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MARINE AND ESTUARINE FINFISH ECOLOGICAL AND HABITAT INVESTIGATIONS

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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.

Throughout the report, multiple references to past annual report analyses are referred to and are interrelated to current data throughout this report. The complete PDF versions of past annual reports can be found under the Publications and Report link on the Fisheries Habitat and Ecosystem (FHEP) website page on the Maryland DNR website. The website address is http://www.dnr.maryland.gov/fisheries/fhep/.

Table of Abbreviations

°C	Celsius, temperature
α	Level of significance
μ (micron)	micrometer or one millionth of a meter
μg/L	Micrograms per liter
μmho/cm or μS/cm	Conductivity measurement as micromhos per centimeter or micro-Siemens per centimeter.
A	Area
A/ha	Structure area per hectare
ASMFC	Atlantic States Marine Fisheries Commission
BI	Blue Infrastructure
BRP	Biological reference point
C	Structures in a watershed
C/ha	Structure counts per hectare
CAD	Computer Aided Design
CBP	Chesapeake Bay Program
cfs	Cubic feet per second, measurement of flow volume
CI	Confidence Interval
COL	Cooperative Oxford Laboratory, NOAA
CPE	Catch per effort
CV	Flow coefficient of variation
DO	Dissolved oxygen
EBFM	Ecosystem-Based Fisheries Management
ER	Environmental Review Program in MD DNR
ESRI	Environmental Systems Research Institute
FERC	Federally Energy Regulatory Commission
FIBI	Fish Index of Biological Integrity (see reference Morgan et al. 2007)
GIS	Geographic Information System
gm	Gram
ha	Hectares
hr	Hour
P_i	Proportion of samples with target species *i*
IA	Impervious surface area estimated in the watershed
in	Inches
IS	Impervious surface
ISRPs	Impervious surface reference points
km	Kilometer
km²	Square kilometers
L_P	Proportion of Tows with yellow perch larvae during a standard time period and where larvae would be expected
M	Median flow
m	Meter
Max	Maximum

MD DNR	Maryland Department of Natural Resources
MDE	Maryland Department of Environment
MDP	Maryland Department of Planning
mg/L	Milligrams per liter
Min	Minimum
mm	Millimeter
MT	Metric ton
$N_{present}$	Number of samples with herring eggs and-or larvae present
N_{total}	Total sample size
N	Sample size
NAD	North American Datum
NAJFM	North American Journal of Fisheries Management
N_i	Number of samples containing target species
NOAA	National Oceanic and Atmospheric Administration
NRC	National Research Council
OM	Organic matter
P_{herr}	Proportion of samples where herring eggs and-or larvae were present
P_i	Proportion of samples with a target species
pH	Power of hydrogen, acidity and basicity measurement
ppt or ‰	Parts per thousand, salinity measurement unit
QA	Quality assurance
r	Correlation coefficient, statistical measurement
RKM	River kilometer
SAS	Statistical Analysis System
SAV	Submerged aquatic vegetation
SD	Standard deviation
SE	Standard error
TA	Estimate of total area of the watershed
TEA	Tidal Ecosystem Assessment Division in MD DNR
TL	Total length
USACOE	United States Army Corps of Engineers
USFWS	United States Fish and Wildlife Service
USGS	United States of Geological Services
V_{target}	Percentage of DO measurements that met or fell below the 5 mg/L target
$V_{threshold}$	Percentage of DO measurements that fell at or below the 3 mg/L threshold

Definitions

Aggradation	To fill and raise the level of a stream bed by the deposition of sediment.
Alosines	American shad, hickory shad, blueback herring, and alewife are Alosines, which belong to the herring family, Clupeidae.
Anadromous Fish (Spawning)	Fish, such as shad, herring, white perch, and yellow perch, ascend rivers from the Chesapeake Bay or ocean for spawning.
Anomalies	Anomalies on fish can be external or internal and consist of growths, lesions, wounds, parasites, and additional physical abnormalities. Anomalies can be caused by natural or human caused activities.
Benthivores	Animals that feed on bottom dwelling prey.
Brackish Water	Water that has more salinity than freshwater. The salinity of brackish water is between 0.5 – 30 ppt.
Coastal Plain	An area underlain by a wedge of unconsolidated sediments including gravel, sand, silt and clay and is located in the eastern part of Maryland, which includes the Chesapeake Bay's eastern and western shores, up to the fall line roughly represented by U.S. Route 1.
Development	Refers to land used for buildings and roads.
Estuary	A body of water in between freshwater and the ocean; an estuary can be subject to both river and ocean influences, such as freshwater, tides, waves, sediment, and saline water.
Estuarine Spawners	Fish species, such as striped bass and the bay anchovy, spawn in the fresh-saltwater interface of the estuary where there is a salinity gradient and have the ability to exhibit cyclic movement during development.
Finfish	Referring to two or more species of fish and excludes shellfish.

Floodplain	Refers to land that is adjacent to a stream or river that experiences flooding during periods of high flow.
Fluvial	Of or pertaining to rivers.
Fresh-Tidal Sub estuary	An area containing mainly freshwater with salinity less than 0.5 ppt, but tidal pulses may bring higher salinity.
Hypoxia	Occurrence of low oxygen conditions.
Icthyoplankton	Refers to the eggs and larvae of fish.
Impervious surface (IS)	Hard surfaces that are not penetrated by water such as pavement, rooftops, and compacted soils.
Mesohaline	A region within an estuary with a salinity range between 5 and 18 ppt.
Non-Tidal Waters (Stream)	Areas that are not influenced by tides.
Oligohaline Sub estuary	A brackish region of an estuary with a salinity range between 0.5 and 5 ppt.
Piedmont	A plateau region located in the eastern United States and is made up of low, rolling hills that contain clay-like and moderately fertile soils.
Planktivores	Animals that feed primarily on plankton (organisms that float within the water column).
Richness	The number of different species represented in a collection of individuals.
Riparian zone	The area between land and a river and/or stream, also known as a river bank.
Rural	Referring to areas undeveloped such as farmland, forests, wetlands and areas with low densities of buildings.
Stock Assessments	Assessments of fish populations (stocks); studies of population dynamics (abundance, growth, recruitment, mortality, and fishing morality).
Stock Level	Refers to the number or population weight (biomass) of fish within a population.

Subestuary — A smaller system within a larger estuary such as a branching creek or tributary within the estuary.

Suburb — An area that has mostly residential development located outside of city or town boundaries.

Threshold — A breaking point of an ecosystem and when pressures become extreme can produce abrupt ecological changes.

Tidal Waters — Waters influenced by tides.

Urban — A developed area characterized by high population, building, and road densities; may be considered a city or town.

Urbanization — Process of conversion of rural land to developed land.

Watershed — Defines a region where all of the water on and under the land drains into the same body of water.

Wetlands — An area of ground that is saturated with water either permanently or seasonally; they have unique vegetation and soil conditions and can either be saltwater, freshwater, or brackish depending on location.

Zooplankton — Animals that drift within the water column; these animals are typically very small, but may be large (jellyfish and comb jellies).

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, Bruce Pyle, Marek Topolski, Alexis Maple, and Justin Falls

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. An equation was developed using nonlinear regression to convert annual estimates of C / ha to estimates of impervious surface (IS) calculated by Towson University from 1999-2000 satellite imagery and estimate levels of C / ha that were equivalent to impervious surface reference points in Sections 1-2 to 1-4. The relationship of C / ha and IS was well described by a non-linear power function as IS = 10.98 • (C / ha)$^{0.63}$, ($r^2 = 0.96$; $P < 0.0001$). Estimates of C / ha that were equivalent to 5% IS (target level of development for fisheries; a rural watershed), 10% IS (development threshold for a suburban watershed), and 15% IS (highly developed suburban watershed) were estimated as 0.27, 0.83, and 1.59 C / ha, respectively.

Stream Ichthyoplankton - During 2011, stream sites in Mattawoman Creek were sampled for eggs and larvae of anadromous herrings, white perch, and yellow perch (hereafter "anadromous fish") by citizen volunteers coordinated by program biologists. Volunteers had also recently sampled Mattawoman Creek (2008-2010), Piscataway Creek (2008-2009), and Bush River (2005-2008) and results from these surveys were contrasted with each other and with surveys conducted by MD DNR in the early 1970s.

Bush River, Piscataway Creek and Mattawoman Creek started at approximately 0.05 C / ha in 1950. In 2009, Bush River (without largely undeveloped Aberdeen Proving Grounds or APG) and Piscataway Creek were at substantially higher levels of development (≈1.40 C / ha, respectively) than Mattawoman Creek (0.88 C / ha). Occurrence of anadromous fish eggs and larvae at sites in fluvial Mattawoman Creek was less consistent during 2008-2011 than during 1971 (0.16 C / ha) and 1991 (~ 0.45 C / ha). Anadromous fish eggs and larvae were nearly absent from sites in fluvial Piscataway Creek during 2008-2009 (one occurrence during 2009), but were found at five stations during 1971 (0.48 C / ha). There was no obvious decline in site occurrence of herring eggs and larvae in the non-APG Bush River stations between 1973 (0.30 C / ha) and 2005-2008, but occurrences of white and yellow perch at sites were far less frequent. Sites in APG could not be sampled every year and this portion of the watershed was dropped from analysis.

Two issues should be considered when attempting to sort out differences between Piscataway Creek and Bush River indicators of herring spawning (occurrence at a site versus P_{herr}, the proportion of samples with herring eggs or larvae): the influence of physiographic province characteristics and statistical adequacy of the two indicators of spawning intensity.

Bush River is located in both the Coastal Plain and Piedmont physiographic provinces, while Piscataway Creek is located entirely within the Coastal Plain. The Piedmont is an area of higher gradient change and more diverse and larger substrates than the Coastal Plain. Processes such as flooding, riverbank erosion, and landslides vary in severity by province and differences in site occupation and P_{herr} between Piscataway Creek and Bush River may indicate somewhat greater resistance to degradation of herring spawning habitat in watersheds located partially in the Piedmont.

Our comparisons were based on the assumption that spawning sites detected in the 1970s were indicative of the extent of habitat; data were not available to formulate other metrics. This approach represented a presence-absence design with low power to detect population changes or conclude an absence of change since only a small number of sites (road crossings) could be sampled and the positive statistical effect of repeated visits was lost by summarizing all samples into a single record of site occupation. We assumed this distribution characterized years of low development. Annual distributions of spawning occurrence detected during the 2000s at higher levels of development were variable for herring in both Mattawoman Creek and Bush River and we interpreted this variability as a sign of habitat instability and declining spawning activity.

Proportion of samples with herring (P_{herr}) provided an alternative estimate based on encounter rate that was sufficiently precise based on 90% confidence interval overlap to categorize three levels of stream spawning: very low levels at or indistinguishable from zero; a low level of spawning that could be distinguished from zero, and a higher level of spawning that could be separated from the low levels. Correlation analyses indicated significant and logical associations among $P_{herr,}$ C / ha, and conductivity (conductivity was considered an indicator of urbanization) consistent with the hypothesis that urbanization was detrimental to stream spawning.

Estuarine Yellow Perch Larval Sampling - We examined hypotheses that development negatively influenced two processes that can be important for yellow perch year-class formation: egg-larval survival and larval feeding success. We converted IS targets and thresholds for summer habitat of juvenile and adult finfish to C / ha equivalents and evaluated how well they applied to the proportion of samples with yellow perch during 1998-2011.

Presence-absence sampling for yellow perch larvae was conducted in the upper tidal reaches of the Nanticoke, Northeast, Elk, Bush, and Severn rivers and Mattawoman, Nanjemoy, and Piscataway creeks during late March through April, 2011. Annual L_p (proportion of tows with yellow perch larvae during a standard time period and where larvae would be expected) provided an economical measure of the product of egg production and egg through early postlarval survival. We used L_p as an index to detect "normal and abnormal" egg through early larval dynamics. We considered L_p estimates from subestuaries that were persistently lower than those measured elsewhere since 1998 indicative of abnormally low survival. Remaining levels were considered normal.

We collected composite samples of early feeding larvae from several sites on Piscataway, Mattawoman, and Nanjemoy creeks, and the Elk and Northeast rivers during several sample trips and examined them for gut contents. Gut fullness was assigned a rank between 0 = empty and 4 = full. Major food items were classified as copepods, cladocerans, or other and their presence or absence was noted. A total of 332 larval guts were examined during 2010 and 532 were examined in 2011.

Development was an important influence on yellow perch larval dynamics and negative changes in these dynamics generally conformed to target and threshold guidelines for development. Once development exceeded the suburban threshold level (0.83 C / ha or 10% IS) and increased towards a more developed suburban landscape (1.59 C / ha or 15% IS), declines in L_p and feeding success became evident. Estimates of L_p from agricultural watersheds below the target level of development ($\leq$ 0.27 C / ha or 5% IS) were variable, but higher on average than suburban watersheds. Highest levels of L_p were consistently detected where forest cover predominated and C / ha was approximately1.20 or less. Minimum L_p consistently declined in forested watersheds as C / ha increased to about 1.20 C / ha and the range of L_p declined once C / ha exceeded 1.40.

Brackish subestuaries with C / ha 1.59 or greater exhibited a persistent depression in L_p (0.33 or less) while remaining systems exhibited extensive variation. A persistent L_p of 0.33 was chosen as a threshold indicating serious deterioration of brackish subestuary larval nursery habitat. Similarly, fresh-tidal Piscataway Creek's (C / ha ~ 1.40) four estimates of L_p 0.65 or less during 2008-2011 were persistently low compared to other fresh-tidal subestuaries and this value was chosen as a fresh-tidal threshold.

The lack of significant correlations of L_p with feeding success indicated that L_p should not be considered as an indicator of the effect of food-related larval processes. Feeding success could impact survival of larger larvae not well sampled by the 0.5 m nets we used to determine L_p.

Feeding success decreased as C / ha increased and its annual variability was much greater at high levels of development (0.88 - 1.41 C / ha). Logistic regressions indicated that C / ha was a significant negative influence on the odds of feeding successfully. Guts contained food in all years and subestuaries except Piscataway Creek during 2011. Copepods were the most prevalent food item. Yellow perch feeding success was strongly and negatively correlated with the proportion of samples where detritus was very low or absent and development was strongly and positively correlated with the proportion of samples where detritus was very low or absent. Feeding success in the lone agricultural drainage studied during 2011 (Nanticoke River) was as high as in the six forested watersheds.

Estuarine Fish Community Sampling - We evaluated habitat of recreationally important juvenile and adult finfish in 4 tidal-fresh, 2 oligohaline, and 3 mesohaline subestuaries of Chesapeake Bay during 2011. Analyses emphasized conditions within tidal-fresh subestuaries.

Correlation analyses of 2003-2011 data by salinity class suggested that C / ha, surface water temperature, and salinity were significantly associated with DO conditions in Chesapeake Bay subestuaries. In mesohaline subestuaries, associations of surface DO with surface water temperature and bottom DO with C / ha were negative and significant, while other two comparisons (bottom temperature with bottom DO and C / ha with surface DO) were not. In oligohaline subestuaries, only a negative correlation of surface DO with surface temperature was significant. None of the correlations were significant in fresh-tidal subestuaries. The trend of declining significance of associations among DO or temperature with salinity indicated stratification in combination with development could be important in formation of poor DO conditions in mesohaline bottom waters, less important in oligohaline subestuaries, and unimportant in tidal-fresh subestuaries.

Mean and median DO in Mattawoman Creek bottom channel habitat has declined since 1989, however, neither fell below the target DO of 5.0 mg/L. Based on 95% CI overlap, estimates of the proportion of DO below the target or threshold (V_{target} and $V_{threshold}$, respectively) in a 61.5 ha SAV bed located at Sweden Point Marina during 2011 (V_{target} = 0.34, SD = 0.04; and $V_{threshold}$ = 0.06, SD = 0.02) were higher than estimates taken in the channel during fish monitoring (V_{target} = 0.15, SD = 0.05; and $V_{threshold}$ = 0) and were not significantly different than V_{target} and $V_{threshold}$ from a continuous monitor located in the SAV bed.

Dissolved oxygen conditions within the Sweden Point Marina SAV bed were worse than those measured in channel waters of Mattawoman Creek. If conditions measured in the SAV bed sampled during 2011 were representative, then the nearly 300 ha of Mattawoman Creek’s 748 ha subestuary covered in SAV could have been more stressful habitat than open channel waters. The DO dynamics in the SAV beds of Mattawoman Creek may not have directly caused fish declines, but may be symptomatic of broader ecological changes occurring in this subestuary as development has proceeded. High growth of SAV in Mattawoman Creek appeared to represent an alternative manifestation of DO stress from development unique to tidal-fresh subestuaries.

Regression analyses indicated that the proportion of bottom trawl samples with juvenile white perch (P_i of juveniles) in tidal-fresh subestuaries was not linearly related to development. A linear model may have been a poor choice for describing a decline of tidal-fresh subestuary bottom channel habitat use by juvenile white perch. The bivariate plot of C / ha and P_i of juveniles indicated that once the development threshold (C / ha = 0.83 3) had been breached, the variation in P_i of juveniles increased substantially. Estimates of P_i of juveniles at development levels less than the threshold were clustered between 0.90 and 1.00. Beyond the threshold, the range expanded to 0.30–1.00.

The linear relationship of C / ha and P_i was significant for adult white perch (r^2 = 0.56, $P < 0.0001$). Residuals of this regression plotted against C / ha suggest that points at lower and higher development (C / ha ≈ 0.45 and 1.40, respectively) were well described by the regression, but the points surrounding the threshold (C / ha = 0.83) were mostly clustered above zero. This suggests that stressors in tidal-fresh subestuaries affect adult white perch P_i in the region of the threshold in a “boom or bust” fashion.

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 devise reference points for development as a similar tool for fish habitat management. The development of development reference points involves determining functional relationships between an indicator of watershed development 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 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 2011 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 2011 emphasized fresh-tidal systems. Previous activities have formulated target and limit impervious surface reference points for brackish subestuaries based on Chesapeake Bay dissolved oxygen (DO) criteria, and associations and relationships of percent of watershed in impervious surface, summer DO, and presence of target species (Uphoff et al. 2011a).

Section 1 - Tax Map Indicators of Development

Impervious surface (IS; paved surfaces, buildings, and compacted soils) has been used as an indicator of watershed development because of its effect on habitat and aquatic life in freshwater systems and because it is a variable in many water quality and quantity models (Arnold and Gibbons 1996; Cappiella and Brown 2001; Wheeler et al. 2005; National Research Council or NRC 2009). Uphoff et al. (2011a) estimated target and limit Impervious Surface Reference Points (ISRPs) 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 blue crab *Callinectes sapidus*, white perch *Morone americana*, striped bass *Morone saxatilis*, and spot *Leiostomus xanthurus* in bottom waters of nine brackish Chesapeake Bay subestuaries.

We have primarily used IS estimates made by Towson University from Landsat, 30-meter pixel resolution satellite imagery (Eastern Shore of Chesapeake Bay in 1999 and western shore in 2001) for each watershed (Barnes et al. 2002) to develop ISRPs for brackish Chesapeake Bay tributaries (Uphoff et al. 2011a). This IS data set has become dated and we do not know when updated estimates of impervious surface may become available. Significant amounts of development can occur in 10-15 years and continued monitoring of fish and habitat conditions need to be matched with more concurrent measures of development.

Tax map data meet our requirements for a standardized, readily updated, and accessible data base related to intensity of development (Uphoff et al. 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 (Maryland Department of Planning or MDP 2010). The primary purpose of these maps is to help State tax assessors locate properties for assessments and taxation purposes. Maryland Department of Planning annually updates the more than 2,800 property maps, or tax maps, for Maryland’s 23 counties. Baltimore City maintains its own property maps. 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. 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).

We currently use counts of structures per hectare (C / ha) as our tax map indicator of development because it requires less processing than square footage and the fits IS data nearly as well (Uphoff et al. 2010). Based on comparisons of 2000 tax map indicators and Towson IS estimates for 1999-2000, IS estimates were strongly related to both counts of structures per or square footage of structure footprints per unit area and these relationships were described by a nonlinear power function (Uphoff et al. 2010). However, there is a need to convert structures per area to IS and we developed an equation for this conversion based on systems we have sampled.

Methods

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 in some cases.

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.

The 1999 tax map data set was used to estimate number of structures (C) per hectare or C / ha for watersheds we have sampled since 2003 (Table 1-1). This set of watersheds was used because we had IS estimates available. 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

$$IS = a \bullet (C / ha)^{b};$$

where a = a scaling factor and b is the exponent determining the rate of increase. The power function was estimated using Proc NLIN in SAS Enterprise. Note that the power function was fit without an intercept which affected estimation of the F statistic, r^2, and P (Freund and Littel 2000). The r^2 and P for the power function presented above were estimated from linear regression of the predicted and observed values, while standard errors for a and b were estimated by Proc NLIN. Of particular interest was the pattern of residuals with C / ha.

Results and Discussion

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

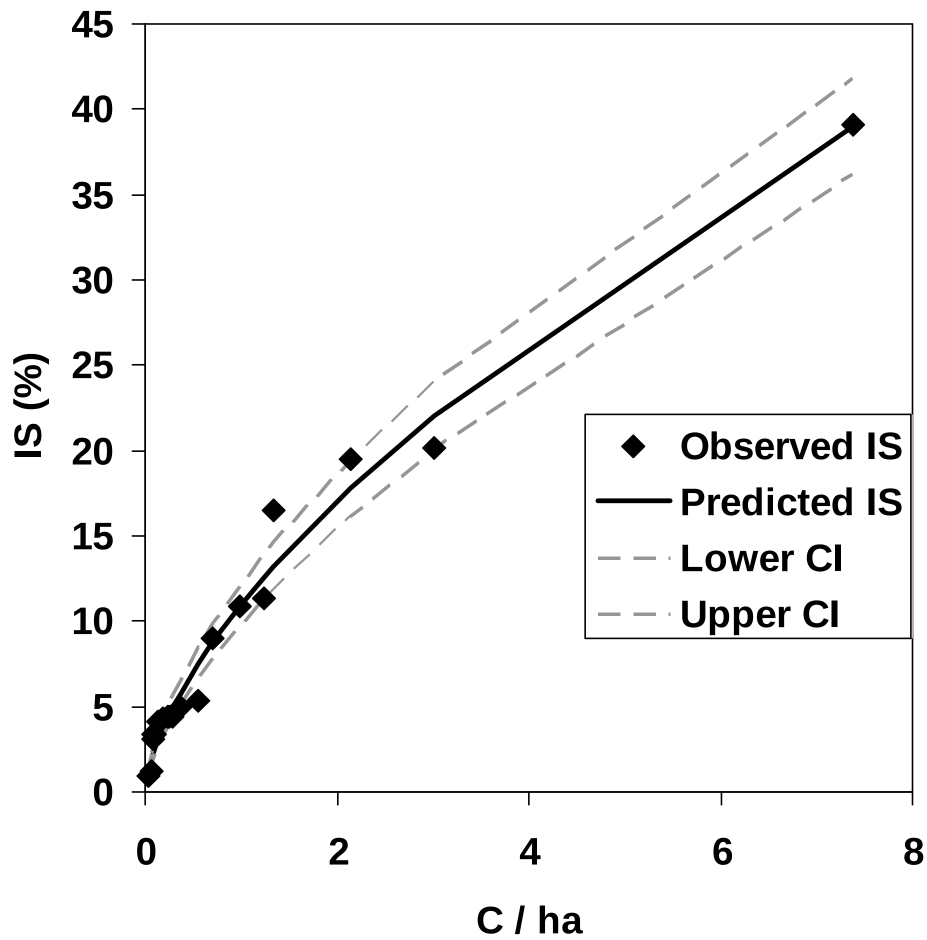
$$IS = 10.98 \bullet (C / ha)^{0.63}, (r^2 = 0.96; P < 0.0001; \text{Figure 1-1});$$

SE's of coefficients a and b were 0.52 and 0.03, respectively. Patterning of residuals with C / ha was not evident (Figure 1-1). This equation was used to convert C / ha to IS.

Table 1-1. Data used for nonlinear regression structures per hectare (C / ha) and percent impervious surface estimates (IS %).

Watershed	IS	C / ha
Nanjemoy Creek	0.9	0.08
Bohemia River	1.2	0.10
Langford Creek	3.1	0.07
Wye River	3.4	0.08
Middle River	3.4	0.23
Corsica River	4.1	0.14
Wicomico River	4.3	0.29
Northeast River	4.4	0.36
Gunpowder River	4.4	0.03
St Clements Creek	4.4	0.19
West River	5.0	0.55
Breton Bay	5.3	0.25
Mattawoman Creek	9.0	0.71
South River	10.9	1.23
Bush River	11.3	0.98
Piscataway Creek	16.5	1.34
Severn River	19.5	2.14
Magothy River	20.2	3.01
Miles River	39.1	7.39

Figure 1-1. Predicted and observed estimates of percent impervious surface (IS) estimated from structure counts per hectare (C / ha). Lower CI and Upper CI refer to the 95% confidence interval of predicted IS.



Section 2 - Stream Ichthyoplankton Sampling

Introduction

A survey to identify anadromous fish spawning habitat in Maryland was conducted during 1970-1986. 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 2011, stream sites in Mattawoman Creek (Figure 2-1) were sampled for eggs and larvae of anadromous herrings (blueback herring, alewife, and hickory shad; these eggs and larvae are very similar; Lippson and Moran 1974), white perch, and yellow perch (hereafter "anadromous fish") by citizen volunteers coordinated by program biologists. Volunteers (also coordinated by program biologists) had also recently sampled Mattawoman Creek (2008-2010), Piscataway Creek (2008-2009), and Bush River (2005-2008; Figure 2-1; McGinty et al. 2009; Uphoff et al. 2010). Mattawoman and Piscataway creeks (watersheds equal 24,441 ha and 17,642 ha; M. Topolski, MD DNR, personal communication) are adjacent watersheds near Washington, DC (Figure 2-1). Piscataway Creek is closer to Washington, DC, than Mattawoman Creek (Uphoff et al. 2010). Bush River (44,167 ha; M. Topolski, MD DNR, personal communication) is near Baltimore, Maryland (located to the northeast; Figure 2-1). Results from surveys of these three systems during the 2000s were contrasted with each other and with surveys conducted by in the early 1970s by O'Dell et al (1975).

Methods of O'Dell et al. (1975) were used by volunteers to collect ichthyoplankton at sites where at least one of the three anadromous species groups had been detected in the early 1970s. Water conductivity was monitored during these volunteer surveys and these data were used to examine whether urbanization had affected stream water quality. Increases in conductivity have been strongly associated with urbanization (Wang and Yin 1997; Paul and Meyer 2001; Wenner et al. 2003; Morgan et al. 2007; Carlisle et al. 2010).

We compared two anadromous fish spawning time-series (occurrence of spawning at sites and proportion of samples with a particular species group of anadromous fish) to tax map indicators of impervious surface (counts of structures per hectare or C/ha; Uphoff et al. 2010) and summarized conductivity data.

Methods

Sites were sampled for the anadromous fish eggs and larvae in Mattawoman Creek, Piscataway Creek, and Bush River during the 2000s were typically at road crossings that O'Dell et al. (1975) determined were anadromous fish spawning sites. 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. All collections during the 2000s were made by citizen volunteers trained and monitored by program biologists.

In Mattawoman Creek during March-May, 2008-2011, ichthyoplankton samples were collected from three tributary sites (MUT3-MUT5) and four mainstem sites (MC1-MC4) (Figure 2-2; Table 2-1). Tributary site (MUT4) was selected base on volunteer interest and only added to sampling sites in 2010. Piscataway Creek stations were sampled during 2008-2009 (Figure 2-3; Uphoff et al. 2010) and Bush River stations were sampled during 2005-2008 (Figure 2-4; McGinty et al. 2009). Table 2-1 summarizes sites, dates, and sample sizes in Mattawoman and Piscataway creeks, and Bush River during 2005-2011.

