Project 3: 2008 Fisheries and Habitat Interactions Project: Development of Habitat-based Reference Points for Chesapeake Bay Fishes of Special Concern: Impervious Surface as a Test Case

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Introduction

Fisheries management uses biological reference points (BRPs) to determine how many fish can be safely harvested from a stock (Sissenwine and Shepherd 1987). The primary objective of Project 3 is to evaluate the concept of using impervious surface reference points (ISRPs) as a similar tool for fish habitat management. Quantitative, habitat-based reference points based on impervious surface for estuarine watersheds are envisioned as a basis for strategies for managing fisheries in increasingly urbanizing coastal watersheds and for communicating the limits of fisheries resources to withstand development-related habitat changes to stakeholders and agencies involved in land-use planning.

The development of ISRPs involves determining functional relationships between a watershed's area covered in impervious cover (or IS; paved surfaces, buildings, and compacted soils) and habitat quality (water quality, physical structure, etc) or a species response (habitat occupation, abundance, distribution, mortality, recruitment success, growth, etc). Exploring these relationships for a suite of focal species was the objective of Project 3.

Land is converted to IS as human population grows and by most measures, human impacts have grown faster than the population (Beach 2002). A variety of studies have documented deterioration of freshwater aquatic ecosystems as IS occupied more than 10% of watershed area (Cappiella and Brown 2001; Beach 2002). Impervious surface increases runoff volume and intensity in streams, leading to physical instability, and increased erosion and sedimentation. This runoff, warmer than water draining forests or other porous lands, becomes a source of thermal pollution. Impervious surface runoff transports a wide variety of excess nutrients that contribute to algae blooms, hypoxia, and anoxia (Beach 2002). The Center for Watershed Protection (http://www.cwp.org/) has developed an IS cover model that expresses the relationship of fluvial stream quality to IS. This model supports the concept of a "10% rule" and further describes watersheds with 11-25% IS as impacted and those with more than 25% as unable to support freshwater aquatic life (Cappiella and Brown 2001). This rule seems to apply to tidal waters where at least some salinity is present as well (Holland et al. 2004; McGinty et al. 2005; Uphoff et al. 2006). Measurable adverse physical and chemical changes in tidal creek ecosystems were described by Holland et al. (2004) when IS exceeded 10-20% and living resources responded negatively when IS exceeded 20-30%. A strong relationship between IS and dissolved oxygen (DO) was found during 2003-2005 in brackish Chesapeake Bay tributaries that were sampled by this project (McGinty et al. 2005).

Dissolved oxygen is an ideal habitat variable to study because fish require well-oxygenated water, it provides insight into both the metabolic and pollution status of a waterbody (Limburg and Schmidt 1990), and it is easily measured in the field. Bell and Eggleston (2004) found that several species of fish and blue crabs in a trawl survey strongly avoided hypoxic conditions, particularly chronic hypoxia, in the brackish Neuse River Estuary, North Carolina. Hypoxia also can disrupt endocrine function associated with successful reproduction (Rudolph *et al.* 2003). Habitat issues associated with impervious surface are not limited to just DO and it is recognized that development *per se*, urbanization and industrialization, contribute significantly to contaminant loads, eutrophication, and physical degradation of coastal areas (Pearce 1991; Beach 2002). Disruption of reproduction in fish could be caused by anthropogenic chemicals (Colborn and Thayer 2000) and alteration of hyrdrologic features in streams needed for anadromous fish spawning habitat (Konrad and Booth 2005). In Maryland's portion of Chesapeake Bay, excessive concentrations of PCBs and organochlorine pesticides have lead to consumption advisories for organochlorine compounds in white perch in most suburbanized estuaries (Maryland Department of Environment, www.mde.state.md.us). These advisories reflect a strong relationship of contamination in Bay white perch with impervious surface (King et al. 2004). Experiments with Atlantic croaker indicated maternal transfer of PCBs to eggs and larvae would result in reduced growth rates and impair behaviors associated with avoidance of predators (McCarthy et al. 2003). Westin et al. (1985) observed slightly better survival of striped bass larvae from eggs with lower concentrations of organochlorine compounds (including PCBs).

Anadromous fish populations in the Hudson River (Limburg and Schmidt 1990) and estuarine fish communities in Chesapeake Bay (Carmichael et al. 1992) appear to respond to development negatively, although their responses have been related to urban land-use in general rather than impervious surface. Strong, negative relationships between impervious surface and freshwater biotic communities and the threshold concept have been supported in brackish sub-estuaries of Chesapeake Bay (McGinty et al. 2006; Uphoff et al. 2007). However, large volumes of out-of-basin water (such as Susquehanna River water in high flow years) entering the Bay's sub-estuaries may serve as a source of relatively clean water that dilutes the effect of upstream watershed inputs and may push impervious surface thresholds higher.

Impervious surface is increasingly used as an indicator tool by local planning and zoning agencies because of compelling scientific evidence of its effect in freshwater systems and because it is a critical input variable in many water quality and quantity models (Arnold and Gibbons 1996; Cappiella and Brown 2001). Chesapeake Bay watershed impervious surface targets and thresholds would be useful for county and state growth planning, watershed-based citizen groups, and interstate finfish habitat management, as well as Maryland Fisheries Service needs. Defining the impact of impervious surface on specific finfish populations would give managers a better understanding of how degraded habitats influence fish production and allow them to account for these effects in managing individual fisheries.

Project activities in 2008 included spring stream anadromous fish icthyoplankton collections, spring yellow perch larval presence-absence sampling and summer sampling of estuarine fish communities, and evaluation of data collected in previous years. These efforts were collectively aimed at defining the impact of impervious surface on target fish species populations and habitats. Each aspect of the project will be presented separately with the report conclusions describing how they collectively promote our understanding of the effects of habitat degradation.

Stream Ichthyoplankton Sampling

Background

An extensive effort to identify anadromous spawning habitat in Maryland was conducted from 1970 to 1986 (O'Dell et al, 1970, 1975, 1980). As a result, statewide maps of spawning habitat were developed to identify areas in need of restoration and also protection. These data have since been the sole source of information that planners use for permitting decisions. Recreating these surveys provides an opportunity explore whether spawning habitat is declining in response to landuse changes in the watersheds. To date, we have sampled three watersheds (Bush River, Piscataway Creek and Mattawoman Creek) using citizen volunteers (Figure 1).

Methods

We employed the same methods used in the historic survey, and revisited sites that historically supported at least one of the three target species, or target families (in the case of herring and shad).

We have sampled the Bush River from 2005-2008 in partnership with Harford County Department of Public Works, Harford County Parks and Recreation, Aberdeen Proving Ground (APG), and Maryland Department of Natural Resources Chesapeake Bay National Estuarine Research Reserve. Historically, 26 sites were sampled in the Bush River Watershed (Figure 2). Effort varied among the years to develop a better understanding of how spawning habitat use has changed over the 36 years that have elapsed since the historic survey was conducted. In 2005, we sampled 15 stations in non-tidal areas. These stations did not support spawning of white perch and yellow perch at the same capacity historically observed. One limitation of the 2005 sampling was that it did not include adult sampling by wire traps. In 2006, we added trap sampling at the most downstream station on each stream to verify plankton results. Additionally, we collaborated with APG staff to sample four historic stations that supported spawning. During 2006, stations on APG continued to support spawning habitat, while Bush River results were consistent with 2005. To better understand if observed differences among sites were driven by changes in land use, we expanded sampling in the Bush River, adding tidal sites to the sampling design. The intent was to compare tidal sites in the Bush River with tidal sites on APG. However, sampling was not conducted on APG in 2007, because of staff shortages. We conducted the full sampling design in 2008 to finalize these comparisons and to assess if the differences that we observed between present and historic data are being driven by the changes in land use that we have observed in the Bush River watershed.

Data for four years of sampling were evaluated by examining the proportion of samples with fish present, based on the estimated amount of impervious surface in the watershed. Impervious surface estimates were obtained from the Bush River Watershed Management Plan (WRAS; Center for Watershed Protection, 2003). Estimates for APG were calculated from 2002 land cover data by applying impervious surface coefficients. We included water area when we calculated total watershed area. We found that this made a tremendous difference in the percent impervious cover (4% with water area included verse 32% without). Based on the general landuse patterns, we applied the 4% estimate, because we felt that it better reflected the on the ground cover. There were two limitations to using these estimates: 1) they are derived from different sources and therefore may reflect different methods in developing the estimates; and 2) because they are from different sources, the scale used to calculate the estimates differs. On Aberdeen, we were not able to break out the individual watersheds for each stream, therefore the estimate for impervious cover includes all APG property. Additionally, the WRAS did not provide estimates for all streams individually, so we had to use reported estimates, along with visual assessment of the land cover data to estimate if impervious cover was high or low. Because we could not get exact measurements for each individual stream, we took all available data and estimated if the stream was above 5% impervious or below 5% impervious. (This 5% threshold was established because of a dichotomous distribution of impervious surface, i.e., watersheds were grouped at less than 5% impervious or exceeded 10%.) We excluded data where estimates could not be clearly discerned. Table 1 shows the estimates that we used to assign impervious cover values to the streams sampled. Ideally, we would like to obtain estimates by stream to refine our analysis, however, staff resources do not permit that at this point.

In Piscataway and Mattawoman Creeks, volunteers were trained to collect samples from sites that showed presence of one or more anadromous species in the original collections made by O'Dell, et al, 1972.

Historically, 17 stations were sampled in Mattawoman Creek and six stations were positive for presence of one or more anadromous species. These six stations plus three additional stations were sampled in 2008.

Thirty stations were sampled in Piscataway creek and the surrounding watersheds in 1971. Twelve of these stations were positive for anadromous fish presence. Of these twelve stations, nine were selected to be sampled for presence of anadromous fish eggs and larvae in 2008.

Ichthyoplankton samples were collected from March through May. Samples were evaluated to determine presence of target anadromous species (white perch, yellow perch, alewife and blueback herring and hickory and American shad). Citizen volunteers were trained to collect samples in the Bush River with oversight by a volunteer coordinator provided by Harford County; DNR staff trained and oversaw volunteer efforts in Piscataway and Mattawoman Creeks. Samples were collected using stream drift nets made of 360-micron mesh, attached to a square frame with a 300 X 460 mm opening. The frame was connected to a wood handle so that the net could be held in place and a threaded collar was placed on the end of the net where a mason jar was connected to collect the sample. Nets were placed in the stream with the opening facing upstream for five minutes. The nets were then retrieved and rinsed in the stream, by repeatedly dipping the lower part of the net and splashing water on the outside of the net to avoid sample contamination. The jar was then removed from the net. A sample label describing site, date, time and collectors was placed in the jar. The jar was sealed and placed in a cooler for transport. After a team finished sampling for the day, they would turn their samples over to the coordinator, who would then fix them with 10% buffered formalin and 2 ml Rose Bengal to stain protein. Water temperature, pH, conductivity and dissolved oxygen were recorded at each site using a hand held YSI model 85. 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 volunteer and signed off by the volunteer coordinator.

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

Presence of white perch, yellow perch and herring and/or shad eggs or larvae at each station was compared to historical presence to determine which streams still supported spawning. Presence of any of these life stages was used as evidence of spawning activity for comparisons with historical designations in O'Dell (1975). The proportions of samples with eggs or larvae of individual target species present and their 95% CI's were calculated for all data in the Bush River. These data were compared by impervious cover classification to examine its impact of fish spawning habitat.

Results and Discussion:

Bush River

A total of twenty-six stations were historically sampled in the Bush River and surrounding watersheds (O'Dell at al, 1975). The Bush River proper had fifteen stations, APG, 6 and Swan and Gashey's Creeks, 5. Of the fifteen historic stations in the Bush River, all stations were sampled again except for Bush Creek (BBS1) because there was not access to the site, and the station on Unnamed Tributary 1 (BUN1) because it was deemed too small to support Anadromous spawning. In addition to the historic stations in the Bush River, we added three stations in 2007. These stations located in the downstream tidal areas that were considered wadeable. They included Winters Run (BWRT), Haha Branch (BHHT) and Grays Run (BGRT). We sampled four of the six stations on APG. Stations on Bridge and Delph Creek were not sampled because anadromous fish were not observed when historically sampled. Figure 2 shows all stations that were sampled historically and present.

In addition to Bush River, volunteers who had military clearance sampled four stations on the Gunpowder. We did not include these data in analysis of the Bush River watershed, but we did report them. These stations were presumably located in a watershed that has undergone little change over the historic time frame. However, these stations were not part of the historic sampling effort.

We obtained 1973 land cover data for the Bush River watershed. This enabled us to compare it to the most recent land cover data that we have from 2002. Figure 3 shows land cover for the two years with dominant land use type identified. Close observation of these maps show that the Bush River watershed has undergone significant land use changes while the APG area has remained unchanged over the thirty year period. This offered us an opportunity to compare historic presence to contemporary presence and examine land use change (specifically impervious cover) as an explanatory variable that could be associated with changes in presence that we observed.

Herring/Shad

Of all twenty-six historic stations sampled in the Bush River, APG and Swan Creek, thirteen supported herring spawning in 1973 (Figure 4). In 2005, we sampled fifteen of the original twenty-six stations. Twelve stations were located, predominately in the nontidal reaches of the Bush River watershed and three stations in Swan Creek. Herring were observed at seven of the twelve stations in the Bush River and 1 of the three in Swan Creek. In the Bush River, herring were observed at two stations where they were historically present and five stations where they were not. In Swan Creek, herring were observed at one station that historically showed presence and one that did not (Figure 5). Figure 6 shows herring presence in 2006 compared to historic presence. In 2006, we sampled the same fifteen stations sampled in 2005 and four additional stations on APG. Herring were observed at eight stations, four in the Bush River, three in APG and one in Swan Creek. Only one station in the Bush River historically had herring present. In 2007 (Figure 7), we sampled eleven stations in Bush River and two stations on Swan Creek. Three stations in the Bush River were new stations that were added in the downstream tidal areas. All stations sampled in 2007 were positive for herring presence. We repeated the same sampling in 2008 that was conducted in 2007, with the addition of the four stations on APG. Herring were observed at four of the nine stations in the Bush River, one of two on Swan Creek and three of four on APG (Figure 8). When we compared the presence of herring over the last four years to the historic presence, it appeared that herring had expanded their use of spawning habitat. Eight stations supported spawning in 1973, whereas nine of the historic stations supported presence of herring in the contemporary sampling program. Additionally, Swan Creek historically showed presence at one station, and recently showed presence at all three stations. However, herring were stocked in Swan Creek in 2005, to test the effect of notching a weir that was believed to preclude upstream migration of anadromous species. APG did not show a change in habitat occupied; stations that historically supported spawning still show presence of eggs and/or larvae. When we evaluated the distribution of spawning, in the Bush River proper, herring did not appear to be migrating as far upstream to spawn as historically documented.

Yellow perch and white perch

Results for yellow perch and white perch are markedly different from herring results. Historic sampling showed that white perch were present at nine stations in the Bush River, four on APG, none on Swan Creek and one on Gashey's Creek. Figure 10 compares historic presence to results from 2005 to 2008. No white perch eggs or larvae were observed at any stream stations in the Bush River. We did set wire fish traps in the Bush River in 2006 and 2007 to determine if adults were present at sites where no eggs or larvae were observed. We did observe ripe adult males at one station (BOP1) in 2007; however, we did not observe eggs or larvae in our samples and therefore concluded that there was no successful spawning at this station. Three of four stations on APG continued to support white perch spawning, and no white perch were observed in Swan Creek. We did not sample Gashey's Creek and therefore, cannot report if changes occurred there.

Yellow perch were historically present at five stations in the Bush River, four on APG and were not observed in Swan or Gashey's Creek. Present sampling indicated yellow perch were present at three stations in the Bush River, three on APG and none on Swan Creek (Figure 11). There has been an apparent decline in spawning habitat use in the Bush River for both yellow perch and white perch over the thirty-five years elapsed since the original sampling was conducted.

To test if this loss can be attributed to land use change, we pooled the data from 2005 through 2008 and assigned an impervious surface estimate to each site. (Table 2 shows the percent presence by station, year and species.) As previously explained, we assigned stations to one of two categories of impervious surface (>5% or <5% impervious surface), based on the estimated impervious surface for a stream. We then calculated proportion of stations with fish present (with the 95% confidence intervals) by impervious category. Figure 12 shows results of this application. For herring there appeared to be no effect of impervious surface on presence of herring as the distributions for each impervious category overlap. However, yellow perch were present in samples more often in watersheds where impervious surface was below the 5% threshold. White perch were not observed at stations where the watershed exceeded 5% impervious surface.

Mattawoman and Piscataway Creeks:

Stations in Mattawoman Creek were sampled in 2008 to determine the extent of spawning habitat still being occupied in comparison with 1971. We have been concerned over landuse changes in Mattawoman's watershed, because past studies documented that Mattawoman is one of the most productive nurseries in Chesapeake Bay (Carmichael et al, 1992). Changes in landcover data between 1973 and 2000 (Figure 13) indicated an increase in urban coverage over the twenty-seven year period. Most of Mattawoman's watershed falls within the designated development district in Charles County (U.S. Army Corps of Engineers 2003). The County has evaluated various growth scenarios for Mattawoman Crrek. The conservative approach caps impervious surface within the watershed at 15% (U. S. Army Corps of Engineers 2003). Considering the documented threats of impervious surface to aquatic resources (see introduction), we wanted recent data on Mattawoman Creek to establish the present status of spawning and to see how it has changed since the 1971 study.

Seventeen stations were sampled in 1971 (Figure 14). Of these stations, six showed evidence of herring spawning. Nine stations were sampled again in 2008 and only three stations showed evidence of herring spawning; these three stations also historically supported spawning (Figure 14). When considering the change in the use of stations, herring did not ascend upstream as far as they had in the past. We do not know if this is a function of habitat loss or spawning stock density.

Yellow perch were observed at only one station historically and it still supported spawning in 2008 (Figure 15). White perch were historically present at two stations, but were observed at just one station (the lowest in the watershed) in 2008 (Figure 16). These data suggest that there has been a decline in spawning habitat occupation by herring and white perch between 1971 and 2008.

Table 3 documents the percent presence of each species by station. Only the lowest station on Mattawoman had more than one sample with a given species present. The two stations that documented herring presence had only one sample where eggs or larvae were observed. Although we were only looking for presence of eggs or larvae, personal experience in this watershed shows a notable decline in abundance of herring eggs and larvae (personal observation, M. McGinty). We will continue to sample Mattawoman in 2009 to determine if these patterns hold and attempt to explain if changes in land use are driving these changes in spawning habitat occupation.

We also sampled stations in Piscataway, Henson and Oxen Creeks, in 2008 (referred to from this point forward as the Greater Piscataway area). As seen in figure 17, land cover has dramatically changed since 1973. Because the watersheds are adjacent to Washington, DC, they have experienced significant urban growth over the past thirty years.

Historically, a total of twenty-nine stations were sampled. Of these stations, twelve supported herring (Figure 18), none of them supported yellow perch (Figure 19) and six supported white perch (Figure 20). Nine of these stations were sampled again in 2008. Anadromous fish were not observed in 2008. Table 4 shows the number of samples collected at each station along with percent presence of each species (all zeros). Volunteers will sample these stations again in 2009.

Mattawoman and the Greater Piscataway area are adjacent watersheds. As stated, Mattawoman is subject to increasing growth pressures, whereas the Greater Piscataway area has undergone significant growth. Both watersheds were sampled in 1971 and then revisited in 2008. Both watersheds have shown declines in habitat use, with the Greater Piscataway area showing a total loss. In order to see if changes in landscape could be a factor in these changes, we show percentage of each land cover category between 1973 and 2000 (the most recent land cover data available; Tables 5 and 6). In 1973, two years after the initial survey, Piscataway's watershed was 23.6% urban (percent urban and impervious surface are measured differently and are not interchangeable for comparisons). In spite of the amount of urban coverage, the greater Piscataway area still supported spawning habitat for herring and white perch. By 2000, the landscape had increased to almost 40% urban and in 2008 did not support spawning. In contrast, Mattawoman was only 12.2% urban in 1973, when the watershed supported herring, white perch and yellow perch spawning. By 2000, urban coverage had almost doubled, and in 2008 there was a decline in habitat use. It's important to note that the present percent of urban cover in Mattawoman (25.9%, Table 5) is similar to the urban cover observed in Piscataway Creek in 1973 (23.6%, Table 6). Considering results from the

Bush River, we suggest these changes in urban coverage (which are related to impervious surface) are contributing to declines in spawning habitat occupation by the target species observed.

Because we have not identified the exact mechanism(s) in the urbanizing landscape that contribute to these observed losses in spawning habitat, we recommend limiting development in watersheds that continue to support spawning habitat, until we can better understand how to protect and possibly restore these habitats.

We will evaluate spawning habitat in Nanjemoy Creek during 2009 where urban cover is still well below 10% (Table 7). This watershed may offer a "minimally disturbed" reference to which we can compare Mattawoman and Piscataway results.

Estuarine Yellow Perch Larval Presence-Absence Sampling

Background

Yellow perch larval presence-absence sampling during 2008 was conducted in the upper tidal reaches of Nanticoke, Bush, South, and Severn rivers and Mattawoman and Piscataway creeks during late March through April (Figure 21). Yellow perch larvae can be readily identified in the field because they are larger and more developed than *Morone* larvae that could be confused with them (Lippson and Moran 1974).

Methods

A conical plankton net towed from a boat collected larvae at 10 sites (7 in Piscataway Creek) per system on 2-3 days each week in the upper portion of estuaries sampled (Figure 21). Nets were 0.5-m in diameter, 1.0-m long, and had 0.5 mm mesh.

Plankton nets were towed for two minutes at about 2.8 km per hour. Larval sampling occurred during late March through late April to –early May, 2008.

Sites in all rivers except Nanticoke River were sampled with little spacing between tows because larval nurseries or the systems themselves were small. Piscataway Creek was only large enough for 7 stations. Extent of area to be sampled was determined from bounds of larval presence in surveys conducted during the 1970s and 1980s (O'Dell 1987).

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

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

The proportion of tows with yellow perch larvae (L_p) was determined annually for dates spanning the first catch through the last date that larvae were consistently present. Uphoff et al. (2005) reviewed presence-absence of yellow perch larvae in past Choptank and Nanticoke River collections and found that starting dates during the first or early in the second week of April were typical and end dates occurred during the last week of April through the first week of May. Sampling during 2008 began during the last week of March and ended after larvae were absent (or nearly so) for two consecutive sampling rounds. In years where larvae disappeared quickly, sampling rounds into the third week of April were included even if larvae were not collected. Confidence intervals (95%) were constructed using the normal distribution to approximate the binomial distribution (Uphoff 1997).

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

Volunteers from the Arlington Echo Outdoor Education Center conducted Severn River collections and volunteers from Anita Leight Estuarine Research Center conducted Bush River collections in 2008 based on the sampling design described above. Bush River sampling was interrupted between April 10 and 22 due to boat breakdown. We had trained these volunteers in sampling and identification.

Historic collections in the Choptank and Nanticoke rivers targeted striped bass eggs and larvae (Uphoff 1997), but yellow perch were also common (J. Uphoff, MD

DNR, personal observation). Larval presence-absence was calculated from data sheets prior to 1998. After 1998, L_p in the Choptank River was determined directly in the field. 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 Choptank and Nanticoke rivers are described in Uphoff (1997).

