments based on potential impacts of the project on the resources of concern to that agency and recommends avoiding, minimizing or mitigating project impacts as appropriate.

## Major Activities in 2010

DNR assigned two staff as the primary environmental reviewer and planner (Bob Sadzinki) and the other as the liaison for the Fisheries Service (Jim Uphoff). For the environmental reviewer and planner, duties included estuarine and marine environmental reviews for Charles, St. Mary’s and Calvert counties for and all statewide landfill, reef and aquaculture applications. Table 1 present an overview of the number of projects by permit type. In summary, 194 applications were reviewed, many of which required significant DNR coordination. The Fisheries Service liaison served as the “clearinghouse” for environmental review applications that require input from Fisheries Service programs.

In addition, the environmental reviewer/planner served as an advisor for programs including Smart Growth, Green Infrastructure, Blue Infrastructure, BayStat/StateStat, and Plan Maryland. We cooperated and coordinated the various landscape-based DNR habitat initiatives and utilized information developed by these programs. These programs were responsible for

- providing multi-disciplinary information to key partners;
- codifying regulatory standards for water quality, especially for the key quantitative parameters that define limits of acceptable habitat quality for important species;
- identifying and prioritizing high quality aquatic habitats for protection; and
- developing key stream management strategies and comprehensible living shorelines, climate change and comprehensive plan policies.

One of the most significant project developments was the streamlining of the oyster aquaculture review. This process enables the applicant to work cooperatively with DNR oyster personnel prior to the application submittal process to select potential oyster aquaculture sites that meet criteria including absence of submerged aquatic vegetation and minimum boating and recreational fishing activities and has resulted in decreased applicant waiting period and improved public relations. In addition, several of the applications were in important recreational fishing areas and we strongly supported maintaining or improving fishing access through minimizing sedimentation and surface runoff from these sites.

Potential future projects include developing a framework to enhance sound coastal and marine resource conservation, management and restoration by

- Completing detailed spatial assessments of coastal habitat, critical natural resources, and associated human uses
- Identification and prioritization of areas containing concentrations of sensitive aquatic habitats and resources and
- Continue to restructure the current GIS system to include additional pertinent data layers including aquatic bottom types and navigational channels.

Table 1. Overview of the number of projects by application type.

Formatted Table

| Application Type | Number of Projects Reviewed |
|---|---|
| Landfill | 18 |
| Aquaculture | 24 |
| Reef | 1 |
| County - Specific | 151 |
| Total | 194 |

## Job 3: Support multi-agency efforts to assess and delineate interjurisdictional finfish habitat and ecosystems.

Jim Uphoff

### Introduction

The objective of Job 3 was to document participation of the Habitat and Ecosystem Interactions Program in habitat, multispecies, and ecosystem-based management approaches important to recreationally important finfish in Maryland's Chesapeake Bay and Atlantic coast. Contributions to various research and management forums by Program staff through data collection and compilation, analysis, and expertise are vital if Maryland is to successfully develop an ecosystem approach to fisheries management. .

### DNR Interagency Effort on Mattawoman Creek

Our program has partnered with multiple DNR agencies to conserve Mattawoman Creek's recreational fisheries and fish habitat. This effort provides a test -bed for development of interagency connections needed for watershed-based protection of fish habitat. The permitting process for a road crossing this watershed has provided the entryway into a broader effort to address comprehensive zoning plans to develop Mattawoman Creek's watershed. We have supplied vital information on aquatic resources in Mattawoman Creek's watershed from our federal aid monitoring and analysis. This information has been presented to DNR's Environmental Review Unit, Secretaries of DNR and Maryland's Department of Environment (MDE). Subsequent meetings on development in this watershed have been held with the Maryland Department of Planning, MDE, and DNR.

### Maryland Fisheries Service Priority Mapping

The goal of this effort is to identify priority fish habitat and fishing locations in Maryland for preservation, restoration and enhancement by developing digitized maps representing important fish species habitats and recreational fishing locations. DNR and other agencies rely on maps that are mostly focused on biodiversity to prioritize areas for land purchases, guide development and review environmental impact of development. Maps based on biodiversity may not always cover Fisheries Service's interests. Fisheries priority maps will represent Fisheries Service's priorities for preserving, restoring and enhancing fisheries resources in a GIS format compatible with other DNR agencies. We are working with regional and species biologists to obtain data, define habitat and fishing locations, and assign rankings to the habitat. We will then overlay these individual species maps to develop priority maps. All data and expert knowledge will be referenced for these locations.