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 • 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 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 through 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. Approximately 2-ml of rose bengal dye 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-or larvae were removed and were retained in a small vial with a label (site, date, and time) and fixed with formaldehyde for later identification under a microscope and for verification by senior biologists. Each sample was sorted systematically a second time for quality assurance (QA). Any additional eggs and-or larvae found were removed and placed in a small labeled (site, date, time, and QA) vial and fixed with formaldehyde for identification under a microscope and for verification. All eggs and-or larvae found during sorting (both in original and QA vials) were identified as either herring / hickory shad, gizzard shad, yellow perch, white perch, unknown (eggs and-or larvae were too damaged to identify) or other (indicating another fish species) and a total count (combining both original and QA vials) for each site was recorded, as well as the presence and absence of each of the above species. During the presence/absence and identification processes, the QA vials only contained additional eggs and-or larvae of species already counted for in the original vials; no new species were detected during the assessment of the QA vials.

Conductivity measurements collected for each date and stream site (mainstem and tributaries) during 2008-2011 from Mattawoman Creek 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 data were similarly summarized for Piscataway Creek mainstem stations during 2008-2009. A subset of Bush River stations that were sampled each year during 2005-2008 (i.e., stations in common) were summarized and stations within largely undeveloped Aberdeen Proving Grounds were excluded (these were not sampled every year). The proportion of annual conductivity measurements exceeding 171 µS / cm was also calculated. Conductivities below 171 µS / cm were associated with "good" fish index of biotic integrity (FIBI) scores based on analysis o f Maryland Biological Stream Survey fish data (Morgan et al. 2007). Comparisons were made with conductivity ranges previously reported for Mattawoman Creek by O'Dell (1975) and Hall et al. (1992).

A water quality database maintained by DNR's Tidewater Ecosystem Assessment (TEA) Division (S. Garrison, MD DNR TEA, personal communication) provided conductivity measurements for Mattawoman Creek during1970-1989. These historical measurements were compared with those collected in 2008-2011 to examine changes in conductivity over time. Monitoring was irregular for many of the historical stations. Table 2-2 summarizes site location, month sampled, total measurements at a site, and what years were sampled. Historical stations and those sampled in 2008-2011 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.

Historical monthly median conductivities at each mainstem Mattawoman Creek site and their trend were plotted and 2008- 2011 spawning season median conductivities from each non-tidal site were added to these plots. Median conductivities from the 2008-2011 estuarine yellow perch larval survey (Section 3 of this report) were 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 months March through May for 2008-2011 and plotted.

Presence of white perch, yellow perch, and herring eggs and-or larvae at each station in 2011 was compared to past surveys to determine which sites still supported spawning. We used the criterion of detection of eggs or larvae at a site (O'Dell et al. 1975) to evaluate occurrence of spawning (see Results and Discussion section). Raw data from early 1970s collections were not available to formulate other metrics.

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. Count data were available for 1991 in a tabular summary at the sample level and these data were converted to presence-absence. Hall et al. (1992) collected ichthyoplankton with 0.5 m diameter plankton nets (3:1 length to opening ratio and 363µ mesh set for 2-5 minutes, depending on flow) suspended in the stream channel between two posts instead of stream drift nets.

Comparisons of site occupation by the species groups and water quality were made among the current study (2008-2011), Odell et al. (1975) and Hall et al. (1992). Changes in spawning site occupation were compared to level of development indicated by C / ha (see Section 1-1) in both watersheds. These estimates were compared to tables of site occupation for Piscataway Creek (2008-2009) and Bush River (2005-2008) collected by volunteers and previously prepared for McGinty et al. (2009) and Uphoff et al. (2010).

The proportion of samples where herring eggs and-or larvae were present (P_{herr}; was estimated for Mattawoman Creek mainstem stations (MC1-MC4) during 1991 and 2008-2011. Past volunteer sampling of ichthyoplankton in Piscataway Creek (2008-2009) and Bush River (2005-2008; McGinty et al. 2009) also provided sufficient sample sizes to estimate P_{herr} for those locations and years. Herring was the only species group represented with adequate sample sizes for annual estimates with reasonable precision. Mainstem stations were used also in Piscataway Creek; however, Tinkers Creek was included as a mainstem station. Bush River "stations in common" were analyzed.

The proportion of samples with herring eggs and-or larvae present was estimated as $P_{herr} = N_{present} / N_{total}$, where $N_{present}$ equaled the number of samples with herring eggs or larvae present and N_{total} equaled the total number of samples taken. The SD of each P_{herr} was estimated as

$$SD = [(P_{herr} \bullet (1- P_{herr})) / N_{total}]^{0.5} \quad \text{(Ott 1977).}$$

The 90% confidence intervals were constructed as $P_{herr} \pm (1.44 \bullet SD)$.

Correlation analysis was used to examine associations among development (C / ha), summarized conductivity measurements (median conductivity and the proportion of conductivity measurements greater than 171μS / cm), and herring spawning intensity (P_{herr}) in Bush River and Piscataway and Mattawoman creeks. Eleven estimates of C / ha and P_{herr} were available (1991 estimates for Mattawoman Creek could be included), while ten estimates were available for the two conductivity summaries (Mattawoman Creek conductivity data were not available for 1991). Conductivity was summarized for the same stations that were used to estimate P_{herr}. Correlations were considered significant at α = 0.05. We expected negative correlations of P_{herr} with C / ha and both conductivity summarizations, while conductivity and C /ha were expected to be positively correlated.

Results

In 2011, conductivity measurements were steady and all but one remained above the 1991 maximum (Figure 2-5). 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. During 2009, conductivity was highly elevated in early March following application of road salt in response to a significant snowfall that occurred just prior to the start of the survey (Uphoff et al. 2010). Conductivity measurements in 2009 steadily declined for nearly a month before leveling off slightly above the 1989-1991 maximum. Conductivities during the 2010 survey were steady and nearly always above the 1989-1991 maximum (Figure 2-5).

Plots of conductivity in Mattawoman Creek by year and site indicated lower and more stable measurements in unnamed tributaries (Figure 2-5). 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). There was a general pattern among years of higher conductivity at the most upstream mainstem site (MC4) followed by declining conductivity downstream to the site on the tidal border (MC1; Figure 2-5). This pattern and low conductivities at the unnamed tributaries indicated that development at and above MC4 was affecting water quality.

Conductivity levels in Piscataway Creek and Bush River were elevated when compared to Mattawoman Creek (Table 2-3). Median conductivity estimates during spawning surveys were always greater than 200 µS / cm in Piscataway Creek and Bush River during the 2000s. Median conductivity in Mattawoman Creek was in excess of 200 µS / cm during 2009 and was less than 155 µS / cm during the remaining three years. Based on comparisons with the 171 µS / cm critical value for the FIBI (Morgan et al. 2007), Piscataway Creek and Bush River were often (92-97% and 84-94% of measurements, respectively) in excess of this criterion during anadromous fish spawning seasons sampled. In Mattawoman Creek, 63% of measurements were in excess of the FIBI criterion during the 2009 spawning survey, and 0-16% were in excess in remaining years (Table 2-3).

The trend in median conductivity with distance from the mouth of Mattawoman Creek during 1970-1989 (C / ha increased from 0.25 to 0.41) was U-shaped (Figure 2-6; 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. Conductivities at mainstem stations (MC2 to MC4) above the confluence of Mattawoman Creek's stream and estuary (MC1) were elevated beyond predicted historical medians during 2008-2011 (particularly in 2009; C / ha ~ 0.86) and increased with upstream distance away from the confluence of the stream and estuary and toward Waldorf (Figure 2-6).

Anadromous fish spawning site occupation in fluvial Mattawoman Creek was less consistent during 2008-2011 than during 1971 and 1989-1991 (historical spawning period; Table 2-4). Herring spawning was detected during 2008-2011 at all historical mainstem stations, but not during all years at stations MC2 and MC4. Herring spawning was detected at all mainstem stations in 1971 and 1991. Stream spawning of white perch in Mattawoman Creek was not detected during 2009 and 2011. Historically, white perch spawning occurred annually at MC1 and intermittently at MC2 and MC3. Yellow perch spawning occurred at station MC1 every year except 2009. Station MC1 is the only stream station in Mattawoman Creek where yellow perch spawning has been detected in surveys conducted since 1971 (Table 2-4).

Stream spawning of anadromous fish nearly ceased in Piscataway Creek between 1971 and 2008-2009 (Table 2-5). Herring spawning was not detected at any site in the Piscataway Creek drainage during 2008 and was only detected on one date and location (one herring larvae on April 28 at PC2) in 2009. Stream spawning of white perch was only detected in 1971 and hasn't since been observed (Table 2-5).

There was no obvious decline in herring spawning in the Bush River stations between 1973 and 2005-2008, but occurrences of white and yellow perch were far less frequent (Table 2-6). During 1973, herring spawning were detected at 7 of 12 Bush River stream sites sampled; however, during 2005-2008 herring spawning were detected in as few as 5 of 12 sites or as many as 8 of 8 sites sampled in the Bush River. White perch spawning in the Bush River was detected at 8 of 12 sites sampled during 1973 and at 1 site during four surveys during 2005-2008 (2007 at BOP1). The pattern of stream spawning site occupation of yellow perch in Bush River was similar to that of white perch spawning: yellow perch spawning were present at 5 of 12 sites during 1973, yellow perch spawning were not present during 3 of 4 surveys during 2005-2008, and yellow perch spawning was detected at 4 of 12 sites during the 2006 survey year (Table 2-6).

All three watersheds, Bush River, Piscataway and Mattawoman Creeks, started at approximately 0.05 C/ha in 1950, (Figure 2-6). In the early 2000s Bush River and Piscataway Creek were at substantially higher levels of development (~1.30 C/ha) than Mattawoman Creek (0.75 C/ha; Figure 2-6).

The spawning survey in Mattawoman Creek during 1971 (O'Dell et al. 1975) was conducted in a watershed with relatively little development (0.16 C/ha; Figure 2-6) and herring and white perch spawning (indicated by occurrence at a site) was widespread (Table 2-3). Detection of anadromous fish spawning at historical sites became intermittent during 2008-2011 in Mattawoman Creek (Table 2-4) when C/ha was estimated to be 0.87-0.88 (Figure 2-6). Development in Piscataway Creek in 1971 (0.47 C / ha: Figure 2-6) was similar to the level in Mattawoman Creek during 1989-1991 (0.41-0.45 C / ha; Figure 2-6) and anadromous fish spawning was consistently detected at sites in both creeks (Table 2-5). The number of sites with anadromous fish spawning fell to near zero in Piscataway Creek during 2008-2009 at 1.40 C / ha (Table 2-5; Figure 2-6). The development level in the Bush River during 1973 was 0.35 C / ha falling between Mattawoman and Piscataway creeks (Figure 2-6) and the detection of stream spawning by anadromous fish was widespread (Table 2-6). While stream spawning of white and yellow perch appeared to have largely ceased in Bush River during 2005-2008, herring spawning continued to be detected at a similar number of sites as in 1973 (Table 2-6).

The 90% confidence intervals of P_{herr} (Figure 2-7) provided sufficient precision to categorize three levels of stream spawning: very low levels at or indistinguishable from zero based on confidence interval overlap (level 0); a low level of spawning that could be distinguished from zero (level 1), and a higher level of spawning that could be separated from the low levels (level 2). Stream spawning in Mattawoman Creek was categorized at levels 1 (2008-2010) and 2 (1991 and 2011); spawning in Piscataway Creek was at level 0; and Bush River spawning was characterized by levels 0 (2006) and 1 (2005, 2007, and 2008; Figure 2-7).

Correlation analyses indicated significant and logical associations among $P_{herr,}$ C/ha, median conductivity, and proportion of conductivity measurements > 171 μS/cm (Table 2-7). Correlations of C/ha with median conductivity or proportion of conductivity measurements > 171 were significantly positive (Table 2-7; Figure 2-8), while correlations of P_{herr} with C/ha, and both summarizations of conductivity were significantly negative (Table 2-7; Figure 2-9). Although not directly related to egg and larval survival, the FIBI conductivity criterion from Morgan et al (2007) provided a summary that was significantly associated with herring spawning intensity.

Discussion

Changes in development, conductivity, and anadromous fish stream spawning in Piscataway and Mattawoman creeks and Bush River agreed with general findings elsewhere that (1) habitat quality in fluvial and tidal streams declined with development and (2) streams and tidal creeks in watersheds with greater than 10% IS (~0.83 C / ha) were degraded (Arnold and Gibbons 1996; Cappiella and Brown 2001; NRC 2009).

Bush River, Piscataway Creek and Mattawoman Creek, started at approximately 0.05 C / ha in 1950. In 2009, Bush River and Piscataway Creek were at substantially higher levels of development (~1.20 and 1.40 C/ha, respectively) than Mattawoman Creek (0.88 C/ha). Occurrence of anadromous fish eggs and larvae at sites in fluvial Mattawoman Creek was less consistent during 2008-2011 than during 1971 (0.16 C / ha) and 1989-1991 (~ 0.45 C / ha). Anadromous fish eggs and larvae were nearly absent from sites in fluvial Piscataway Creek during 2008-2009 (one occurrence during 2009), but were found at five stations during 1971 (0.48 C / ha). There was no obvious decline in site occurrence of herring eggs and larvae in the Bush River stations between 1973 (0.30 C / ha) and 2005-2008, but occurrences of white and yellow perch at sites were far less frequent.

Proportion of samples with herring eggs or larvae (P_{herr}) provided an alternative estimate based on encounter rate that was sufficiently precise to categorize three levels of stream spawning: very low levels at or indistinguishable from zero based on 90% confidence interval overlap; a low level of spawning that could be distinguished from zero, and a higher level of spawning that could be separated from the low levels. Correlation analyses indicated significant and logical associations among P_{herr}, C/ha and conductivity (conductivity was considered an indicator of urbanization) consistent with the hypothesis that urbanization was detrimental to stream spawning.

Some of the variability in the associations of C/ha with both summarizations of conductivity (Figure 2-8) may have reflected an acute episode of high conductivity that reflected road salt application just prior to the 2009 sampling season (Uphoff et al. 2010). Chronic conditions were captured in remaining years when snowfall was minimal or episodic effects had passed. Road salt application has a strong influence on conductivity in urban streams throughout the year (Kaushal et al. 2005; Morgan et al. 2007; Daley et al. 2009).

The different method used to collect icthyoplankton in Mattawoman Creek during 1991 may have biased that estimate of P_{herr}, although presence-absence data tend to be robust to errors and biases in sampling (Green 1979). For example, neither net diameter nor tow time biased the estimation of the proportion of plankton tows with striped bass eggs in Maryland's spawning rivers (Uphoff 1997). The addition of an estimate or estimates of P_{herr} from low impervious surface watersheds with herring runs may help resolve whether this bias among collection methods is truly significant. We intend on pursuing this sampling during 2012.

Removal of 1991 data lowered the correlation between C/ha and P_{herr} ($r = -0.60$, $\alpha = 0.07$). This point represented the sole "low" development sample available and its removal might be expected to have a large impact on the strength of the correlation. However, the significant correlations of the two conductivity summarizations with both C/ha and P_{herr} were not affected since these analyses were based on data collected during 2005-2011. These correlations with conductivity strongly supported the hypothesis that development was negatively associated with habitat conditions needed for herring spawning in streams. Conductivity was strongly and positively associated with C/ha in our analysis and with urbanization in other studies (Wang and Yin 1997; Paul and Meyer 2001; Wenner et al. 2003; Morgan et al. 2007; Carlisle et al. 2010). Limburg and Schmidt (1990) found a highly nonlinear relationship of densities of anadromous fish (mostly alewife) eggs and larvae to urbanization in Hudson River tributaries with a strong negative threshold at low levels of 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 (Uphoff et al. 2011b). 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 (Uphoff et al. 2011b). The Bush River streams continued to support herring spawning even as development increased, but stream spawning by white and yellow perch was greatly reduced. Changes in hydrology in Bush River have not been completely investigated in time for this report.

Development in Bush River's watershed (absent Aberdeen Proving Grounds) is at approximately the same level as Piscataway Creek's watershed and white perch stream site occupation has declined sharply in both systems. Yellow perch stream spawning had been detected in Bush River in the 1970s (but not in fluvial Piscataway Creek) and site occurrence diminished greatly between 1973 and 2005-2008. Herring spawning in Piscataway Creek nearly ceased. The same cannot be said for occupation of stream spawning sites by herring in Bush River. While changes in herring spawning at sites were difficult to detect in Bush River, estimates of P_{herr} there were categorized as low (levels 0 or 1), but not as consistently low as Piscataway Creek (2008 and 2009 at level 0). Three issues should be considered when attempting to define differences between Piscataway Creek and Bush River indicators of herring spawning (occurrence of eggs or larvae at a site versus P_{herr}): the influence of physiographic province characteristics, the influence of stock size, and statistical adequacy of the two indicators of spawning intensity.

Mattawoman and Piscataway Creeks are adjacent Coastal Plain watersheds that represent a continuum of response along an urban gradient emanating from Washington, DC. Piscataway Creek's watershed is both smaller than Mattawoman Creek's and closer to Washington, DC (Uphoff et al. 2010). Bush River is located in the urban gradient emanating from Baltimore, Maryland, and is located in both the Coastal Plain and Piedmont physiographic provinces (Clearwater et al. 2000). Processes such as flooding, riverbank erosion, and landslides vary in severity by province (Cleaves 2003).

Unconsolidated sediments (layers of sand, silt, and clay) underlie the Coastal Plain and broad plains of low relief and wetlands characterize the terrain (Cleaves 2003). Coastal Plain streams have low flows and sand or gravel bottoms (Boward et al. 1999). The Piedmont is underlain by metamorphic rocks and characterized by narrow valleys and steep slopes, with regions of higher land between streams in the same drainage. Most Piedmont streams are of moderate slope with rock or bedrock bottoms (Boward et al. 1999). The Piedmont is an area of higher gradient change and more diverse and larger substrates than the Coastal Plain (Harris and Hightower 2011) that may offer greater variety of herring spawning habitats than the Coastal Plain.

Site variability of herring spawning in Bush River during 2005-2008 involved "colonization" of new sites as well as absence from sites of historical spawning. If the distribution of sites in 1973 described the "true" distribution of spawning, then variability detected in Bush River spawning during 2005-2008 could have signified ephemeral spawning habitat resulting from a combination of urban and Piedmont province stream processes. American shad select spawning habitat based on macrohabitat features (Harris and Hightower 2011) and continuous presence of herring spawning in Bush River could reflect adjustments in distribution that herring make to find remaining suitable spawning habitats. Alewife spawn in sluggish water flows, while blueback herring spawn in sluggish to swift flows (Pardue 1983), and American shad spawn in moderate to swift flows (Hightower and Sparks 2003). Spawning substrates for herring include gravel, sand, and detritus (Pardue 1983). Urbanization and physiographic province both affect discharge and sediment supply of streams (Paul and Meyer 2001; Cleaves 2003) that, in turn, could affect location, substrate composition, extent and success of spawning. Detritus loads in subestuaries is a strongly associated with development (see Section 1-3) and urbanization affects the quality and quantity of organic matter in streams (Paul and Meyer 2001) that feed into subestuaries.

Site occupation could also have reflected low population sizes; however, species surveyed during 2008-2011 were not at similar relative stock levels. 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). 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; Maryland Fisheries Service 2012). There is little indication of a higher herring stock level in the upper Chesapeake Bay and a lower one in the Potomac River that might explain differences in site occupation between Bush River and Piscataway Creek.

Application of presence-absence data in management needs to consider whether absence reflects a disappearance from habitat or whether habitat sampled is not really habitat for the species in question (MacKenzie 2005). Our comparisons were based on the assumption that spawning sites detected in the 1970s were indicative of the extent of habitat. O'Dell et al. (1975) summarized spawning activity as the presence of any species group's egg, larva, or adult (latter from wire trap sampling) at a site and we used this criterion (spawning detected at a site or not). Raw data for the 1970s were not available to formulate other metrics. This approach represented a presence-absence design with low power to detect population changes or conclude an absence of change since only a small number of sites could be sampled (limited by road crossings) and the positive statistical effect of repeated visits (Strayer 1999) was lost by summarizing all samples into a single record of occurrence in a sampling season. A single year record was available for each of the watersheds in the 1970s and we assumed this distribution applied over multiple years of low development. Annual distributions of spawning occurrence detected during the 2000s at higher levels of development were variable for herring in both Mattawoman Creek and Bush River and we interpreted this variability as a sign of habitat instability and declining spawning activity.

Proportion of positive samples (P_{herr} for example) provides an economical alternative estimate of relative abundance based on encounter rate rather than counts. Encounter rate is readily related to the probability of detecting a population (Strayer 1999). Proportions of positive or zero catch indices were found to be robust indicators of abundance of yellowtail snapper *Ocyurus chrysurus* (Bannerot and Austin 1983), age-0 white sturgeon *Acipenser transmontanus* (Counihan et al. 1999), Pacific sardine

Sardinops sagax eggs (Mangel and Smith 1990), Chesapeake Bay striped bass eggs (Uphoff 1997), and longfin inshore squid *Loligo pealeii* fishery performance (Lange 1991). Annual estimates of positive stream samples for white perch and yellow perch would have limited power since they historically occurred at fewer sites than herring, resulting in much lower annual sample sizes. Pooling across years might allow for sample-based presence-absence comparisons among systems and perhaps years within systems, but cannot provide comparisons with the much less developed state of watersheds in the 1970s.

An unavoidable assumption of the correlation analysis of P_{herr}, C/ha, and summarized conductivity was continuity across systems. Extended time-series of watershed specific data were not available and watersheds at different levels of development were used as a substitute for time-series. Mixing physiographic provinces in this analysis has the potential to introduce bias.

Volunteer-based sampling of stream spawning during 2005-2011 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 spawning sites when multiple years of data were available.

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, and Bush River 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). 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 Bush River 2005-2008, Piscataway Creek 2008-2009, and Mattawoman Creek during 2008-2011.

System	Year	Number of Sites	1st Sampling Date	Last Sampling Date	Number of Dates	N
Bush	2005	13	18-Mar	15-May	16	99
Bush	2006	13	18-Mar	15-May	20	114
Bush	2007	14	21-Mar	13-May	17	83
Bush	2008	12	22-Mar	26-Apr	17	77
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
Mattawoman	2011	7	5-Mar	15-May	14	73

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. Summary statistics of conductivity (µmho / cm) for mainstem stations in Piscataway and Mattawoman creeks during 2008-2011. Count > 171 = count of conductivity measurements greater than threshold for a "good" fish index f biotic integrity (Morgan et al. 2007). Unnamed tributaries were excluded from analysis. Tinkers creek was included with mainstem stations in Piscataway Creek.

	Year						
Conductivity	2005	2006	2007	2008	2009	2010	2011
				Mattawoman			
Mean				120.1	244.5	153.7	116.3
Standard Error				3.8	19.2	38	4.6
Median				124.6	211	152.3	131
Kurtosis				2.1	1.41	1.3	-0.92
Skewness				-1.41	1.37	0.03	-0.03
Range				102	495	111	170
Minimum				47	115	99	55
Maximum				148.2	610	210	225
Count				39	40	43	69
Count > 171				0	25	7	1
				Bush			
Mean	269	206	263	237			
Standard Error	25	5	16	6			
Median	230	208	219	234			
Kurtosis	38	2	22	7			
Skewness	6	-1	4	0			
Range	1861	321	1083	425			
Minimum	79	0	105	10			
Maximum	1940	321	1187	435			
Count	81	106	79	77			
Count > 171	72	89	66	72			
				Piscataway			
Mean				218.4	305.4		
Standard Error				7.4	19.4		
Median				210.4	260.6		
Kurtosis				-0.38	1.85		
Skewness				0.75	1.32		
Range				138	641		
Minimum				163	97		
Maximum				301	737		
Count				29	50		
Count > 171				28	46		

Table 2-4. Presence-absence of herring (blueback herring, gizzard shad, and alewife) and white perch stream spawning in Mattawoman Creek during 1971, 1989, and 2008-2011. 0 = site sampled, but spawning not detected; 1 = site sampled, spawning detected; and blank indicates no sample. Station locations are identified on Figure 2-2.

	Year							
Station	1971	1989	1990	1991	2008	2009	2010	2011
Herring								
MC1	1	1	1	1	1	1	1	1
MC2	1	1	1	1	0	0	1	1
MC3	1			1	1	1	1	1
MC4	1			1	0	0	1	1
MUT3	1				0	0	0	1
MUT4							0	0
MUT5	1				1	0	0	0
White Perch								
MC1	1	1	1	1	1	0	1	0
MC2	0	0	1	0	0	0	0	0
MC3	1			0	0	0	0	0
Yellow Perch								
MC1	1	1	1	1	1	0	1	1

Table 2-5. Presence-absence of herring (blueback herring, gizzard, shad and alewife), white perch, and yellow perch stream spawning in Piscataway Creek during 1971 and 2008-2009. 0 = site sampled, but spawning not detected; 1 = site sampled, spawning detected; and blank indicates no sample. Station locations are identified on Figure 2-3.

	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 2-6. Presence-absence of herring (blueback herring, gizzard, shad and alewife), white perch, and yellow perch stream spawning in Bush River during 1973 and 2005-2008. 0 = site sampled, but spawning not detected; 1 = site sampled, spawning detected; and blank indicates no sample. Station locations are identified on Figure 2-4.

	Year				
Station	1973	2005	2006	2007	2008
Herring					
BBR1	0	1	1	1	1
BBR2	0	0	0		
BCR1	1	0	0	1	0
BGR1	0	1	1	1	
BGR2	1	0	0		
BGRT					0
BHH1	0	0	1	1	1
BHHT					0
BJR1	0	1	1	1	0
BOP1	1	1	1	1	1
BSR1	1	0	0		
BWR1	1	0	0	1	0
BWR2	1	0	0		
BWRT					1
BUN1	1	1	1	1	
White Perch					
BBR1	1	0	0	0	0
BBR2	0	0	0		
BCR1	1	0	0	0	0
BGR1	1	0	0	0	
BGR2	1	0	0		
BGRT					0
BHH1	0	0	0	0	0
BHHT					0
BJR1	0	0	0	0	0
BOP1	1	0	0	1	0
BSR1	0	0	0		
BWR1	1	0	0	0	0
BWR2	1	0	0		
BWRT					0
BUN1	1	0	0	0	
Yellow Perch					
BBR1	1		0		0
BBR2	1		1		
BCR1	0		0		0
BGR1	1		1		
BGR2	0	0	1	0	
BGRT					0
BHH1	0	0	0		0
BHHT					0
BJR1	1	0	0	0	0
BOP1	0	0	0	0	0
BSR1	0	0	0	0	
BWR1	1	0	1	0	0
BWR2	0	0	0		
BWRT					0
BUN1	0	0	0	0	

Table 2-7. Correlation matrix for structures per hectare (C / ha), median conductivity during spawning surveys, the proportion of conductivity measurements less than 171 μS / cm, and proportion of samples with herring eggs or larvae (P_{herr}). Statistic r = correlation coefficient, α = level of significance, and N = sample size.