Choptank River and Nanticoke River collections made prior to 1991 were considered an historic reference and their mean L_p (0.66) was used as an estimate of central tendency. Nine of 11 reference estimates of L_p fell between 0.4-0.8 and this was used as the range of the "typical" minimum and maximum. The 95% CI's of L_p of rivers sampled during 2008 were compared to the mean and "typical" range of historic values. Risk of L_p during 2008 falling below a criterion indicating potential poor reproduction was estimated as one minus the cumulative proportion (expressed as a percentage) of the L_p distribution function equaling or exceeding the "typical" minimum (0.4). This general technique of judging relative status of L_p was patterned after a similar application for striped bass eggs (Uphoff 1997).

Regression was used to test whether L_p during 1998-2008 was linearly influenced by IS. Estimates were available for Choptank River (1998-2004: IS = 2.1%), Nanticoke River (2004-2008; IS = 1.2%), Severn River (2004-2008; IS = 17.0%), Bush River (2006-2008; IS = 12.8%), Corsica River (2006-2007; IS = 4.0%), Langford Creek (2007; IS = 0.9%), South River (IS = 10.0%), Mattawoman Creek (IS = 8.5%), and Piscataway Creek (IS = 14.9%). Separate regression analyses of L_p versus IS were conducted for fresh-tidal (< 1‰) and brackish tributaries. Uphoff et al. (2008) reported that differences in IS thresholds for white perch juveniles and adults existed between fresh-tidal and brackish tributaries that reflected substantial differences in levels of DO in bottom waters. Water column stratification is more likely when salinity is present and is a major influence on oxygen depletion (Kemp et al. 2005).

Mean salinity of dates and sites used to calculate L_p were estimated for each system. Data were available for Choptank River collections during 1998, 2000, and 2001; Nanticoke River during 2006-2008; Severn River during 2004-2008; Bush and Corsica rivers during 2006-2008, and Langford Creek during 2007, South River, Mattawoman Creek, and Piscataway Creek (all three in 2008). Uphoff et al. (2007) compared salinity (‰) and temperature data (°C) during 1998-2006 larval surveys to requirements of yellow perch larvae (temperatures > 20 °C and salinity > 2 $^{o}/_{oo}$ were considered detrimental; Piavis 1991) to determine the extent and duration of suitable habitat in the past. There was little indication that temperature influenced L_p (Uphoff et al. 2005; 2007) and comparisons with temperature were discontinued. However, high salinities have been implicated in contributing to low L_p (Uphoff et al. 2005; 2007). These mean salinities were plotted and linearly regressed against L_p to examine this relationship and to evaluate whether salinity > 2 $^{o}/_{oo}$ was detrimental.

Results and Discussion

Proportion of tows with larval yellow perch in brackish systems, Severn River (L_p = 0.14, SD = 0.05, N = 50; 17.5 % IS), South River (L_p = 0.08, SD = 0.04, N = 50; 10.0 % IS), and Nanticoke River (L_p = 0.19, SD = 0.05, N = 58; 1.2 % IS) during 2008 was significantly lower than historic reference range of L_p (Figure 22) based on 95%

confidence interval overlap. Confidence intervals of L_p in fresh-tidal systems, Mattawoman Creek (L_p = 0.67, SD = 0.06, N = 70; 8.5% IS), Piscataway Creek (L_p = 0.47, SD = 0.07, N = 47; 14.9% IS), and Bush River (L_p = 0.49, SD = 0.05, N = 90; 12.8% IS) fell within the historic range. Risk of falling below the "typical" historic minimum of L_p = 0.4 during 2008 was near one in brackish systems and near zero in fresh-tidal systems.

The linear regression of IS (%) and L_p (proportion) in brackish systems during 1998-2008 was significant (r^2 = 0.25, P = 0.02, N = 20; Figure 23) and was described by the equation

$L_p = (-0.017*IS) + 0.52.$

A significant relationship could not be detected with the five points from fresh-tidal systems (Figure 23).

Mean salinity was not linearly related to L_p at $P < 0.05$, but examination of the scatter plot indicated a possible threshold level of salinity ($\approx$ 4‰) above which L_p was consistently below the historic median and near the historic minimum (Figure 24). The suggested mean salinity threshold at 4‰ was considerably greater than 2‰ habitat requirement used previously (Piavis 1991). Below 4‰, there was wide variation in L_p (Figure 24).

Interpretation of the influence of salinity on L_p may be clouded by rivers with higher impervious surface (Severn and South rivers) representing 5 of 6 values; the other point was from Corsica River. One observation for Severn River was at a mean salinity that resulted in higher L_p elsewhere (Langford Creek in 2007; L_p = 0.83 at 3.5 ‰). Other factors related to IS, could be suppressing L_p in Severn and South rivers (Uphoff et al.

2005) and high salinity is coincidental or constitutes a minor contribution. Severn River generally grouped into the highest mortality group regardless of salinity treatment in experiments with yellow perch prolarvae from several Maryland tributaries (Victoria et al. 1992).

Mortality related to salinity offers a partial explanation of variation in L_p among tributaries. Mortality of yellow perch eggs and prolarvae in experiments generally increased with salinity and was complete by 12‰ (Sanderson 1950; Victoria et al. 1992). Eggs hatched successfully (< 30% mortality) at 6.7-8.8‰. The range of suitable salinities for prolarvae was lower than that for eggs and survival was highest at 2-9‰ and abnormal behavior of larvae held for about a week at 8‰ suggested that delayed mortality would occur (Victoria et al. 1992).

Two observations of note emerged after reviewing 2008 collections. The first is the possibility of different relationships of L_p and IS in fresh-tidal and brackish tributaries. Fresh-tidal systems have only been sampled in four years (1990 and 2006-2008) and have exhibited the highest L_p in each of these years in spite of being collected from systems with 8.5-14.9% IS. Mattawoman Creek L_p in 1990 was represented by a point estimate because of low sample size (N = 10). In 2006-2007, confidence intervals of the "best" L_p overlapped among fresh-tidal (Bush River, 12.8% IS) and some low IS brackish systems sampled (Corsica River and Langford Creeks, ≈ 4% IS).

The second observation stems from the occasional poor showing of the Nanticoke River, which is considered a brackish low IS reference system. Since 2004, Nanticoke River has been in the historic range 3 of 5 years and below it in two years (Figure 25). Poor years (below the reference minimum) for L_p are not just a feature of brackish high

IS systems, but consistently poor L_p is - five straight years of L_p below historic minimum reference occurred since 2004 in Severn River. South River exhibited L_p expected from a stressed system in 2008. Choptank River (a second low IS reference system) during 1998-2004 also exhibited variation of L_p within and below the historic range that was similar to the Nanticoke River (Figure 25).

Interpretation of annual L_p is not straightforward because it integrates the product of egg production, and egg through larval survival. All of these factors would need to be moderate to high to produce average to strong L_p, but only one needs to be low to result in low L_p. If survival of each life stage is independent of the other, a log-normal distribution of L_p might be expected (Hilborn and Walters 1992), i.e., high estimates of L_p would be uncommon and would represent the upper tail of the distribution. However, distribution of L_p since 1965 in areas other than Severn and South rivers does not appear to conform to a lognormal distribution and may adhere to a uniform or dome-shaped distribution (Figure 26). This suggests survival may not be independent across egg through postlarval stages.

Our judgment of L_p in recent years was based upon comparisons with rural Eastern Shore systems in the past because long time-series did not exist for our non-reference systems. These reference rivers have larger watersheds and more extensive regions of fresh-tidal water than some brackish tributaries we sampled. Uphoff et al. (2005) cautioned that comparability of smaller brackish tributaries with rural Eastern Shore reference systems could be biased. However, L_p estimates from tributaries other than Nanticoke or Choptank rivers (and excluding Severn River) during 2006-2007 have compared favorably with our historic reference (Figure 25).

Summer Estuarine Seining and Trawling

Sampling Areas

Impervious Surface Estimates

Table 8 summarizes percent impervious surface (IS) cover, non-water watershed area, and tidal water surface area estimates for watersheds sampled in 2008. Estimates for Bush River, Corsica River, Piscataway Creek, and Mattawoman Creek were from the University of Towson March 2001, Landsat 7, 30 meter pixel resolution for the western shore and October 1999 data for the Eastern Shore (estimates used in McGinty et al. 2006). Impervious surface estimated for Tred Avon River was from King et al. (2004) because an estimate for this watershed was not available elsewhere. Remaining estimates were based on Maryland Department of Planning (or MDDOP 1994a) estimates available from http://mddnr.chesapeakebay.net/wsprofiles/surf/prof/prof.html.

Surface area of water, in acres, 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. Lower limit of each water body was arbitrarily determined by drawing a straight line between the downriver-most points on opposite shores.

General land-use for all watersheds (i.e., percent urban, forest, etc.; all non-water acreages) was based on MDDOP (1994a). Urban land-use consisted of low through high density residential and industrial designations.

Eight watersheds were sampled in 2008, two in the Upper Bay, four mid-bay and two in the Potomac drainage (Figure 27). Nanjemoy Creek was substituted for

Piscataway Creek in 2008. Piscataway Creek had too much submerged aquatic vegetation (SAV) to be effectively sampled. Nanjemoy Creek was sampled previously in 2003.

Upper-Bay Sampling Areas

The Bush River (36,964 watershed and 7,966 tidal water acres) is located on the western shore north of Baltimore. It had the second highest level of impervious surface (12.8%) of all rivers sampled this year (Table 8). It is predominately forested (48% of the watershed) with urban areas comprising 24% of the watershed, agriculture, 22% and wetlands, 6% (Figure 28).

The Northeast River is a moderately urbanized watershed in Cecil County, Maryland. It covers 40,377 acres, has 3,908 acres of tidal water, and has 6.1% impervious cover (Table 8). It is 15.9% urban, 39.1% agriculture, 45.2% forest 0.1% wetland and 0.4% barren (Figure 29).

Mid-Bay Sampling Areas

Corsica River, a tributary of the Chester River, has a watershed of 23,924 acres of which 4.0% is impervious surface (Figure 30; Table 8). Tidal water comprised 1,256 acres. Approximately 65% of the watershed is in crops, 28% is forested; urbanized areas account for 6%, and 1% is wetland. The Corsica River watershed has been selected to receive nearly $19 million to implement comprehensive watershed management measures. More information on Corsica River restoration is available at http://www.mde.state.md.us/ResearchCenter/Publications/General/eMDE/vol2no3/corsica.asp.

Langford Creek, a tributary of the Chester River, is located in on the Eastern Shore. Its confluence with the Chester River lies directly across from the mouth of the

Corsica River (Figure 31). Its watershed (0.9% IS) is very similar in size (23,871 acres with 2,905 acres of tidal water) and land-use to Corsica River (Table 8). Agriculture occupies 69% of the watershed; forests occupy 26%; urban areas comprised 4%; and wetlands, 1%.

Tred Avon River is a tributary of the Choptank River on the Eastern Shore (Figure 32). Its watershed comprises 23,518 acres and tidal waters occupy 4,338 acres. Urban land comprised 22% of the watershed, agriculture 39%, forest 38%, and wetlands less than 1%. Impervious surface covers 5.6% of the watershed (Table 8).

The Wye River, on Maryland's Eastern Shore, drains land in both Talbot and Queen Anne's County. The watershed covers 50,460 acres, tidal water covers 6,142 acres, and 1.2% of the watershed is IS (Table 8). It is dominated by agriculture which comprises 69.9% of the watershed. Forest covers 25.9%, urban land 3.9%, wetlands 0.7 and barren land 0.1% (Figure 33).

Potomac Sampling Areas

Two tributaries of the Potomac River were sampled in 2008. Mattawoman Creek's watershed is 60,300 acres with 1,799 acres of tidal water and 8.5% IS (Table 8). Forest occupies 63% of the watershed; agriculture covers 14%; urban areas, 22%; and wetlands, 1 % (Figure 34). Mattawoman Creek has extensive military holdings within the watershed. The fluvial and tidal portion of Mattawoman Creek in Charles County has been slated for development to 15% IS. A significant fraction of the stream is located in Prince Georges County and is zoned for low IS development.

Nanjemoy Creek is located in Charles County, Maryland. The watershed is 40,377 acres with forestland comprising 74%, agriculture, 16% urban, 6% and wetlands, 4%. Impervious surface covers 1.8% of the watershed (Figure 35, Table 8).

General Statistical Considerations: Presence-Absence Sampling

Presence-absence was used to answer important management questions because it reduced expensive sample processing, was robust to errors and biases in sampling, and reduced statistical concerns about contagious distributions and high frequency of zeros; (Green 1979; Mangel and Smith 1990; Uphoff 1997). Presence-absence was calculated as the proportion of samples and its 95% confidence interval containing a target species and life stage by using the normal distribution to approximate the binomial probability distribution (Ott 1977). This approximation can be used when the sample size is greater than or equal to 5 divided by the smaller of the proportion of positive or zero tows (Ott 1977). Interpreting absence can pose interpretation problems (Green 1979) and sampling and analyses were generally designed to confine presence-absence to areas and times where species and life stages in question had been documented.

In 2008, we sampled most of the areas sampled in 2007. We discontinued sampling in Piscataway Creek, because Submerged Aquatic Vegetation (SAV) was too dense to allow for efficient sampling. We substituted Nanjemoy Creek on the Potomac. These changes will help better meet study objectives to: (1) better define the relationship of IS, fish habitat, and fish relative abundance in tidal freshwater and (2) test the relationship developed from brackish water tributaries exhibiting different levels of development (where spatial differences were assumed to represent change in a watershed over time) on tributaries likely to undergo a change from rural to suburban (temporal change in the same watershed). Tidal fresh tributaries (2‰ or less salinity) sampled in 2008 were Mattawoman Creek, Piscataway, Bush River, and Northeast River (Figure 27); IS was estimated to cover about 1-10% of these watersheds. Nanjemoy Creek is a low oligohaline system on the Potomac, just south of Mattawoman Creek. The impervious cover on Nanjemoy Creek is less than 2%. Corsica River, Tred Avon River, Langford Creek, and Wye River are brackish water (greater than 5‰) tributaries located on the Eastern Shore that were estimated to have less than 6% impervious surface (Table 8). Corsica River, Tred Avon River, and Wye River are located near towns that are undergoing development (Centerville, Easton, and Wye Mills, respectively). Langford Creek was selected as a control system (predominately for Corsica River) because it is not located near towns that are the foci of development on the Eastern Shore.

Four evenly spaced sample sites were located in the upper two-thirds of each tributary. Sites were not located near the subestuary's mouth to reduce influence of mainstem Bay or Potomac River waters on measurements of watershed water quality.

Each fixed site was sampled once a visit and there were two visits each month during July-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 dissolved oxygen concentrations. However, sites located in the middle would likely not be influenced by the random start location as much as sites on the extremes because of the bus-route nature of the sampling design. If certain sites needed to be sampled on a given tide then the crew leader deviated from the sample route to accommodate this need. Trawl sites were generally in the channel, adjacent to seine sites. At some sites, seine hauls could not be made because of permanent obstructions, thick aquatic vegetation, or lack of beaches. The latitude and longitude of the trawl sites was taken in the middle of the trawl area, while seine latitude and longitude were taken at the exact seining location.

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

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

A 4.9 m semi-balloon otter trawl was used to sample fish in mid-channel bottom habitat. The trawl was constructed of treated nylon mesh netting measuring 38.1 mm stretch in the body and 33 mm stretch in the codend, with an untreated 12 mm stretch knotless mesh liner. The headrope was equipped with floats and the footrope was equipped with a 3.2 mm chain. The net 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. Trawling was in the same direction as the tide. The trawl was set up tide to pass the site halfway through the tow. This allowed the same general area to be trawled regardless of tide direction. A single tow was made for six minutes at 3.2 km/hr (2.0 miles/hr) at a 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 • 66 mm floats spaced at 0.61 m (24 inch) intervals and the lead-line had 57 gm (2 ounce) lead weights spaced evenly at 0.55 m (18 inch) intervals. One end of the seine was held on shore, while the other was stretched perpendicular to shore as far as depth permitted and then pulled with the tide in a quarter-arc. The open end of the net was moved towards shore once the net was stretched to its maximum. Once both ends of the net were on shore, the net was retrieved by hand in a diminishing arc until the net was entirely pursed. The section of the net containing the fish was then placed in a washtub of water for processing. The distance the net was stretched from shore, maximum depth of the seine haul, primary and secondary bottom type, and percent of seine area containing aquatic plants were recorded.

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

Water quality data were compared to fish habitat criteria (Table 9) and reported as deviations from a target or limit (McGinty et al. 2006). These were examined by watershed to determine habitat suitability for target species. Percent of violations of these requirements were calculated by river. Presence-absence was used as an index of relative abundance for each target species in nearshore (seine) or bottom waters (trawl) because their catch distributions were not normally distributed, nor could normality be induced by transformation (McGinty et al. 2006).

Results and Discussion

2008 Data summary

We examined water quality data to determine if habitat requirements were met for the target species (Table 9). For the most part, temperature remained below the 31°C criteria (Figure 36). Nanjemoy Creek exceeded the criteria 7.5% of the time and Wye River, 2.9% of the time (Table 10). All rivers had dissolved oxygen concentrations that fell below the 5.0 mg/L criteria (Figure 37). The Wye River had the greatest percent occurrence (42.2%) and the Bush River the fewest (2.2%) (Table 10). Figure 38 shows the distribution of salinity by watershed. The only station that had salinities greater than 13 ppt was Tred Avon (4.3% of measurements; Table 10). Figure 39 shows the distribution of bottom dissolved oxygen by river sampled in 2008. All rivers had violations of the 5.0mg/L criteria. Wye had the greatest number of violations (42.2%) and Bush River had the fewest (2.2%) (Table 10). Additionally we applied a threshold of 3.0 mg/L based on previous work that showed this is a feasible threshold below which probability of fish presence is greatly reduced (Uphoff et al, 2008). Bush River and Northeast did not have oxygen concentrations below 3.0 mg/L. Langford had the greatest at 8.2%, followed by Mattawoman (7.9%), Tred Avon (7.5%), Corsica (6.1%), Wye

(5.6%) and Nanjemoy (2.5%) (Table 10). General assessment of these data suggests that while these watersheds are not completely free from habitat criteria violations, they are adequate to support fish communities as evidenced in the fish summary data.

A total of 54,756 fish (29,580 in the trawl and 25,176 in the seine) were captured representing 48 species in 2008. Of these species, nine species comprised 90% of the catch. These species, in descending order included, white perch, Atlantic menhaden, bay anchovy, spot, gizzard shad, brown bullhead, pumpkinseed, blueback herring and striped killifish. Nine species comprised 90% of the catch in the seine, including Atlantic menhaden, white perch, gizzard shad, blueback herring, striped killifish, pumpkinseed, Atlantic silverside, mummichog and spot (in descending order). In the trawl, four species comprised 90% of the catch. In descending order, they included white perch, bay anchovy, spot and brown bullhead.

Seining was conducted in all rivers except Mattawoman Creek. Mattawoman could not be seined because SAV was too dense. Bush River had the greatest number of species at 27. Nanjemoy had the second greatest number, 18, then in descending order, Northeast, Corsica, Langford, Tred Avon and Wye Rivers. Catch per seine was greatest in the Bush River, with Corsica, Langford, Wye, Nanjemoy, Northeast and Tred Avon following in descending order. (Table 11 summarizes the seine catch statistics by river.)

Trawling was conducted in all rivers sampled. Table 12 shows the summary statistics by river. Speices richness in descending order was Northeast, with 22 species, Bush River, 21, Mattawoman and Nanjemoy, 19, Langford and Tred Avon, 15, and Corsica and Wye Rivers 13. Species comprising 90% of the catch varied from 3 to 5 species with white perch dominating in the lower salinity areas and bay anchovy in the higher salinities. Nanjemoy Creek had the highest catch per effort, followed by Bush River, Langford Creek, Tred Avon, Northeast, Corsica, Wye and Mattawoman.

Species richness patterns and the catch per effort do not appear to be associated with impervious cover. The Bush River had the greatest impervious cover of all rivers sampled and yet it had the greatest species richness and catch per effort in the seine and second greatest richness and catch per effort in the trawl. We calculated water to land ratio for each watershed sampled, and Bush River had the greatest water to land ratio at 0.22. Tred Avon, had a ratio of 0.18, Wye River and Langford Creek had a 0.12 ratio, Northeast a 0.10 ratio, Corsica and Nanjemoy a 0.05 ratio, and Mattawoman 0.02. The large water acreage in the Bush River combined with the fact that the area is tidal-fresh may work together to allow for greater flushing of this tributary. There could also be a dilution factor at work in the Bush River. Interestingly, Bush River showed the fewest water quality violations in 2008 (Table 10). Additionally, 6% of the Bush River watershed is comprised of wetlands. We are just beginning to consider the importance of wetlands and these other land features as potential mitigating factors in understanding the impacts of land conversion on aquatic habitats and fisheries. We will continue to explore these factors in the future to gain a better understanding of their influence on receiving waters.

Exploring Tidal Fresh habitats

Uphoff et al. (2008) reported a negative relationship between dissolved oxygen and impervious cover (summarized in Figure 40). However, bottom dissolved oxygen in the tidal fresh tributaries has been positively related with percent impervious surface (Figure 40). Figure 41 shows the distribution of bottom DO readings in tidal fresh tributaries sampled during 2006-2008 by impervious surface level. Watersheds with the highest impervious surface have the fewest bottom DO readings (< 5.0 mg/L). It is possible that tidal fresh areas with greater impervious surface have different flushing dynamics and because there is no stratification due to salinity, flushing rates could be greater in these habitats. Salinity is a major source of differences in density that impedes mixing and promotes stratification in brackish systems and water column stratification is a major influence on oxygen depletion in Chesapeake Bay (Kemp et al. 2005). We also consider the possibility that because phosphorus is the limiting nutrient in tidal fresh systems and because there has been extensive management of phosphate resulting in significant reduction in loads, the excess nutrients associated with increased runoff, do not have a direct impact on the tidal fresh receiving waters.

One other difference that we have noted in tidal fresh tributaries, is abundant SAV compared to the brackish systems previously sampled. As previously noted, we have had to alter our sampling plan because of dense coverage of SAV in various watersheds. We are unable to sample Piscataway Creek, and can no longer seine Mattawoman Creek because of the abundance of SAV. And while it may preclude efficient sampling, we have observed an increase in water clarity. Figure 42 shows box and whisker plots of secchi depth by impervious cover. The two stations with highest water clarity are Mattawoman Creek (8.5% impervious) and Piscataway Creek (16.7% impervious). These two tributaries are located in the Upper Potomac River where SAV coverage has been widespread and increasing over the past few years. During 2006, Mattawaoman Creek had 45% SAV coverage and Piscataway Creek had 80% coverage (versus 23% in 2003; VIMS SAV estimates (www.vims.edu/bio/sav/index.html).

We evaluated the percent presence of target species in trawls and seines in tidal fresh areas in relation to impervious surface (Figures 43a &b, 44a & b). We pooled all data for all years sampled (there was unequal effort among years because of necessary changes in sampling areas). Aside from white perch adults and juveniles, all other target species showed somewhat random presence, not associated with impervious surface. However, white perch juveniles and adults in the trawl showed a marked decline the tidal-fresh tributary with the highest impervious surface. It is possible that this decline in Piscataway Creek reflects an influence of high SAV coverage; however, the proportion of trawls with white perch was similar during 2003 (23% SAV) and 2006 (80% SAV).

We explored long term data from Mattawoman Creek to determine if there was a change in water quality or fish presence that could be responding to changes in land use in the watershed. Figures 45 and 46 show bottom dissolved oxygen concentrations (mg/L and saturation) since 1989. There appears to be a decline in concentrations over time, with more recent years showing some violations of the 5.0mg/L criteria. When we first observed this, we considered the possibility that we were observing a natural response in a system that goes from dominance by algal species to SAV. However, when we plotted dissolved oxygen saturation, we observed that saturations were beginning to fall below 75% with a few concentrations of less than 50% saturation in recent years. Mattawoman Creek's watershed is presently just below 9% impervious surface, and it is possible that this is an early response to habitat changes due to landscape development.