### Striped Bass Habitat and Hypoxia

Our program is collaborating with DNR's striped bass program and NOAA's Cooperative Oxford Laboratory to evaluate the impact of hypoxia on striped bass distribution by comparing locations of past and present tagging recaptures within Chesapeake Bay during summer. Historical tagging records (late 1950s- early 1960s) that were in notebooks have been entered into a data base to compare to USFWS tagging data 1984 to present. Both GIS and statistical approaches will be used. NOAA at Oxford Lab will provide summer hypoxia / oxygen distributions. Upper and mid-Bay habitat occupied by most tagged striped bass in summer during the 1950s and 1960s is now considerably more hypoxic than it was at that time and the extent that movement to this area has been maintained is unknown. USFWS tagging data may allow us to determine whether in-Bay migration patterns have changed.

**Maryland DNR Mapping**

Program staff supplied data layers of important fish habitats to DNR's Blue Infrastructure Project. The Blue Infrastructure (BI) Near-shore Assessment is a detailed spatial evaluation of coastal habitat, critical natural resources, and associated human uses in the tidal waters and near-shore area of Maryland's coastal zone. The near-shore assessment serves as a link between Maryland's terrestrial and aquatic environments and contributes to prioritization systems that help target Maryland's conservation and management activities to maintain and improve coastal habitats.

**Bill Reports**

Program staff helped prepare bill reports for DNR to submit to the Maryland General Assembly supporting improved management of road salt use and stormwater runoff. We reviewed the federal Chesapeake Bay Clean Water Act for Fisheries Service.

**Critical Areas Commission**

Program staff spent a day on the Choptank River striped bass spawning area with planning staff of the Maryland Critical Areas Commission explaining the importance of watershed conservation on fish habitat and fisheries. The Critical Areas Commission oversees the development and implementation of local land use programs on all land within 1,000 feet of e Chesapeake Bay and its tributaries to Minimize adverse impacts on water quality; conserve fish, wildlife, and plant habitat in the Critical Area; and establish land use policies for development.

**Integrated Assessment (IA)**

We are collaborators with NOAA's Integrated Assessment project operated out of the Cooperative Oxford Laboratory (COL). The intent of the project is to develop indicators of ecological health for Chesapeake Bay. Fish are a significant component of the study. The IA samples Corsica, West, Magothy, and Middle Rivers and Nanjemoy Creek quarterly. Fish sampling is based on sites sampled by our program in the past or currently. We supplied training, manpower, and data to the IA.

**Assessment of Stressors at the Land-Water Interface**

We are collaborators with this effort to understand effects of shoreline modification on fish and other macrofauna in shallow water habitat in Chesapeake Bay and Delmava's coastal bays. This is a NOAA funded project consisting of eight institutions lead by the Smithsonian Environmental Research Center. We have supplied advice on sampling locations, techniques, and products needed for management.

**Chesapeake Bay Program Ecosystem Based Fisheries Management**

Maryland Sea Grant, in coordination with state and federal agency partners and research institutions, has developed and coordinated the Ecosystem-Based Fisheries Management (EBFM) Project for Chesapeake Bay since January, 2008. This project implements a new technical and scientific foundation for EBFM and moves beyond traditional single species management to consider the interconnections between species, their physical and living environments, and human influences. Jim Uphoff is a member of the Fisheries Ecosystem Workgroup as Chair of the Striped Bass Team and is also a member of the Food Web Team. Margaret McGinty is a member of the habitat Suitability Team. Information developed by our federal aid project has been incorporated into EBFM briefing documents for striped bass and Atlantic menhaden (available through the Maryland Sea Grant website http://www.mdsg.umd.edu/programs/policy/ebfm/ ).

**FERC Relicensing of Conowingo Dam**

Jim Uphoff was a member of a FERC panel evaluating a dispute between MD and PA resource agencies and Exelon Power Company over relicensing of Conowingo Dam. Management of flow for fish habitat was one of the main considerations. Unfortunately, FERC regulations emphasize power generation and are not required to consider restoration of natural flow regimes.

**North American Journal of Fisheries Management (NAJFM) Article**

We have an article, Impervious Surface, Summer Dissolved Oxygen, and Fish *Distribution in Chesapeake Bay Subestuaries: Linking Watershed Development, Habitat Conditions, and Fisheries Management*, accepted by NAJFM for publication pending revision. This manuscript is based on our federal aid activities during 2003-2005.

**ASMFC Multispecies Technical Committee**

Biomass reference points for Atlantic menhaden that accounted for predatory demand of bluefish, weakfish, and striped bass were developed from the existing menhaden stock assessment. These reference points were forwarded to the ASMFC Menhaden Technical Committee for consideration.

**Striped Bass Food Habit Database**

We have entered food habit data for striped bass from the Chesapeake Bay area collected by volunteers from the Chesapeake Bay Ecological Foundation. Over 7,000 striped bass have been sampled since 2006, mostly at fish cleaning stations and largely by one individual (James Price). These data have been applied to the ASMFC Multispecies Virtual Population Analysis and are available for any request.