Variable	Statistics	C / ha	Median conductivity	P > 171 uS / cm
Median conductivity	r	0.83		
	α	0.0029		
	N	10		
P > 171 uS / cm	r	0.90	0.95	
	α	0.0004	<0.0001	
	N	10	10	
P_{herr}	r	-0.74	-0.67	-0.72
	α	0.009	0.0344	0.0188
	N	11	10	10

Figure 2-1. Watersheds sampled for stream spawning anadromous fish eggs and larvae in 2005-2011. Coastal Plain and Piedmont Regions are indicated.

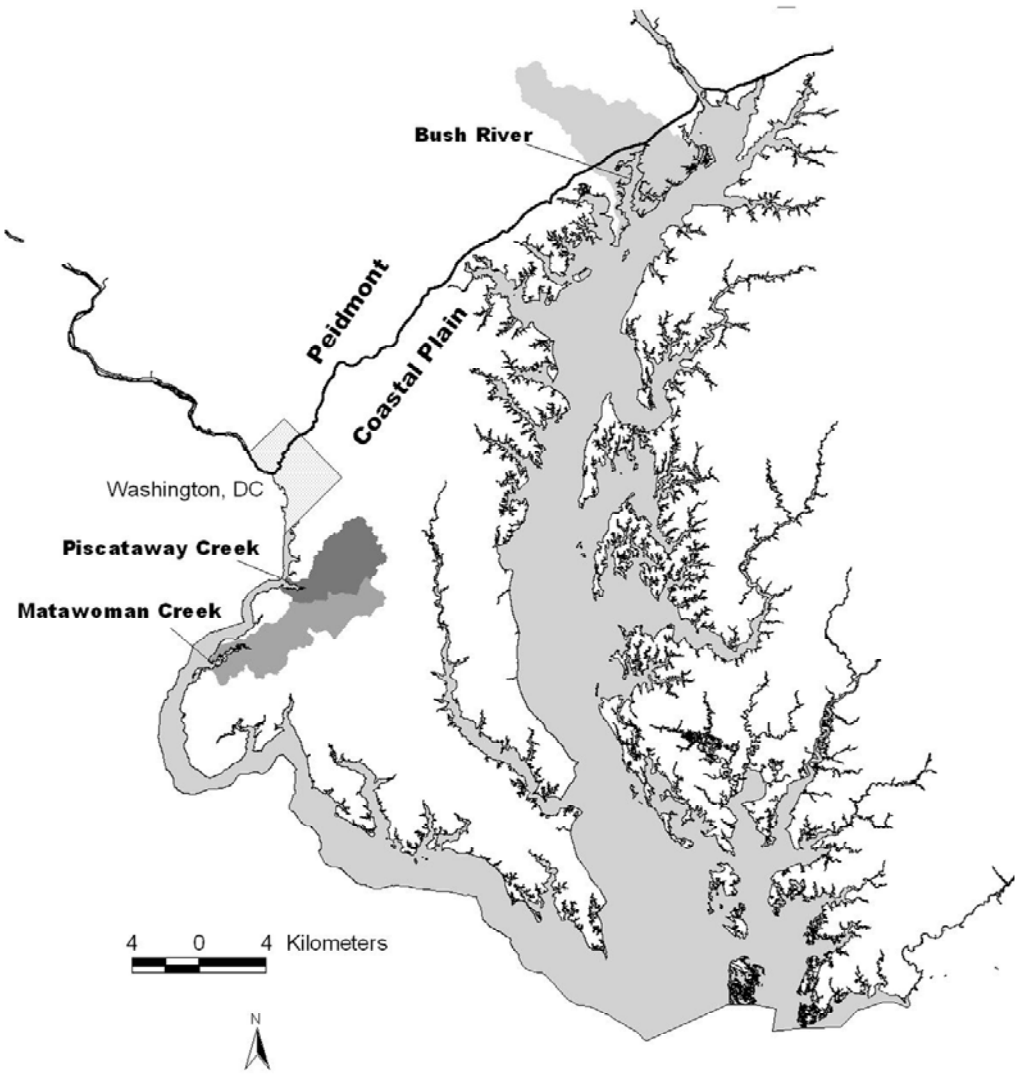


Figure 2-2. Mattawoman Creek's 1971 and 2008-2011 sampling stations.

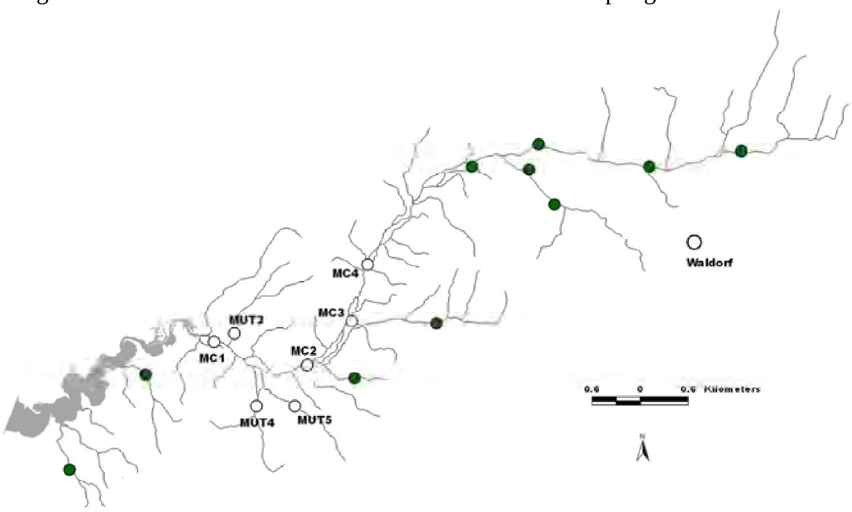


Figure 2-3. Piscataway Creek's 1971 and 2008-2009 sampling stations.

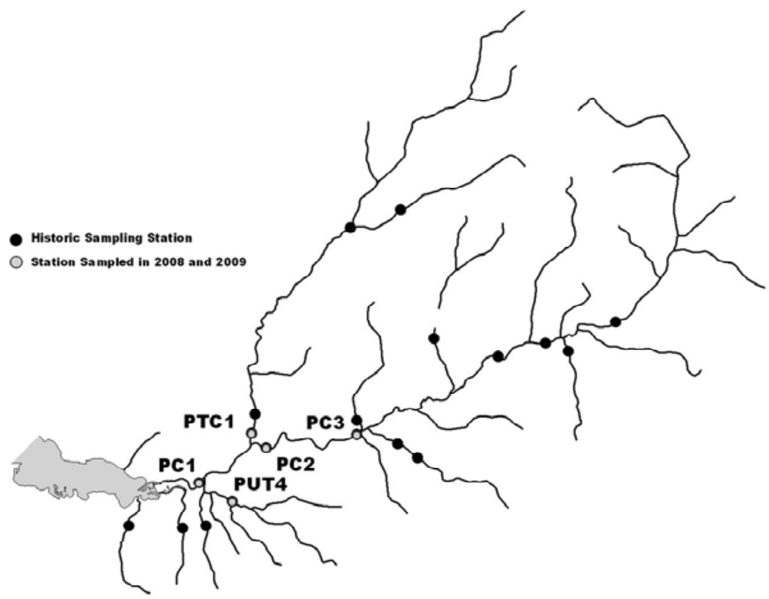


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Figure 2-4. Bush River's 1973 and 2008-2009 sampling stations. Stations in Aberdeen Proving Grounds have been separated from other Bush River stations.

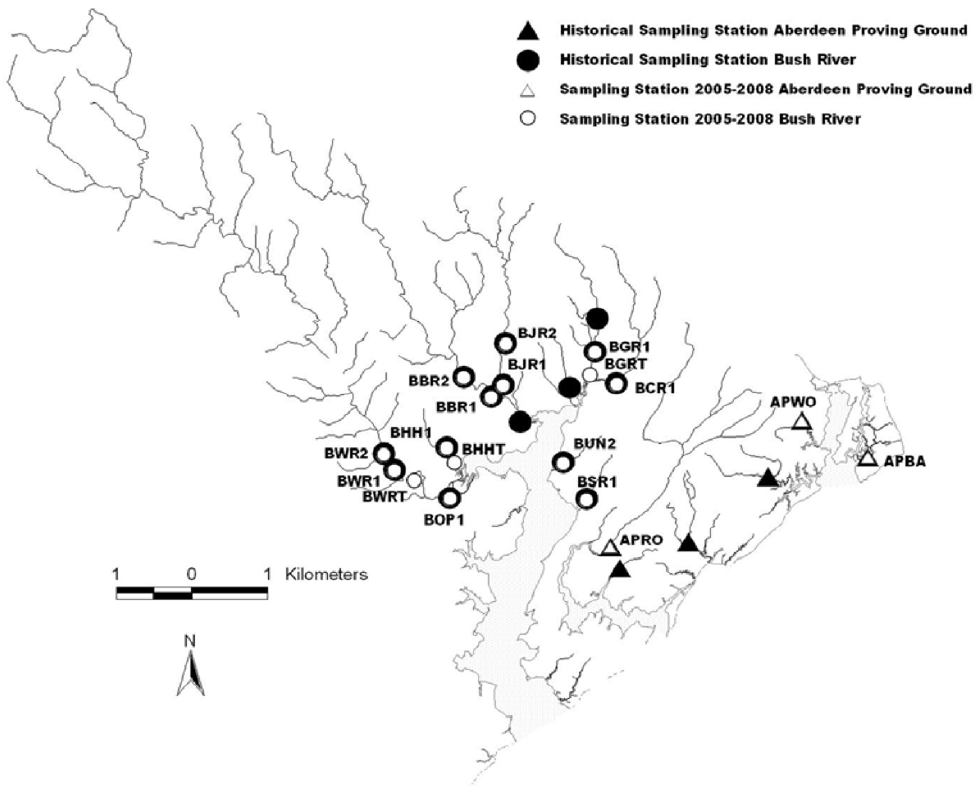


Figure 2.5 Stream conductivity measurements (µS / cm), by station and date, in Mattawoman Creek during (A) 2008, (B) 2009, (C) 2010, and (D) 2011. Lines indicate conductivity range measured at mainstem sites (MC1 – MC4) during 1991 by Hall et al. (1992)

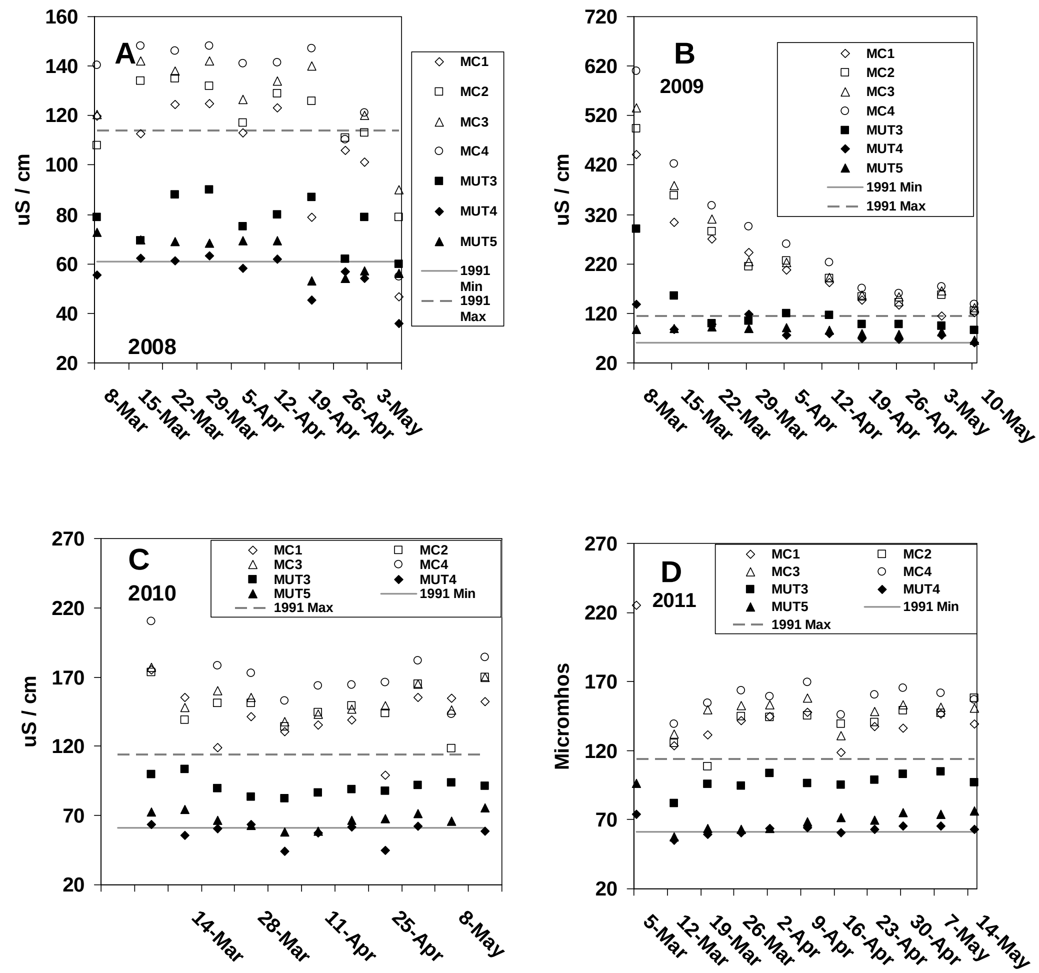


Figure 2-6. Historical (1970-1989; see Table 2-2) monthly median conductivity measurements in Mattawoman Creek (between the subestuary mouth and Waldorf) plotted against distance from the mouth. Tidal (open squares) and non-tidal stations (open triangles) are designated. Predicted historic station medians are indicated by the solid line and dotted lines indicate 95% CIs. Measurements from the 2008-2011 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.

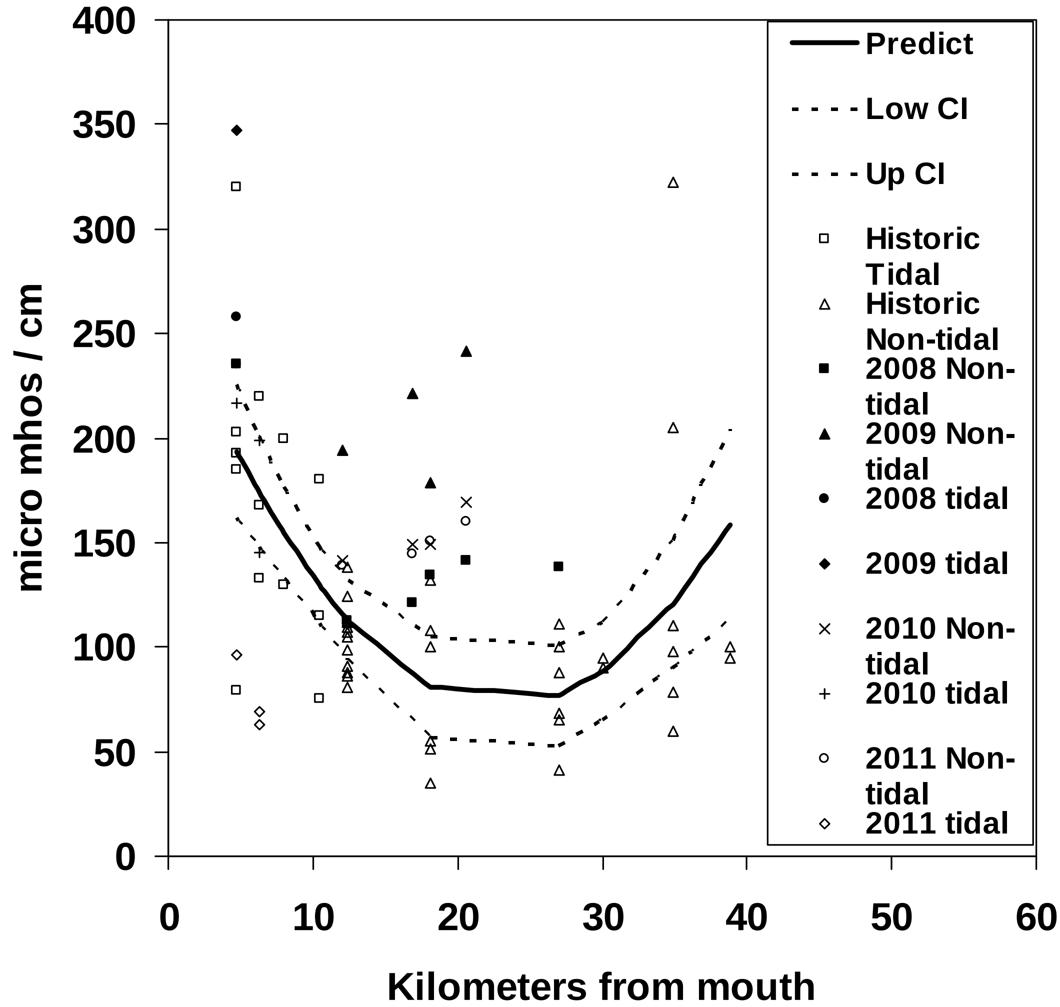


Figure 2-6. Trends in counts of structures per hectare (C / ha) during 1950-2010 in Piscataway Creek, Mattawoman Creek, and Bush River watersheds. Estimates of C / ha were not available for 2011. Large symbols indicate years when stream ichthyoplankton was sampled.

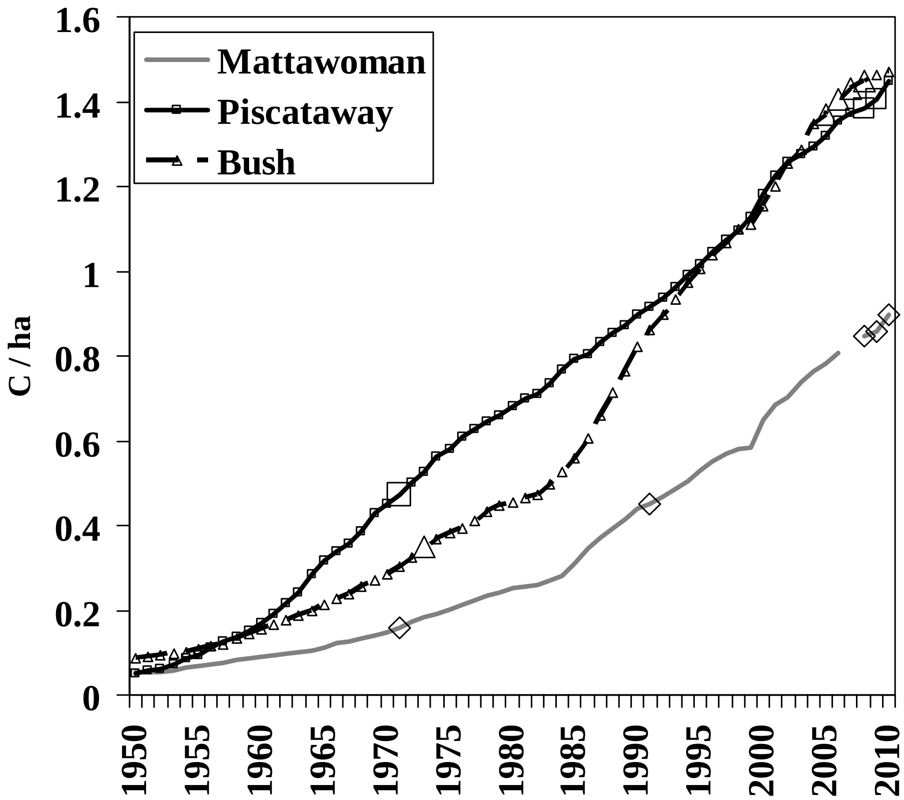


Figure 2-7. Proportion of samples (P_{herr}) with herring and its 90% confidence interval for stream ichthyoplankton surveys in Mattawoman Creek, Piscataway Creek, and Bush River.

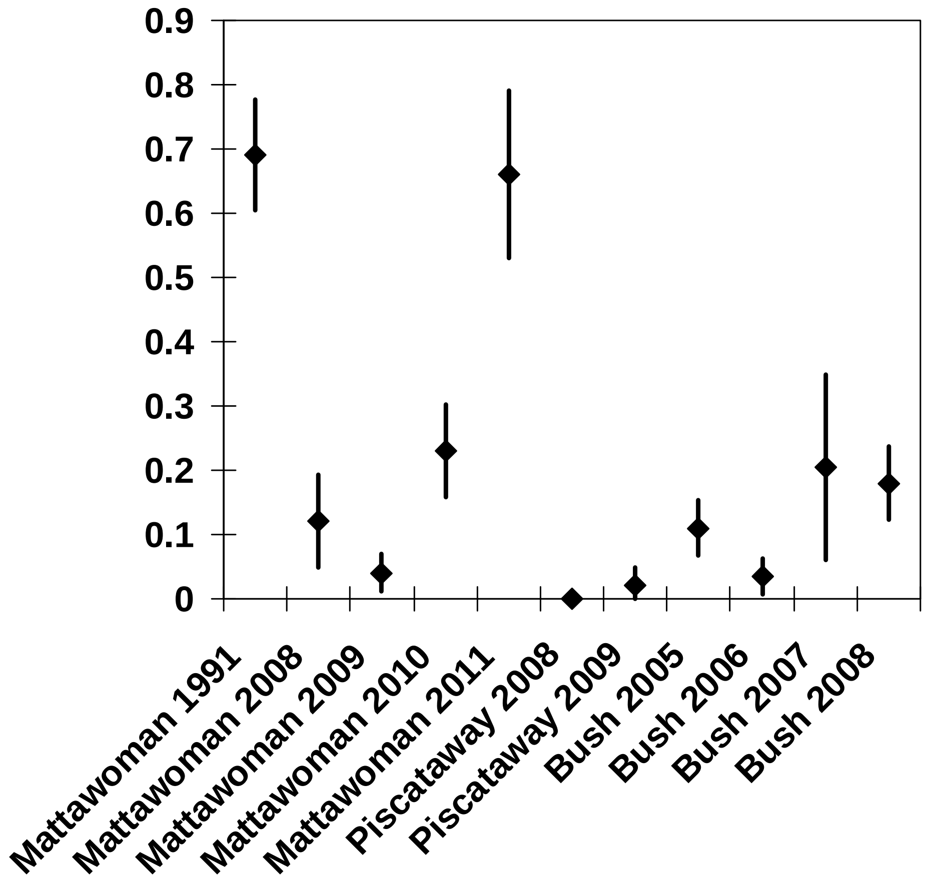


Figure 2-8. (A) Median conductivity during spring spawning surveys and level of development (C / ha). (B) Proportion of conductivity measurements greater than 171 μS / cm and C / ha.

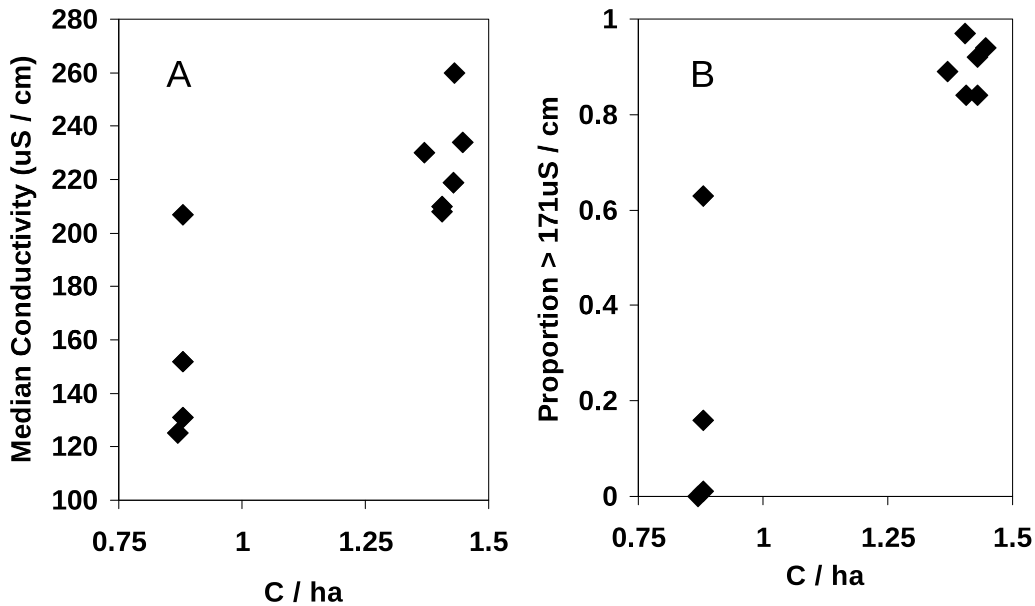
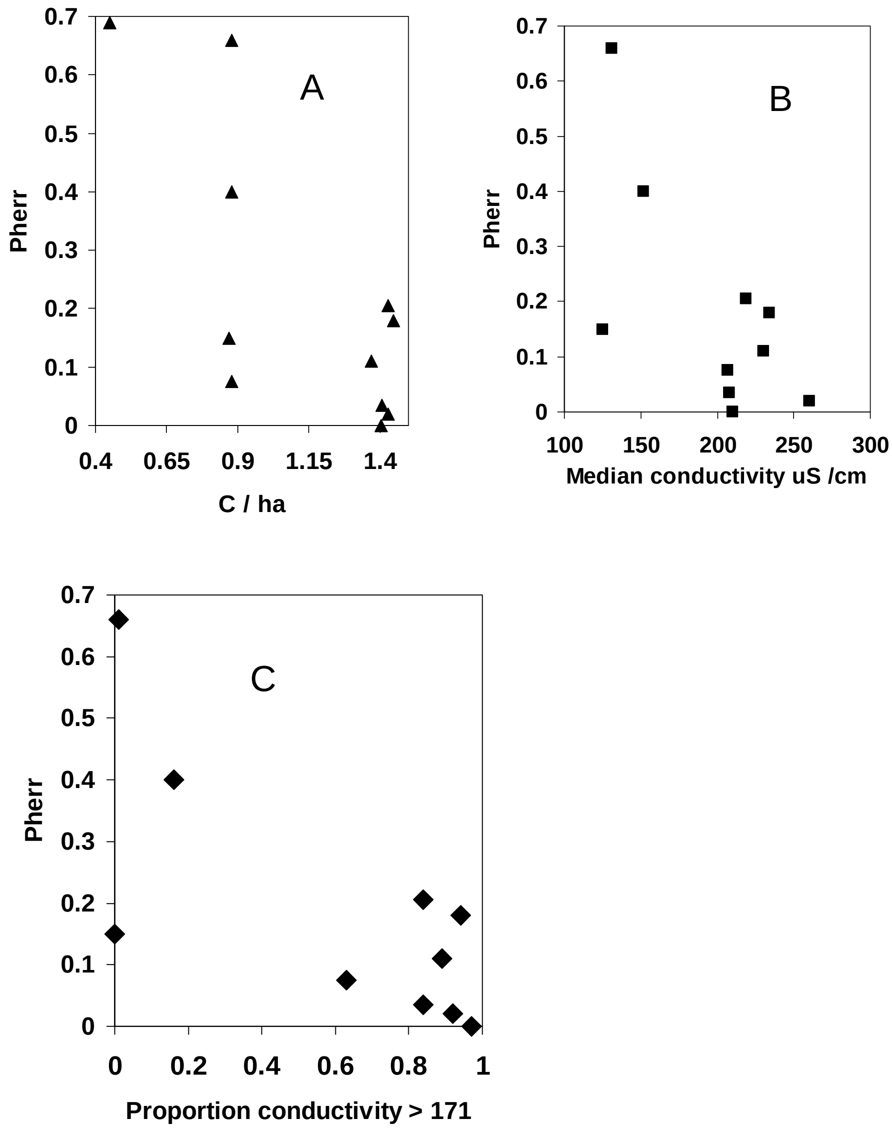


Figure 2-9. (A) Proportion of stream samples with herring eggs or larvae (P_{herr}) and level of development (C / ha). (B) Pherr and median spawning survey conductivity. (C) P_{herr} and proportion of conductivity measurements greater than 171 μS / cm.