We also examined presence of the key target species in Mattawoman Creek trawl samples over the same time frame. Blueback herring and alewife appear to be declining, with the other target species showing random or stable distributions (Figure 47). It is possible that the herring species are responding to increased impervious cover in the watershed, as we did see a reduction in the presence of herring in the spawning survey compared to historical presence. However, herring populations have been declining coast- wide and the declines that we are seeing could be driven by coastal stock abundance more so than local habitat variations. We will explore this in the future as we cooperate with other projects collecting similar data in other watersheds in Chesapeake bay.

In an effort to continue to explore the impacts of impervious surface in the tidal fresh tributaries, we are expanding sampling in 2009 to evaluate as much as feasible as series of tidal fresh habitats watersheds that reflect a gradient of impervious surface.

Conclusions

The first years of this impervious surface work produced an understanding of the impacts of impervious surface on fish habitat (DO dynamics) and communities in brackish tributaries to the Chesapeake Bay (Uphoff et al. submitted). We translated this understanding into a management framework of impervious surface reference points that can help guide fisheries managers in better management and allocation of resources (Uphoff et al. submitted).

It would appear that fresh-tidal tributaries do not exhibit impervious surface-DO related conditions that are detrimental to fish habitat as readily as brackish tributaries, but other IS related problems remain in fresh-tidal tributaries. Anadromous fish stream spawning habitat appears to be negatively influenced by impervious cover. Impervious surface increases runoff volume and intensity in streams, leading to physical instability, increased erosion, sedimentation, and thermal pollution (Beach 2002). Toxic metals and organic compounds may also be found in this runoff (Beach 2002). Siltation, impoundment, removal of substrate, physical alterations, toxic or organic pollution, and increased acidification were cited as possible mechanisms that would depress anadromous fish spawning as urbanization of the Hudson River watershed progressed (Limburg and Schmidt 1990). We have associated spawning habitat losses to increased impervious cover, and therefore recommend limiting development in important nursery habitats in order to preserve their function. Additionally, because the tidal fresh habitats reflect better water quality conditions and serve as nursery habitats for important target species, we recommend extreme caution in planning for future development in these watersheds.

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Table 1. Method applied to estimate the category of impervious cover at sites sampled in the Bush River.

Source of Impervious Estimate	Category of Estimated Impervious Surface	Stream	Watershed
Calculations Based on Landcover	<5	Back	APG
Calculations Based on Landcover	<5	Mosquito	APG
Calculations Based on Landcover	<5	Romney	APG
Calculations Based on Landcover	<5	Woodrest	APG
WRAS	>5	Bynum	Bush
WRAS	>5	Cranberry	Bush
WRAS	<5	Grays	Bush
WRAS	>5	Haha	Bush
WRAS	<5	James	Bush
WRAS	>5	Otter Point Creek	Bush
Visual Estimate of Land Cover	<5	Sod	Bush
Visual Estimate of Land Cover	<5	Unnamed 2	Bush
WRAS	>5	Winter	Bush
Unavailable/Excluded		Swan	Swan

Table 2. Bush River Ichthyoplankton percent presence by species, station and year.

	2005				2006				2007				2008			
Station	# Samples	%her	% yp	% wp	# Samples	%her	% yp	% wp	# Samples	%her	% yp	% wp	# Samples	%her	% yp	% wp
BBR1	10	30.0	0.0	0.0	8	0.0	0.0	0.0	10	30.0	0.0	0.0	9	33.0	0.0	0.0
BBR2	9	0.0	0.0	0.0	8	0.0	0.0	0.0								
BCR1	9	0.0	0.0	0.0	9	0.0	0.0	0.0	9	11.1	0.0	0.0	8	0.0	0.0	0.0
BGR1	9	11.1	0.0	0.0	9	11.1	11.1	0.0	10	30.0	0.0	0.0				
BGRT									10	30.0	0.0	0.0	5	0.0	0.0	0.0
BHH1	8	0.0	0.0	0.0	9	11.1	0.0	0.0	9	11.1	0.0	0.0	9	11.1	0.0	0.0
BHHT									10	20.0	0.0	0.0	8	0.0	0.0	0.0
BJR1	9	11.1	0.0	0.0	9	11.1	0.0	0.0	10	50.0	0.0	0.0	9	0.0	0.0	0.0
BJR2	9	0.0	0.0	0.0	8	0.0	0.0	0.0								
BOP1	8	37.5	0.0	0.0	10	10.0	0.0	0.0	9	56.0	0.0	0.0	9	44.4	11.1	0.0
BSC1	8	25.0	0.0	0.0	9	11.1	0.0	0.0	8	37.5	0.0	0.0	6	0.0	0.0	0.0
BSC2	8	25.0	0.0	0.0	10	0.0	0.0	0.0	8	50.0	0.0	0.0	7	14.3	0.0	0.0
BSC3	8	0.0	0.0	0.0	10	0.0	0.0	0.0	8	38.0	0.0	0.0				
BSR1	7	0.0	0.0	0.0	10	0.0	0.0									
BUN1	7	14.3	0.0	0.0	8	12.5	12.5	0.0	10	20.0	0.0	0.0				
BWR1	8	0.0	0.0	0.0	10	0.0	0.0	0.0	9	33.0	0.0	0.0	9	0.0	0.0	0.0
BWR2	8	0.0	0.0	0.0	10	0.0	0.0	0.0								
BWRT									9	56.0	0.0	0.0	9	66.7	11.1	0.0
GPCA					5	0.0	20.0	60.0	8	13.0	13.0	0.0	6	0.0	0.0	0.0
GPSW					5	0.0	40.0	40.0	8	0.0	0.0	0.0	5	60.0		20.0
GPWA					3	0.0	0.0	33.3	8	12.5	37.5	25.0	6	16.7	0.0	33.3
GPWR					5	0.0	0.0	20.0	8	0.0	12.5	0.0	5	40.0	0.0	0.0
BACK					8	0.0	0.0	25.0					7	37.5	12.5	12.5
MOSQ					8	25.0	25.0	12.5					9	57.1	28.6	0.0
ROM					8	33.3	0.0	0.0					8	55.6	0.0	0.0
WOODREST					8	12.5	12.5	50.0					10	30.0	30.0	0.0

Table 3. Total samples collected by site for Mattawoman Creek, and percent presence of white perch, yellow perch and shad or herring observed as eggs or larvae for 2008.

Station	Stream	Number of Samples Expected	Number of Samples Collected	Percent Presence yellow perch	Percent Presence white perch	Percent Presence shad/herring
MC1	Mattawoman Creek	10	10	30	10	50
MC2	Mattawoman Creek	10	10	0	0	0
MC3	Mattawoman Creek	10	9	0	0	11
MC4	Mattawoman Creek	10	10	0	0	0
MC5	Mattawoman Creek	10	10	0	0	0
MOWR1	Old Woman Creek	10	10	0	0	0
MUT3	Unnamed Tributary	10	10	0	0	0
MUT4	Unnamed Tributary	10	10	0	0	0
MUT5	Unnamed Tributary	10	10	0	0	10

Table 4. Total samples collected by site for Piscataway Creek, and percent presence of white perch, yellow perch and shad or herring observed as eggs or larvae for 2008.

Station	Stream	Number of Samples Expected	Number of Samples Collected	Percent Presence yellow perch	Percent Presence white perch	Percent Presence shad/herring
PC1	Piscataway Creek	8	8	0	0	0
PC2	Piscataway Creek	8	8	0	0	0
PC3	Piscataway Creek	8	6	0	0	0
PHC1	Henson Creek	8	8	0	0	0
POX1	Oxen Run	8	7	0	0	0
PRUT1	Unnamed Tributary	8	3	0	0	0
PSC1	Swan Creek	8	8	0	0	0
PTC1	Tinkers Creek	8	7	0	0	0
PUT4	Unnamed Tributary	8	8	0	0	0

Table 5. Landuse change in the Mattawoman watershed.

Landuse category	Percent Cover73	Percent Cover 2000
Agriculture	15.7	12
Forest	68.4	58.1
Urban	12.2	25.9
Water	2.9	3
Wetlands	0.8	1

Table 6. Landuse change in the Piscataway watershed.

Landuse category	Percent Cover73	Percent Cover 2000
Agriculture	18.1	14.2
Forest	55.8	43.1
Urban	23.6	39.9
Water	2	2.2
Wetlands	0.2	0.2

Table 7. Landuse change in the Nanjemoy watershed.

Landuse category	Percent Cover73	Percent Cover 2000
Agriculture	15.6	14.7
Forest	71.9	69.4
Urban	3.2	6.7
Water	5.4	5.3
Wetlands	4	3.8

Table 8. Percent impervious cover, total non-water acres, and area of tidal water for the watersheds sampled in 2008.

Area	Watershed	Med Sal	% Impervious	Total Acres	Tidal water area
Upper-Bay	Bush River	0.6	12.8	36,964	7,966
Mid-Bay	Corsica River	6.9	4	23,924	1,256
Mid-Bay	Langford Creek	6.7	0.9	23,871	2,906
Potomac	Mattawoman Creek	0.3	8.5	60,300	1,848
Potomac	Nanjemoy*	4.4	1.8	46,603	2,345
Upper-Bay	Northeast	0.1	6.1	40,377	3,884
Mid-Bay	Tred Avon River	9.7	5.6	23,518	4,338
Mid-Bay	Wye	9.5	1.2	50,460	6,142

*Source: Maryland Surf Your Watershed

Table 9. Water quality requirements for juvenile (J) and adult (A) target species.

Water Quality Criteria Requirements	Striped Bass	Yellow Perch	White Perch	Alewife	Blueback Herring	American Shad	Spot	Atlantic Croaker	Atlantic Menhaden
TEMPERATURE (^{o}C)	14.0-26.0 J	19.0 -24.0 J	15.2 - 31.0 J	17.0 - 23.0 J	11.5 - 28.0 J	15.6 - 23.90 J	6.0 - 25.0 J	17.5 - 28.2 J	16.9 - 28.2 J
	20.0 – 22.0 A Preferred	12.0 – 22.0 A	21.5 – 22.8 A preferred	16.0 – 22.0 A	8.0-22.8 A	8.0-30.0 A	12.0 - 24.0 A	14.9 - 31.4 A	6.0 - 25.0 A
SALINITY (ppt)	0 – 16.0 J	0 – 5.0 J	0 – 8.0 J	0 – 28.0 J	0 – 28.0 J	0 – 30.0 J	0.1-25.0 J	0.5 - 21.0 J	0.5 - 15.0 J
		5.0 – 8.0 J preferred		0 – 5.0 J optimum	0 – 5.0 J optimum	0 – 5.0 J optimum			
	14.0 – 21.0 A	0 – 13.0 A	0 – 18.0 A	0 – 35.0 A	0 – 35.0 A	0 – 35.0 A	4.0-29.0 A	4.0 - 21.0 A	4.0.- 29.0 A
	10.0 – 27.0 A tolerated								
DISSOLVED OXYGEN (mg/l)	>5.0 J, A	minimum of	minimum of 5.0 – 7.0 J/A	minimum of 3.6 J A	minimum of 3.6 J	4.0 – 5.0 J A	2 - >5.0 J A		> 4.5 J, A
		5.0 J A		> 5.0 preferred	> 5.0 preferred	>5.0 preferred	>5.0 preferred		

Table 10. Percentage of time overall habitat conditions (all depths in the channel and near shore) did not support the highest maximum temperature, threshold and target D.O. and the lowest maximum salinity for the target species during July-September, 2008 and percentage of time bottom dissolved oxygen in the channel was below 5.0 mg/L and 3.0 mg/L.

Salinity Calssification	Watershed	Percentage Impervious	Temperature > 31°C	DO < 5.0 mg/L	Salinity >13 ppt	Bottom DO < 5.0 mg/L	BottomDO < 3.0 mg/L
Mesohaline	Langford	0.9	0.0	32.9	0.0	32.9	8.2
Mesohaline	Wye	1.2	2.9	42.2	0.0	42.2	5.6
Mesohaline	Corsica	4.0	0.0	28.1	0.0	29.2	6.1
Mesohaline	Tred Avon	5.6	0.0	26.9	4.3	26.9	7.5
Oligohaline	Nanjemoy	1.8	0.0	12.5	0.0	12.5	2.5
Fresh-tidal	Northeast	6.1	7.5	6.8	0.0	6.8	0.0
Fresh-tidal	Mattawoman	8.5	0.0	10.5	0.0	10.5	7.9
Fresh-tidal	Bush	12.8	0.0	2.2	0.0	2.2	0.0

Table 11. Catch statistics and impervious cover in seines by river in 2008.

River	Number of Samples	Number of Species	Species Comprising 90% of Catch	Percent Impervious	Total Catch	Number of Fish per Seine
Langford	22	12	Atlantic menhaden	0.9	4231	192
			White perch			
			Striped killifish			
Corsica	17	14	Atlantic menhaden	4	3864	227
			White perch			
			Mummichog			
			Striped killifish			
Mattawoman	0			8.5		
Bush	24	27	Gizzard shad	12.8	7252	302
			White perch adult			
			White perch juvenile			
			Atlantic menhaden			
			Pumpkinseed			
			Spottail shiner			
			Banded killifish			
			Spottail shiner			
Nanjemoy	17	18	Atlantic menhaden	1.8	2379	140
			White perch juvenile			
			White perch adult			
			Gizzard shad			
			Mummichog			
			Atlantic silverside			
			Pumpkinseed			
Wye	21	7	Atlantic menhaden	1.2	2986	142
			White perch adult			
			Atlantic silverside			
			Striped killifish			
Tred Avon	24	10	White perch adult	5.6	1933	81
			Striped killifish			
			Atlantic silverside			
			Atlantic menhaden			
			Spot			
			Mummichog			
Northeast	24	15	Blueback herring	6.1	2531	105
			White perch adult			
			White perch juvenile			
			Pumpkinseed			
			Gizzard shad			
			Bay anchovy			
			Spottail shiner			
			Yellow perch juvenile			
			Bluegill			
			Largemouth bass			

Table 12. Catch statistics and impervious cover in trawl by river in 2008.

River	Number of Samples	Number of Species	Species Comprising 90% of Catch	Percent Impervious	Total Catch	Number of Fish per Trawl
Langford	24	15	White perch adult	0.9	5143	214
			Bay anchovy			
			Spot			
Corsica	24	13	White perch adult	4	3549	148
			Bay anchovy			
			Spot			
Mattawoman	24	19	White perch adult	8.5	989	41
			White perch juvenile			
			Bluegill			
			Spottail shiner			
			Pumpkinseed			
Bush	18	21	White perch adult	12.8	4385	244
			White perch juvenile			
			Gizzard shad			
			Brown bullhead			
			Bay anchovy			
Nanjemoy	17	19	White perch juvenile	1.8	4425	260
			Bay anchovy			
			Brown bullhead			
			White perch adult			
Wye	24	13	Bay anchovy	1.2	2964	124
			Spot			
			White perch adult			
Tred Avon	24	15	Bay anchovy	5.6	4065	169
			Spot			
			Hogchoker			
			Weakfish			
Northeast	24	22	White perch juvenile	6.1	4060	169
			White perch adult			
			Gizzard shad			
			Brown bullhead			
			Bay anchovy			

Figure 1. Stream ichthyoplankton sampling areas.

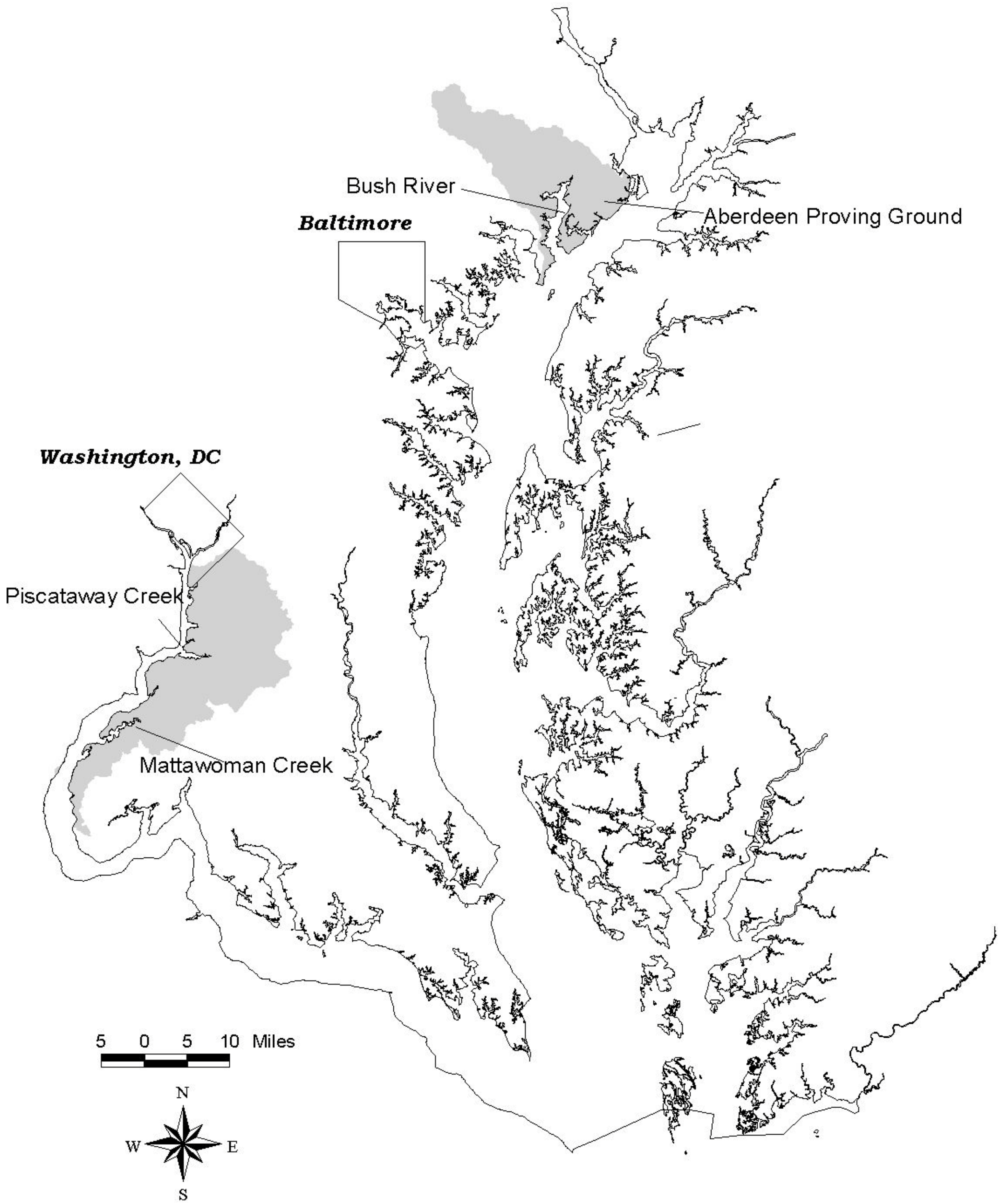


Figure 2. Historic and present sampling stations in the Bush River.

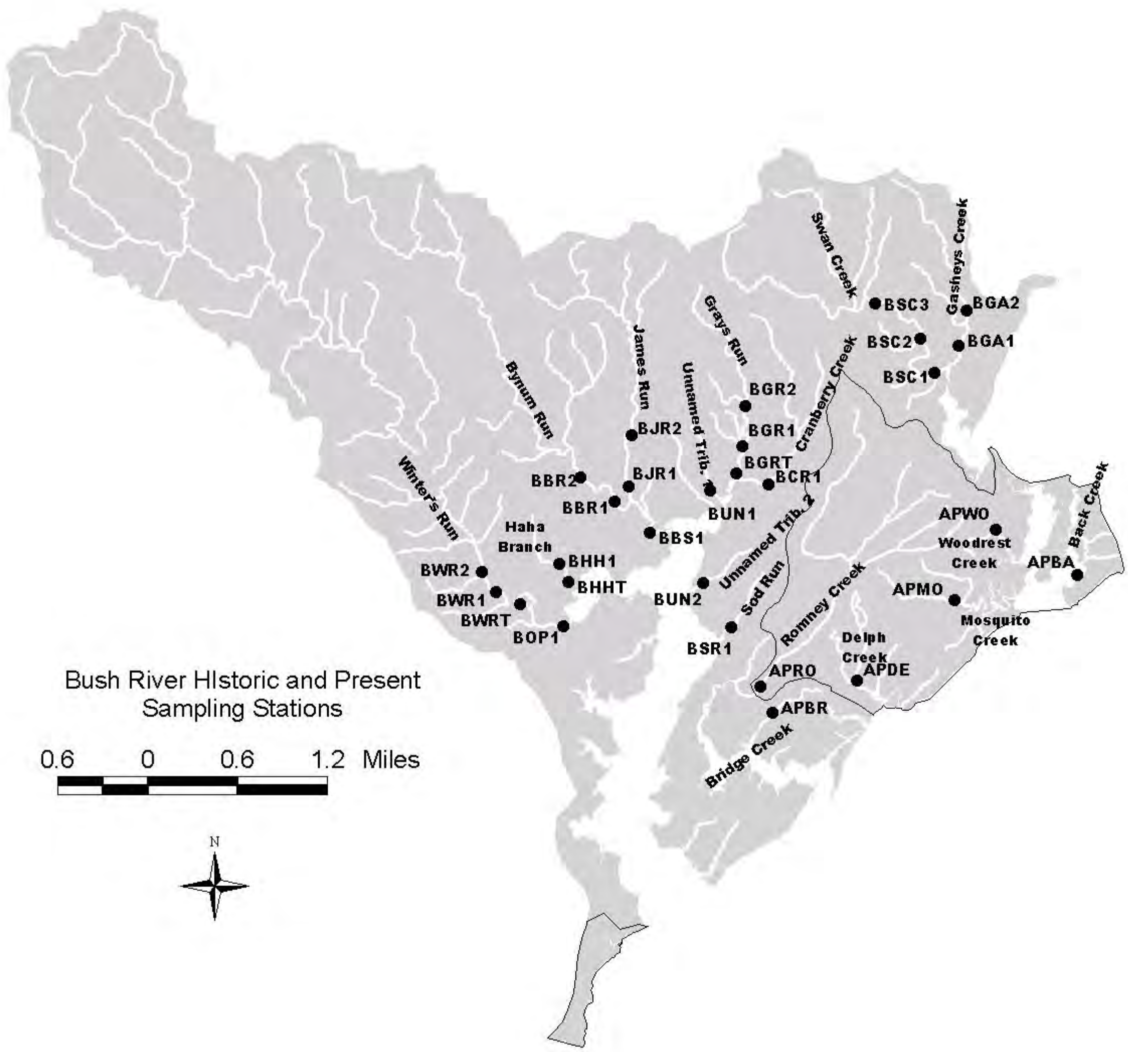
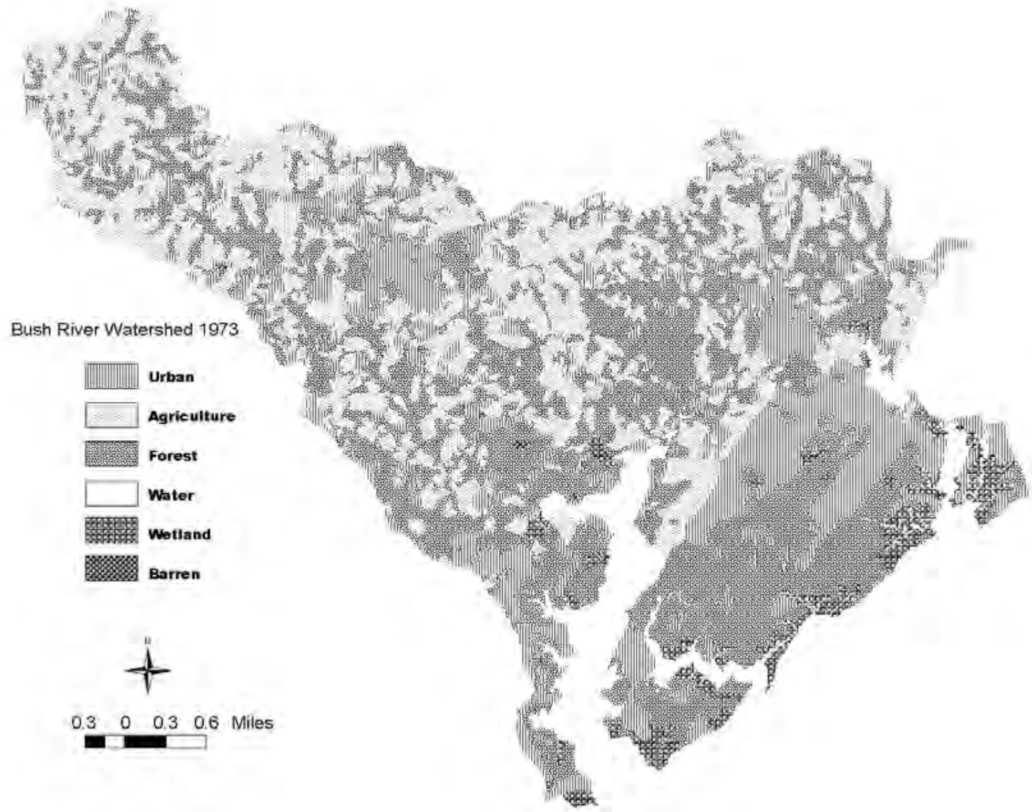


Figure 3. Land cover in the Bush River watershed, 1973 and 2002.



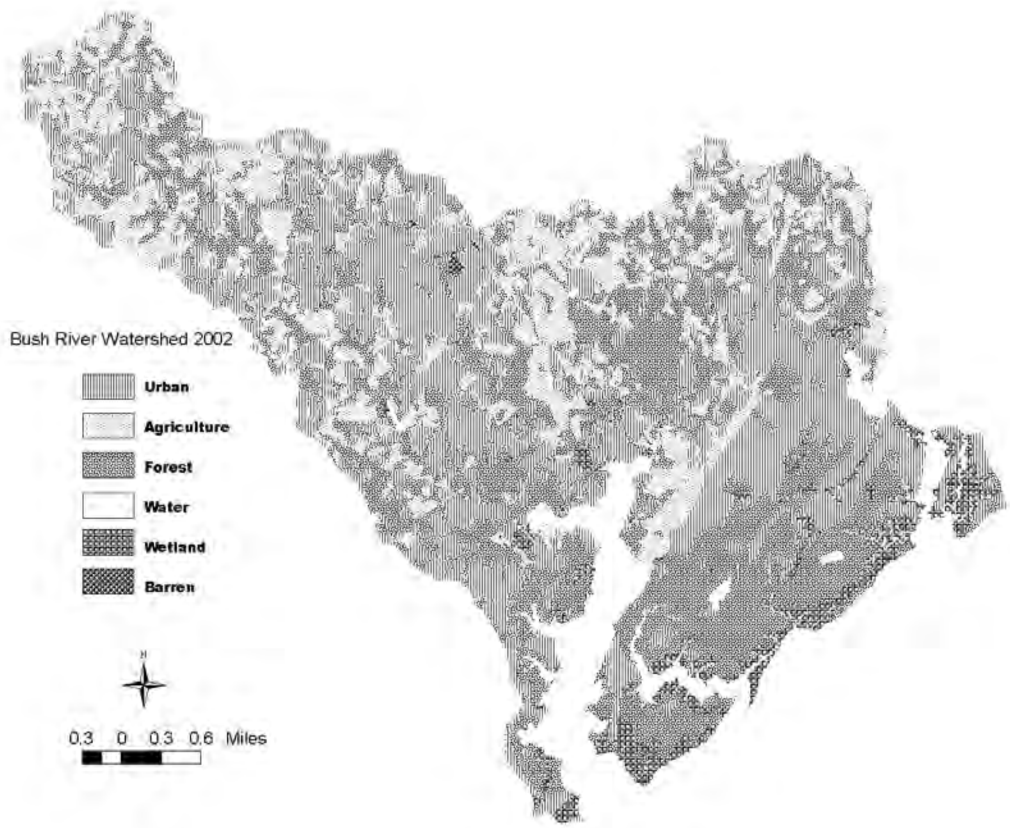


Figure 4. Stations sampled and herring presence in 1973.

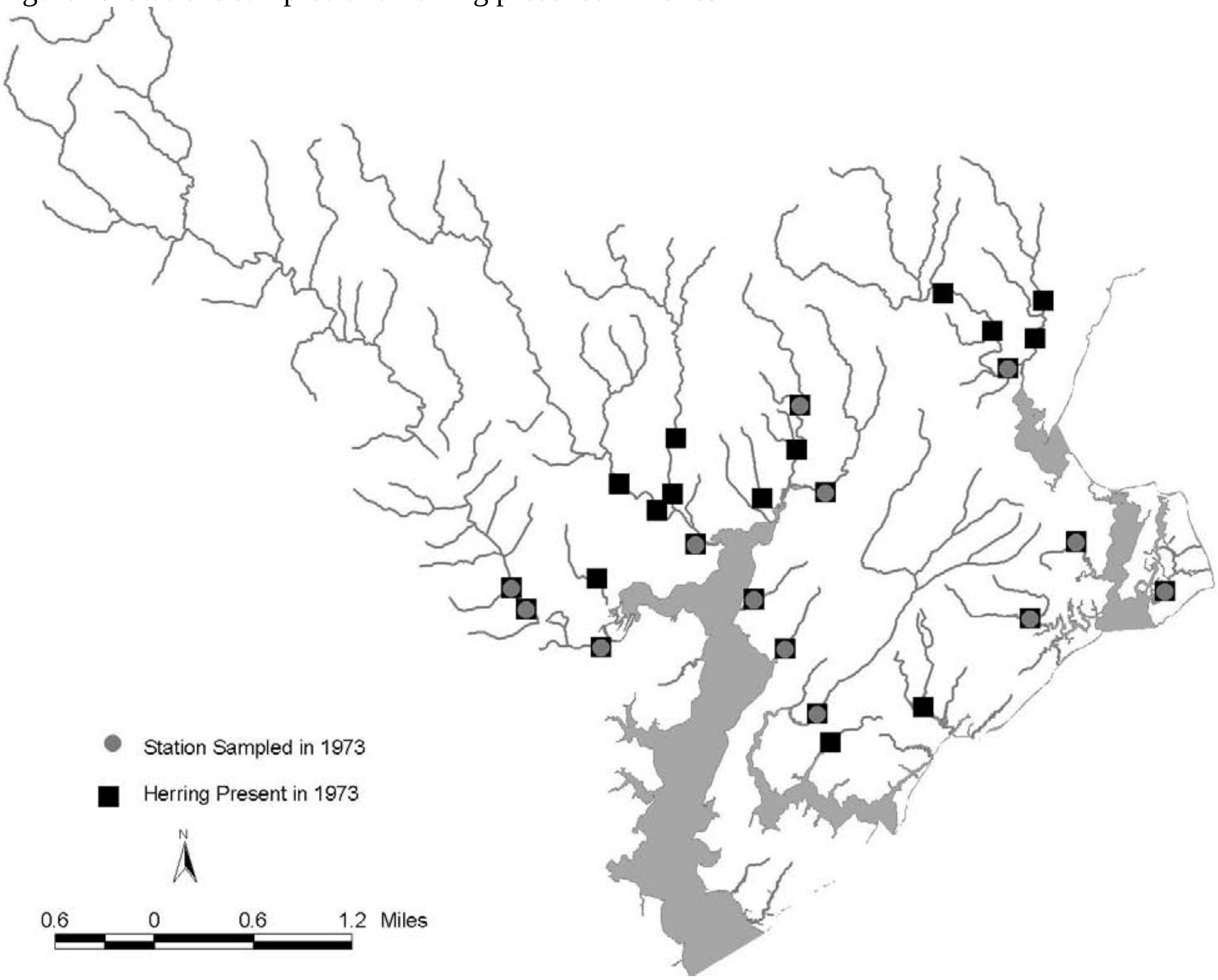


Figure 5. Stations sampled in 2005 and 2005 herring presence compared to presence in 1973.

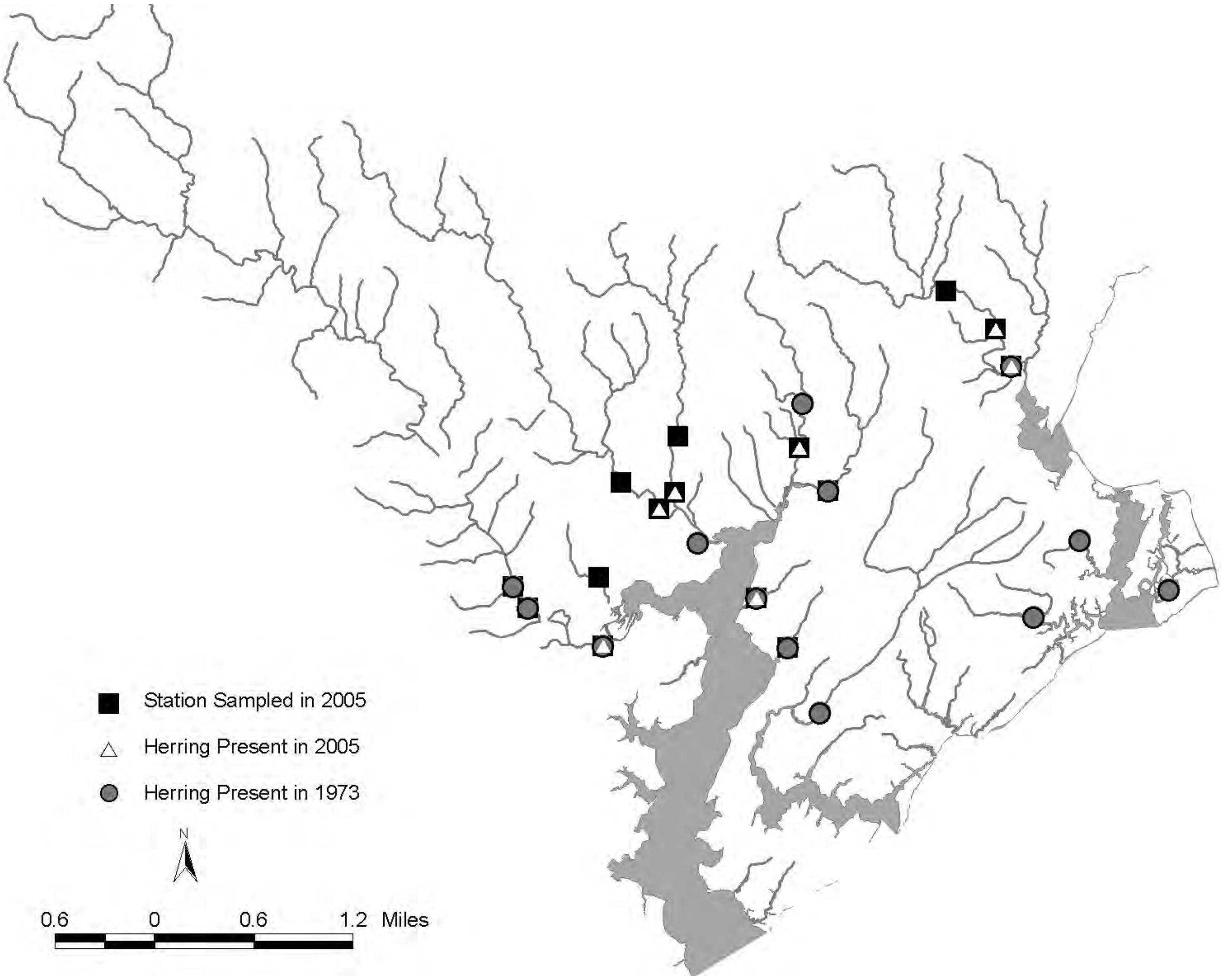


Figure 6. Stations sampled in 2006 and 2006 herring presence compared to presence in 1973.

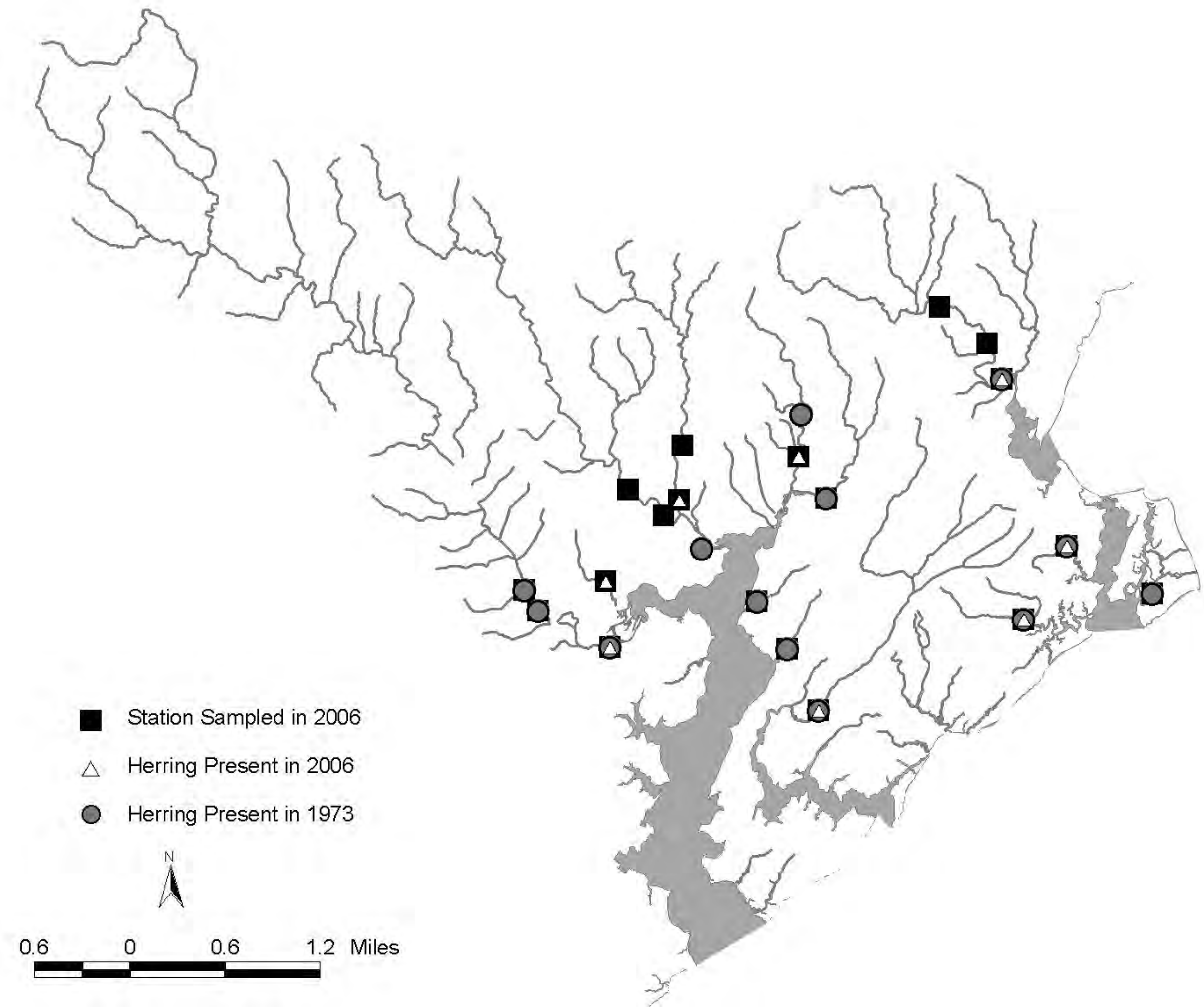


Figure 7. Stations sampled in 2007 and 2007 herring presence compared to presence in 1973.

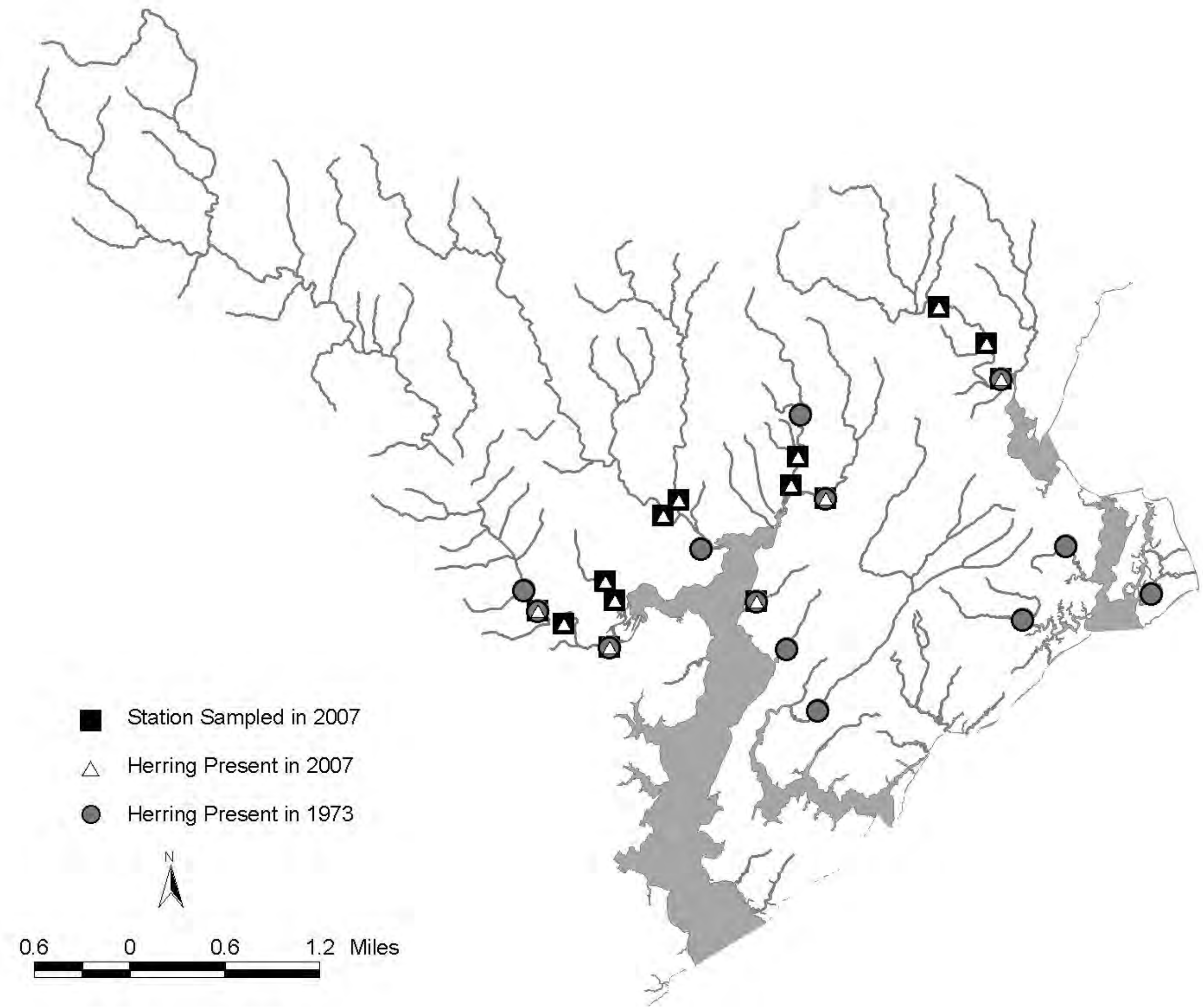


Figure 8. Stations sampled in 2008 and 2008 herring presence compared to presence in 1973.

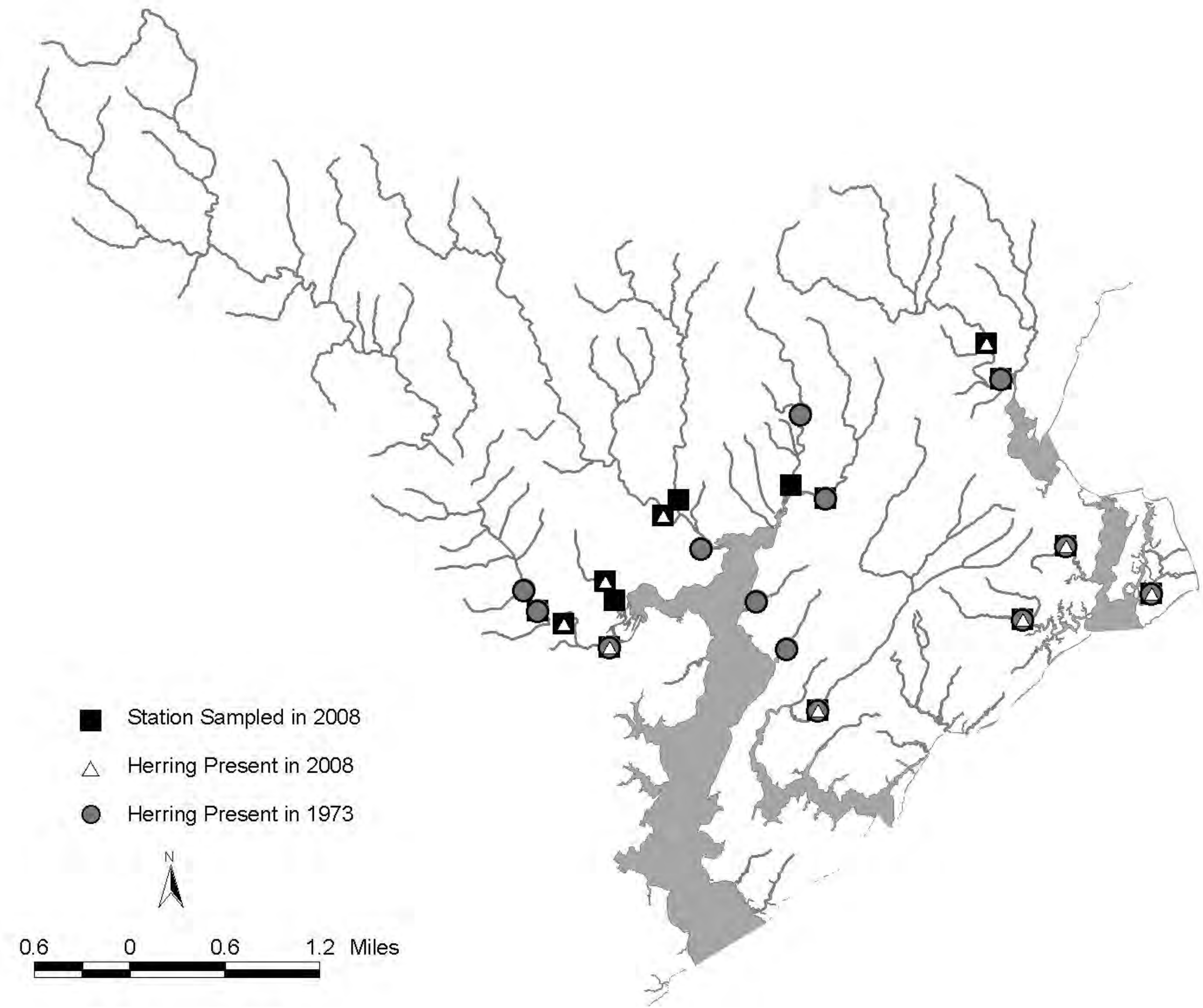


Figure 9. Historic stations sampled with comparisons between historic and present (2005-2008) presence of herring in the Bush River.