Section 3 - Estuarine Yellow Perch Presence-Absence Sampling

Introduction

Presence-absence sampling for yellow perch larvae was conducted in the upper tidal reaches of the Nanticoke, Northeast, Elk, Bush, and Severn rivers and Mattawoman, Nanjemoy, and Piscataway creeks during late March through April, 2011 (Figure 3-1). Yellow perch larvae were readily identified in the field since they are larger and more developed than *Morone* larvae that could be confused with them (Lippson and Moran 1974). Annual L_p (proportion of tows with yellow perch larvae during a standard time period and where larvae would be expected) provided an economically collected measure of the product of egg production and egg through early postlarval survival. We used L_p as an index to detect “normal and abnormal” larval dynamics. We considered L_p estimates from subestuaries that were persistently lower than those measured in other subestuaries sampled since 1998 indicative of abnormally low survival. Remaining levels were considered normal.

We converted IS targets and thresholds outlined in Uphoff et al. (2011a) for summer habitat of juvenile and adult finfish to C / ha equivalents and evaluated how well C / ha equivalents to ISRPs applied to L_p during 1998-2011. Hilborn and Stokes (2010) advocated setting reference points for fisheries based on historical stock performance because they are based on experience, easily understood, and not based on modeling. In general, we expected poor L_p to prevail once the development threshold was exceeded and highest levels of L_p to occur at or below the development target.

Uphoff et al. (2011a) modified the target and limit (or threshold) convention that Caddy and McGarvey (1996) described for exploitation into a general ISRP framework for managing common estuarine resident species in Chesapeake Bay. The ISRPs were based on dissolved oxygen (DO) criteria and associations and relationships of IS, summer DO, and presence of indicator juvenile and adult finfish and blue crabs. The limit ISRP (10% IS) set a safe upper limit of watershed development and the target ISRP (5.5% IS) set a lower level of development which was desirable for maintaining habitat quality needed for fisheries (Uphoff et al. 2011a).

During 2010-2011, we sampled gut contents of yellow perch larvae to investigate whether feeding success and diet composition (1) were associated with 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; Miller et al. 1988; Heath1992.). In our analyses, we included factors in addition to C / ha: detritus load, larval length, mean water temperature, and mean conductivity. Years of high spring discharge favor anadromous fish recruitment in Chesapeake Bay (Hoffman et al. 2007; Martino and Houde 2010) and may represent episodes of hydrologic transport of accumulated detritus from watersheds that fuel zooplankton production and feeding success (McClain et al. 2003). Larval fish size is critical to larval feeding and starvation (Miller et al. 1988), while water temperature and conductivity have been important variables for larval dynamics of striped bass larvae in Chesapeake Bay (Uphoff 1989; 1992; Martino and Houde 2011). While Uphoff (1992), associated conductivity with toxic water quality episodes in Choptank River, it may also provide a measure of proximity to the Estuarine

Turbidity Maximum (ETM). The ETM is a region of elevated turbidity, suspended sediments, and organic matter found in Coastal Plain estuaries just before the salt front that supports retention and high production of zooplankton eaten by striped bass larvae (North and Houde 2001; 2003; Martino and Houde 2010). Higher feeding success at higher conductivity might indicate closer proximity to the ETM in brackish subestuaries.

Methods

Conical plankton nets were towed from boats 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. Temperature, conductivity, and salinity were measured at each site on each sample date.

Ten sites were sampled in Nanjemoy Creek, Mattawoman Creek, Severn River, Elk River, Northeast River, and Nanticoke River. Seven sites were sampled in Piscataway Creek (Figure 3-1). Elk and Northeast rivers were sampled once or twice a week and all other subestuaries except Severn River were sampled twice per week. Sampling in Severn River was sporadic due to unforeseen problems.

Larval sampling occurred during late March through mid-to-late April, 2011, in all systems except Bush River; sampling occurred through mid-May in Bush River. 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. The jar was allowed to settle and then the amount of detritus was assigned a rank:

0 = clear to not enough to define a layer;
1 = defined layer on bottom;
2 = more than defined layer and up to ¼ full;
3 =more than ¼ to ½ and;
4 = more than ½ full.

If a jar contained enough detritus to obscure examination for larvae, 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 and trained volunteers from the Anita Leight Estuary Center conducted sampling on Bush River. These volunteers had been instructed by project biologists on collection techniques and larval identification.

We collected composite samples of larvae from several sites on Piscataway, Mattawoman, and Nanjemoy creeks, and the Elk and Northeast rivers during several sample trips. A subsample of larvae 12 mm TL or less was examined for gut contents from each sample. These larvae represented first-feeding and early postlarvae, larvae that absorbed their yolk and began active feeding (Hardy 1978; Rogers and Westin 1981). Larvae were measured to the nearest millimeter. 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 as

$$L_p = N_{present} / N_{total};$$

where $N_{present}$ equaled the number of samples with yellow perch larvae present and N_{total} equaled the total number of samples taken. The SD of L_p was estimated as

$$SD = [(L_p \bullet (1- L_p)) / N_{total}]^{0.5} \text{ (Ott 1977).}$$

The 95% confidence intervals were constructed as

$$L_p \pm (1.96 \bullet SD; \text{ Ott 1977; Uphoff 1997).}$$

In general, sampling to determine L_p began during the last days of March or first days of April and ended after larvae were absent (or nearly so) for two consecutive sampling rounds. In years where larvae disappeared quickly, sampling rounds into the third week of April were included in analysis even if larvae were not collected. 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 2011, sampling began on March 29 in Piscataway, Mattawoman and Nanjemoy creeks, and they were sampled through April 21; samples through April 19 were used to estimate L_p. Sampling began on March 29 and April 6 in the Northeast and Elk rivers, respectively. Sampling of these two upper Bay rivers ended on May 10, and samples through April 22 were used to estimate L_p. Nanticoke River was sampled between April 1 and 29 and samples taken during April 6-29 were used to estimate L_p. Bush River was first sampled on March 29 and last sampled on May 9; dates between March 28 and April 29 were used for estimating L_p. Severn River collections were made during 2011, but equipment malfunctions and volunteer schedules reduced sampling for L_p to two dates (S. Barry, Arlington Echo, personal communication).

Historical collections in the Choptank and Nanticoke rivers targeted striped bass eggs and larvae (Uphoff 1997), but yellow perch larvae 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. During 1998-2004, 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 (1998-2010) 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 2011 and estimates for 2010 were substituted. Estimates of C / ha for 2010 were not available for Mattawoman and Piscataway creeks, and Nanticoke River; 2009 estimates were substituted (M. Topolski, MDDNR, personal communication).

Estimates of C / ha for the IS target and limit were estimated from the power function developed in Section 1 that converts C / ha to IS based on Towson University satellite data interpretation. The target proposed in Uphoff et al. (2011a), 5.5% IS, was reduced to 5% to meet IS guideline being developed by Maryland’s Department of Natural Resources (J. Uphoff, personal observation). The IS threshold of 10% in Uphoff et al. (2011a) remained unchanged. An estimate equivalent to 15% IS was also made to designate suburban watersheds that were developed well beyond the threshold.

Uphoff et al. (2010) determined that significant ($\alpha \le 0.05$) negative linear relationships existed for IS and L_p, but these relationships were different for fresh-tidal (< 2‰) and brackish tributaries ($\ge$ 2‰). Uphoff et al. (2011b) updated this linear regression analysis, but tested whether L_p was influenced by C / ha for these two salinity categories. We updated this analysis through 2011 in order to account for three data changes: (1) Nanjemoy Creek’s salinity classification was changed and (2) corrected Bush River estimates of C / ha; and (3) corrected Nanticoke River estimates of C / ha.

Nanjemoy Creek is positioned in a region of Potomac River between fresh-tidal and brackish subestuaries and it was classified as fresh-tidal in Uphoff et al. (2011b). Conductivity data summarized for analysis of feeding success during 2010 and 2011 (described below) indicated that Nanjemoy Creek was similar to Nanticoke River which was classified as brackish. Nanjemoy Creek was reclassified as a brackish system in this analysis. Levels of C / ha assigned to Bush River in Uphoff et al. (2011b) were in error and new estimates that included both APG (Aberdeen Proving Grounds) and non-APG portions of the watershed (M. Topolski, MD DNR, personal communication) were used. Estimates of C / ha were revised for Nanticoke River as well (M. Topolski, MD DNR, personal communication).

A two-stage regression approach was used to analyze data collected during 1998-2011. First, separate linear regressions of C / ha against L_p were estimated for brackish and fresh-tidal subestuaries. If the 95% CIs of slopes overlapped and the 95% CIs of the intercepts did not overlap, the multiple regression approach used in Uphoff et al. (2011b) was applied. This multiple regression of C / ha and salinity class against L_p assumed slopes were equal for two subestuary salinity categories, but intercepts were different (Freund and Littell 2006). Salinity was modeled as an indicator variable in the multiple regression, 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 level of development. Table 3-1 presents data used in these regressions. Level of significance was set at $\alpha \le 0.05$. Residuals were inspected for trends, non-normality and need for additional terms. Vertical reference lines were added to the plot of observed and predicted L_p and C / ha that depicted C / ha representing 5% IS, 10% IS, and 15% IS. These sets of vertical lines delineated C / ha indicating rural watersheds (target IS of 5% or less), a developing watershed (greater than 5% IS target, but less than the 10% IS threshold), a watershed at the suburban threshold (10% IS), and a well-developed suburban watershed (15% IS).

An additional view of the relationship of L_p and C / ha was developed by including salinity classification (brackish or fresh-tidal) and dominant land use classification in the plots of L_p and C / ha. Watershed estimates of L_p were classified by predominant land cover type (urban, agriculture, or forest representing the largest acreage in the watershed) estimated for 1994 by Maryland's Department of Planning (MD DNR 1999). Urban land consisted of high and low density residential, commercial, and institutional acreages (MD DNR 1999). Four classifications were represented in the 1998-2011 data: fresh-tidal subestuary with predominant forest cover, brackish subestuary with predominant forest cover, brackish subestuary with predominant agriculture, and brackish subestuary with predominant urban land cover. Vertical reference lines were added to the plot of observed and predicted L_p and C / ha that depicted C / ha representing 5% IS, 10% IS, and 15% IS as described above.

The mean of feeding success rank was calculated annually for each subestuary sampled in 2010-2011, as was mean total length (TL in mm) of larvae. The proportion of guts without food (P0) was estimated for each subestuary 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 with mean feeding rank, P0, mean TL, P_{cope}, P_{clad}, and P_{othr} (2010-2011 estimates) were tested with correlation analysis. Correlations of L_p with P0 and mean feeding rank were used to evaluate whether larval relative abundance was associated with feeding success. An additional set of correlation analyses examined associations among mean feeding success rank, mean TL, P_{cope}, P_{clad}, and P_{othr}.

We used detritus P0 (proportion of samples without detritus, i.e., rank = 0) as our indicator of detritus availability and correlated detritus P0 against C / ha and feeding parameters that were significantly associated with C / ha. The distribution of detritus ranks assigned to samples in 2011 was highly skewed towards zero and few ranks greater than 1 were reported. Detritus P0 was estimated for 2011, so correlation analyses were confined to 2011 data.

We used logistic regression to determine if C / ha, larval total length (TL, mm), mean water temperature (°C), and mean conductivity (µS / cm) influenced odds of feeding ranks (0-4) being attained during 2010-2011 (SAS 1995; Wright 1998). A model with all parameters was initially run and, if variables were not significant at $\alpha \leq 0.05$, a reduced model using the remaining significant variables was run. Mean water temperature and conductivity for dates that samples of larvae were collected from subestuaries were used. Estimates of C / ha for 2009 or 2010 were used depending on availability. Individual measurements of TL were analyzed. 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. Proc Logistic in SAS was used for analyses (SAS 1995).

Level of significance was set at $\alpha \leq 0.05$. An additional set of logistic regressions reduced the feeding categories to 0 or 1 (gut without or with food, respectively) and used the factors and analytical strategy described above. This model estimated the odds ratios of factors influencing whether food was present (food presence = 1).

Results

Based on 95% CIs, all estimates of L_p during 2011 were judged sufficiently precise to detect significant differences among subestuaries (Figure 3-2). Estimates of L_p for brackish subestuaries (Nanjemoy Creek and Nanticoke River) bracketed estimates for fresh-tidal subestuaries (Mattawoman and Piscataway creeks, and Elk, Northeast, and Bush rivers; (Figure 3-2). Yellow perch larvae were not captured during the two sample cruises (S. Barry, Arlington Echo, personal communication). Due to low sampling effort, we do not interpret this as an absence of yellow perch larvae in Severn River, but it is consistent with very low L_p estimated there during the past three years.

Western shore brackish subestuaries with small watersheds and high IS (South, Severn, and Magothy rivers) have exhibited a persistent depression in L_p, while remaining systems have exhibited extensive variation (Figure 3-3). These suburban western shore subestuaries have consistently ranked low (from 18th to 29th out of 29 estimates). Estimates of C / ha for these watersheds were greater than 1.6 while remaining brackish subestuaries had levels of C / ha less than 0.27 (Table 3-1). Maximum L_p (0.33) for subestuaries exhibiting persistent depression (four subestuaries, ten estimates) was chosen as a threshold indicating serious deterioration of brackish subestuary larval nursery habitat. Estimates of L_p would need to be consistently at or below this level to be considered "abnormal" as opposed to occasional depressions exhibited by rural subestuaries such as the Choptank and Nanticoke rivers (Figure 3-3).

Similarly, fresh-tidal Piscataway Creek's four estimates of L_p (2008-2011) consistently ranked low when compared to other fresh-tidal subestuaries sampled (13th to 17th out of 17 estimates; Figure 3-4). The maximum for Piscataway Creek's four estimates, $L_p = 0.65$, was chosen as a threshold indicating serious deterioration of fresh-tidal larval habitat. Estimates of L_p would need to be consistently at or below this level rather than occasional incursion exhibited by less developed fresh-tidal subestuaries such as the Bush and Northeast rivers (Figure 3-4).

Estimates of C / ha that were equivalent to 5% IS, 10% IS, and 15% IS were estimated as 0.27, 0.83, and 1.59 C / ha, respectively.

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 (Table 3-3). The mean slopes for C / ha estimated for fresh-tidal subestuaries were steeper, but 95% CI's overlapped CI's estimated for slopes of brackish subestuaries (Table 3-3).

Overall, the multiple regression approach offered a better fit (Table 3-3). The range of C / ha values available for analysis was greater in brackish subestuaries (0.07-2.74) than fresh-tidal (0.41-1.43; Figure 3-5). Predicted L_p over the observed ranges of C / ha would decline from 0.58 to 0.10 in brackish subestuaries and from 0.85 to 0.67 in fresh-tidal subestuaries (Figure 3-5). A plot of residuals against C / ha indicated that fresh-tidal Piscataway Creek (C / ha $\approx$ 1.4) may not have conformed to a model of linear changes with development (Figure 3-6). Residuals for the four Piscataway Creek points were always negative, while other watersheds sampled in multiple years had both positive and negative residuals (Figure 3-6).

The plot of L_p against C / ha that included salinity (brackish or fresh-tidal) and dominant land use (urban, agriculture, or forest) classifications indicated that (1) predominantly urban watersheds had the lowest L_p estimates, (2) forest cover may provide some positive benefit at higher levels of development, and (3) agriculture may have a negative impact on L_p at low levels of development (Figure 3-7). Consistently low L_p (range = 0.03-0.33, mean = 0.20) occurred at C / ha of 1.59 or greater (~ 15% IS), even when forest cover was the predominant land use at 1.59 C / ha. Urban land cover was the dominant classification for observations beyond 1.59 C / ha. At target levels of development (< 0.27 C / ha or < 5% IS), the lone brackish watershed dominated by forest cover (Nanjemoy Creek) exhibited L_p (range = 0.83-0.99) that was at or in excess of the highest estimates of the four predominantly agricultural watersheds sampled (L_p range = 0.19-0.83, mean = 0.50). Three of 17 L_p estimates from agricultural watersheds were below the maximum L_p estimate of the urban watersheds. Fresh-tidal subestuary watersheds dominated by forest cover between the target and threshold levels of development (0.83 C / ha) and beyond to 1.40 C / ha exhibited variable L_p (range = 0.39–0.83, mean = 0.75) that was higher on average than less developed agricultural watersheds. Estimates of L_p from forested fresh-tidal subestuary watersheds declined sharply between 1.20 and 1.40 C / ha (Figure 3-7).

A total of 332 larval guts were examined during 2010 and 532 were examined in 2011. Guts contained food in all years and subestuaries except Piscataway Creek during 2011 (Table 3-3). Copepods were the most prevalent food item and were found in 51-100% of guts sampled. Cladocerans were found in 71% of guts in the Nanticoke River and 0-22% of guts in the remaining year and subestuary combinations. The “other” food item category represented in a high fraction of guts in Piscataway Creek (53%) in 2010 and 1-30% of guts in remaining subestuaries during 2010-2011. The percentage of guts without food ranged from 0 to 19% in all subestuary and year combinations except in Mattawoman and Piscataway creeks during 2011 (42% and 100%, respectively). Mean fullness rank ranged between 1.9 and 2.3 in all subestuary and year combinations except Mattawoman and Piscataway creeks during 2011 (0.9 and 0.0, respectively; Table 3-2).

Strong associations of C / ha with P_{cope} (r = -0.79, α = 0.0004), P0 (r = 0.64, α = 0.03), and mean fullness (r = -0.75, P = 0.008) were detected. Importance of copepods was indicated by strong associations of P_{cope} with P0 (r = -0.94, α < 0.0001) and mean fullness rank (r = 0.94, α < 0.0001; Table 3-4). Mean fullness rank was strongly and negatively associated with P0 (r = -0.90, α = 0.0002). Remaining variables were not significantly associated (Table 3-4). Estimates of L_p were not significantly associated with P0 (r = -0.02, α = 0.95) or mean fullness rank (r = -0.19, α = 0.57).

Estimates of detritus P0 ranged from 0.56 to 1.00 (Table 3-2). An estimate of detritus P0 from Bush River was included in the correlation analysis with C / ha (N = 7), but indicators of feeding success and food type from there were not available (remaining analyses N = 6). The proportion of samples without detritus was significantly associated with C / ha (r = 0.97, α = 0.0002), P_{cope} (r = -0.86, α = 0.027), P0 (r = 0.90, α = 0.014), and mean fullness rank (r = -0.83, α = 0.043).

Summarized temperature and conductivity data used as predictor variables in logistic regressions are presented in Table 3-5. Larval TL and C / ha were significant influences on the odds of yellow perch larvae attaining a feeding rank in the full model, but temperature and conductivity were not (analysis not shown). In the reduced model, TL positively influenced the odds of attaining a feeding rank (α = <0.0009), while C / ha was a negative influence (α = <0.0001). Levels of significance of the intercepts indicated that the model could distinguish the cumulative probabilities of ranks 1-3 (rank = 3; α < 0.0009) or 1-4 (rank = 4; α < 0.0001) being different than 0. While the level of significance was less than α = 0.03 for rank = 1, it was not significant at α < 0.05 for rank = 2. This inconsistency indicated that only the highest feeding ranks (feeding = 3 or 4) could be interpreted as meaningful. Maximum rescaled R^2 was 0.15, indicating that other factors or individual history (location, success in feeding previously, etc) greatly influenced feeding success. Predictive ability of the model was modest; 63% of larval fullness ranks were successfully classified and 34% were classified incorrectly (Table 3-6).

Temperature, TL, and C / ha were significant variables in the full model that treated feeding as binomial data (gut with or without food), but conductivity was not (analysis not shown). The predictive ability of the reduced binomial feeding model was better than that of the previously described model using feeding ranks: 75% of larval fullness ranks were successfully classified and 24% were classified incorrectly (Table 3-7). Maximum rescaled R^2 equaled 0.20. Development (C / ha) was a negative influence (α < 0.0001) on whether larvae fed or not, while larval length (α = 0.0009) and water temperature (α = 0.026) were positive influences (Table 3-7).

Discussion

Development was an important influence on yellow perch larval dynamics and negative changes in these dynamics generally conformed to ISRP guidelines in Uphoff et al. (2011a). Once development exceeded the threshold level (0.83 C / ha or 10% IS) and increased towards a more developed suburban landscape (1.59 C / ha or 15% IS), declines in L_p and feeding success became evident. Estimates of L_p from agricultural watersheds below the target level of development ($\leq$ 0.27 C / ha or 5% IS) were variable, but higher on average than suburban watersheds. Feeding success in the lone agricultural drainage studied during 2011 (Nanticoke River) was as high as in the six forested watersheds. There was some suggestion that extensive forest cover in a watershed was more beneficial for L_p than agriculture or development.

We recommend interpreting influences of land cover classifications on L_p cautiously due to minimal variation of land use within salinity classifications. Our “experimental design” was limited to patterns of development that exist. All estimates of L_p at or below target levels of development (0.27 C / ha or 5% IS; forested and agricultural watersheds) or at and beyond high levels of development (1.59 C / ha or 15% IS; urban watersheds) were from brackish subestuaries; estimates of L_p for development between these levels were from fresh-tidal subestuaries with forested watersheds. Larval dynamics at the target level of development primarily reflected Eastern Shore agricultural watersheds. We need L_p estimates from below target development, agricultural, fresh-tidal watersheds and forested, brackish watersheds, with development between the target and threshold. We are unsure that these combinations exist where yellow perch spawning occurs.

Land use estimates for 1994 were used for classifications in Figure 3-7 and it is probable that dominant land use shifted in some watersheds – most likely from forested to urban at higher levels of C / ha. Preliminary analysis of 2010 land cover data from the Maryland Department of Planning indicated that three watersheds designated as forested between 1.2 and 1.6 C / ha would be reclassified as urban (South River, Piscataway Creek, and Bush River). All others primary land covers would remain the same.

Assuming catchability does not change greatly from year to year, egg production and egg through early postlarval survival would need to be high to produce strong L_p, but only one factor needed to be low to result in lower L_p. Abnormal dynamics were indicated by persistently low levels of L_p in subestuaries with suburban watersheds. Low L_p occurred sporadically in less developed systems. In brackish subestuaries, persistently low L_p estimates were confined to suburban western shore brackish subestutaries located in the Baltimore - Washington, DC, corridor (Severn, South, and Magothy rivers). It is unlikely that low L_p had always existed in these tributaries since all supported productive and largely unregulated recreational fisheries into the 1970s (the C / ha threshold was met in Severn River during 1972) and hatching rates of eggs in a Severn River yellow perch hatchery were high into the 1950s, the end of the period of record (Uphoff et al. 2005). Egg hatching success of Severn River yellow perch had declined drastically by the early 2000s and estimates of L_p were low (Uphoff et al. 2005). Piscataway Creek was the only fresh-tidal subestuary exhibiting persistently low L_p (relative to other fresh-tidal systems) and it was more developed than the other fresh-tidal subestuaries sampled. However, Piscataway Creek was not as developed as the suburban western shore brackish subestuaries and mean L_p in Piscataway Creek during 2008-2011 (0.51) was very close to that of agricultural subestuaries with watersheds in the target region of development.

High estimates of L_p that were equal to or approaching 1.0 have been routinely encountered and it is likely that counts would be needed to measure relative abundance if greater resolution was desired. Mangel and Smith (1990) indicated that presence-absence sampling of eggs would be more useful for indicating the status of depleted stocks and count-based indices would be more accurate for recovered stocks. Larval indices based on counts have been used as a measure of year-class strength generally (Sammons and Bettoli 1998) and specifically for yellow perch (Anderson et al. 1998). Additional discussion of presence-absence sampling characteristics can be found in the Section 2-1 Discussion.

Characterizations of larval survival normally are derived from count data that requires labor-intensive bench sorting. Estimates of L_p were largely derived in the field and only gut contents required laboratory analysis. Gut content analysis represented a separate study rather than a requirement for estimating L_p. Tighter budgets necessitate development of less costly indicators of larval survival in order to pursue ecosystem-based fisheries management.

The lack of significant correlations of L_p with feeding success indicated that L_p should not be considered as an indicator of the effect of food-related larval processes. Newly hatched larvae or newly feeding larvae of fish are more sensitive to toxic water quality conditions than other stages (Peterson 1982) and low L_p and could indicate survival related to those conditions.

Feeding success could impact survival of larger larvae not well sampled by the 0.5 m nets we used to determine L_p. Zooplankton supply (cladocerans and copedpods) for first-feeding yellow perch larvae has been identified as an influence on survival in Lake Michigan (Dettmers et al. 2003; Redman et al. 2011; Weber et al. 2011), Canadian boreal lakes (Leclerc et al. 2011), and survival of European perch *Perca fluviatis* in the Baltic Sea (Ljunggren et al. 2003). 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 (North and Houde 2001; 2003; Hoffman et al. 2007; Martino and Houde 2010). Yellow perch larvae share habitat in Chesapeake Bay with striped bass and white perch (J. Uphoff, personal observation), but little has been published on larval yellow perch dynamics and feeding ecology in the Bay (Uphoff 1991).

Feeding success decreased as C / ha increased, but annual variability in both P0 and mean fullness rank was much greater at the two highest levels of development (0.88 and 1.41 C / ha than at the lower levels (Figure 3-8). During 2010, P0 estimates for the watersheds over the development threshold were within the range exhibited by less developed watersheds and mean fullness rank was slightly lower. During 2011, feeding success was much less at C / ha = 0.88 and sampled larvae did not obtain food at C / ha = 1.41 (Figure 3-8). It is difficult to know what level of feeding success might indicate starvation, but it seems nearly certain when all larvae examined from a system do not obtain food.

In our analyses, we assumed that mainstem Potomac or Susquehanna River water was not a major influence on subestuary water quantity, water quality, and zooplankton supply. Sampling for yellow perch larvae occurred in the upper portions of subestuaries and this should have minimized the influence of mainstem waters, although some intrusion would have been possible at the most downstream sites in the smallest systems closest to the major rivers (i.e., Piscataway Creek for the Potomac River and Northeast River for the Susquehanna River). The strong associations of L_p, feeding success, and presence of copepods in larval guts with watershed development indicated that local conditions prevailed.

Estimates of mean conductivity in subestuaries sampled during 2010-2011 (Table 3-5) offered further evidence that local conditions were captured. Increases in stream conductivity have been strongly associated with urbanization (Wang and Yin 1997; Paul and Meyer 2001; Wenner et al. 2003; Morgan et al. 2007; Carlisle et al. 2010) and has been noted in anadromous fish spawning streams in Maryland's portion of Chesapeake Bay (see Section 2-1). Mean daily conductivities (219-249 μS / cm) in fresh-tidal Piscataway Creek's subestuary were elevated over those of fresh-tidal Mattawoman Creek's subestuary (range = 139-182 μS / cm) in spite of Piscataway Creek's upstream location on the Potomac River. In 2010, mean conductivities at two Chesapeake Bay Program monitoring stations corresponding to the mouths of Piscataway and Mattawoman creeks averaged 211-212 μS / cm (once-monthly measurements at six depths during March and April; W. Romano, MD DNR, personal communication). Elevated conductivity in Piscataway Creek indicated that urbanization impacted estuarine water quality as well as stream water quality.