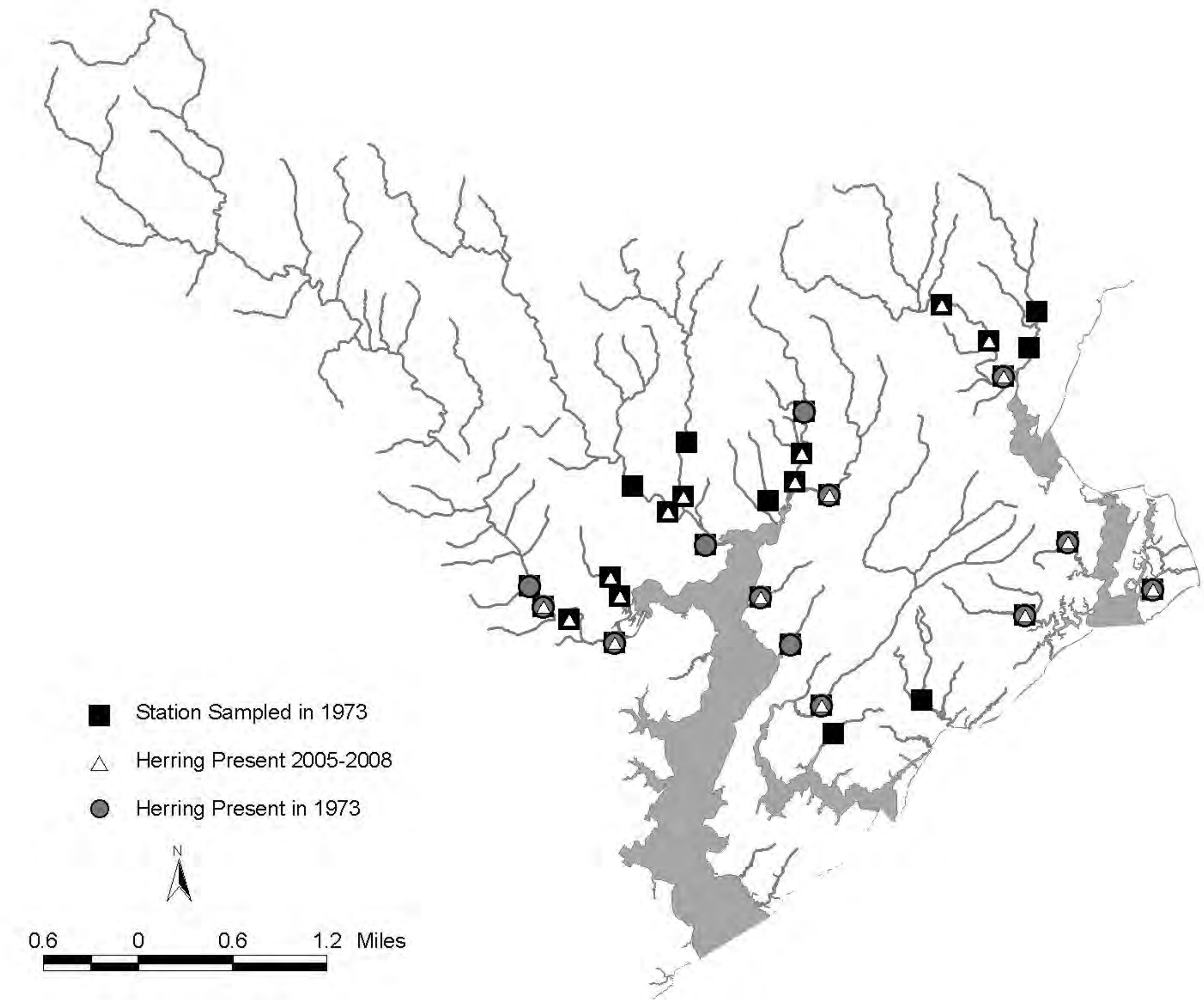


Figure 10. Historic stations sampled with comparisons between historic and present (2005-2008) presence of white perch in the Bush River.

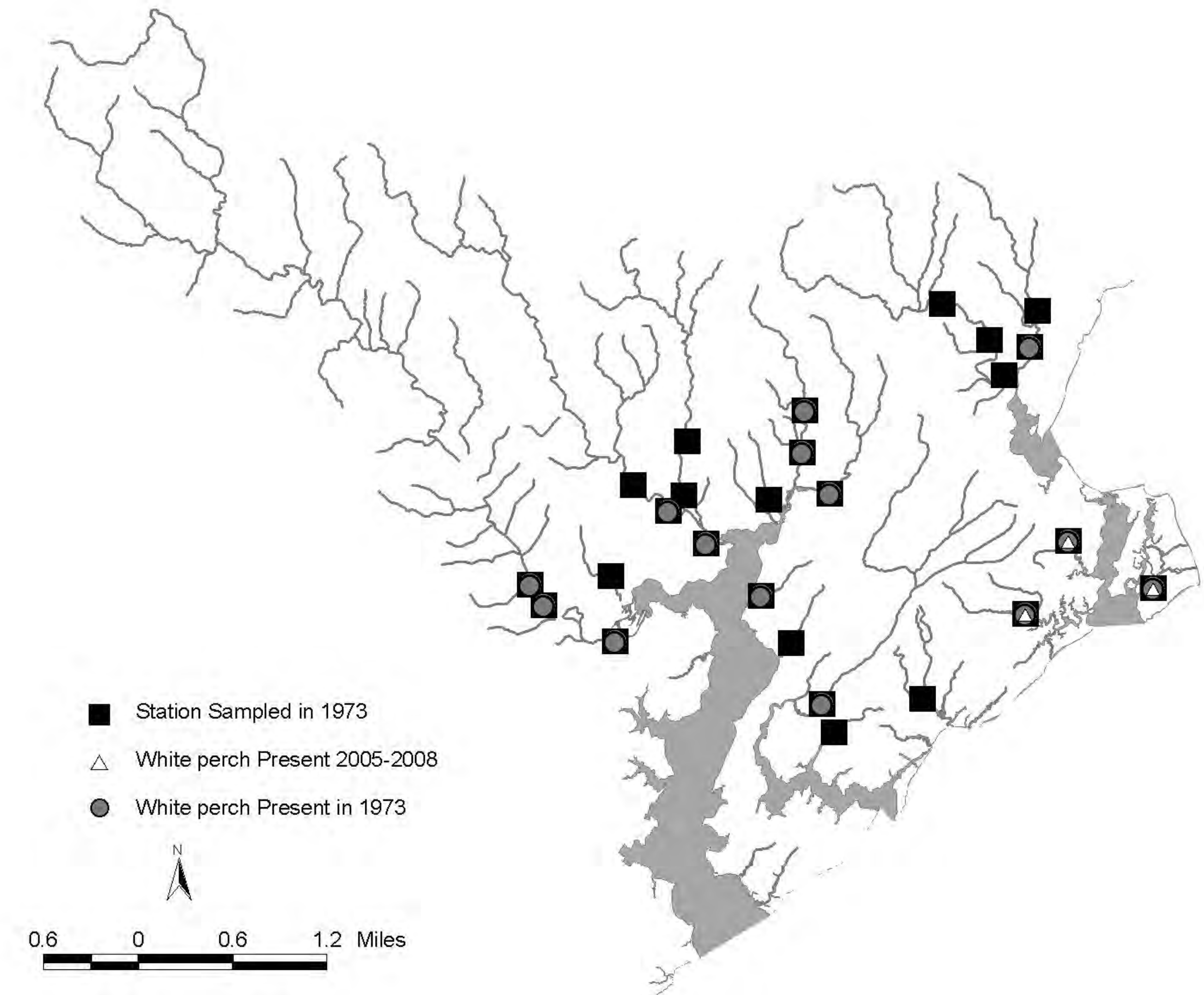


Figure 11. Historic stations sampled with comparisons between historic and present (2005-2008) presence of yellow perch in the Bush River.

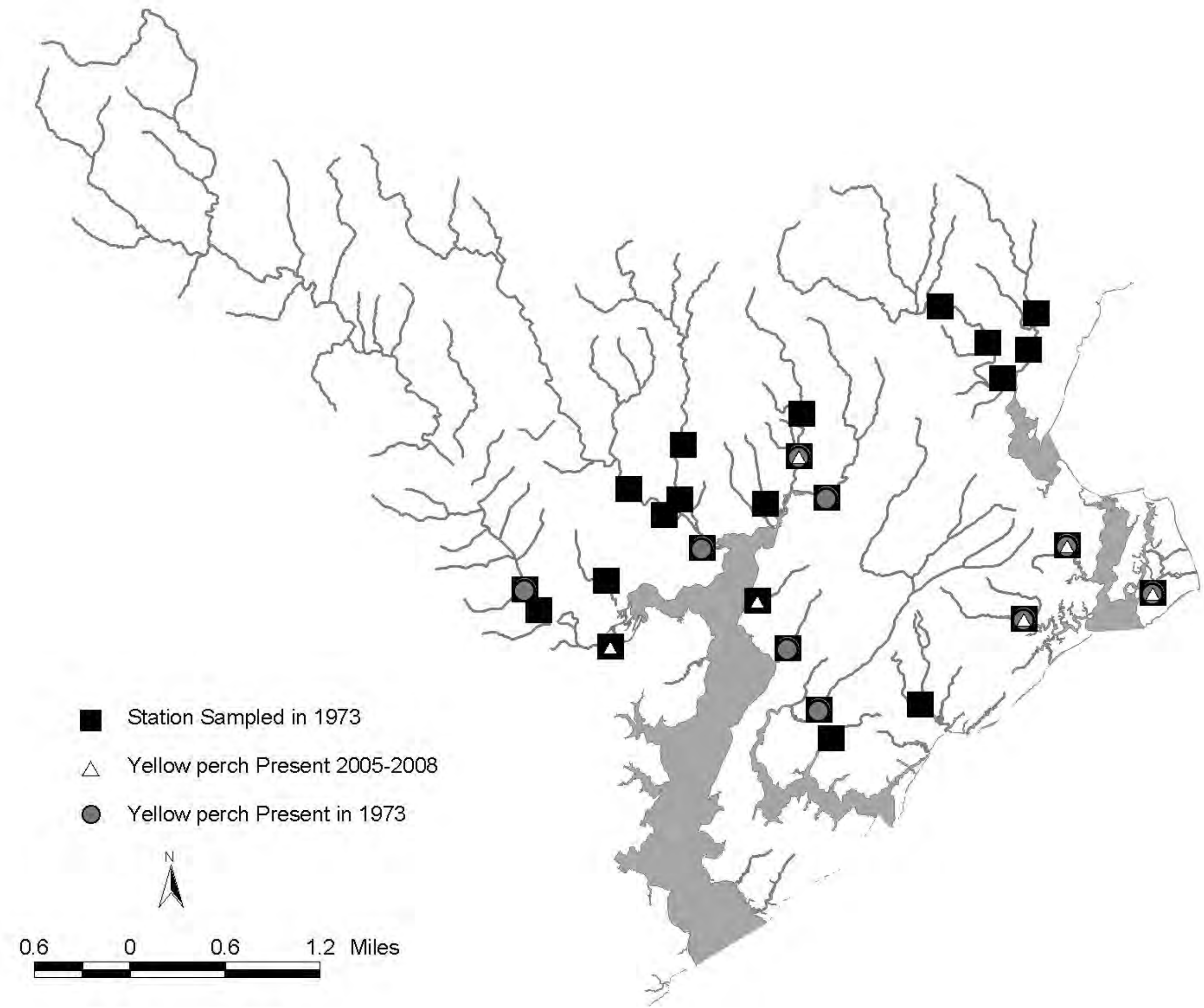


Figure 12. Proportion of herring, yellow perch and white perch present (with 95% confidence intervals) in Bush River, 2005-2008 by impervious cover groupings, with the two categories of impervious surface (>5% or <5% impervious surface).

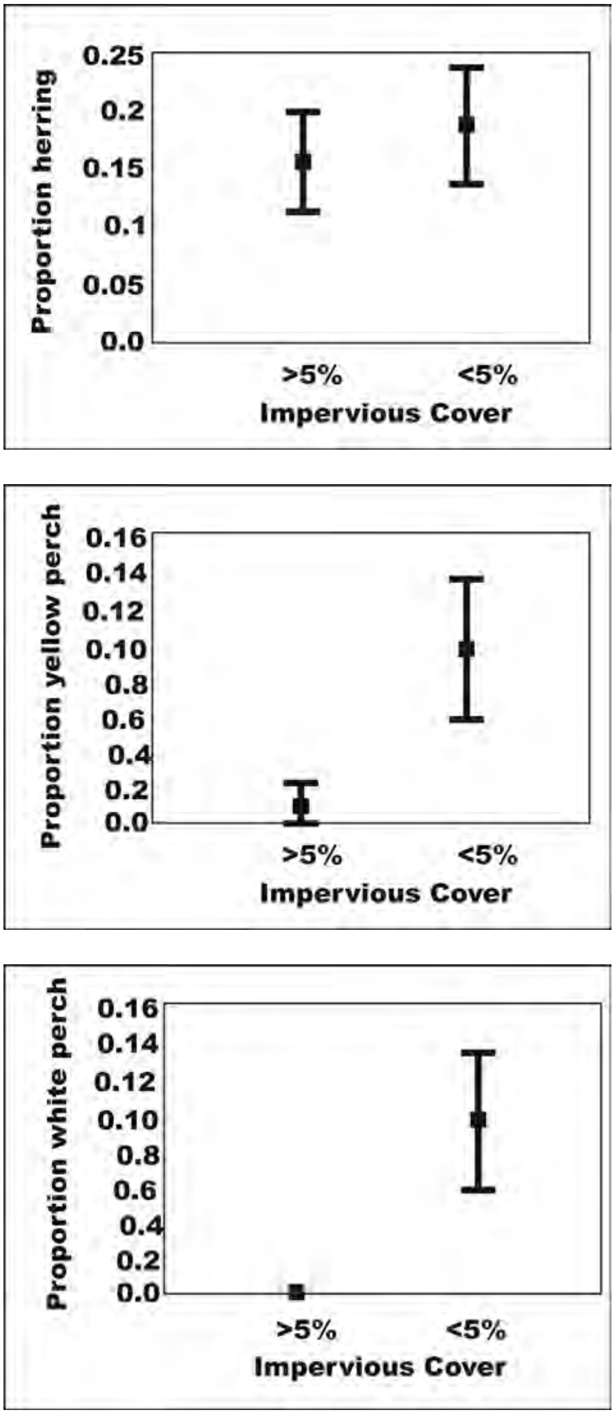
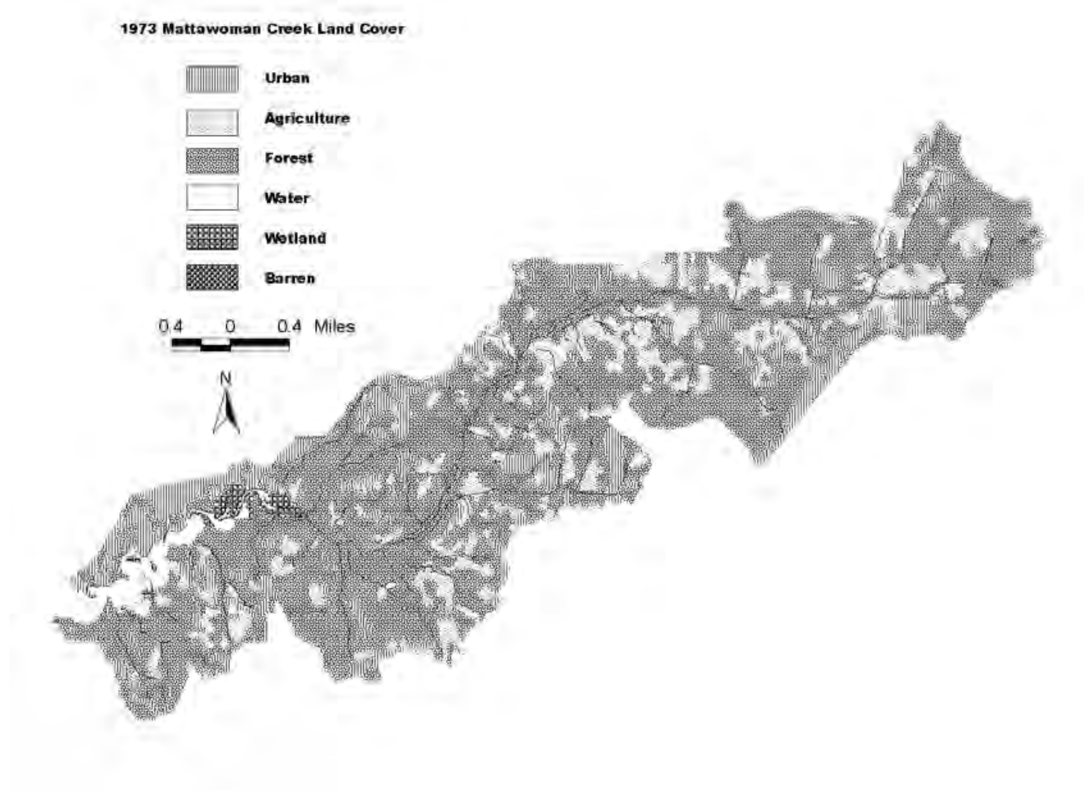


Figure 13. Land cover in the Mattawoman Creek watershed, 1973 and 2000.



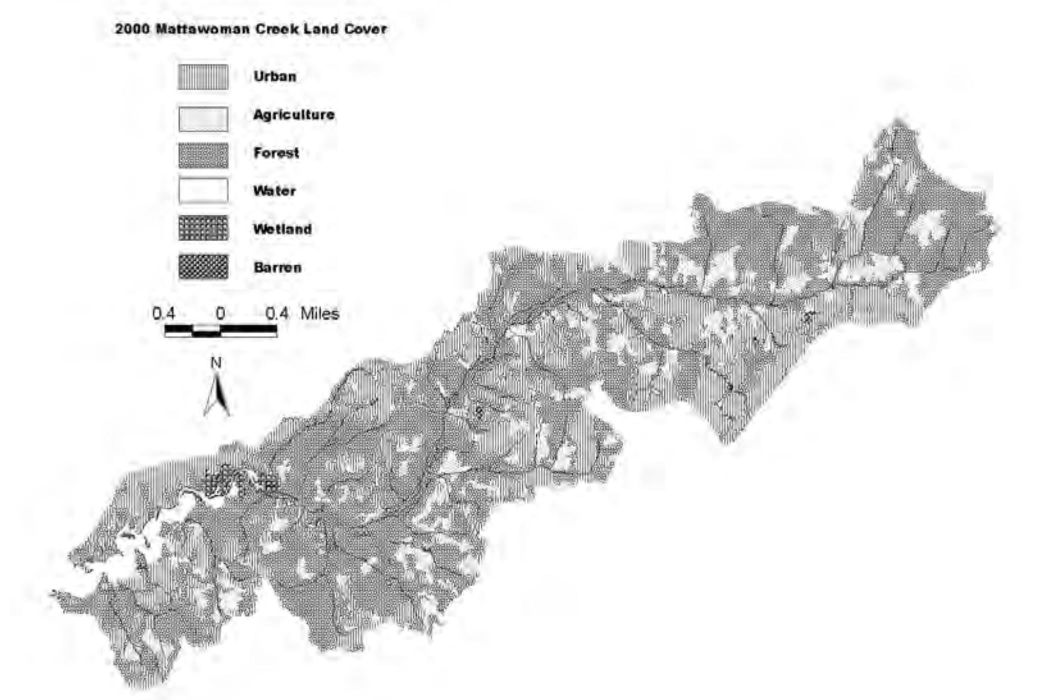


Figure 14. Historic stations sampled with comparisons between historic and present (2005-2008) presence of herring in Mattawoman Creek.

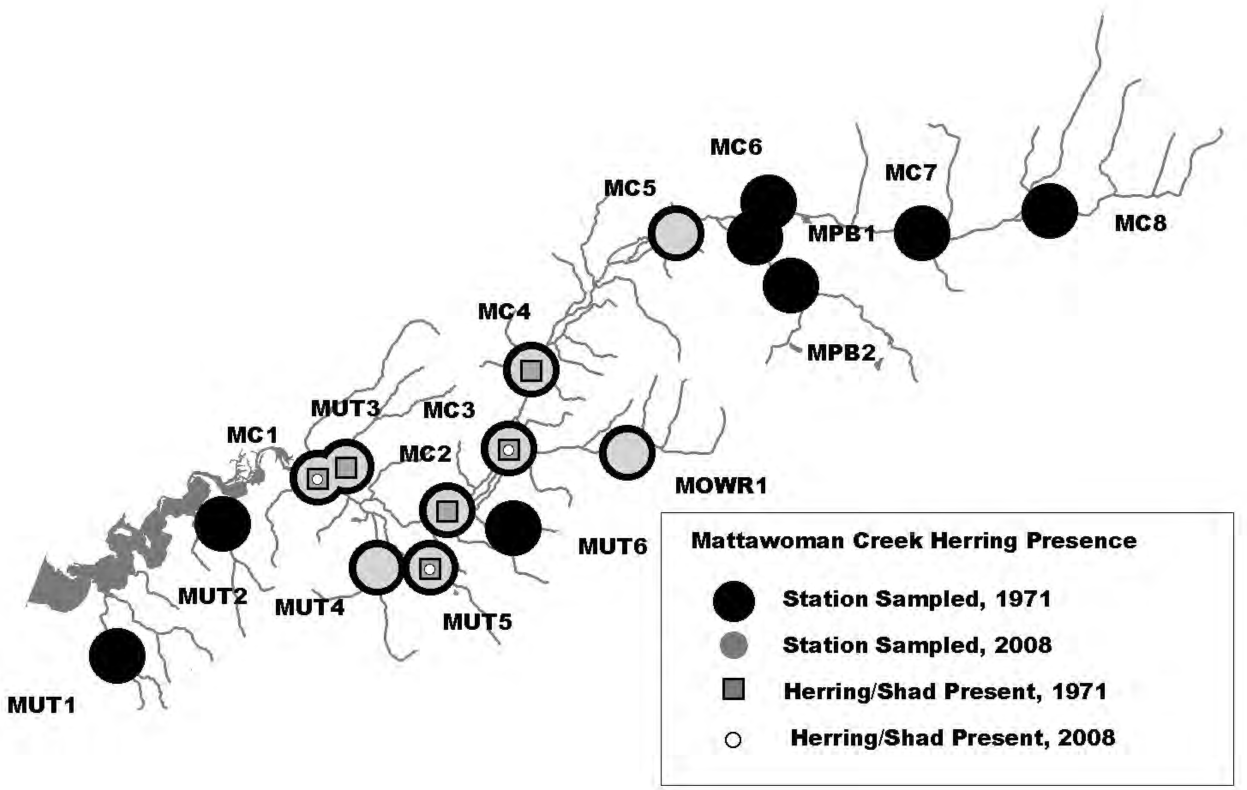


Figure 15. Historic stations sampled with comparisons between historic and present (2005-2008) presence of yellow perch in Mattawoman Creek.

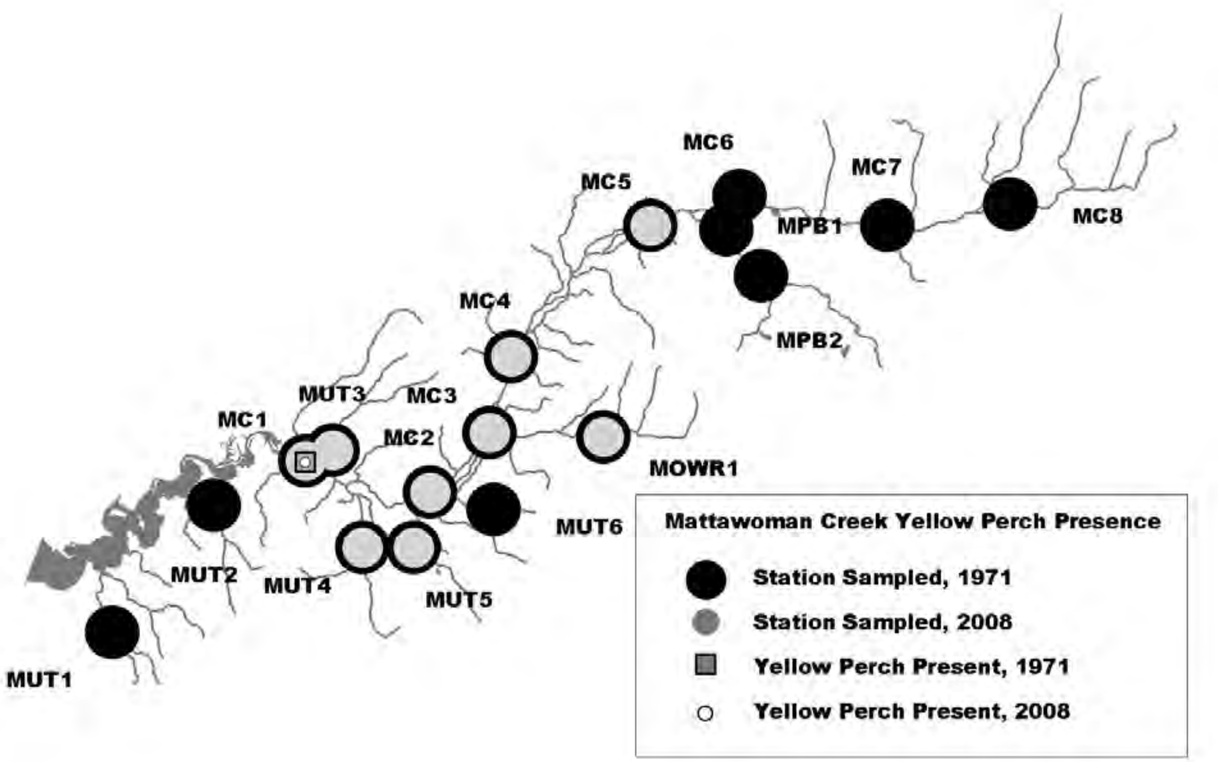


Figure 16. Historic stations sampled with comparisons between historic and present (2005-2008) presence of white perch in Mattawoman Creek.

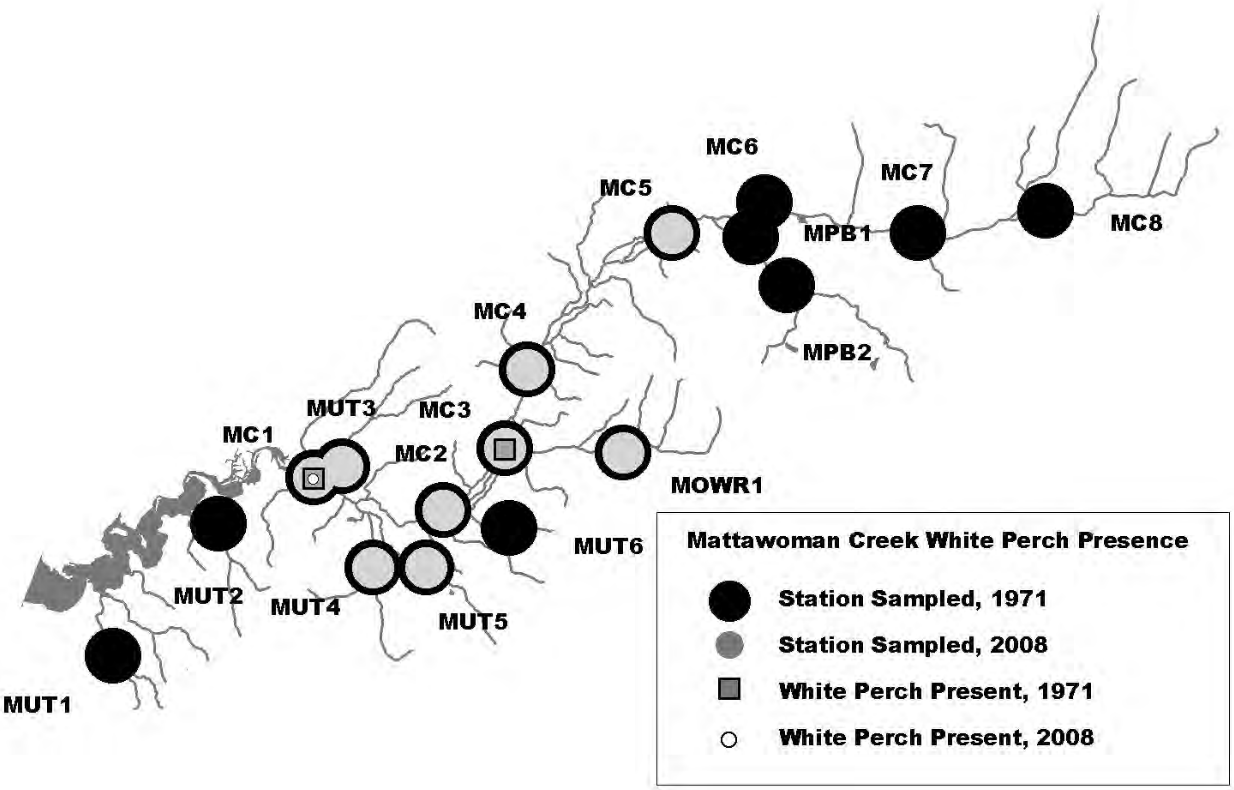


Figure 17. Land cover in the Piscataway and surrounding watersheds, 1973 and 2000.

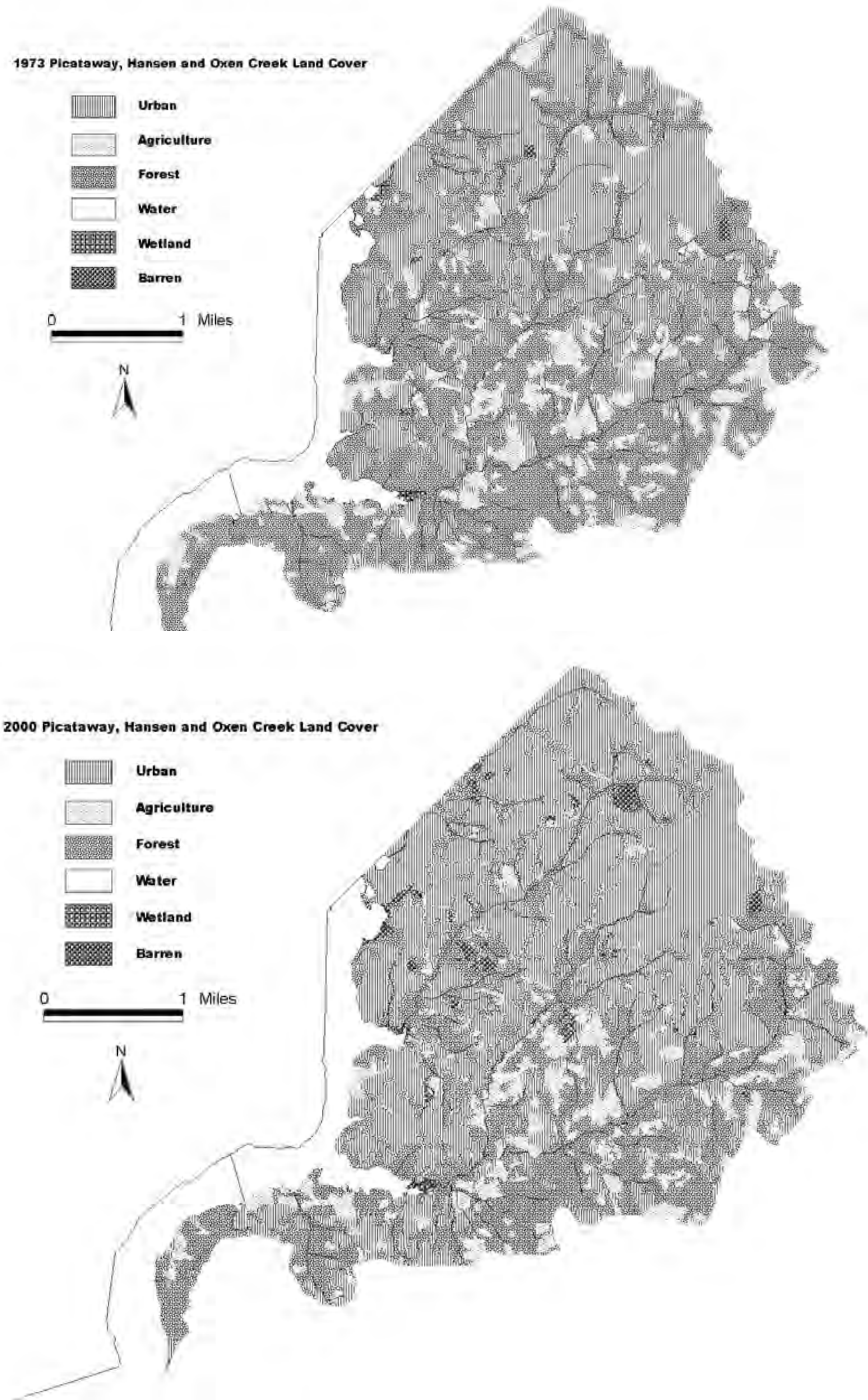


Figure 18. Historic stations sampled with comparisons between historic and present (2005-2008) presence of herring in Piscataway and surrounding watersheds.

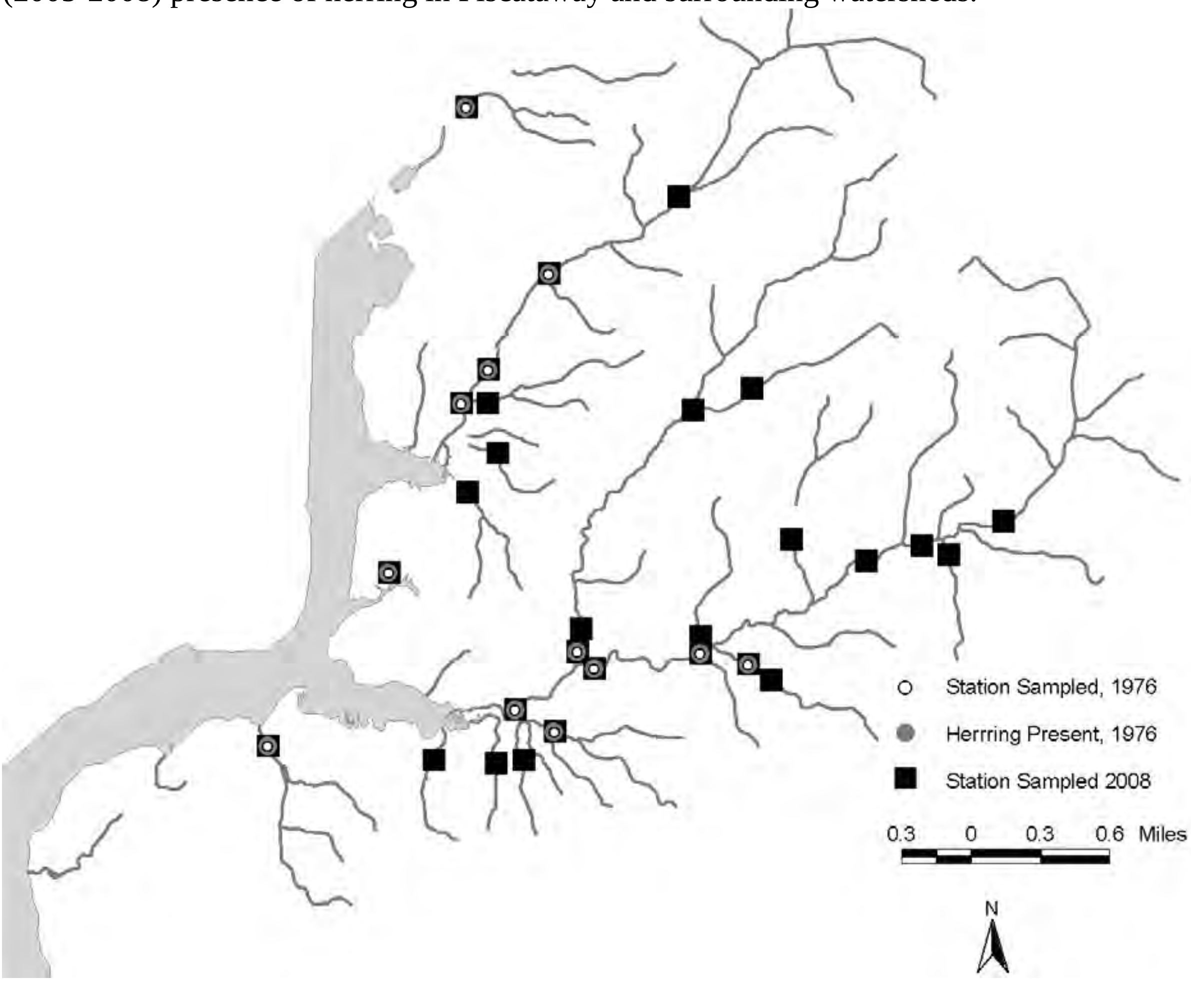


Figure 19. Historic stations sampled with comparisons between historic and present (2005-2008) presence of yellow perch in Piscataway and surrounding watersheds.

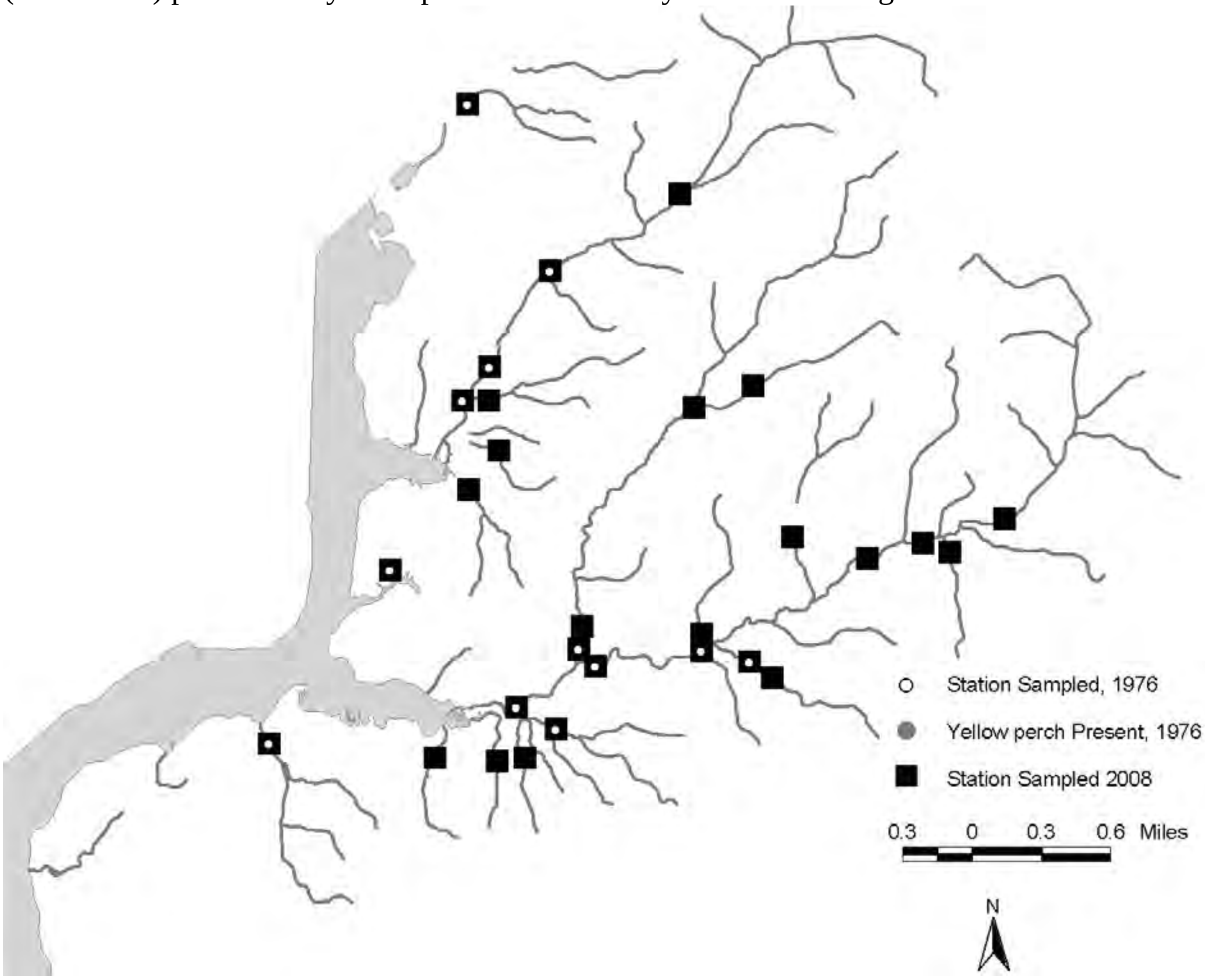


Figure 20. Historic stations sampled with comparisons between historic and present (2005-2008) presence of white perch in Piscataway and surrounding watersheds.

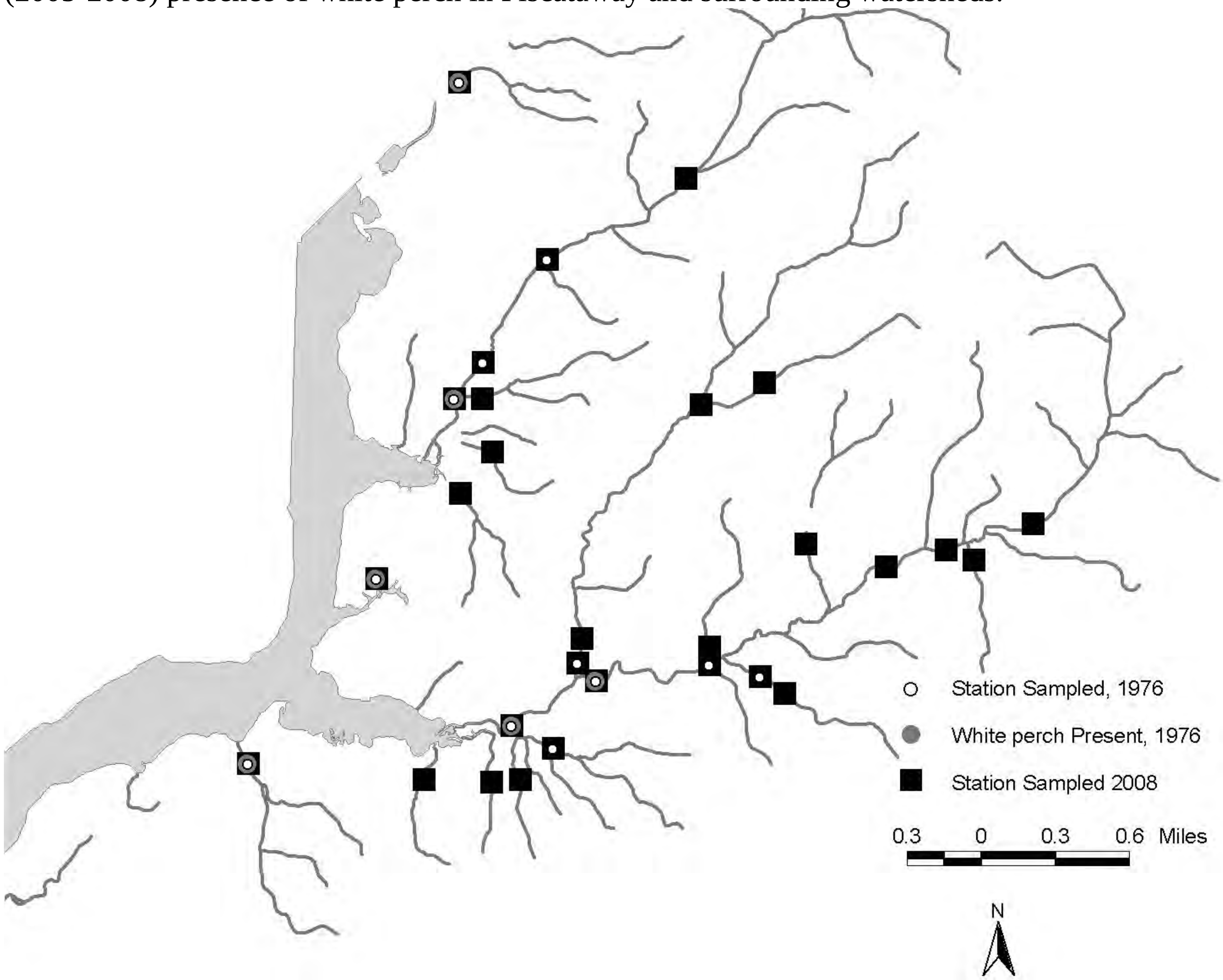


Figure 21. Tidal rivers sampled for yellow perch presence in 2008.