Yellow perch feeding success during 2011 was highly correlated with presence of detritus (organic matter or OM). Stable isotope signatures of York River, Virginia, American shad larvae and zooplankton indicated that terrestrial OM largely supported one of its most successful year-classes. Lesser year-classes of American shad on the York

River were associated with low flows, OM largely based on phytoplankton, and lesser zooplankton production (Hoffman et al. 2007). High flows provided a large subsidy of OM from the York River's watershed to the estuary that fueled higher 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. (2011a) found that the percentage of Maryland's Chesapeake Bay subestuary watersheds in wetlands declined hyperbolically as IS increased, so this source of OM diminished with development. It is possible that the influence of forest cover suggested in Figure 3-7 was reflected in the levels of OM observed during 2011. All of the subestuaries sampled during 2011, except Nanticoke River, were forest dominated. Percent wetland was much higher in Nanticoke River (16%) than in the remaining subestuary watersheds (<6%; MD DNR 1999) and could account for the high detritus indices there.

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).

We applied the empirical-statistical approach recommended by Austin and Ingham (1978) and Crecco and Savoy (1984, 1987) for resolving the effects of environment on fish recruitment to evaluate the role of development on yellow perch larval dynamics. They recommended offering a working hypothesis and then testing the validity with empirical data and a thorough statistical analysis. In our case, we were looking at the hypothesis that development negatively influenced two processes that can be important for yellow perch year-class formation (egg-larval survival and feeding success of first-feeding larvae) rather than year-class success itself.

We used a general indicator of development (C / ha) in our analyses because negative effects of development involved multiple stressors difficult to isolate. Effects of multiple stressors are usually worse than the worst single stressor alone (Breitburg et al. 1998; Folt et al. 1999). Studies of yellow perch larval dynamics to date have suggested that development may affect yellow perch eggs and larval habitat through altered hydrologic features and water quality in spawning streams, lethal levels of salinity in suburban subestuary nurseries, reduced terrestrial input of OM, and reduced zooplankton abundance (Uphoff et al. 2005; Uphoff et al. 2010; 2011b). Significant PCB concentrations in white perch were closely related to IS in 14 Chesapeake Bay subestuaries (King et al. 2004) and chemicals such as PCBs transferred from the mother are associated with depressed survival of larvae (Westin et al. 1985; Longwell et al. 1996). Depressed egg and larval viability observed in developed brackish subestuaries may be an outcome of extensive exposure of adults to inadequate dissolved oxygen during the previous summer as ovaries of yellow perch are repopulated with new germ cells (Uphoff et al. 2005). Histologic examination of ovaries and testes suggested a lack of final maturation of the oocytes and proliferation of Leydig cells (interstitial cells involved in synthesis of testosterone) in yellow perch from the Severn and South rivers that varies annually (V.Blazer, U.S. Geological Survey, personal communication). Monitoring of pharmaceuticals and other chemicals of emerging concern that may affect pathways that regulate these cellular changes are underway (V.Blazer, U.S. Geological Survey, personal communication).

Table 3-1. Estimates of proportions 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	0.18	1
2004	Choptank	0.41	0.12	1
2004	Severn	0.29	2.09	1
2005	Nanticoke	0.67	0.19	1
2005	Severn	0.33	2.15	1
2006	Nanticoke	0.35	0.19	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	0.19	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	0.19	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	0.20	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 3-1 (continued).

Year	Subestuary	L_p	Counts / ha	Salinity class
2010	Mattawoman	0.82	0.88	0
2010	Severn	0.03	2.25	1
2010	Nanjemoy	0.96	0.09	1
2010	Piscataway	0.54	1.43	0
2010	Northeast	0.68	0.41	0
2010	Elk	0.75	0.56	0
2011	Nanticoke	0.52	0.20	1
2011	Mattawoman	0.99	0.88	0
2011	Severn		2.25	1
2011	Nanjemoy	0.99	0.09	1
2011	Piscataway	0.65	1.43	0
2011	Northeast	1	0.41	0
2011	Elk	0.65	0.56	0
2011	Bush	0.96	1.21	0

Table 3-2. Summary of results of regressions of proportions of tows with yellow perch larvae (L_p) and counts of structures per hectare (C / ha). Separate regressions by salinity (tidal-fresh ≤ 2.0 ‰ and brackish > 2.0 ‰) and a multiple regression using salinity as a class variable (tidal-fresh = 0 and brackish = 1) are presented.

ANOVA	Brackish					
	df	*SS*	*MS*	*F*	*Significance F*	
Regression	1	0.847539517	0.84754	19.43212	0.000149234	
Residual	27	1.177615299	0.043615			
Total	28	2.025154816				
r^2	0.42					
	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*
Intercept	0.585	0.050	11.75442	3.98E-12	0.482878201	0.687108986
Slope C / ha	-0.173	0.039	-4.40819	0.000149	-0.253320884	-0.09240138

ANOVA	Fresh-tidal					
	df	*SS*	*MS*	*F*	*Significance F*	
Regression	1	0.138965594	0.138966	4.691428	0.046833903	
Residual	15	0.444317557	0.029621			
Total	16	0.583283151				
r^2	0.24					
	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*
Intercept	1.008411451	0.128047054	7.875319	1.04E-06	0.735485617	1.281337285
Slope C / ha	-0.260922062	0.120464274	-2.16597	0.046834	-0.517685582	-0.00415854

ANOVA	Brackish and fresh-tidal salinity (Sal) categories (1 and 0, respectively)					
	df	*SS*	*MS*	*F*	*Significance F*	
Regression	2	1.928075539	0.964038	25.32758	5.39064E-08	
Residual	43	1.636699156	0.038063			
Total	45	3.564774695				
R^2	0.54					
	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*
Intercept	0.925861463	0.059186921	15.64301	2.34E-19	0.806499662	1.045223264
Slope C / ha	-0.178772978	0.035381587	-5.05271	8.52E-06	-0.250126747	-0.10741921
Salinity	-0.336165537	0.060053521	-5.59777	1.4E-06	-0.457275003	-0.21505607

Table 3-3. Summary of estimates used in correlation analysis of yellow perch larval feeding success. C / ha = counts of structures per acre. P0 = 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. *N* = number of yellow perch larvae examined. Detritus P0 = proportion of samples with detritus. Bush River data were available for analysis of detritus, but not feeding success.

Subestuary	Year	C/ha	Mean fullness	P0	P Cladocera	P Copepod	P Other	Mean TL	Detritus P0	*N*
Elk	2010	0.56	2.7	0.05	0.02	0.95	0.13	11.1		110
Mattawoman	2010	0.88	2.0	0.09	0.15	0.78	0.09	9.2		55
Nanjemoy	2010	0.09	2.9	0.00	0.10	1.00	0.15	9.1		48
Northeast	2010	0.41	2.3	0.19	0.22	0.72	0.30	8.4		64
Piscataway	2010	1.43	1.9	0.13	0.00	0.55	0.53	9.4		55
Elk	2011	0.56	2.8	0.08	0.00	0.96	0.01	8.9	0.76	90
Mattawoman	2011	0.88	0.9	0.42	0.02	0.51	0.07	9.3	0.78	110
Nanjemoy	2011	0.09	2.2	0.07	0.03	0.83	0.20	9.0	0.56	150
Nanticoke	2011	0.20	3.3	0.08	0.71	0.92	0.16	8.6	0.55	51
Northeast	2011	0.56	2.4	0.08	0.00	0.91	0.09	8.3	0.58	90
Piscataway	2011	1.43	0.0	1.00	0.00	0.00	0.00	8.4	1.00	32
Bush	2011	1.21							0.92	

Table 3-4. Correlation matrix of feeding success (P0 and Mean full) food item presence (P Cladocera, P Copepod, and P other) ,and mean TL of yellow perch larvae during 2010-2011. Abbreviations and labels are defined in Table 3-3; *r* = correlation coefficient and *P* = level of significance.

Parameter	Statistic	P0	P Cladocera	P Copepod	P Other	Mean TL
Mean_full	r	-0.90	0.45	0.94	0.16	0.16
	P	0.0002	0.16	<.0001	0.63	0.63
Po	r		-0.21	-0.94	-0.32	-0.28
	P		0.54	<.0001	0.33	0.41
P Cladocera	r			0.26	0.06	-0.24
	P			0.4381	0.8528	0.4702
P Copepod	r				0.02	0.24
	P				0.95	0.48
P Other	r					0.09
	P					0.79

Table 3-5. Variables, summarized by date, used in logistic regression models of factors influencing larval yellow perch feeding success. Temperature (water temperature in °C) and Conductivity (μS / cm) are means for sites sampled on the date.

Subestuary	Year	Date	Temperature	Conductivity
Nanjemoy	2011	7-Apr	13.4	795
Nanjemoy	2011	12-Apr	17.5	886
Nanjemoy	2011	14-Apr	17.5	886
Nanjemoy	2011	19-Apr	17.1	961
Mattawoman	2011	7-Apr	14.3	179
Mattawoman	2011	12-Apr	17.7	182
Mattawoman	2011	14-Apr	17.7	182
Mattawoman	2011	19-Apr	16.6	144
Piscataway	2011	14-Apr	15.5	219
Elk	2011	15-Apr	15.7	222
Elk	2011	19-Apr	13.7	273
Elk	2011	22-Apr	13.3	225
Northeast	2011	15-Apr	14.4	193
Northeast	2011	19-Apr	13.2	165
Northeast	2011	22-Apr	14.1	170
Nanticoke	2011	11-Apr	13.1	1266
Nanticoke	2011	25-Apr	18.2	1021
Nanticoke	2011	29-Apr	21.4	647
Nanjemoy	2010	6-Apr	20.3	407
Nanjemoy	2010	13-Apr	18.3	314
Mattawoman	2010	6-Apr	20.8	139
Mattawoman	2010	8-Apr	22.0	151
Piscataway	2010	6-Apr	19.0	235
Piscataway	2010	8-Apr	20.9	234
Piscataway	2010	13-Apr	17.3	249
Elk	2010	14-Apr	15.7	272
Elk	2010	6-May	22.5	279
Northeast	2010	6-Apr	18.3	171
Northeast	2010	14-Apr	15.7	191

Table 3-6. 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. 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).

Response Profile

Ordered Value	Fullness	Total Frequency
1	4	225
2	3	171
3	2	152
4	1	174
5	0	132

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
15.4028	6	0.0173

Model Fit Statistics

Criterion	Intercept Only	Intercept and Covariates
AIC	2729.518	2605.485
SC	2748.517	2633.985
-2 Log L	2721.518	2593.485

Table 3-6 continued.

R-Square 0.1392 Max-rescaled R-Square 0.1452

Testing Global Null Hypothesis: BETA=0

Test	Chi-Square	DF	Pr > ChiSq
Likelihood Ratio	128.0326	2	<.0001
Score	114.9817	2	<.0001
Wald	124.6301	2	<.0001

Analysis of Maximum Likelihood Estimates

Parameter		DF	Estimate	Standard Error	Wald Chi-Square	Pr > ChiSq
Intercept	4	1	-2.1959	0.3813	33.1624	<.0001
Intercept	3	1	-1.2446	0.3760	10.9587	0.0009
Intercept	2	1	-0.4317	0.3742	1.3310	0.2486
Intercept	1	1	0.8289	0.3781	4.8078	0.0283
C_ha		1	-1.7123	0.1641	108.9262	<.0001
Length		1	0.2158	0.0404	28.5045	<.0001

Odds Ratio Estimates

Effect	Point Estimate	95% Wald Confidence Limits	
C_ha	0.180	0.131	0.249
Length	1.241	1.146	1.343

Table 3-6 continued

Association of Predicted Probabilities and Observed Responses

Percent Concordant	63.4	Somers' D	0.292
Percent Discordant	34.3	Gamma	0.299
Percent Tied	2.3	Tau-a	0.232
Pairs	289323	c	0.646

Table 3-7. Summary of results of the logistic regression of presence or absence of food in yellow perch larval guts against counts of structures per hectare (C / ha) and larval length (mm) from SAS Proc Logistic. Model indicates odds ratio for food being present.

Response Profile

Ordered Value	Feed	Total Frequency
1	1	722
2	0	132

Probability modeled is Feed=1.

Model Convergence Status

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

Model Fit Statistics

Criterion	Intercept Only	Intercept and Covariates
AIC	737.378	635.914
SC	742.128	654.914
-2 Log L	735.378	627.914

R-Square 0.1182 Max-rescaled R-Square 0.2048

Table 3.7 continued.

Testing Global Null Hypothesis: BETA=0

Test	Chi-Square	DF	Pr > ChiSq
Likelihood Ratio	107.4643	3	<.0001
Score	110.6589	3	<.0001
Wald	92.1600	3	<.0001

Analysis of Maximum Likelihood Estimates

Parameter	DF	Estimate	Standard Error	Wald Chi-Square	Pr > ChiSq
Intercept	1	-0.5667	0.8661	0.4281	0.5129
C_ha	1	-2.4454	0.2670	83.9035	<.0001
Length	1	0.2515	0.0760	10.9632	0.0009
Temperature	1	0.0992	0.0444	4.9925	0.0255

Odds Ratio Estimates

Effect	Point Estimate	95% Wald Confidence Limits	
C_ha	0.087	0.051	0.146
Length	1.286	1.108	1.492
Temperature	1.104	1.012	1.205

Table 3-7 continued.

Association of Predicted Probabilities and Observed Responses			
Percent Concordant	75.0	Somers' D	0.511
Percent Discordant	23.9	Gamma	0.517
Percent Tied	1.1	Tau-a	0.134
Pairs	95304	c	0.755

Figure 3-1. Sampling areas for the 2011 yellow perch larval presence absence study. Nanticoke River watershed delineation was unavailable for Delaware and Northeast and upper Elk River were unavailable for Pennsylvania.

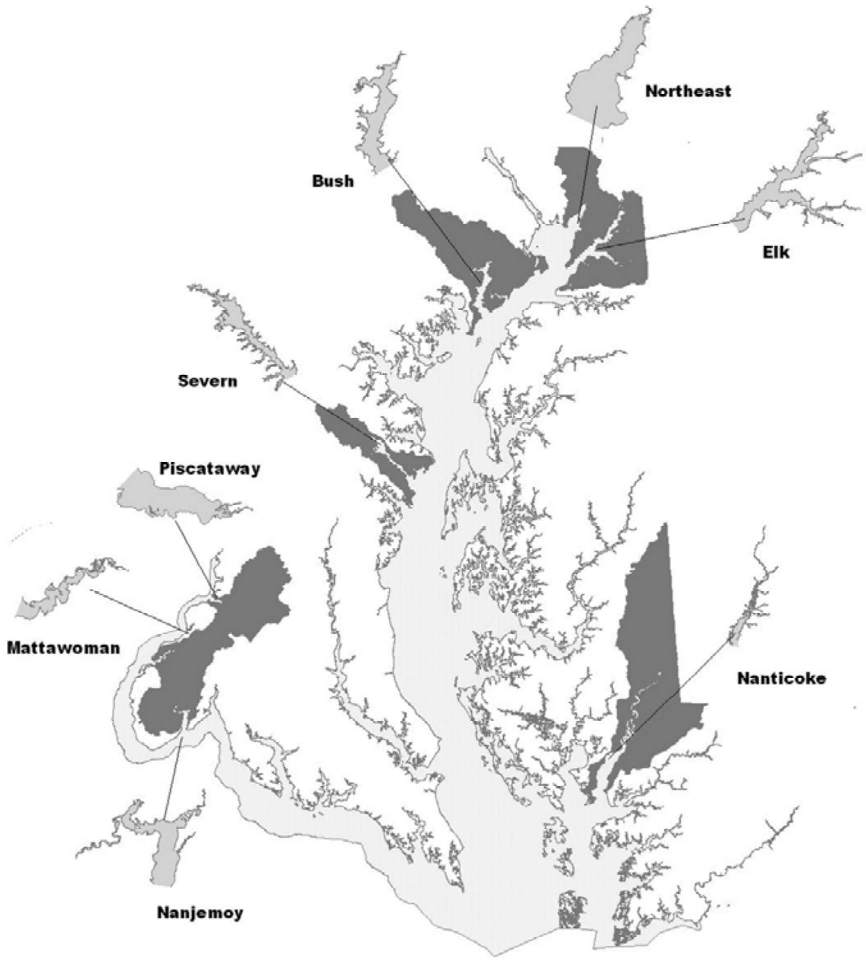


Figure 3-2. Proportion of tows with larval yellow perch (L_p) and its 95% confidence interval in systems studied during 2011. Mean Lp of brackish tributaries indicated by diamond and fresh-tidal mean indicated by dash.

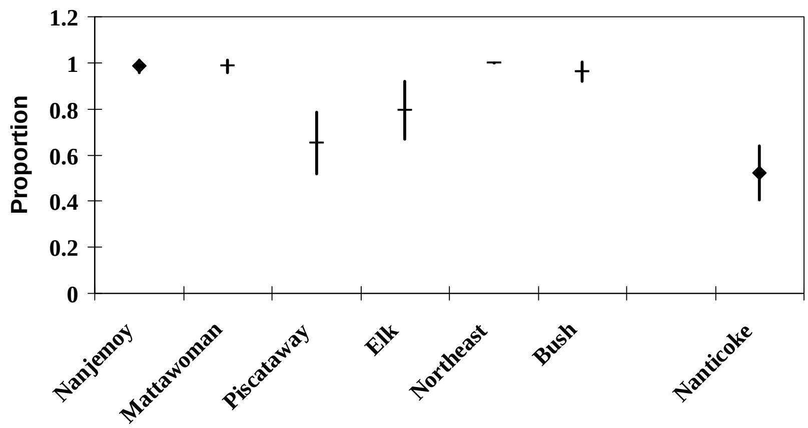


Figure 3-3. Proportion of tows with yellow perch larvae (L_p) for brackish subestuaries, during 1965-2011. Dotted line provides reference for persistent poor Lp exhibited in developed brackish subestuaries.

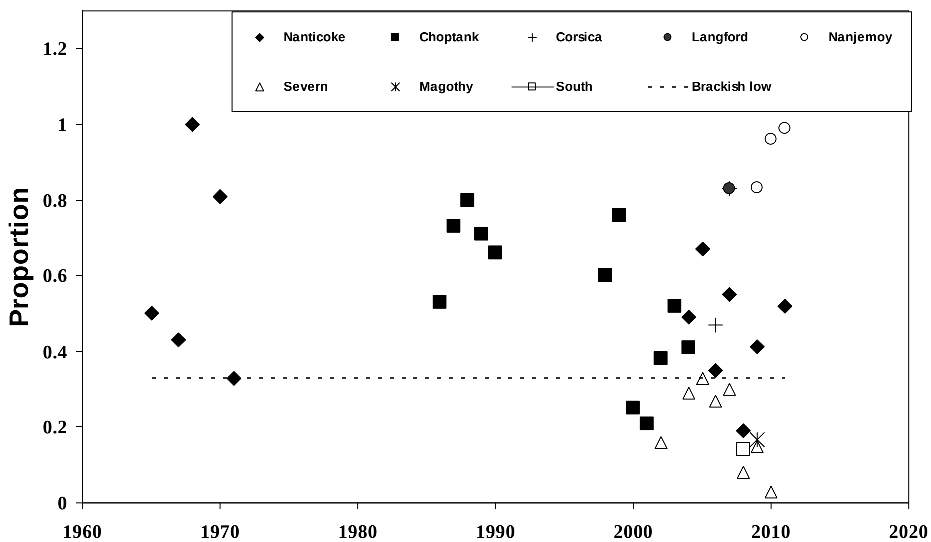


Figure 3-4. Proportion of tows with yellow perch larvae (*Lp*) for fresh-tidal subestuaries, during 1990-2011. Dotted line provides reference for consistent poor *Lp* exhibited in a more developed fresh-tidal subestuary (Piscataway Creek).

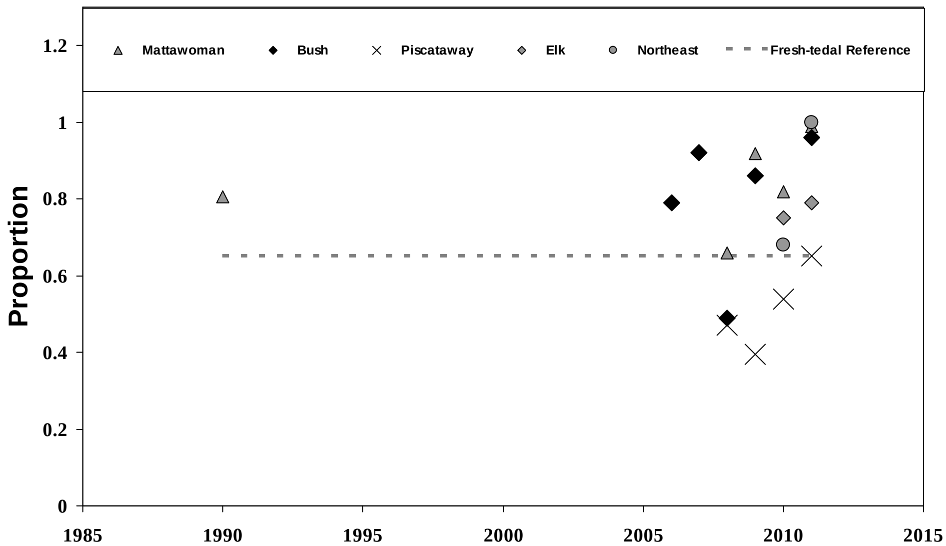


Figure 3-5 . Relationship of proportion of plankton tows with yellow perch larvae and development (structures per hectare or C / ha). Separate intercepts are estimated for fresh-tidal and brackish subestuaries, but they share a common slope. Vertical lines indicate levels of C / ha representing a target level of impervious surface (IS; 5% IS = rural watershed), a threshold level of IS (10% IS = suburban threshold), and a high level of development (15% IS).

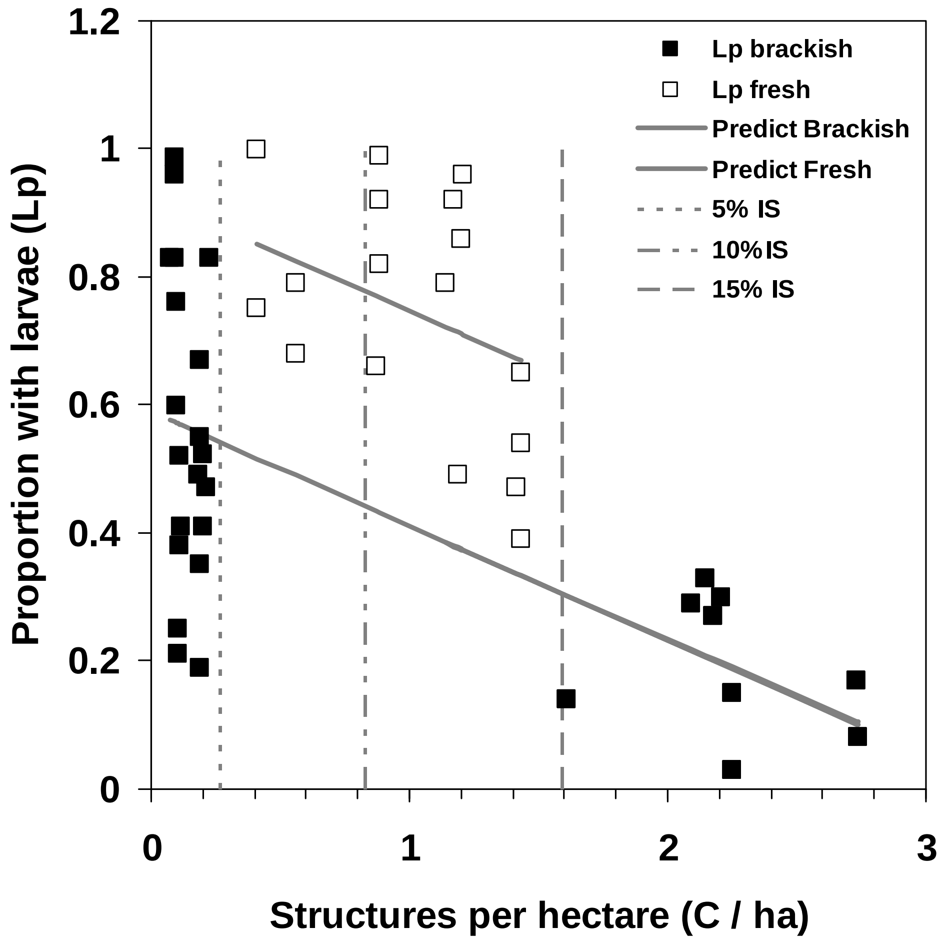


Figure 3-6. Residuals of relationship of proportion of plankton tows with yellow perch larvae and development (structures per hectare or C / ha). Separate relationships are estimated for fresh-tidal and brackish subestuaries. An “X” designates residuals of fresh-tidal Piscataway Creek that indicate this subestuary may not conform to the fresh-tidal relationship.

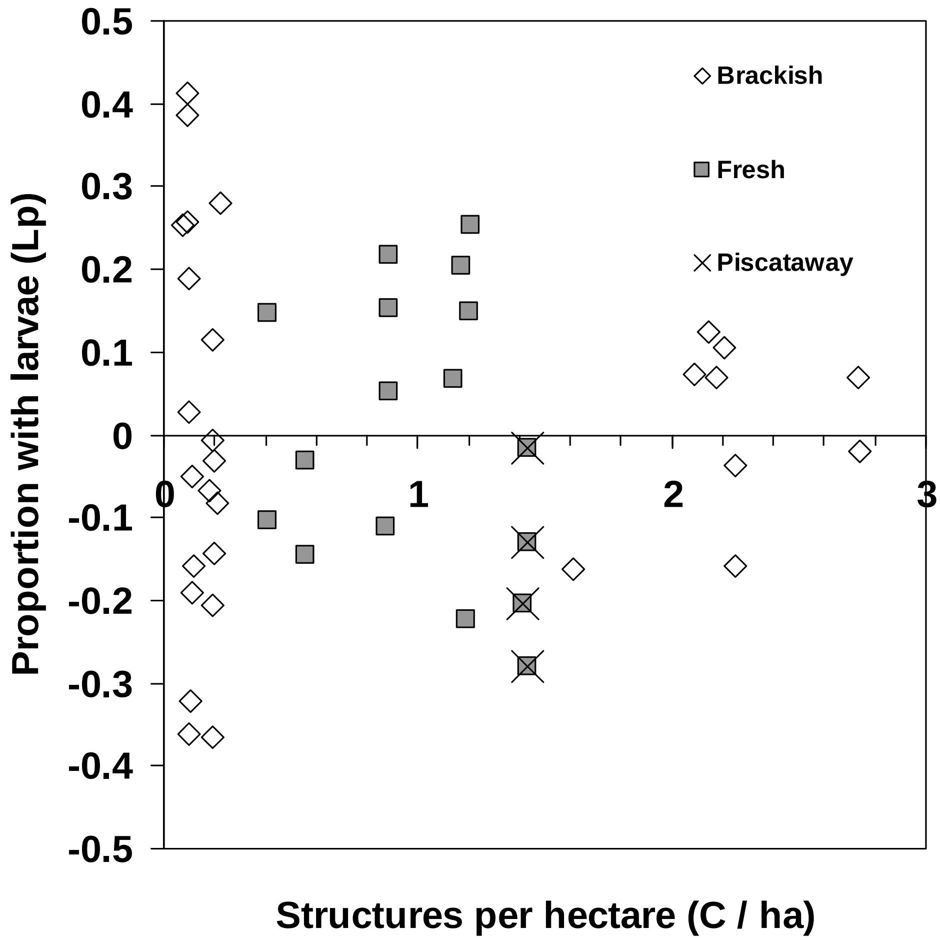


Figure 3-7. Relationship of proportion of plankton tows with yellow perch larvae, development (structures per hectare or C / ha), and dominant class of land cover (MD DNR 1999). Vertical lines indicate levels of C / ha representing a target level of impervious surface (IS; 5% IS = rural watershed), a threshold level of IS (10% IS = suburban threshold), and a high level of development (15% IS).

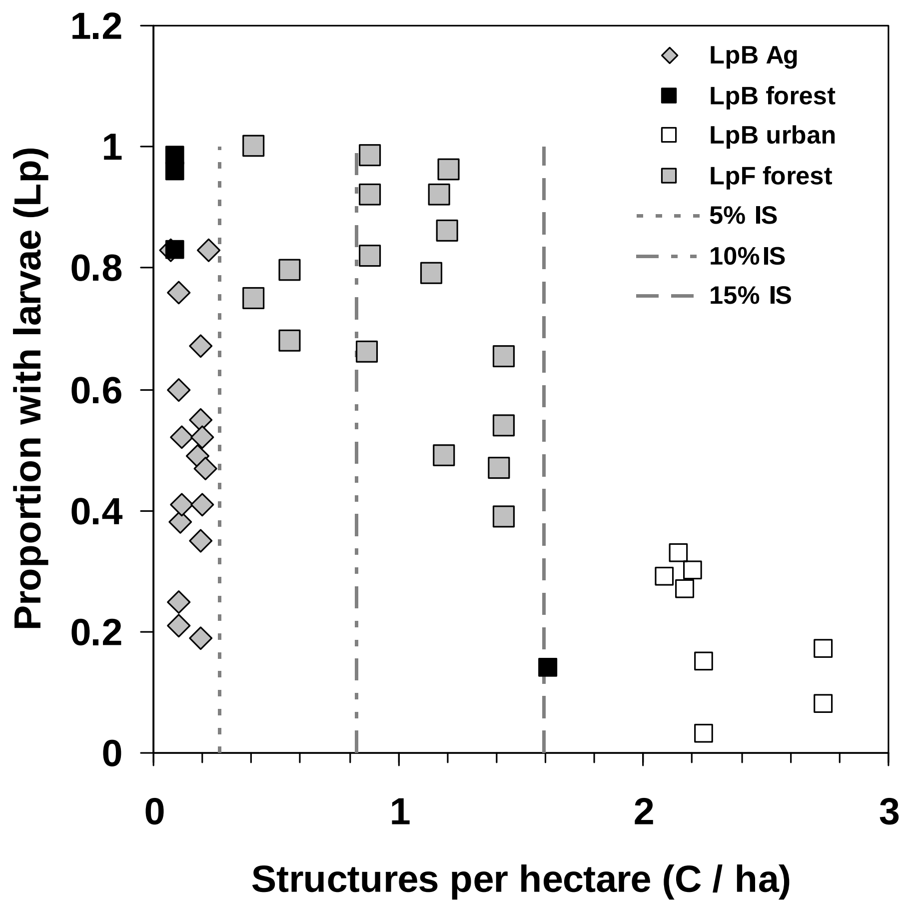
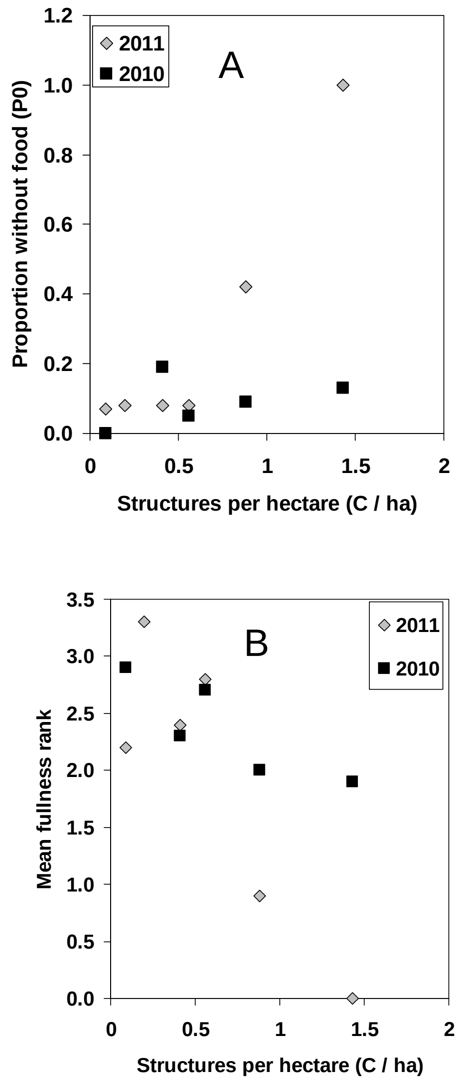


Figure 3 -8. (A). Proportion of larval yellow perch guts without food versus structures per hectare (C / ha) plotted by year. (B) Mean fullness rank of larval yellow perch guts versus structures per hectare (C / ha) plotted by year.



Section 4 - Estuarine Fish Community Sampling

Introduction

Reviews by Wheeler et al. (2005) and the National Research Council (NRC 2009) documented deterioration of non-tidal freshwater aquatic habitat as IS occupied more than 10% of watershed area. Uphoff et al. (2011a) estimated target and limit ISRPs for brackish (mesohaline) Chesapeake Bay subestuaries based on Chesapeake Bay DO criteria, and associations and relationships 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 bottom DO was only occasionally at or above 5 mg/L (target DO). Mean bottom DO seldom exceeded 3.0 mg / L above 10% IS (suburban threshold; Uphoff et al. 2011).

Although bottom DO concentrations respond to IS in brackish subesturaries, we have seen adequate concentrations of DO in bottom channel habitat of fresh-tidal subesturies at suburban levels of development (Uphoff et al. 2011b). We suggested these areas were not succumbing to low oxygen because they were well mixed. However, in Mattawoman Creek correlations of declining bottom DO and water column chlorophyll a, and increasing SAV and C / ha were strong and indicated that dynamics of these parameters could be inter-related. The increase in SAV and decrease in bottom DO could be interpreted as an improvement in habitat conditions; however, Uphoff et al. (2011b) documented substantial downward shifts in number of species and abundance of finfish from Mattawoman Creek concurrent with these changes. Frequent DO below the target and threshold level were recorded by a continuous monitor within a dense SAV bed at Sweden Point Marina in Mattawoman Creek (Uphoff et al. 2011b). These data suggest SAV in Mattawoman Creek may be associated with DO deficits in shallow water. In 2011, we employed volunteers to sample DO within the entire SAV bed adjacent to Sweden Point Marina to determine whether this bed harbored stressful habitat conditions beyond the location of the continuous monitor.

We continued to evaluate nursery and adult habitat for recreationally important finfish in subestuaries of Chesapeake Bay during 2011. This report emphasizes habitat in fresh-tidal subestuaries, but brackish subestuaries were sampled as well.

Methods

We sampled five subestaries in Chesapeake Bay during 2011: Mattawoman Creek, Piscataway Creek, Middle River, Gunpowder River, and Tred Avon River (Figure 4-1). We obtained data on four additional tributaries sampled by staff from the Alosine Project (Corsoca River, Northeast River, and Wicomico River) and NOAA's Integrated Assessment Project (Nanjemoy Creek; Figure 4-1). Housing density (C / ha) and impervious surface (IS) were as described in Section 1. 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.

Ideally, four evenly spaced haul seine and bottom trawl sample sites were located in the upper two-thirds of each subestuary. Nanjemoy and Piscataway creeks were exceptions and were sufficiently covered by three sites. Sites were not located near the tributary mouth to reduce influence of the mainstem Bay or Potomac River waters on water quality measurements.

Sites were sampled once every two weeks during July through September. 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 likely not be influenced by the random start location as much as sites on the extremes because of the bus-route nature of the sampling design. If certain sites needed to be sampled on a given tide then the crew leader deviated from the sample route to accommodate this need. Trawl sites were generally in the channel, adjacent to seine sites. At some sites, seine hauls could not be made because of permanent obstructions, SAV beds, or lack of beaches. We used GPS to record the latitude and longitude at the middle of the trawl site, while seine latitude and longitude were taken at the exact seining location.

Water quality parameters were recorded at all sites. Temperature (ºC), dissolved oxygen or DO (mg/L), conductivity (μS / cm), salinity (‰), and pH were recorded for the surface, middle, and bottom of the water column at the trawl sites and at the surface of the seine site. Mid-depth measurements were omitted at 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.

Target species were striped bass, yellow perch, white perch, alewife, blueback herring, American shad, spot, Atlantic croaker, and Atlantic menhaden. With the exception of white perch, adults of the target species were rare and target species catches were comprised of juveniles. Gear specifications and techniques were selected to be compatible with other Fisheries Service surveys.

A 4.9 m semi-balloon otter trawl was used to sample fish in the mid-channel bottom habitat. The trawl was constructed of treated nylon mesh netting measuring 38 mm stretch-mesh in the body and 33 mm stretch-mesh in the codend, with an untreated 12 mm stretch-mesh knotless mesh liner. The headrope was equipped with floats and the footrope 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 towrope. Trawls were towed in the same direction as the tide. The trawl was set up tide 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 tub for processing.

An untreated 30.5 m • 1.2 m bagless knotted 6.4 mm stretch mesh beach seine, the standard gear for Bay inshore fish surveys (Carmichael et al. 1992; Durell 2007), was used to sample inshore habitat. The float-line was rigged with 38.1 mm by 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 for processing. The distance the net was stretched from shore, maximum depth of the seine haul, primary and secondary bottom type, and percent of seine area containing aquatic vegetation were recorded.

All fish captured were identified to species and counted. Striped bass and yellow perch were separated into juveniles and adults. White perch were separated into three categories (juvenile, small and harvestable size) based on size and life stage. The small white perch category consisted of ages-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. Small and harvestable white perch were combined when catches were summarized as adults.

Dissolved oxygen concentrations were evaluated by watershed against a target of 5.0 mg / L and a threshold of 3.0 mg / L (Uphoff et al. 2011a). The target DO was sufficient to support aquatic life needs in Chesapeake Bay and has been used in the regulatory framework to determine if a water body is meeting its designated aquatic life uses. This criterion was associated with asymptotically high presence of target species in bottom channel habitat in brackish subestuaries (Uphoff et al. 2011a). Presence of target species declined sharply when bottom DO fell below the 3.0 mg / L threshold (Uphoff et al. 2011a). In each subestuary, we estimated the percentages of DO samples that did not meet the target or threshold for all samples (surface to bottom) and for bottom waters alone. The percentages of 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.

Salinity influences distribution and abundance of fish (Hopkins and Cech, 2003; Cyrus and Blaber, 1992; Allen, 1982) and DO (Kemp et al. 2005). We classified subestuaries using salinity categories of the Venice System for the Classification of Marine Waters (Oertli 1964). We grouped analyses by these classifications when examining the effects of development. Tidal-fresh ranged from 0 to 0.5 ‰ ; oligohaline, 0.5 -5.0 ‰, meshohaline, 5.0 -18.0 ‰; and polyhaline, greater than 18.0 ‰ (Oertli 1964). We used all available salinity means from subestuaries we studied during 2003-2011 to classify subestuaries.

Our primary interest was in the relationship of C / ha to DO in surface and bottom channel waters. Historical changes in forest, agriculture, wetland, and developed lands in Chesapeake Bay's watershed have been associated with changes in nutrient loading, assimilation and buffering that influenced DO in mainstem Chesapeake Bay (Kemp et al. 2005; Brush 2009; Murphy et al. 2011). Temperature and salinity were potential influences on DO because of their relationships with DO saturation and stratification (Kemp et al. 2005; Murphy et al. 2011).

We correlated mean surface temperature with mean surface DO, mean bottom temperature with mean bottom DO, and C / ha with surface and bottom DO for each salinity class. We chose annual means of surface or bottom DO and water temperature in summer at all sites within a subestuary for analyses to match the geographic scale of C /

ha estimates (whole watershed) and characterize chronic conditions. This analysis explored multiple hypotheses related to DO conditions. Structure per hectare estimates were considered proxies for nutrient loading and processing (Uphoff et al. 2011a) in the subestuaries in this analysis. Water temperature would indicate system respiration and stratification influences (Kemp et al. 2005; Murphy et al. 2011). Conducting correlation analyses by salinity classification provided a means of isolating the increasing influence of salinity on stratification from temperature. Separate correlation analyses were conducted for surface or bottom temperature with C / ha to examine whether these variables were independent. Data collected during 2003-2011 surveys were analyzed. Annual estimates of C / ha were used, but 2011 values were set at the same as 2010 since 2011 tax map data were not available. Analyses were considered significant at $\alpha \leq 0.05$.

We continued to explore the long-term changes in DO dynamics in Mattawoman Creek. We depicted long-term changes in DO dynamics in the main channel with box and whisker plots of annual measurements taken during July-October 1989-2011 and examined V_{target} amd $V_{threshold}$.

We also examined monthly DO violations from a continuous monitor located in a dense SAV bed at Sweden Point Marina. This meter was deployed from April through October and recorded continuous water quality readings every 15 minutes. An aerator was in operation at Sweden Point Marine during bass tournaments to reduce release mortality. Times of operation were not recorded.

To examine the extent of low DO dynamics within the entire 61.5 ha Sweden Point SAV bed, we recruited volunteers to sample surface and bottom DO using a transect-based design (Figure 4-2). Transect sampling was chosen for ease of execution and convenience for the volunteers (Hansen et al. 2007). Sampling was conducted during daylight between 1000 and 1330 hours on weekends. We had checked several weeks of DO readings taken at the Sweden Point continuous monitor during 2010 and found that they fluctuated with the tide (lowest usually on the low tide), but were not influenced by time of day (J. Uphoff, MD DNR, unpublished analysis). A detailed protocol was provided to the volunteers.

Seven transects were established and five equally spaced sites (ideally) were located on each transect (Figure 4-2). Volunteers randomly chose several transects to sample (ranging from on to three a day depending on the number of volunteers) on eight visits during July – September. Transect C was located in the channel maintained for boating and was expected to have less vegetation than remaining transects. One site was located near shore; the furthest site was at the edge of the SAV bed; one was located in the middle; another between shore and the middle; and a one between the middle and the end of the SAV bed. These distances were relative to the extent of the SAV bed. Starting points were at the beginning or end of a transect (i.e., sites 1 or 5) and were chosen at random. Sample locations were recorded with GPS.

Volunteers recorded surface and bottom water quality (depth, DO, temperature, pH, and conductivity) using a probe mounted in a plastic large-mesh basket on a boat hook that was pushed into the SAV. This arrangement allowed the probe to be pushed down into thick SAV. Density of SAV coverage was assessed using a standard SAV assessment protocol that ranked the amount of coverage within a 0.5 square meter grid. If coverage within the grid was very sparse (0-10% coverage) it received a 1; if coverage was 11-40% it was classified as a 2, 41-70% a 3 and 71-100%, 4. If SAV was absent, it was coded 0. A graphical representation of SAV coverage categories was provided to the volunteers to use as a reference.

Estimates of V_{target} and $V_{threshold}$ means and 95% CIs in the SAV bed were compared to estimates from 2011 fish sampling in channel waters (depths combined for both locations). The SD's were calculated by the same equations used for P_{herr} (Section 2) and L_p (Section 3; Ott 1977). We used the GPS coordinates to map where surface and bottom DO was less than 3 mg / L, less than 5 mg / L, and greater than 5 mg / L.

Proc GLM in SAS (Littel et al. 2002) was used to conduct analysis of variance (ANOVA) of factors influencing DO within the SAV bed. The full ANOVA model used was

$$\ln DO = Depth * SAV * Site * Transect * Date;$$

where ln DO was natural log-transformed DO; Depth = surface or bottom; SAV = SAV density category; Site = relative location on transect; and Date was the Julian date converted to SAS date. Depth, SAV, Site, and Transect were class variables while Date was considered continuous. Only main effects were modeled. A reduced model was developed from the main effects with significant Type III sums of squares. Residuals were inspected for normality. Sample sizes for surface and bottom DO measurements were similar (N = 83 and 87, respectively). Un-transformed surface and bottom DO measurements were not normally distributed and variances were not equal. The ln-transformation of DO reduced the variances so that an F-test could not detect a difference between bottom and the surface, but distributions of measurements were not normally distributed. Review of ANOVA requirements in Green (1979) indicated that results based on on ln-transformed DO would be robust. Analyses were considered significant at $\alpha \leq 0.05$. Residuals were examined for departures from normality.

Target species catch data were treated as presence-absence to estimate relative abundance of each indicator species as P_i, the proportion of trawl or seine samples with a target species. Proportions of samples with a target species (P_i) and their SD's were calculated by the same equations used for P_{herr} (Section 2) and L_p (Section 3; Ott 1977).

We used linear regression to examine the relationship of C / ha and P_i in tidal-fresh subestuaries for species meeting the absence criterion described below. We used annual estimates of P_i from trawl sampling during 2003-2011. Analyses were considered significant at $\alpha \leq 0.05$. Residuals were examined for normality and outliers.

Presence-absence was ecologically meaningful, minimized errors and biases in sampling, and reduced statistical concerns about lack of normality and high frequency of zero catches that were expected given the hypothesis that increased development leads to reduced habitat suitability (Green 1979; Bannerot and Austin 1983; Mangel and Smith 1990; Uphoff et al. 2011a).

Interpreting absence can pose problems (Green 1979; MacKenzie 2005) 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. To minimize ambiguity in interpreting absence, we compiled seine and trawl catches to calculate percentage of sites where each target species was encountered at least once. A high chance of occurrence among all sites, in the vicinity of 90%, indicated that a species was likely to occur at all sites and sustained absence was related to habitat conditions at the site (Uphoff et al. 2011a).

Results and Discussion

Table 4-1, summarizes C / ha, non-water watershed area, housing density and tidal water surface area estimates for the nine watersheds sampled in 2011. Based on 2006-2011 salinity distributions, tidal-fresh subestuaries sampled during 2011 included Mattawoman Creek, Piscataway Creek, Northeast River, and Gunpowder River (Table 4-2). Nanjemoy Creek and Middle Rivers were considered oligohaline. Corsica River, Nanjemoy Creek, Tred Avon River, and Wicomcio River were mesohaline (Table 4-2). We did not sample any polyhaline subestuaries.

All rivers except Gunpowder and Piscataway Creek had non-zero estimates of V_{target} and $V_{threshold}$ in surface and bottom waters during 2011 (Table 4-3). Corsica River had the highest V_{target} followed by Wicomico, Tred Avon, Nanjemoy, Mattawoman, Northeast Creek, and Middle River (Table 4-3). When we evaluated V_{target} in bottom channel waters, Corsica River had the highest estimate, followed by Wicomico, Tred Avon, Nanjemoy, Northeast Creek, Mattawoman Creek, and Middle River. Out of these rivers, only four rivers the Corsica, Wicomico, Northeast and Tred Avon had non-zero estimates of $V_{threshold}$, during 2011 (Table 4-3).

Correlation analyses of 2003-2011 data suggested that C / ha, surface water temperature, and salinity were significantly associated with DO conditions in Chesapeake Bay subestuaries (Table 4-4). In mesohaline subestuaries, associations of surface DO with surface water temperature and bottom DO with C / ha were negative and significant, while other two comparisons (bottom temperature with bottom DO and C / ha with surface DO) were not. In oligohaline subestuaries, only a negative correlation of surface DO with surface temperature was significant. None of the correlations were significant in fresh-tidal subestuaries (Table 4-5).

The trend of declining significance of associations among DO or temperature with salinity classification indicated stratification could be important in development of poor DO conditions in mesohaline waters, less important in oligohaline subestuaries, and unimportant in tidal-fresh subestuaries. System respiration was potentially important in mesohaline and oligohaline systems. Structures per hectare was negatively associated with bottom DO in mesohaline subestuaries where stratification was interpreted as present, while C / ha was positively associated with surface DO in tidal-fresh subestuaries where stratification was interpreted as absent (Table 4-4). Associations of surface and bottom DO with development in meshohaline subestuaries were consistent with associations found in Uphoff et al. (2011a); some of the same data, as well as additional data, were used in the analysis presented here. Neither surface nor bottom temperature were significantly correlated with C / ha (surface water temperature, $r = 0.07$, $P = 0.53$; and bottom water temperature, $r = 0.13$, $P = 0.023$). Sample sizes of mesohaline subestuaries were over twice as high as oligohaline or tidal-fresh subestuaries, so ability to detect significant associations in mesohaline subestuaries was greater.

Mean and median DO in Mattawoman Creek bottom channel habitat has declined since 1989, however, neither fell below the target DO of 5.0 mg/L (Figure 4-3). The estimate of V_{target} for bottom channel habitat during 2011 was the highest of the time-series, but $V_{threshold}$ equaled zero (Figure 4-4).

Estimates of V_{target} and $V_{threshold}$ during July-September from the continuous monitor at Sweden Point Marina (N = 8831 to 8832 annually during 2004-2011) were generally high since 2009 (0.2 and higher for V_{target} and 0.04 and higher for $V_{threshold}$;

Figure 4-5). Estimates were lower in 2011 (V_{target} = 0.27 and $V_{threshold}$ = 0.04) than 2010 (V_{target} = 0.63 and $V_{threshold}$ = 0.41); however, interpretation is confounded because Fisheries Service operated an aerator within the area during tournaments to assure survival of bass released. Even with this aerator, V_{target} was higher than in 2009, while $V_{threshold}$ was lower (Figure 4-5).

A total of 170 DO measurements were taken by volunteers on eight dates during July 10 to September 19, 2011. Dissolved oxygen measurements for each depth, site, and transect are summarized in Table 4-5. Distributions of DO values were bimodal for surface and bottom measurements, with modes at 4 mg / L and 7-8 mg / L (Figure 4-6). The mode at 4 mg / L was greater than that at 7 mg / L in bottom measurements, while the mode of surface measurements at 4 mg / L was smaller than the mode at 8 mg / L. Measurements of DO in excess of 10 mg / L were more common for surface samples in the SAV bed (Figure 4-6). Based on 95% CI overlap, estimates of V_{target} and $V_{threshold}$ in SAV samples (V_{target} = 0.34, SD = 0.04; and $V_{threshold}$ = 0.06, SD = 0.02) were higher than estimates taken in the channel during fish monitoring (V_{target} = 0.15, SD = 0.05; and $V_{threshold}$ = 0) and were not significantly different than V_{target} and $V_{threshold}$ from the continuous monitor at the Marina.

Maps of locations of surface (Figure 4-7) or bottom (Figure 4-8) DO measurements indicated that below target values prevailed at transects A, C, and E, while remaining transects experienced DO in excess of the target most often. Below target and threshold readings were more common at the bottom (36 out of 87) than the surface (23 of 83). Seven measurements (surface and bottom pooled) less than 3 mg / L were made at site 1 (nearest shore) and one each was made at site 2, site 3 (middle of SAV bed), and site 5 (edge of SAV bed). The proportion of combined surface and bottom DO measurements between 3 and 5 mg / L at sites 1 and 2 (P = 0.35, SD = 0.06) were not significantly different than sites 3-5 (P = 0.27, SD = 0.04) based on 95% CI overlap.

In the full ANOVA model ($\alpha < 0.0001$), depth, site, and transect had significant effects on ln DO ($\alpha \leq 0.05$), date was marginally significant at $\alpha = 0.056$, and SAV density class was not significant. Only SAV density class was excluded from the reduced model. The reduced model was significant at $\alpha < 0.0001$ and explained 39% of variation in ln DO and all terms were significant at $\alpha \leq 0.04$ (Table 4-6). Model parameter estimates indicated a positive influence of date on DO. Surface DO was significantly higher than bottom and decreased as location changed from the outer edge of the bed to shore. There were significant transect effects, but these were not systematic. Transect A had DO lower than G; transects D and F had higher DO than G; and remaining transects were not significantly different than G (Table 4-6).

Dissolved oxygen conditions within the Sweden Point Marina SAV bed were worse than those in channel waters of Mattawoman Creek. Low DO conditions in Mattawoman Creek occurred more often in shallow waters between the shoreline and channel rather than in the channel itself. The shore zone is typically where the best habitat conditions occur in developed mesohaline subestuaries in Chesapeake Bay (Uphoff et al. 2011a). If conditions measured in the large Mattawoman Creek SAV bed sampled during 2011 were representative, then the nearly 300 ha of Mattawoman Creek's 748 ha subestuary covered in SAV could have been stressful habitat (Figure 4-8). Beds of SAV in Mattwoman Creek began expanding in the late 1990s from 50 ha or less to reach an asymptotically high level near 300 ha by 2002 (Figure 4-9). This expansion coincided with a large decline in fish abundance and species richness in the subestuary and development that surpassed the threshold level (Uphoff et al. 2009; 2010). The DO dynamics in the SAV beds of Mattawoman Creek may not have directly caused fish declines, but may be symptomatic of broader ecological changes occurring in this subestuary as development has proceeded.

Recovery of SAV is one of the central tenets of the Chesapeake Bay Program, with the premise that it is critical habitat for finfish (NCBO 2012) and better for fish production than a pelagic phytoplankton driven system. We have observed the opposite in Mattawoman Creek (Uphoff et al. 2009; 2010). Recovery of SAV as intended by the Chesapeake Bay Program is to be driven by nutrient reductions, while SAV recovery in Mattawoman Creek has been concurrent with increased nutrient loading resulting from development. Sediment loads in Mattawoman Creek from construction and stream bank erosion are high (Gellis et al. 2008) and increased nutrient loading there was strongly associated with sediment level increases that occurred after 2003 (J. Uphoff, MDDNR, unpublished analysis).

High growth of SAV in Mattawoman Creek appeared to represent an alternative manifestation of DO stress from development unique to tidal-fresh subestuaries. Increased development, combined with stratification and system respiration combine to create low DO conditions in bottom channel habitat of mesohaline subestuaries (Uphoff et al. 2011a). Both tidal-fresh subestuaries in our study (Piscataway and Mattawoman Creeks) with development beyond the C / ha threshold have extensive SAV growth in shallow water (≈ 86% and 40% coverage of water area). The two tidal-fresh subestuaries in our study below the development threshold, Gunpowder and Northeast rivers, exhibited 14% and 3% coverage, respectively (2010 estimates; Virginia Institute of Marine Science 2012). A significant portion of SAV species in both Mattawoman and Piscatway creeks were introduced (Hydrilla and Eurasian milfoil), but native species are abundant as well. Sampling of channel waters does not indicate as much sign of stress as V_{target} and $V_{threshold}$ estimates from this habitat are low in both subestuaries (Table 4-3).

Urbanization can lead to increases in some species of SAV in lakes in Wisconsin (Mikulyuk et al. 2011). Structural differences among SAV species offer different habitat to fish and invertebrates and SAV in general tends to increase biomass of macroinvertebrates and reduce foraging efficiency of fish. Cascading trophic effects are many. SAV can alter water quality and DO changes substantially change nutrient and gas chemistry that determines habitat quality for aquatic animals, even on time scales as short as one day (Mikulyuk et al. 2011).

A total of 128,385 fish (trawl and seine) representing 57 species groups were sampled in 2011. Of these species, eight comprised 90% of the catch. These species groups included white perch juveniles and adults, spottial shiner, gizzard shad, Atlantic silverside, bay anchovy, blueback herring and pumpkinseed. Only two, white perch and blueback herring, were target species.

Seining was conducted in all rivers except Mattawoman and Piscataway Creeks, where extensive SAV beds prevented it. Seining in Middle River was sporadic because of high water and dense SAV in the seine sites. A total of 42,534 fish representing 47 species were captured in the seine. Eleven species groups comprised 90% of the catch, including white perch juveniles and adults, gizzard shad, Atlantic silverside, blueback herring, spottial shiner, white perch, mummichog, bay anchovy, pumpkinseed, banded killifish and Atlantic menhaden.