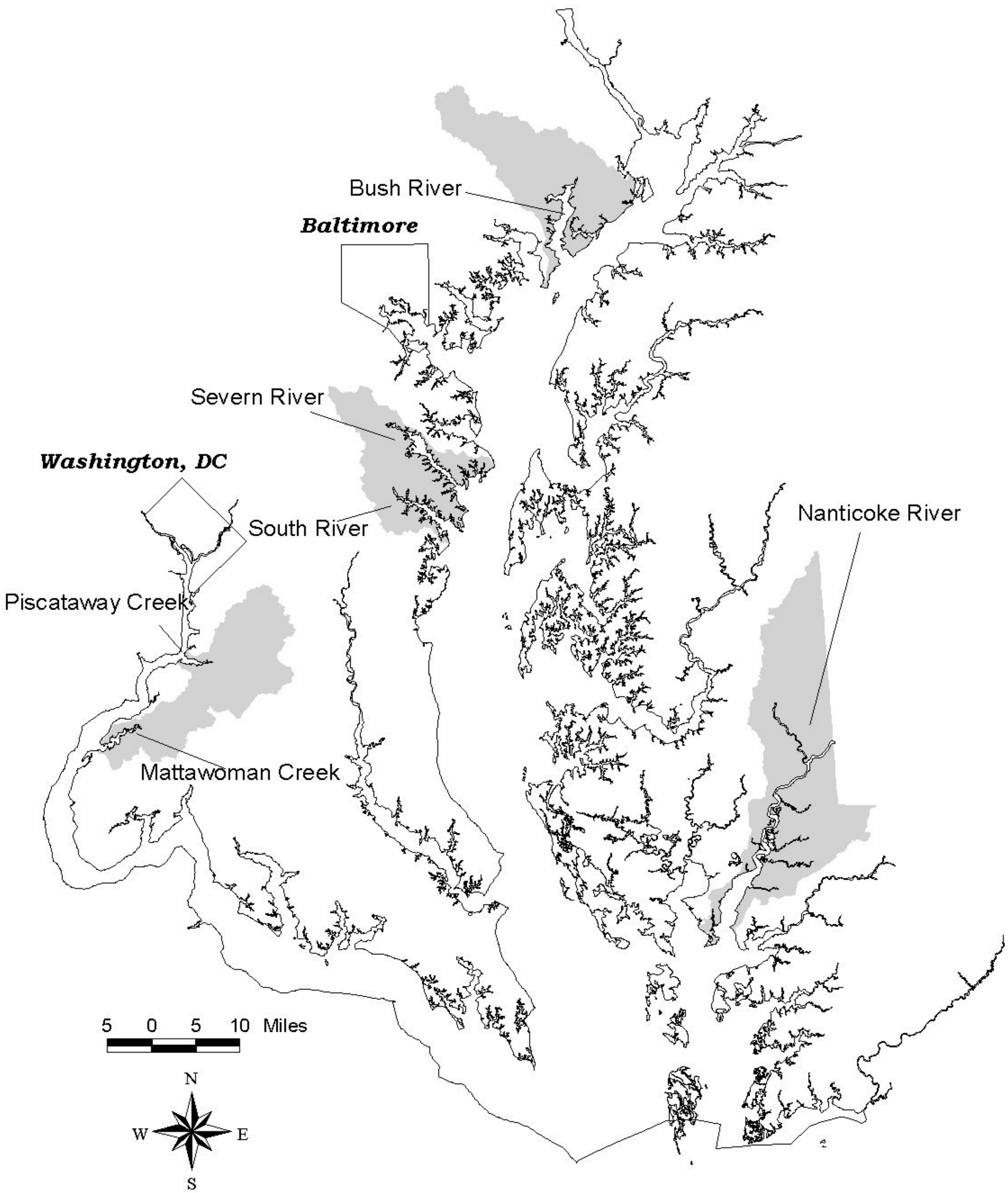


Figure 22. Proportion of tows with larval yellow perch and its 95% confidence interval in systems studied during 2008. Mean of brackish tributaries indicated by diamond and fresh-tidal mean indicated by dash. High and low points of “Historic” data indicate spread of 9 of 11 points and midpoint is the mean of historic period.

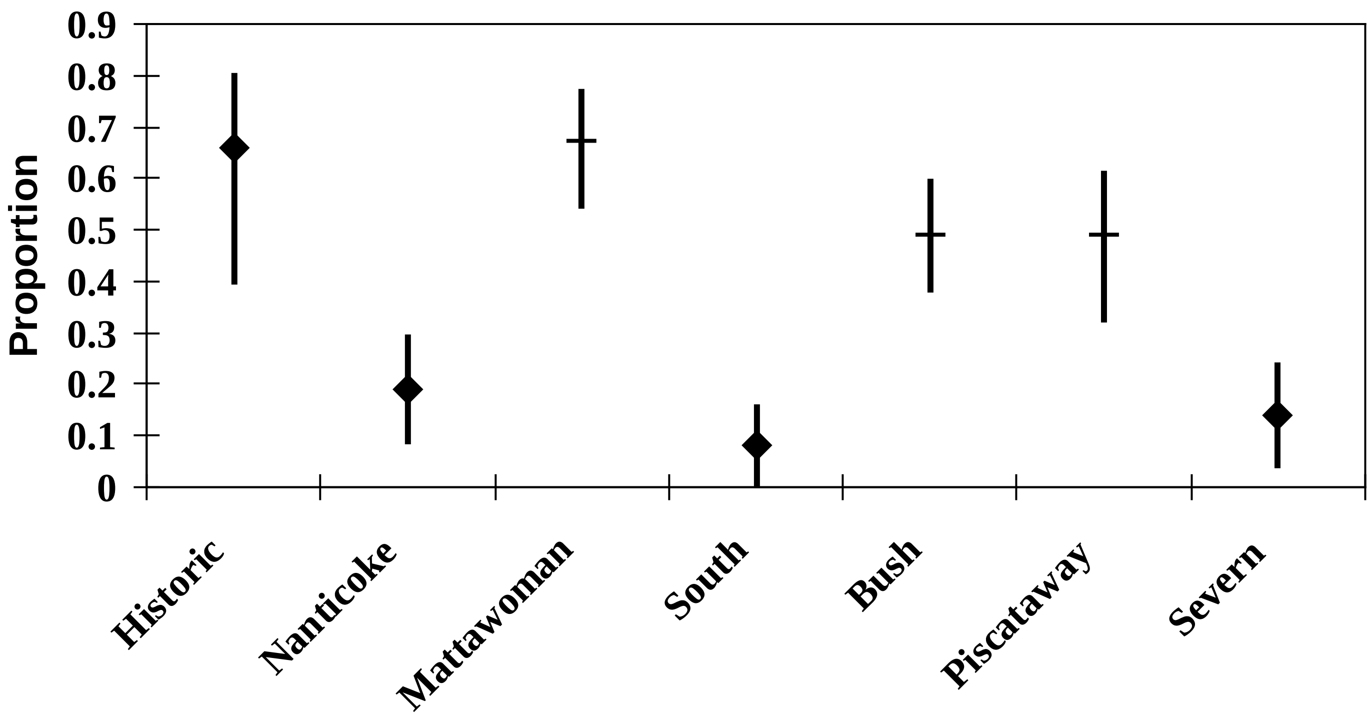


Figure 23. Plot of impervious surface (% of watershed) versus proportion of plankton tows with yellow perch larvae (Lp).

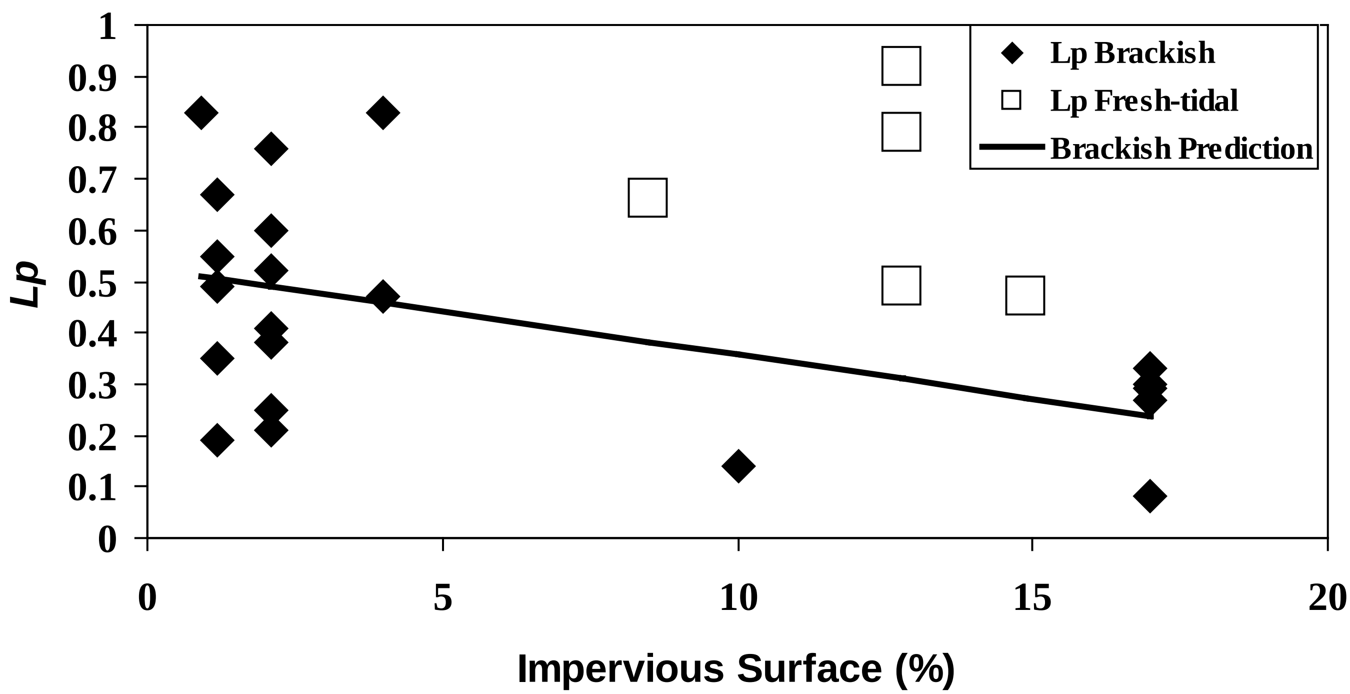


Figure 24. Plot of mean salinity in nursery area versus proportion of plankton tows with yellow perch larvae (*Lp*). Empty squares indicate Severn River and solid diamonds indicate remaining systems.

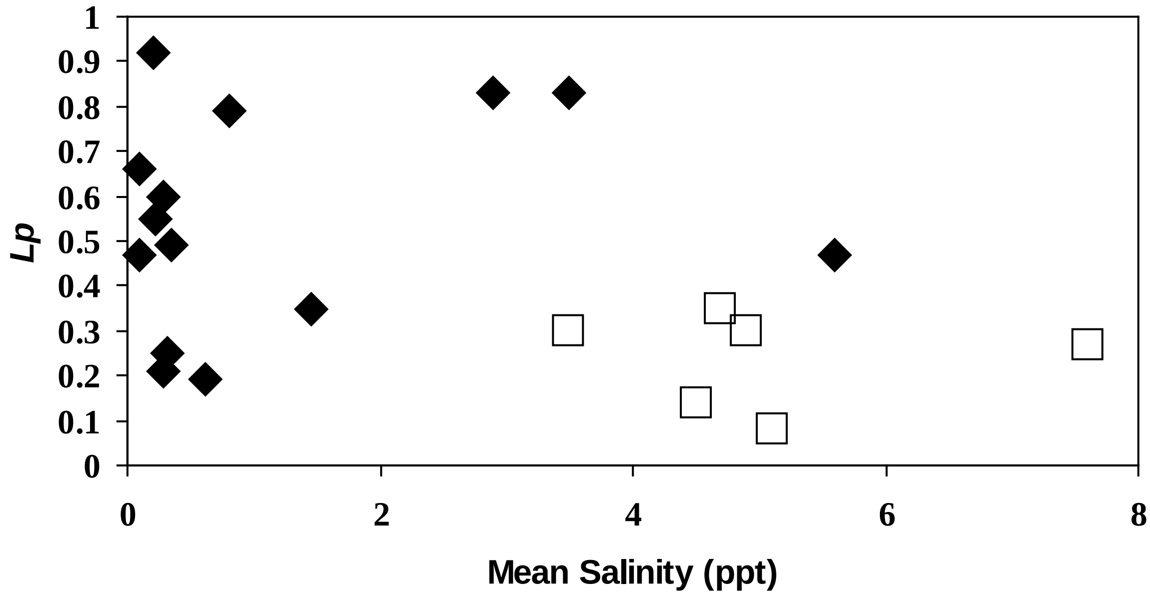


Figure 25. Proportion of tows with yellow perch larvae, by river, during 1965-2008. Dotted lines indicates reference system (Nanticoke and Choptank rivers) and period (prior to 1991) "typical" range.

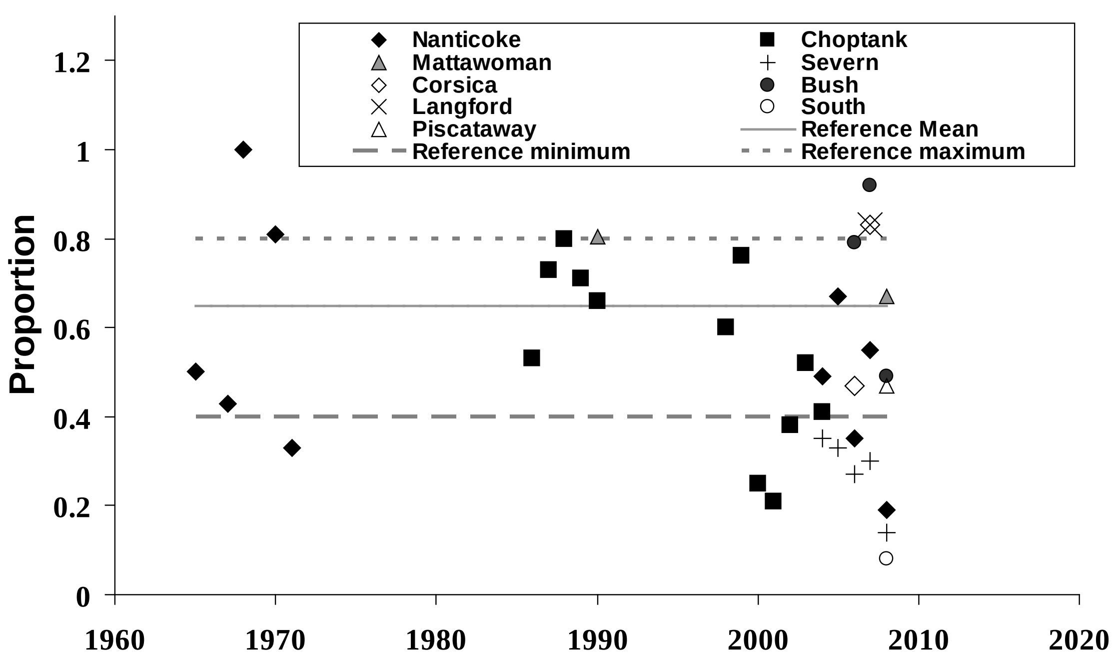


Figure 26. Number (N) of estimates of proportion of plankton tows with yellow perch larvae (Lp) falling within a category during 1965-2008. Severn and South rivers are omitted due to possible suppression of Lp due to factors related to impervious surface.

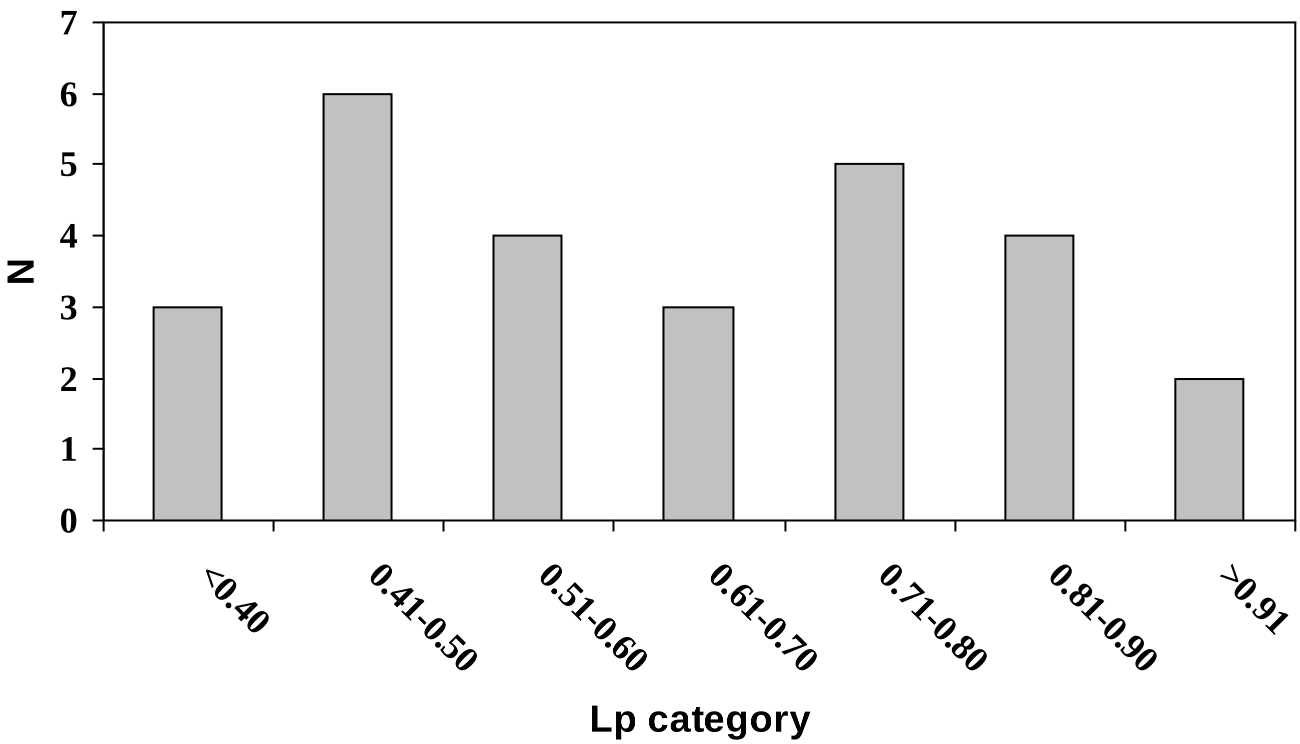


Figure 27. Watersheds sampled for juvenile and adult target species relative abundance and habitat conditions in 2008.

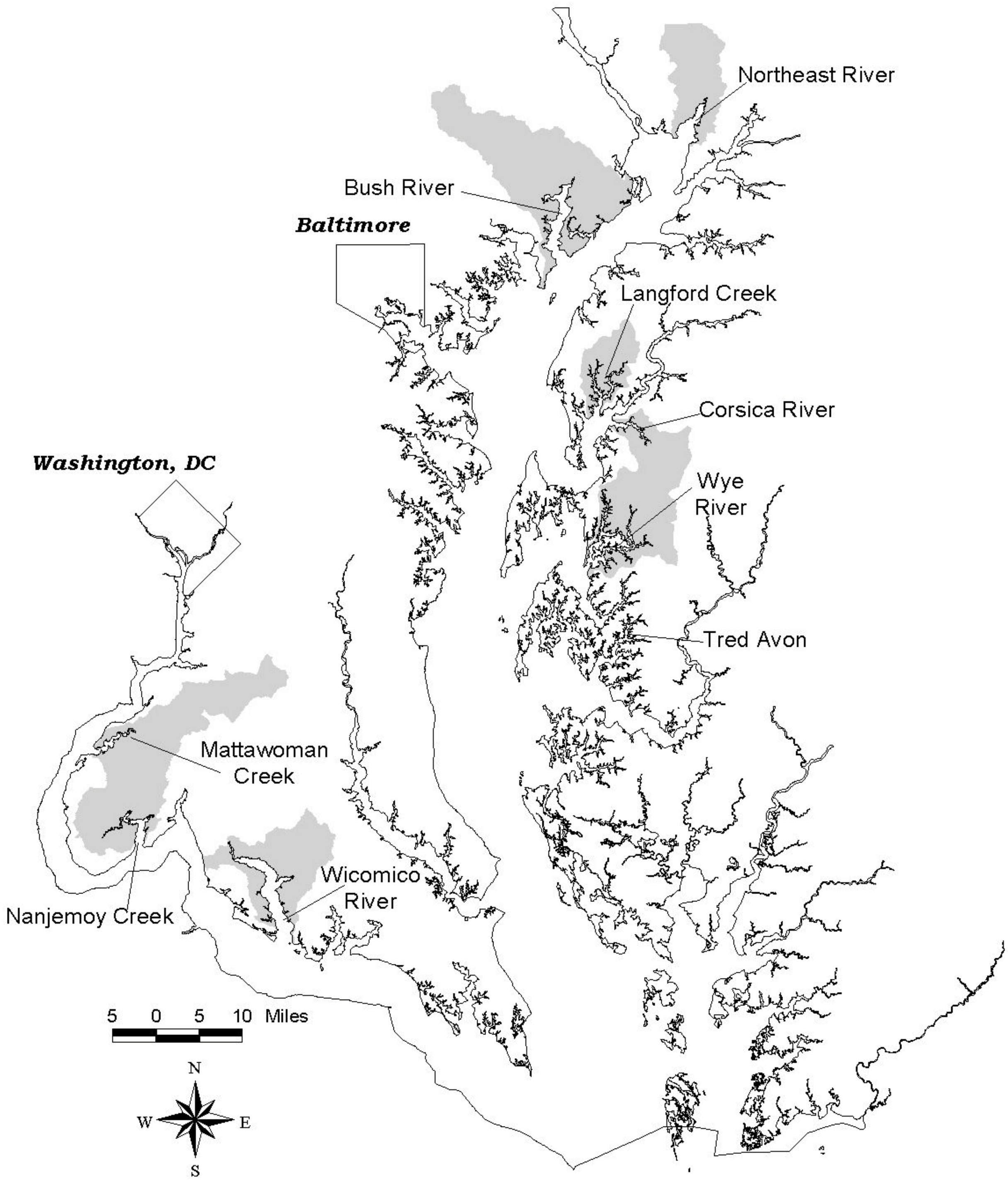


Figure 28. Land use and sampling stations n the Bush River watershed.

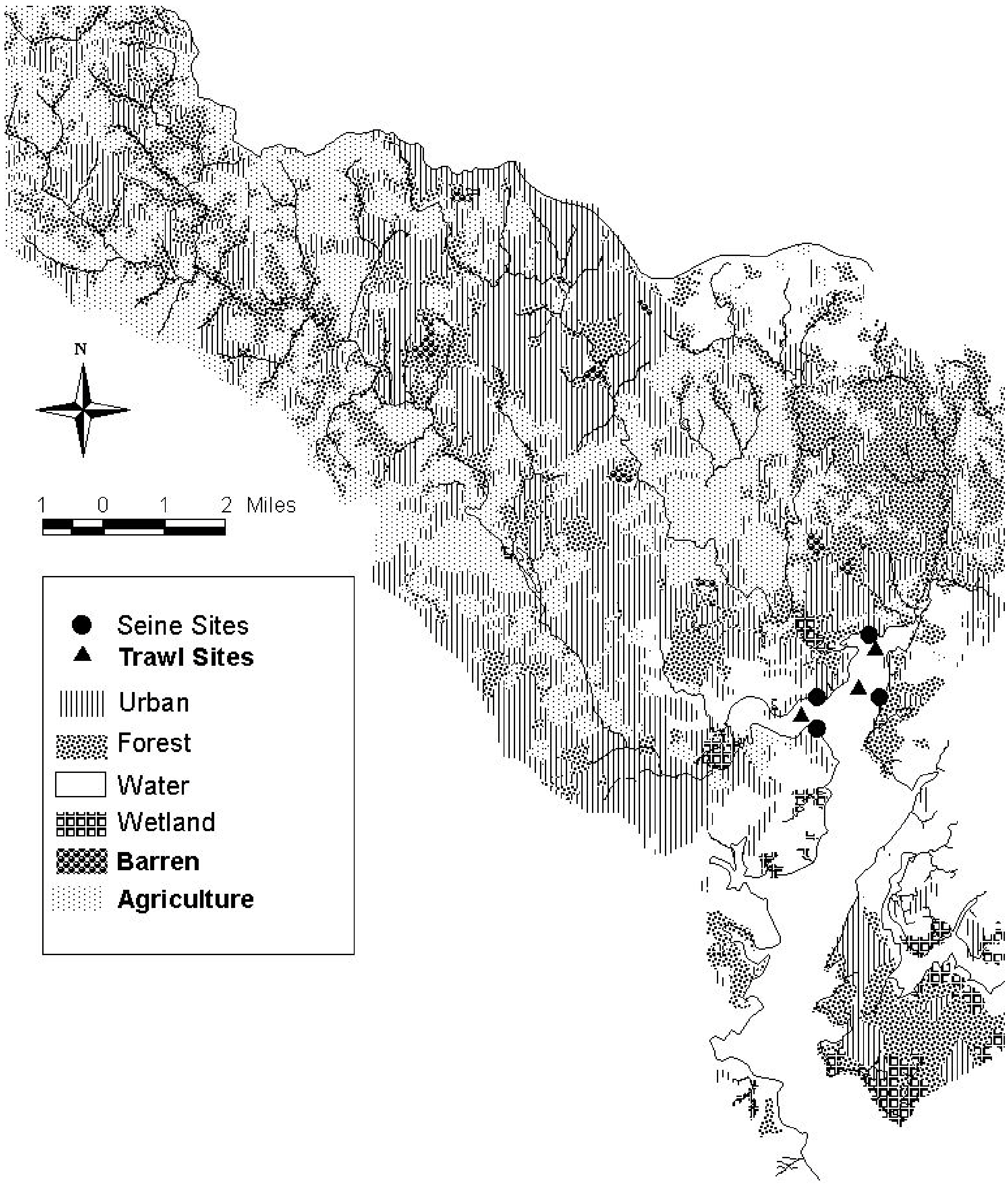


Figure 29. Land use and sampling stations in the Northeast River watershed.