Seine catches during 2011 are summarized by river in Table 4-7. The Gunpowder and Northeast rivers were the only tidal-fresh rivers seined this year and catch per effort (CPE) and species richness were higher in the Gunpowder River (C / ha = 0.77) than in the Northeast River (C / ha = 0.45) . Juvenile white perch dominated the seine catch in Gunpowder River and blueback herring were the most abundant species in the Northeast River.

Highly developed Middle River (C / ha = 3.31) had the highest CPE, followed by Nanjemoy (C / ha = 0.09), and Corsica River (C / ha = 0.24; Table 4-7). Nanjemoy Creek collections had 33 species, with 8 comprising 90% of the total catch. Middle River, had 28 species and 7 comprised 90% of the catch. The Corsica River had the lowest CPE and species richness of the oligohaline systems, with 22 species observed and 5 comprising 90% of the total catch (Table 4-7).

Wicomico and Tred Avon rivers, both mesohaline subestuaries, were sampled in 2011. The Tred Avon river has a higher housing density (0.77 C / ha), but also had a higher number of species (26) and CPE (262.0) than the Wicomico River (0.34 C / ha; 18 species and CPE = 244.2; Table 4-7). Atlantic silverside and white perch juveniles were the dominant species in the seine in both rivers. In Tred Avon River, mummichog, banded killifish, and striped killifish, striped bass juveniles and Atlantic menhaden comprised 90% of species collected. In the Wicomico, bay anchovy, blueback herring, Atlantic menhaden and white perch adult defined the dominant species (Table 4-7).

Bottom trawl sampling was conducted in all systems (Table 4-8). A total of 82,608 fish were captured, representing 49 species. Four species groups comprised 90% of the total catch for the trawl: white perch adults and juveniles, spottail shiner, and bay anchovy.

Of the four tidal-fresh rivers sampled, Piscataway Creek (C / ha = 1.43) had the highest number of species, followed by Gunpowder River (C / ha = 0.77), Mattawoman Creek (C / ha = 0.88), and Northeast River (C / ha = 0.45; Table 4-8). Piscataway Creek also had the highest CPE, followed by Gunpowder River, Northeast River and Mattawoman Creek. Piscataway Creek was the most developed system. Four species comprised 90% of the catch in Mattawoman Creek, compared to three in other rivers. White perch were among the most abundant species in all four rivers, and was the only target species among the dominant species in the trawl (Table 4-8).

Among oligohaline systems, Middle River (C / ha = 3.31) had one more species than Corsica River (C / ha = 0.24) and Nanjemoy Creek (C / ha = 0.09; Table 4-8). White perch was the most abundant species in all three rivers in the trawl. Nanjemoy Creek had the highest CPE, followed by Middle River, and Corsica River (Table 4-8).

Among the two mesohaline rivers, Tred Avon had the highest number of species, highest number of species comprising 90% of the catch and highest CPE (Table 4-8).

White perch juveniles and adults were the only species group to meet the absence criterion in tidal-fresh subestuaries. White perch juveniles and adults were present 90% and 86% of the time, respectively.

Regression analyses indicated that bottom trawl P_i of juvenile white perch in tidal-fresh subestuaries was not linearly related to development. The regression of C / ha and P_i for juvenile white perch was not significant at $P \leq 0.05$ ($r^2 = 0.12$, $P = 0.12$, $N =$

23; Figure 4 – 10). A linear decline of P_i may be a poor choice of a model for describing a decline of tidal-fresh subestuary bottom channel habitat use by juvenile white perch. The bivariate plot of C / ha indicated that once the threshold region (C / ha = 0.83; see Section 3) had been breached the variation in P_i increased substantially. Estimates of P_i at development levels less than the threshold were clustered between 0.90 and 1.00. Beyond the threshold, the range expanded to 0.30 – 1.00 (Figure 4 – 10).

The relationship of C / ha and P_i was significant for adult white perch (r^2 = 0.56, P < 0.0001, N = 23; Figure 4 - 10). The equation describing the relationship for adult white perch was

$$P_i = (-0.47 \bullet C / ha) + 1.20;$$

where P_i = the proportion of trawl samples with adult white perch. Standard errors of the slope and intercept were 0.08 and 0.09, respectively. Residuals of this regression plotted against C / ha (Figure 4-10) suggest that points at lower and higher development (C / ha ≈ 0.45 and 1.40, respectively) were well described by the regression, but the points surrounding the threshold (C / ha = 0.83) were mostly clustered above zero. This suggests that stressors in tidal-fresh subestuaries affect adult white perch P_i in the region of the threshold in a “boom or bust” fashion.

Table 4-1. Percent impervious cover (IS), structures per hectare (C / ha), total non-water area, and area of tidal water for the watersheds sampled in 2011.

Area	Watershed	IS	C/ha	Total Hectares	Water Hectares
Mid-Bay	Corsica	4.1	0.241	9,682	508
Mid-Bay	Middle River	39.1	3.310	2,735	863
Mid-Bay	Tred Avon River	7.5	0.736	9,518	1,756
Potomac	Mattawoman Creek	9.0	0.883	24,403	748
Potomac	Nanjemoy	0.9	0.091	18,860	949
Potomac	Piscataway	16.5	1.433	17,636	347
Potomac	Wicomico	4.3	0.335	19,978	566
Upper-Bay	Gunpowder River	4.4	0.774	17,591	4,052
Upper-Bay	Northeast	4.4	0.450	16,341	1,572

Table 4-2. Mean salinity during 2003-2011 sampling and salinity classification for watersheds sampled during summer 2011.

Area	Watershed	Salinity Class	Mean Salinity	Minimum Salinity	Maximum Salinity
Mid-Bay	Tred Avon River	Mesohaline	7.4	5.7	8.9
Potomac	Wicomico River	Mesohaline	6.6	0.0	10.6
Mid-Bay	Corsica River	Mesohaline	3.9	0.3	6.3
Potomac	Nanjemoy Creek	Oligohaline	2.6	0.2	5.9
Mid-Bay	Middle River	Oligohaline	1.4	0.5	2.9
Upper-Bay	Gunpowder River	Tidal Fresh	0.5	0.1	1.4
Potomac	Mattawoman Creek	Tidal Fresh	0.2	0.0	0.3
Potomac	Piscataway Creek	Tidal Fresh	0.2	0.1	0.2
Upper-Bay	Northeast River	Tidal Fresh	0.1	0.1	0.1

Table 4-3. Percentages of all DO measurements and bottom DO measurements that did not meet target and threshold conditions during July-September, 2011, for each river sampled.

Salinity Class	Watershed	C/ha	DO all % < 5.0 mg/L	Bottom DO % < 5.0 mg/L	Bottom DO % < 3.0 mg/L
Mesohaline	Tred Avon River	0.736	22.0	45.4	9.0
Mesohaline	Wicomico River	0.335	45.9	60.9	17.4
Oligohaline	Corsica River	0.241	74.1	85.0	30.0
Oligohaline	Nanjemoy River	0.091	17.0	22.7	0.0
Oligohaline	Middle River	3.310	3.3	5.0	0.0
Tidal Fresh	Gunpowder River	0.774	0.0	0.0	0.0
Tidal Fresh	Mattawoman Creek	0.883	14.6	20.8	0.0
Tidal Fresh	Northeast River	0.450	13.5	33.3	12.5
Tidal Fresh	Piscataway Creek	1.433	0.0	0.0	0.0

Table 4-4. Correlations of annual surface or bottom mean DO with matching water temperature at depth (surface or bottom) or watershed development (C / ha = structures per hectare) by salinity class.

DO Depth	Statistics	Depth temperature	C / ha
		Mesohaline	
Surface	r	-0.59	-0.13
	P	<0.0001	0.41
	N	44	37
Bottom	r	0.2	-0.48
	P	0.2	0.0004
	N	44	43
		Oligohaline	
Surface	r	-0.55	0.28
	P	0.018	0.26
	N	18	18
Bottom	r	-0.23	-0.06
	P	0.36	0.81
	N	18	18
		Tidal-Fresh	
Surface	r	-0.006	0.41
	P	0.98	0.07
	N	20	20
Bottom	r	0.09	0.37
	P	0.69	0.11
	N	20	20

Table 4-5. DO measurements made during volunteer sampling of an extensive SAV bed in Mattawoman Creek during 2011. Site refers to relative distance across the SAV bed; 1 is closest to shore, 3 is in the middle of the SAV bed, and 5 is at the edge of the bed. See Figure 4-2 for location of transects.

7/10/2011		Transect						
		A	B	C	D	E	F	G
Site								
1	Surface				12.6			
	Bottom				3.9			
2	Surface				9.2			
	Bottom				7.0			
3	Surface				10.5			
	Bottom				6.7			
4	Surface				10.9			
	Bottom				10.5			
5	Surface				9.2			
	Bottom				8.4			

7/16/2011		Transect						
		A	B	C	D	E	F	G
Site								
1	Surface		6.5				9.0	
	Bottom		5.7				9.0	
2	Surface		5.9				9.3	
	Bottom		6.4				8.1	
3	Surface		7.6				10.0	
	Bottom		4.8				7.1	
4	Surface		8.7				9.9	
	Bottom		4.4				7.3	
5	Surface		7.1				11.3	
	Bottom		3.6				5.7	

Table 4-5 (continued).

7/24/2011		Transect						
		A	B	C	D	E	F	G
Site								
1	Surface					12.1		
	Bottom	3.1				11.4		
2	Surface	6.0				3.0		
	Bottom	3.8				3.2		
3	Surface	6.5				7.9		
	Bottom	2.9				6.0		
4	Surface	4.3				10.0		
	Bottom	3.6				8.9		
5	Surface	5.2				9.0		
	Bottom	3.6				5.4		

7/31/2011		Transect						
		A	B	C	D	E	F	G
Site								
1	Surface			8.0				
	Bottom	6.0		2.7				4.9
2	Surface	3.3		5.1				
	Bottom	2.1		4.7				6.8
3	Surface	5.9		7.4				5.0
	Bottom	4.1		6.3				4.0
4	Surface	7.8		7.3				6.0
	Bottom	4.7		6.1				5.3
5	Surface	4.1		7.8				5.0
	Bottom	2.8		7.1				4.3

Table 4-5 (continued).

8/21/2011		Transect						
		A	B	C	D	E	F	G
Site								
1	Surface		6.3		5.0			
	Bottom		6.2		4.5	7.1		
2	Surface		9.1		7.9	5.0		
	Bottom		6.7		5.3	4.8		
3	Surface		6.2		8.9	8.3		
	Bottom		5.4		6.6	7.1		
4	Surface		9.4		10.6	8.4		
	Bottom		7.9		7.8	7.3		
5	Surface				10.4	7.9		
	Bottom				8.7	6.5		

		Transect						
9/4/2011		A	B	C	D	E	F	G
Site								
1	Surface						2.1	2.4
	Bottom						0.6	2.4
2	Surface						11.2	8.0
	Bottom						9.8	7.9
3	Surface						8.9	8.2
	Bottom						7.7	7.1
4	Surface						9.8	7.9
	Bottom						8.2	7.4
5	Surface						9.6	7.2
	Bottom						7.4	6.4

Table 4-5 (continued).

9/11/2011		Transect						
		A	B	C	D	E	F	G
Site								
1	Surface			2.3				
	Bottom	3.5		2.8		3.8		
2	Surface	3.1		3.8		3.8		
	Bottom	3.2		3.9		3.5		
3	Surface	3.6		3.8		3.9		
	Bottom	3.5		3.7		3.6		
4	Surface	3.8		4.3		3.9		
	Bottom	3.7		3.6		3.8		
5	Surface	4.2		4.0		4.6		
	Bottom	4.1		4.1		4.6		

9/18/2011		Transect						
		A	B	C	D	E	F	G
Site								
1	Surface		5.4					
	Bottom		4.8		7.3			
2	Surface		6.4		6.6			
	Bottom		6.4		6.0			
3	Surface		6.8		7.7			
	Bottom		6.5		7.3			
4	Surface		6.7		7.0			
	Bottom		6.8		6.8			
5	Surface		6.7		7.0			
	Bottom		6.6		6.7			

Table 4-6. Output of the reduced ANOVA model (Proc GLM; SAS) of factors influencing ln DO in an extensive SAV bed in Mattawoman Creek during July-September, 2012. Site refers to relative distance; site = 1 is closest to shore, 3 is in the middle of the SAV bed, and 5 is at the edge of the bed. See Figure 4-2 for location of transects and Figures 4-7 and 4-8 for locations of surface and bottom samples. Depth refers to surface or bottom measurements. Dates sampled are in Table 4-5 and have been converted to SAS dates in the analysis.

Dependent Variable: ln_DO

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	12	12.76155328	1.06346277	8.63	<.0001
Error	161	19.83085809	0.12317303		
Corrected Total	173	32.59241137			

R-Square	Coeff Var	Root MSE	ln_DO Mean
0.391550	19.95765	0.350960	1.758525

Source	DF	Type I SS	Mean Square	F Value	Pr > F
Date	1	0.29352636	0.29352636	2.38	0.1246
Transect	6	8.41125585	1.40187597	11.38	<.0001
Site	4	2.59238283	0.64809571	5.26	0.0005
Depth	1	1.46438825	1.46438825	11.89	0.0007

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Date	1	0.51028039	0.51028039	4.14	0.0435
Transect	6	8.57612733	1.42935455	11.60	<.0001
Site	4	2.26167790	0.56541947	4.59	0.0015
Depth	1	1.46438825	1.46438825	11.89	0.0007

Table 4-6 (continued).

Parameter	Estimate		Standard Error	t Value	Pr > |t|
Intercept	-41.74516497	B	21.42602256	-1.95	0.0531
Date	0.00000003		0.00000001	2.04	0.0435
Transect A	-0.34298550	B	0.10691670	-3.21	0.0016
Transect B	0.15683361	B	0.10667062	1.47	0.1434
Transect C	-0.18435629	B	0.11414916	-1.62	0.1083
Transect D	0.30871859	B	0.10537780	2.93	0.0039
Transect E	0.04499414	B	0.10474904	0.43	0.6681
Transect F	0.27020567	B	0.11168819	2.42	0.0167
Transect G	0.00000000	B	.	.	.
Site 1	-0.27550510	B	0.08850106	-3.11	0.0022
Site 2	-0.12093122	B	0.08372279	-1.44	0.1506
Site 3	-0.02092730	B	0.08242839	-0.25	0.7999
Site 4	0.07234345	B	0.08291074	0.87	0.3842
Site 5	0.00000000	B	.	.	.
Depth Bottom	-0.18464891	B	0.05355209	-3.45	0.0007
Depth Surface	0.00000000	B	.	.	.

Note: The X'X matrix has been found to be singular, and a generalized inverse was used to solve the normal equations. Terms whose estimates are followed by the letter 'B' are not uniquely estimable.

Table 4-7. Seine catch summaries and watershed development, by river, in 2011.

River	Stations Sampled	Number of Samples	Species	Species Comprising 90% of Catch	C / ha	Total Catch	Fish per Seine
Corsica	3	19	22	Atlantic silverside white perch juvenile spottail shiner mummichog white perch adult	0.241	3169	166.8
Gunpowder	4	15	31	white perch juvenile gizzard shad spottail shiner blueback herring white perch adult silvery minnow pumpkinseed	0.774	5084	338.9
Middle	3	18	28	gizzard shad white perch juvenile blueback herring spottail shiner pumpkinseed yellow perch juvenile Atlantic silverside	3.31	12496	694.2
Nanjemoy	3	22	33	white perch juvenile gizzard shad spottail shiner Atlantic menhaden white perch adult mummichog blueback herring silvery minnow	0.091	7115	323.4
Northeast	4	24	28	blueback herring white perch juvenile gizzard shad white perch adult bay anchovy spottail shiner	0.45	3008	125.3
Tred Avon	4	24	26	Atlantic silverside white perch juvenile mummichog banded killifish striped killifish striped bass juvenile	0.736	6289	262.0

Table 4-7 (continued.

River	Stations Sampled	Number of Samples	Species	Species Comprising 90% of Catch	C / ha	Total Catch	Fish per Seine
Wicomico	4	22	18	Atlantic menhaden Atlantic silverside white perch juvenile bay anchovy blueback herring Atlantic menhaden white perch adult	0.335	5373	244.2

Table 4-8. Trawl catch summaries and watershed development, by river, in 2011

River	Stations Sampled	Number of Samples	Species	Species Comprising 90% of Catch	C / ha	Total Catch	Fish per Trawl
Corsica	4	27	21	white perch juvenile white perch adult	0.241	12187	451.4
Gunpowder	4	16	26	white perch juvenile white perch adult bay anchovy brown bullhead	0.774	7231	451.9
Mattawoman	4	24	24	spottail shiner white perch juvenile white perch adult bluegill	0.883	7252	302.2
Middle	4	24	22	white perch juvenile white perch adult bay anchovy	0.883	13477	561.5
Nanjemoy	3	22	21	white perch juvenile bay anchovy white perch adult	0.091	15871	721.4
Northeast	4	24	21	white perch juvenile white perch adult brown bullhead	0.45	7438	309.9
Piscataway	3	18	27	white perch juvenile spottail shiner tesselated darter	1.433	12892	716.2
Tred Avon	4	24	21	Atlantic silverside white perch juvenile mummichog banded killifish striped killifish striped bass juvenile Atlantic menhaden	0.736	6289	135.3
Wicomico	4	24	16	white perch juvenile bay anchovy white perch adult	0.335	3012	125.5

Figure 4-1. Tributaries sampled by seining and trawling during summer, 2011. Watershed area has been indicated by grey shading. Watershed of Tred Avon River was not delineated.

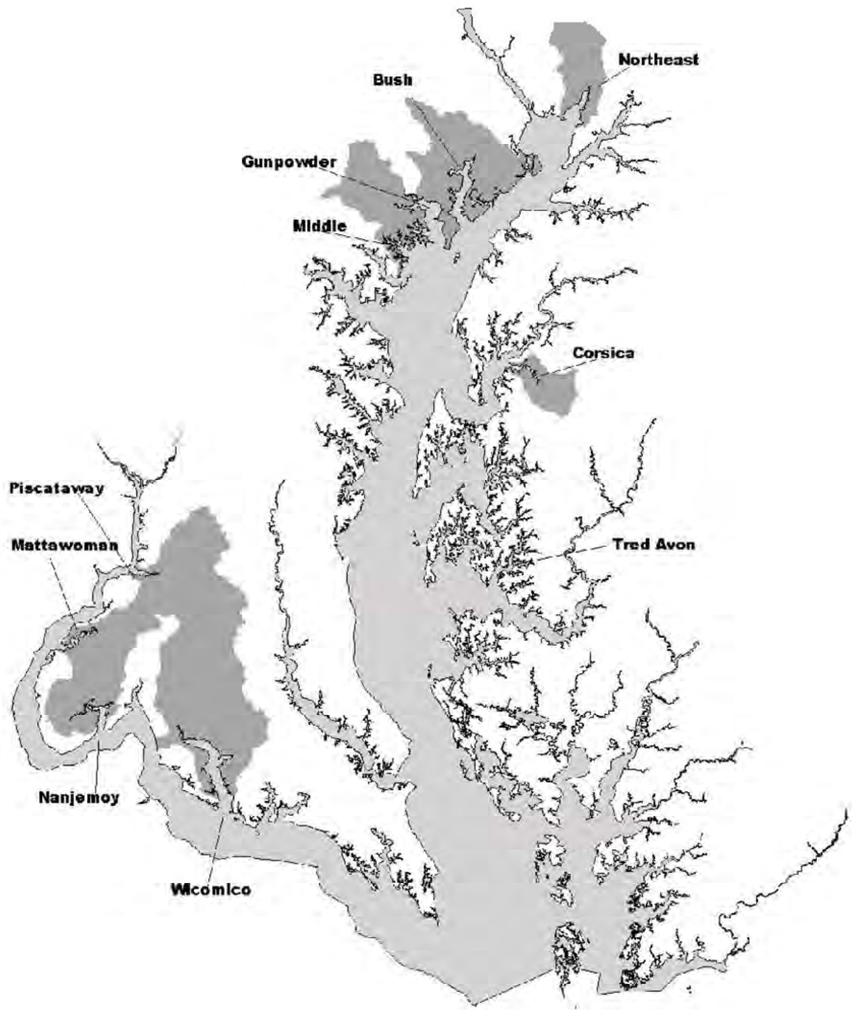


Figure 4-2. Location of transects sampled for DO by volunteers during July-September, 2011. Inset (A) indicates location of SAV bed within Mattawoman Creek and (B) indicates location of Mattawoman Creek within Chesapeake Bay.

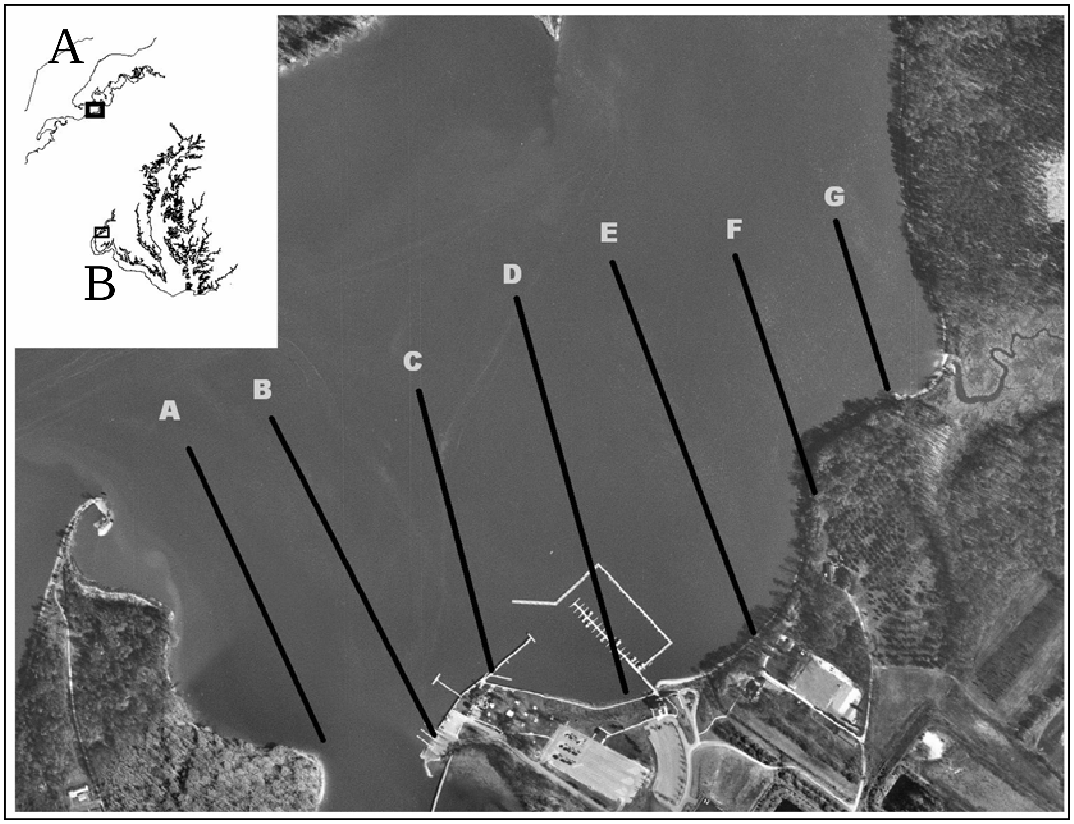


Figure 4-3. Notched box plot of bottom DO in Mattawoman Creek during 1989-2011. In this plot, notches are added to the box plot to roughly indicate the significance of differences

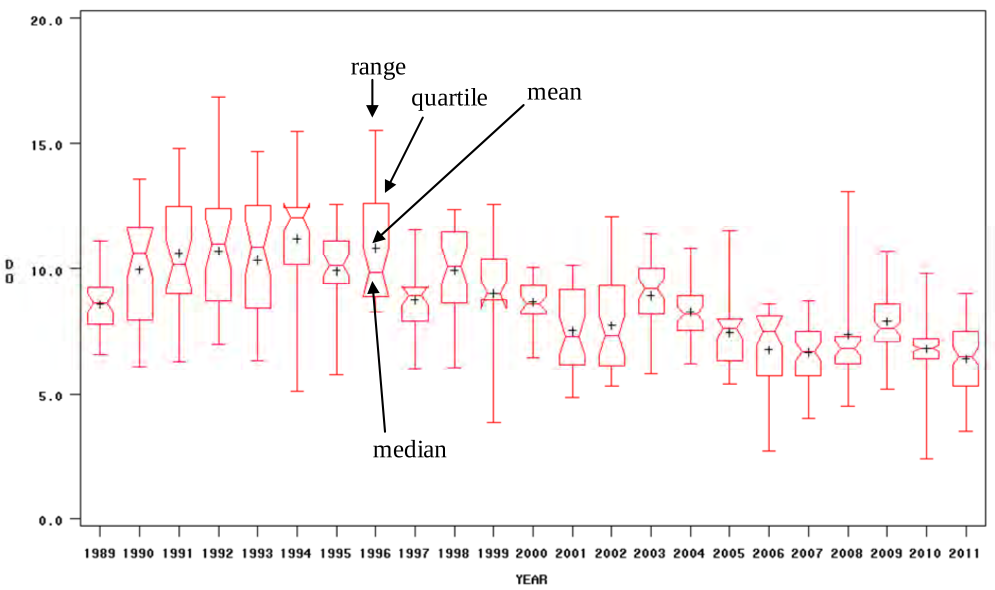


Figure 4-4. Proportion of measurements below target and limit DO in Mattawoman Creek bottom channel habitat during summer, 1989-2011.

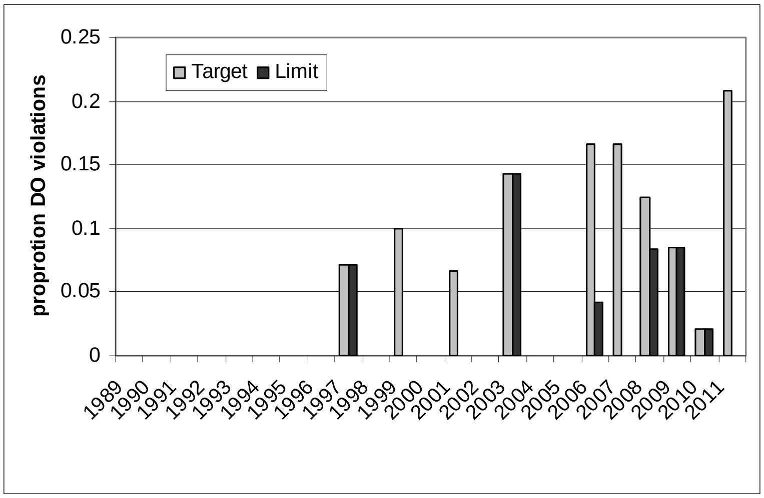


Figure 4-5. Proportions of DO measurements at the Sweden Point (Mattawoman Creek) continuous monitor that were below the target (5 mg / L) or threshold (3 mg / L) during July-September, 2004-2011.

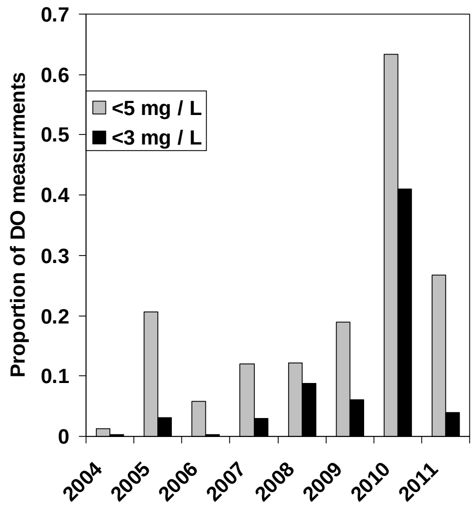


Figure 4-6. Frequency of DO measurements in surface an bottom samples taken from a SAV bed in Mattawoman Creek during July – September, 2011.

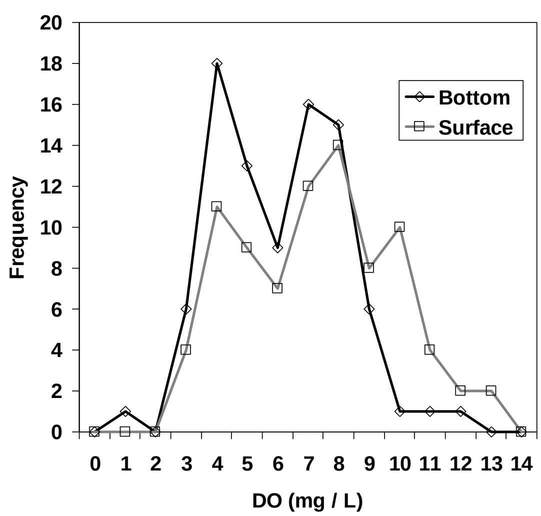


Figure 4-7. Location of surface DO measurements below target and threshold levels and above the target level during July-September, 2011, within a large SAV bed adjacent to Sweden Point Marina at Mattwoman Creek. Star indicates the location of an aerator used for releases during fishing tournaments and diamond indicates location of continuous monitor.

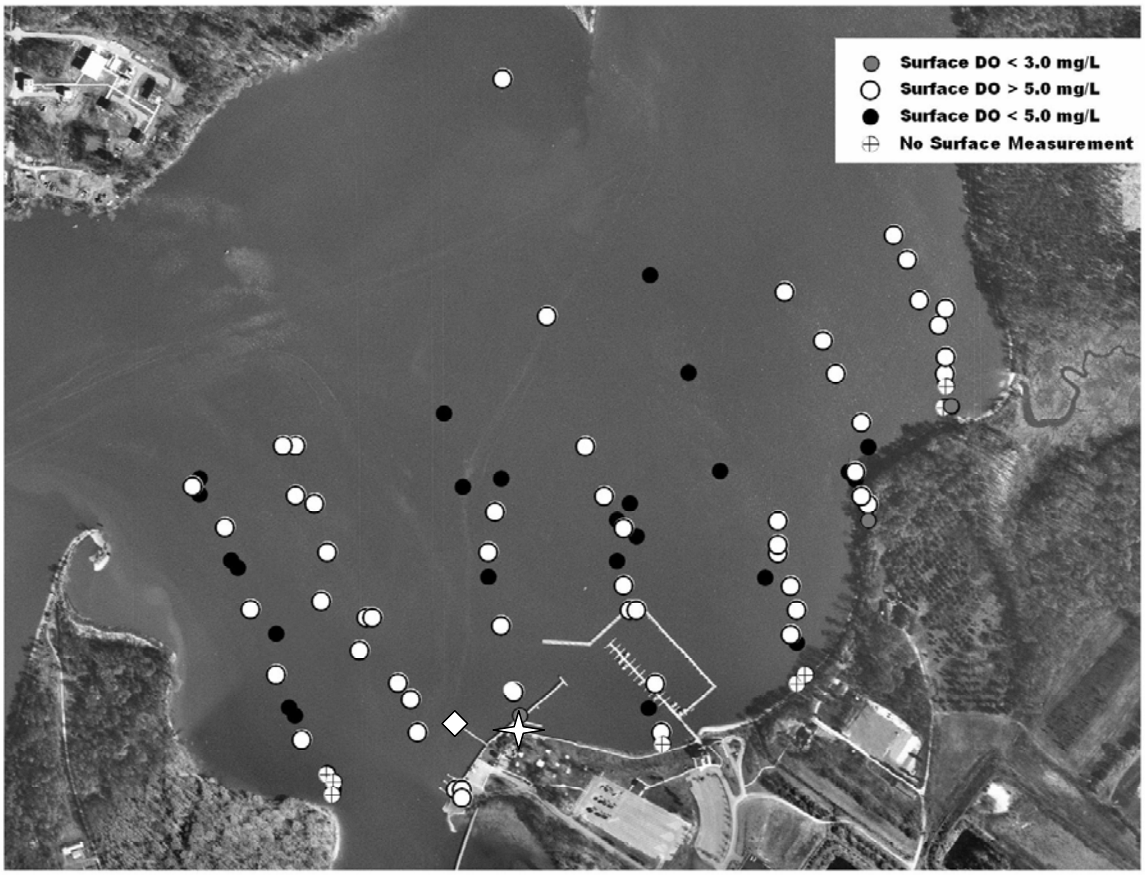


Figure 4-8. Location of bottom DO measurements below target and threshold levels and above the target level during July-September, 2011, within a large SAV bed adjacent to Sweden Point Marina at Mattwoman Creek. Star indicates the location of an aerator used for releases during fishing tournaments and diamond indicates location of continuous monitor.

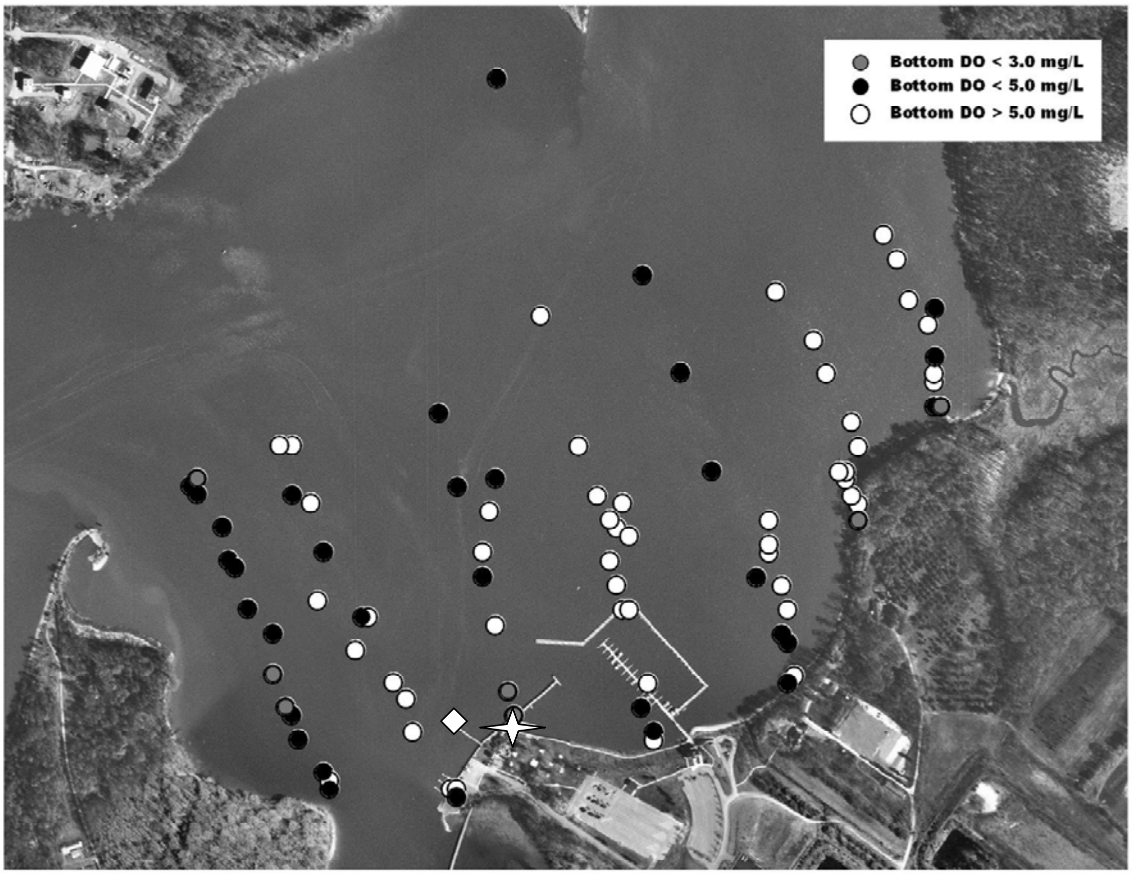


Figure 4-9. Coverage and density of SAV in Mattawoman Creek from 1989-2010 estmated by the Virginia Institute of Marine Science (2012).

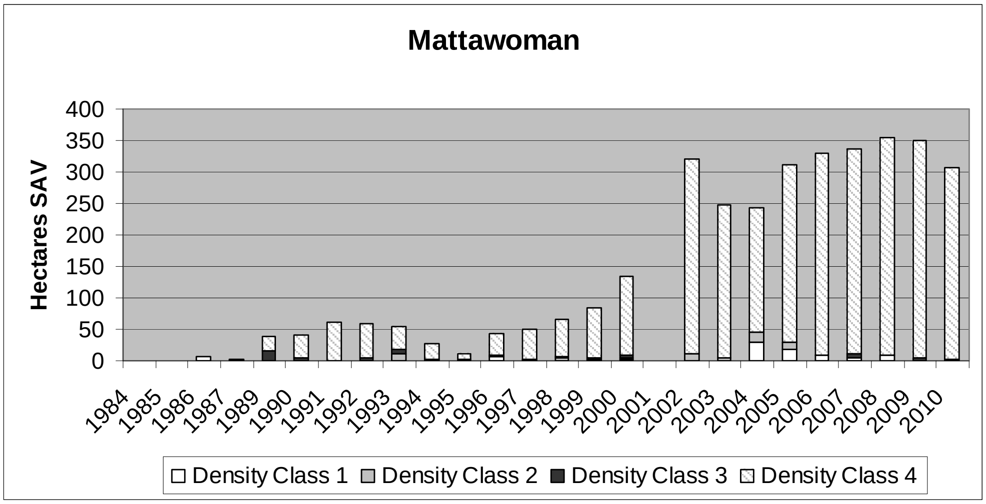
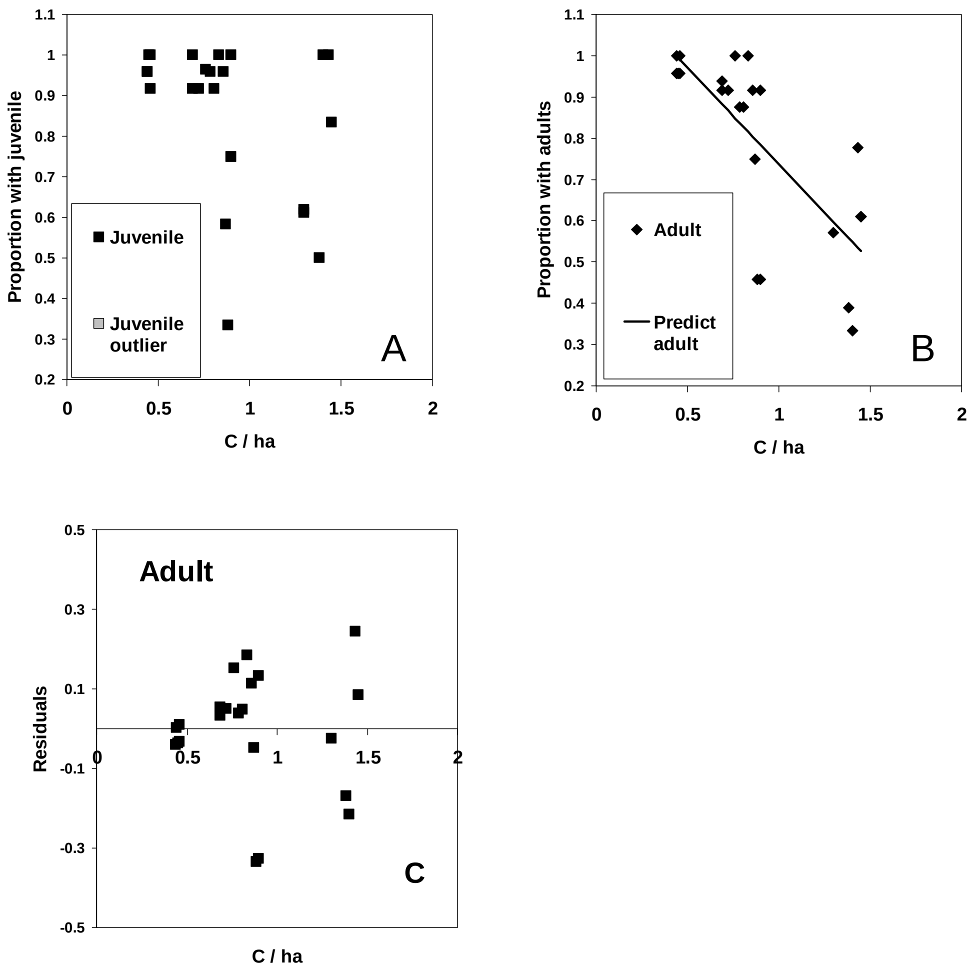


Figure 4-10. Bivariate plots of development (C / ha) and proportions of trawl samples taken in tidal-fresh subestuaries with white perch (A) juveniles and (B) adults. Absence of line for adults indicates linear regression was not significant at $P \leq 0.05$. Predicted line for adults indicates a significant regression. (C) Residuals of the linear regression with C / ha for adult white perch plotted against C / ha.



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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 environmental review policy for the Department. The activities of these positions are funded through this federal aid grant: ER activities were entirely funded under Job 2.

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 2011

In 2010, DNR had assigned two staff members as the primary environmental reviewer and planner (Bob Sadzinski) and the other as the liaison for the Fisheries Service (Jim Uphoff), but in 2011, Bob Sadzinski became both the reviewer and the Fisheries Service liaison.

Duties for this position included estuarine and marine environmental reviews for Charles, St. Mary's and Calvert counties and in 2011 DNR reviews in Anne Arundel and Prince George's Counties were also assigned to this project. In addition, this project reviewed statewide landfill, reef and aquaculture applications. Table 1 presents an overview of the number of projects by permit type.

In 2011, 362 applications were reviewed by this project, many of which required significant DNR coordination. Due to the consolidation of responsibilities and the addition of two counties, reviews in 2011 significantly increased from 2010. Although difficult to quantify, annual permit reviews for this position are likely to remain at this level or if the economy improves, could significantly increase.

In addition, the environmental reviewer continued to serve as an advisor for 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 and included;

- 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. This 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 assist in restructure the current GIS system to include additional pertinent data layers including aquatic bottom types and navigational channels.

Table 1. Overview of the projects by application type and year.

Application Type	Number of Projects Reviewed	
	2010	**2011**[1]
Aquaculture	24	14[2]
Reef	1	4
Living Shoreline	0	64
County - Specific	141	250
Surface Mine	10	16
Landfill	18	14
Total	**194**	**362**

[1] Two additional counties were assigned to the reviewer in 2011.
[2] The environmental review unit ceased reviewing aquaculture permits in April 2011 because of the streamlined process with MDE and the Corp of Engineers.

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

Jim Uphoff, Margaret McGinty, Alexis Maple, and Justin Falls

Introduction

The objective of Job 3 was to document participation of the Fisheries Habitat and Ecosystem Program (FHEP) 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.

Maryland Fisheries Service - Fisheries Habitat and Ecosystem Program Website

We developed a website that features the FHEP, particularly its focus on understanding how urbanization limits habitat for fish. The website is located at http://dnr.maryland.gov/fisheries/fhep/index.asp. It offers information on how habitat changes impact Maryland's fisheries in the Chesapeake Bay and information on community planning. Links provide the public and anglers with information on developments in their county, current issues being examined by FHEP and case studies revealing the effects of development. The website also offers access to past and current reports and publications. The website will be continuously updated to provide additional information for the public and anglers.

Environmental Review Unit Bibliography Database

The FHEP updated a bibliography of references deemed helpful in addressing land use impacts for the Environmental Review Unit (ERU). The bibliography was initiated to assemble information and references for environmental review and habitat related monitoring and research. The bibliography includes literature pertaining to development's impacts on:
fish assemblage changes;
decreased fish health;
decrease of fish biotic integrity;
increased peak flow;
reduced base flow;
increased concentrations of chemical pollutants in urbanized watershed stormwater runoff;
thermal pulses and altered thermal regimes in receiving waters;
lower dissolved oxygen levels;
increased total dissolved solids;
modified stream structure and function;
increased sediment load;
increased water conductivity;
habitat degradation, loss, and fragmentation;
"urban heat island" effect;

increased storm runoff;
decreased landscape and riverscape aesthetics;
decreased aquifer recharge;
reduced water-storing capacity;
soil modifications;
shift in wildlife occurrence and abundance;
and altered the natural energy and material cycles of ecosystems.
The bibliography continues to be updated with new scientific literature and a PDF of every available reference is saved in the database for easy access. The ERU bibliography is constantly being updated by FHEP staff.

DNR Interagency Effort on Mattawoman Creek

The FHEP partnered with multiple DNR agencies on an ecosystem-based management plan for Mattawoman Creek's watershed. Mattawoman Creek provides an exceptional recreational fishery for largemouth bass, provides spawning and nursery habitat for anadromous fish, and has a diverse tidal-fish community. Maryland DNR initiated this effort as a pilot project to develop a proactive approach to strategically target DNR assistance, information and resources to protect the most ecologically valuable resources threatened by development under the spirit that "an ounce of prevention is worth a pound of cure".

Land use change associated with development is a threat to Maryland's natural resources and ecosystem functions. Authority for land use decisions in Maryland largely lies with local government. The comprehensive planning process that each county undergoes periodically provides an opportunity for natural resource managers to influence planning and zoning to conserve fisheries and other natural resources.

In response to a request from Charles County, a MD DNR workgroup including the FHEP, convened in 2010 to provide natural resource-focused guidance on planning and zoning for Charles County's revision of its comprehensive growth plan. Criteria related to resource value, degree of threat and likelihood of success were met before DNR committed to this effort. The aquatic and terrestrial resources within the watershed ranked high in quality from a statewide perspective. Projected development within the watershed exceeded biological thresholds that would result in irreparable terrestrial and aquatic habitat changes. Most importantly, the likelihood of success was favorable since Charles County was willing to enter a partnership with DNR and consider the agency's recommendations in their comprehensive planning process.

At the onset, it became apparent that multiple resource agencies at federal and state levels were interested in providing a comprehensive set of land use, growth management, and resource management assessments and recommendations. A cross-agency science and support team was formed and nine taskforces were created, addressing eight elements described below plus data management and analysis. These groups met over a three month period to assemble the various reports and recommendations included in this report. A near-complete draft was provided to Charles County in December, 2011. This report is available on the DNR website http://www.dnr.state.md.us/ccp/pdfs/MEPR_Dec2011.pdf.

The report assessed potential cumulative impacts of development on the resources of the Mattawoman Watershed in Charles County Maryland. Its premise was that growth within the watershed prompted by current zoning virtually assured future watershed deterioration. The premise was supported by the experience with more urbanized environments within Maryland.

Review of the County's growth policies and regulations indicated they were disconnected from the intent to protect Mattawoman Creek's ecosystem functions.

A number of reforms to the current County regulatory framework were proposed for consideration by the County: changes to zoning, restructuring the transferable development rights program, reforms to direct planned development away from the sensitive resources of Mattawoman Creek's watershed, and reductions of forest fragmentation, impervious surfaces, and impacts to water quality. The recommendations were designed to support existing policies and permit Mattawoman Creek to support the County's economy through productive and diverse natural resources that sustain biodiversity, recreational and commercial fisheries, hunting, forestry, ecotourism, and other rural activities and businesses.

The full report included the following elements.

1. Land Use and Growth Management provided an overview of past, present and future land use and growth effects on Mattawoman Creek's resources.
2. Fisheries Resources presented the relationships of development and the health of Mattawoman Creek's fish and fisheries.
3. Stream Systems evaluated the current condition of the watershed's stream systems and aquatic biodiversity.
4. Wetlands, Coastal Resources and Coastal Climate Change focused on the condition and extent of wetland and coastal resources. Climate change issues specific to the coastal zone, including sea-level rise, coastal habitat adaptation and shoreline erosion were also evaluated.
5. Forest Resources discussed the extent, quality, and water quality protection value of forests within the watershed.
6. Wildlife and Rare Species Habitats identified the unique wildlife and rare species habitats found within the watershed.
7. Water Resources Management for a Future Climate provided guidance on how water resource management efforts should be modified in response to changes in precipitation and temperature resulting from climate change.
8. Stormwater Management offered guidance on implementing stormwater management practices for both retrofits and new development.

Spatial Planning

Presently, we have maps to identify critical spawning and nursery habitat for key anadromous species. We developed these maps by identifying the natural distribution of each species and ranking areas based on likelihood of habitat occupation. Stressors that limit distribution (in this case impervious surface) were assessed and ranked. Stressor data were combined with natural distribution data and ranked based on present habitat condition. We ranked data into three categories (good, fair and poor) based on the watersheds' potential to support spawning under existing levels of development. We combined all anadromous species maps to produce one map for Maryland. (Figure 1).

This map is being used with a series of other resource maps, to guide land management strategies geared toward land acquisition and conservation.

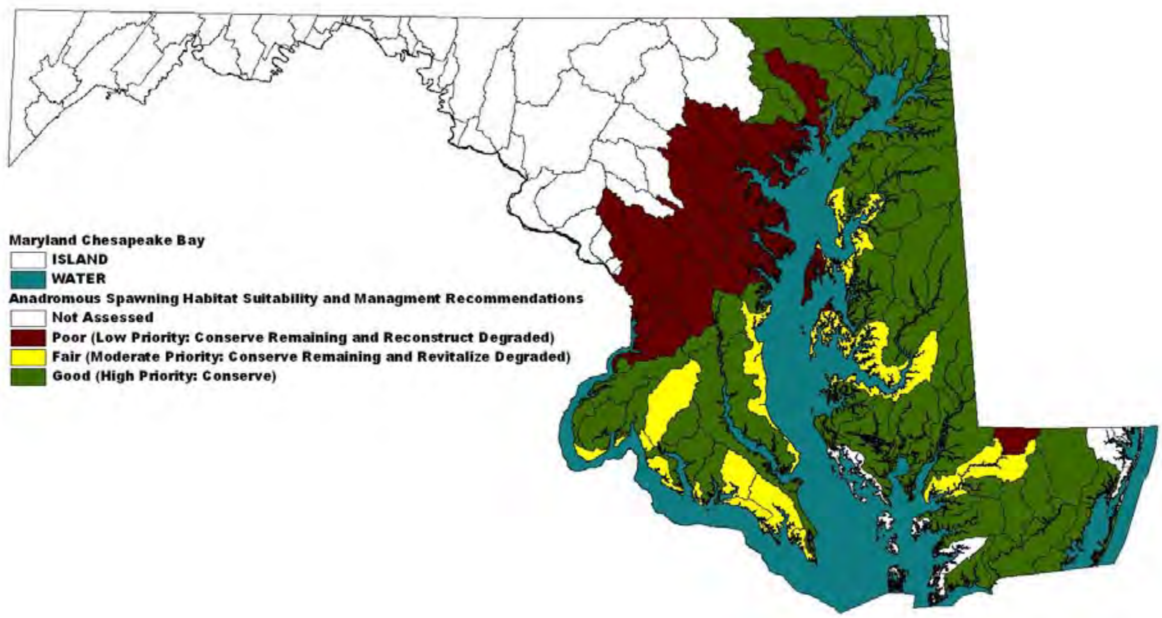

Figure 3-1. Watersheds in Maryland delineated by their suitability in supporting anadromous spawning. Poor habitat areas no longer support viable spawning. We recommend conserving remaining habitat and reconstructing degraded habitat in these poor spawning areas. Fair spawning habitat can still support spawning, however, they are likely areas on the edge due to natural limits of distribution or increased urbanization. We recommend conserving remaining habitat and revitalizing degraded habitat. Areas identified as good habitats are areas that still support viable spawning, because they are well within the natural range for spawning and urbanization impacts are low. We recommend conserving these habitats and restoring minimally degraded habitats.

Legislative Assistance

Program staff prepared a message for the Director of Fisheries Service outlining the need for fishermen to support Maryland's Program Open Space funding. Program Open Space was created to buy land for open space and recreation at a pace equal to development. This program is funded by a tax on real estate sales. There was a proposal from the Department of Legislative Services during the 2011 legislative session to transfer Program Open Space funds to the General Fund and replace them with $50 million a year for the next several years. Land conservation important for recreational fishing would end up with less money under this proposal. The proposal was defeated.

Chesapeake Bay Program

The FHEP participated in a workshop on zooplankton monitoring. The Bay Program discontinued zooplankton monitoring in 2002 and was considering restoration of partial funding. We maintained that zooplankton monitoring is essential for Ecosystem-based Fisheries Management.

The FHEP made a presentation on Mattawoman Creek's fish habitat to the Healthy Watershed Goal Implementation Team (GIT) in September, 2011, and two presentations on watershed development and fisheries management at the Fisheries Goal Implementation Team workshop in Alexandria VA in December, 2011. The Fisheries GIT is composed of the leadership of MD Fisheries Service, VMRC, PRFC, and ASMFC. These two presentations explained our findings and activities to date and the Fisheries GIT appeared interested in the approach FHEP has provided for Fisheries Service and DNR. Following this meeting, FHEP worked with the Chesapeake Bay Commission on a handout *Land Conservation = Fish Conservation*: *New Science Brings New Meaning* (http://dnr.maryland.gov/fisheries/fhep/pdf/CBC_Land_Conservation_Fish_Conservation_Fact_Sheet.pdf). This handout summarized information presented at the GIT meeting to Chesapeake Bay Program decision-makers.

Cooperative Research

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.

We are collaborators on a project entitled Assessment of Stressors at the Land-Water Interface that seeks 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.

We are collaborators on U.S. Fish and Wildlife Service and U.S. Geological Survey research on the effect of water quality and contaminants, land use and yellow perch spawning success in Chesapeake Bay.

We are collaborators with Dr. Walter Boynton and his staff at Chesapeake Biological Laboratory who are modeling nutrient dynamics in Mattawoman Creek. This effort may help explain the dynamics of the ecological changes in this system that may be impacting the fish community and fisheries.

Journal Publications

Impervious Surface, Summer Dissolved Oxygen, and Fish Distribution in Chesapeake Bay Subestuaries: Linking Watershed Development, Habitat Conditions, and

Fisheries Management, was published NAJFM (31:554-566). This manuscript is based on our federal aid activities during 2003-2005.

Jim Uphoff is a coauthor on an article, *Biological Reference Points for Nutritional Status of Chesapeake Bay Striped Bass* (*Morone saxatilis*), submitted to NAJFM by John Jacobs, Reginal Harrell, and Kyle Hartman. Results in this paper indicate that 1) determination of tissue moisture alone allows for the accurate calculation of percent lipid and energy density; 2) weight at length indices are generally less sensitive indicators of nutritional status than tissue moisture analysis; and 3) the relative body fat index correlates strongly with measured lipid. The article proposes that the proportion of striped bass with less than 80% moisture and/or classified as having no observable visceral body fat as thresholds of starvation for ecosystem approaches to fisheries management of striped bass.

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 8,000 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.

Presentations and Outreach

We made presentations based on our work to the Maryland Water Monitoring Council, Towson University natural resource economics classes, the Mattawoman Creek workgroup (described previously), the Environmental Management of Enclosed Coastal Seas 9th annual meeting, and the Maryland Stream Conference. We organized a special session on Mattawoman Creek at the latter conference**.**