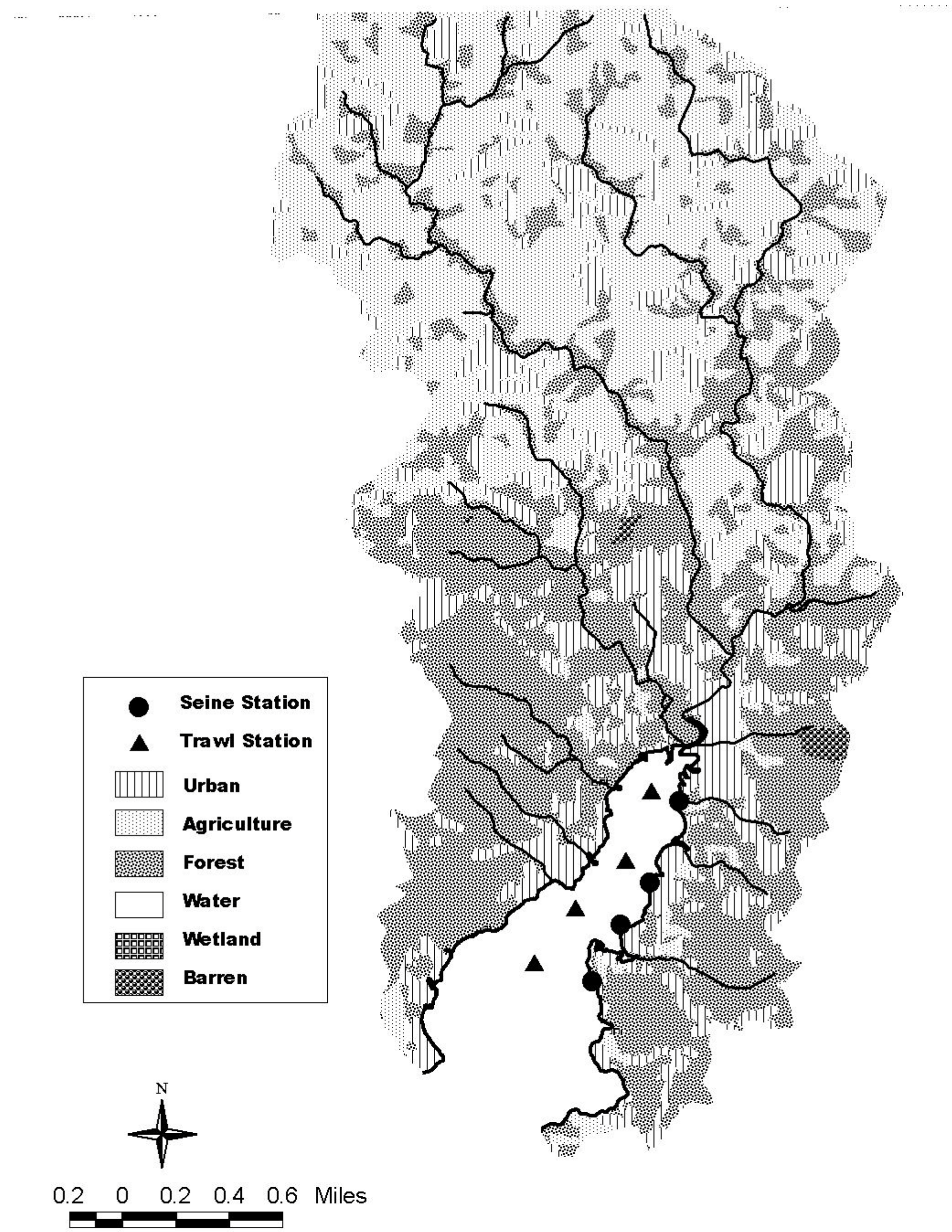


Figure 30. Land use and sampling stations in the Corsica River watershed.

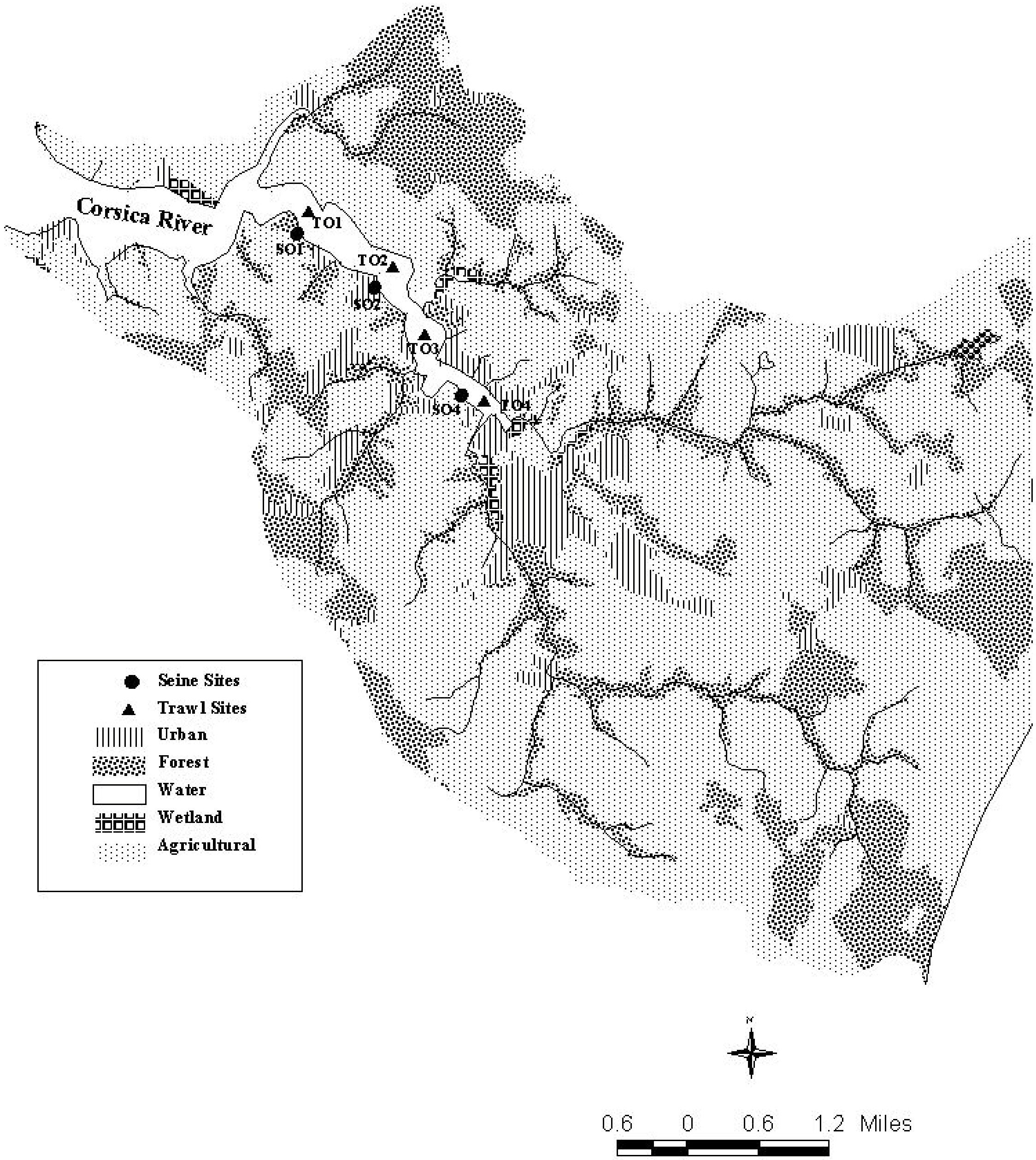


Figure 31. Land use and sampling stations in the Langford Creek watershed.

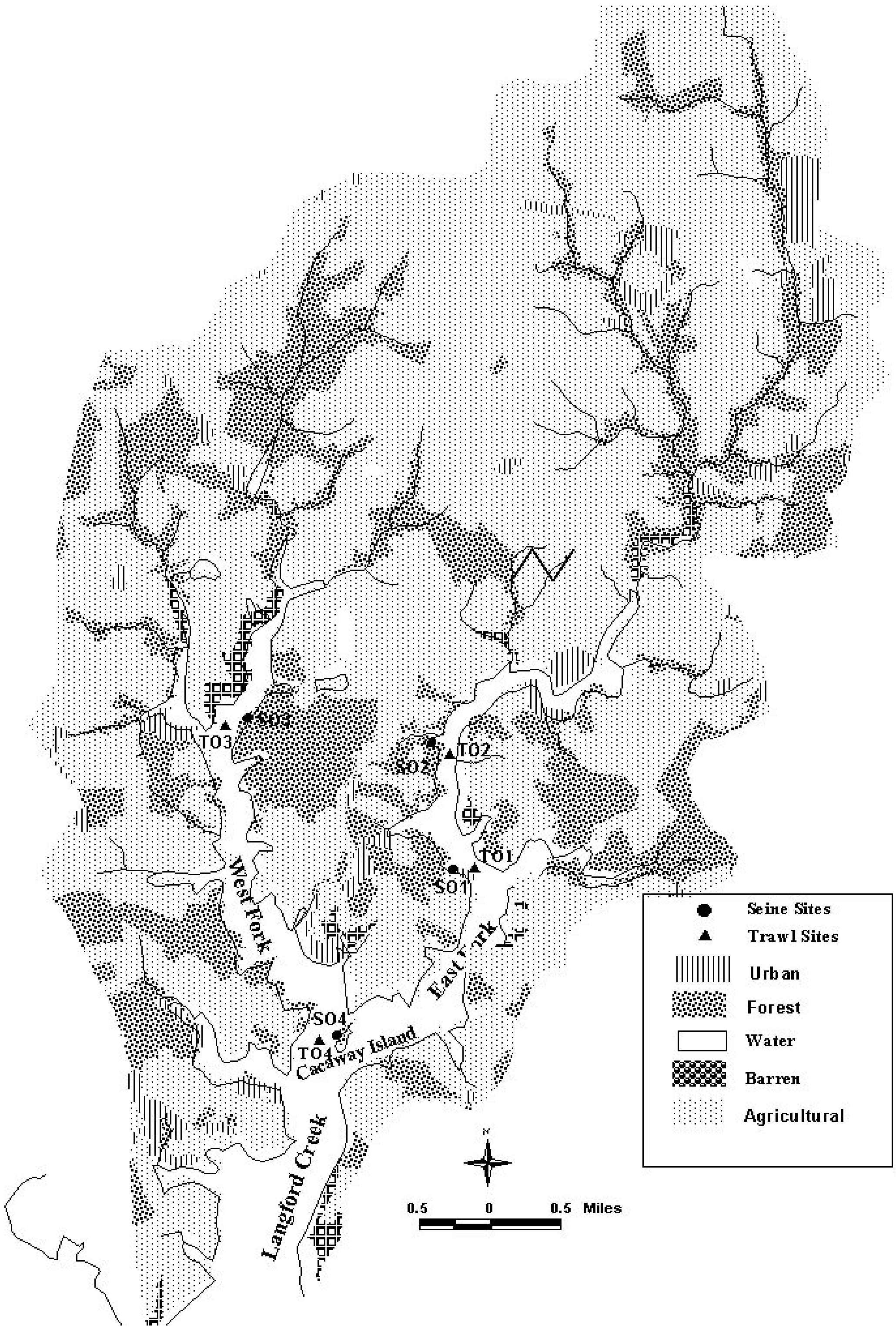


Figure 32. Land use and sampling stations in the Tred Avon watershed.

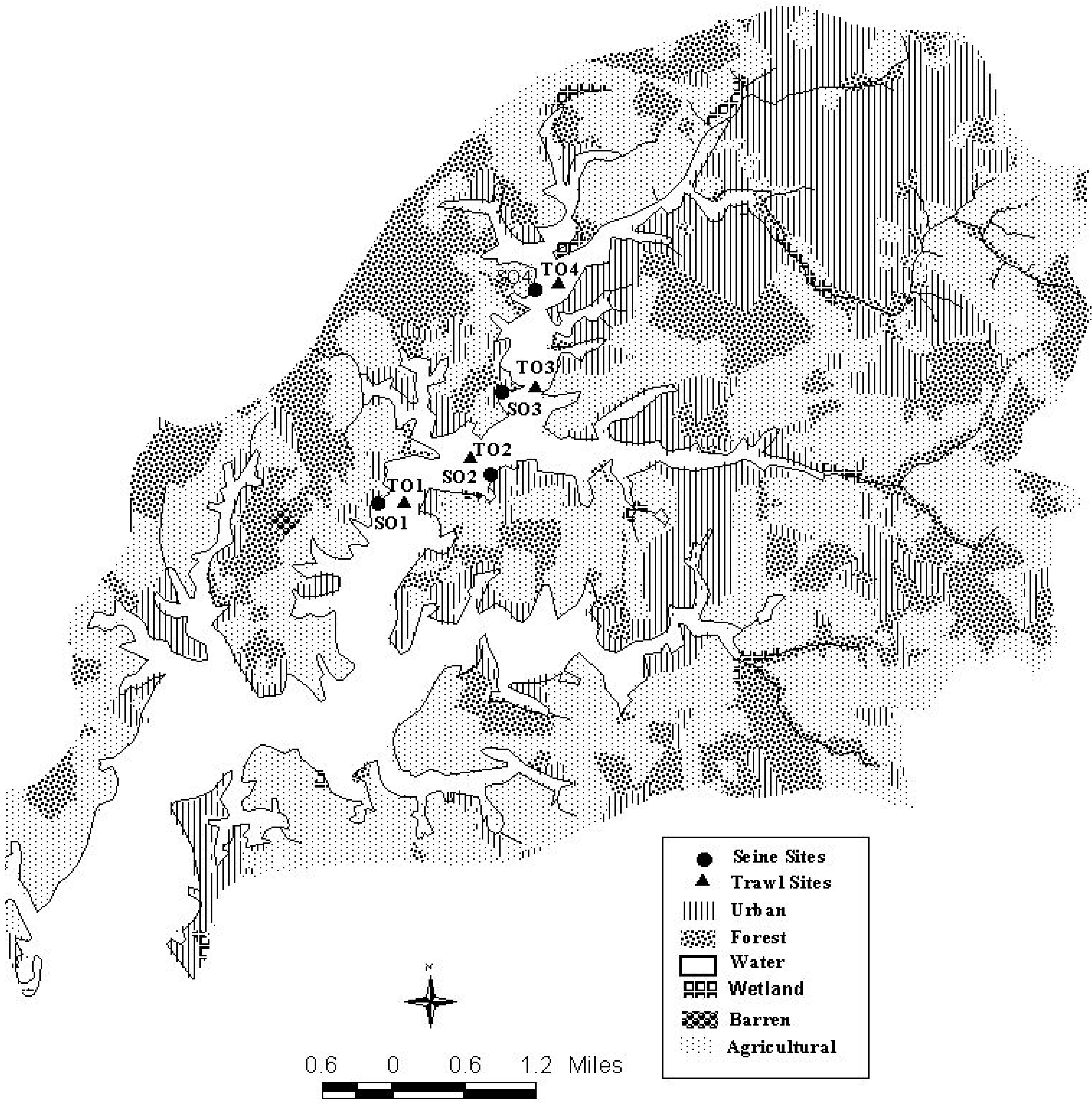


Figure 33. Land use and sampling stations in the Wye River watershed.

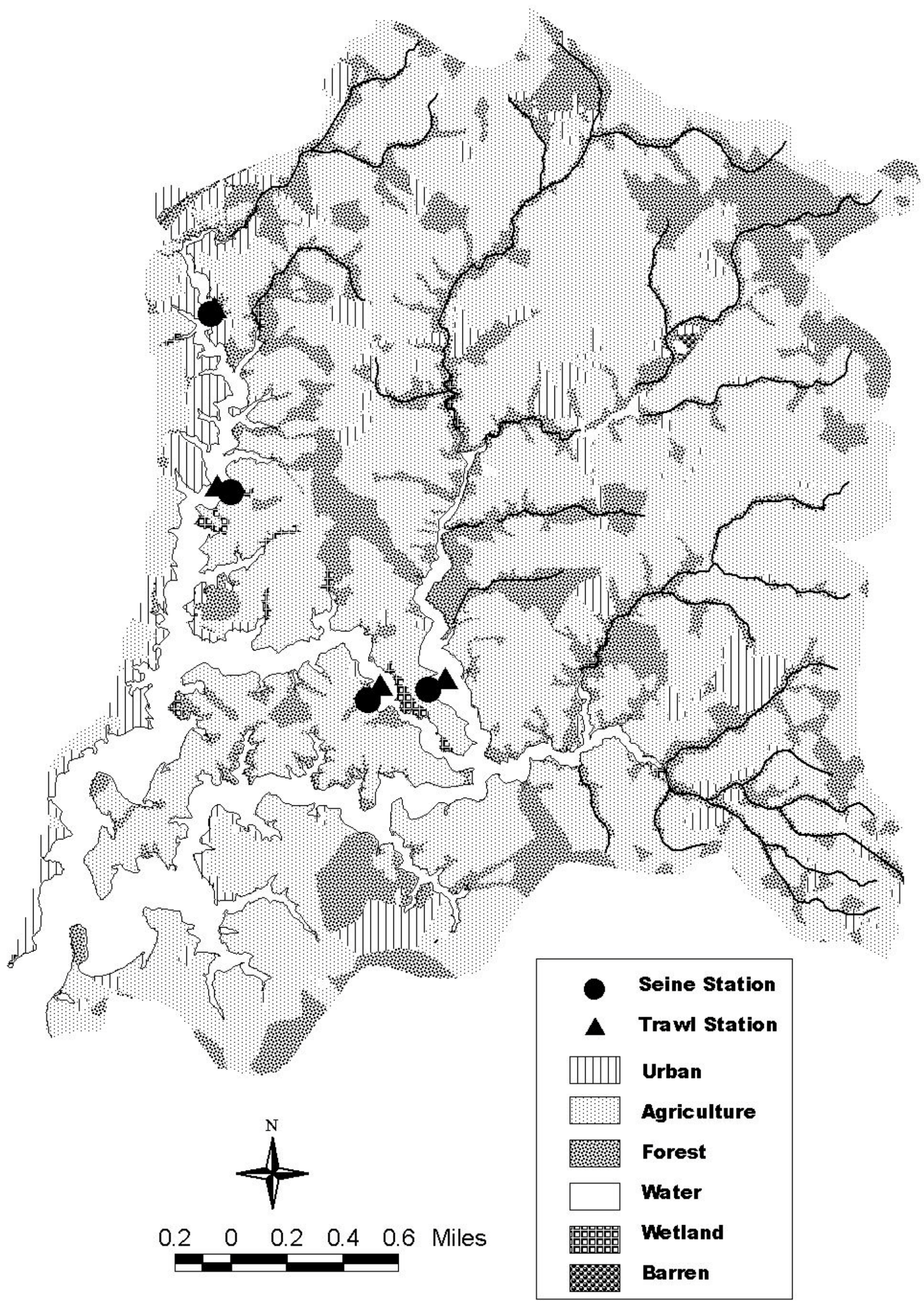


Figure 34. Land use and sampling stations in the Mattawoman Creek watershed.

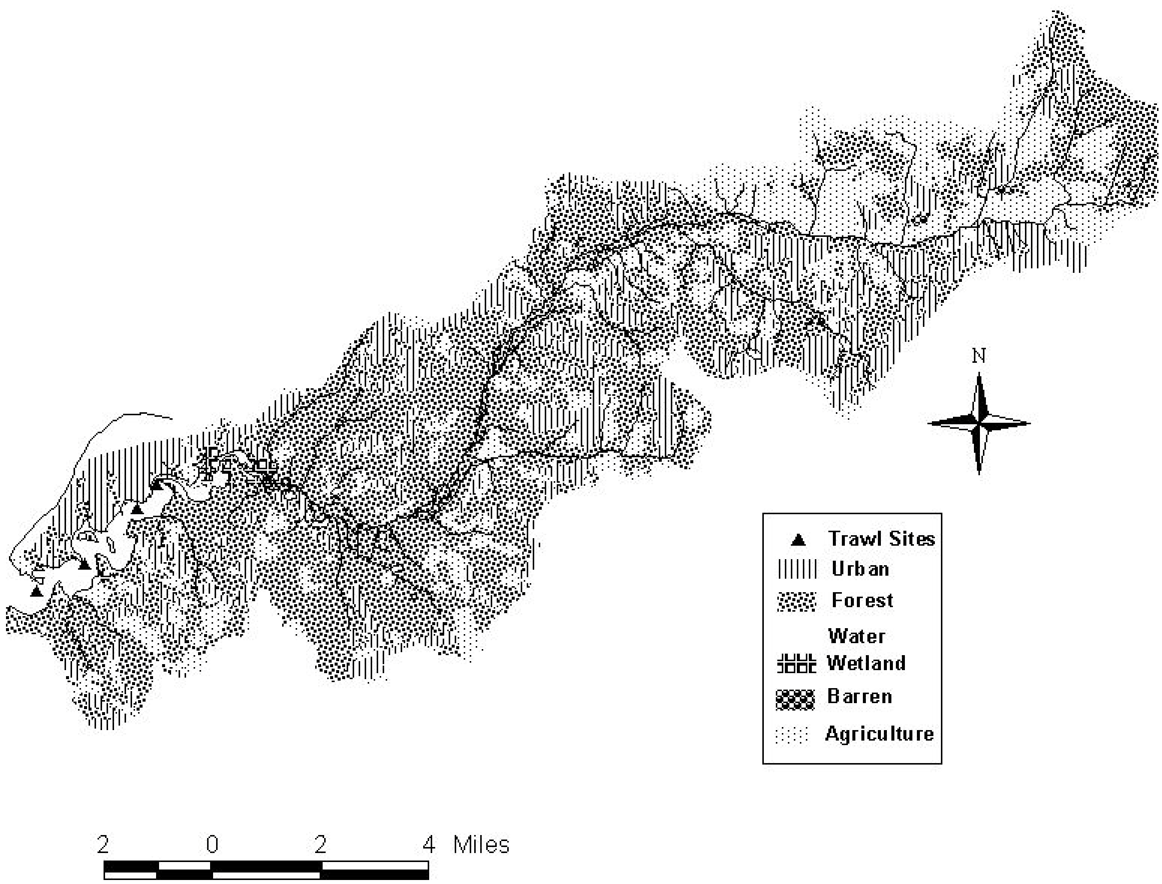


Figure 35. Land use and sampling stations in the Nanjemoy Creek watershed.

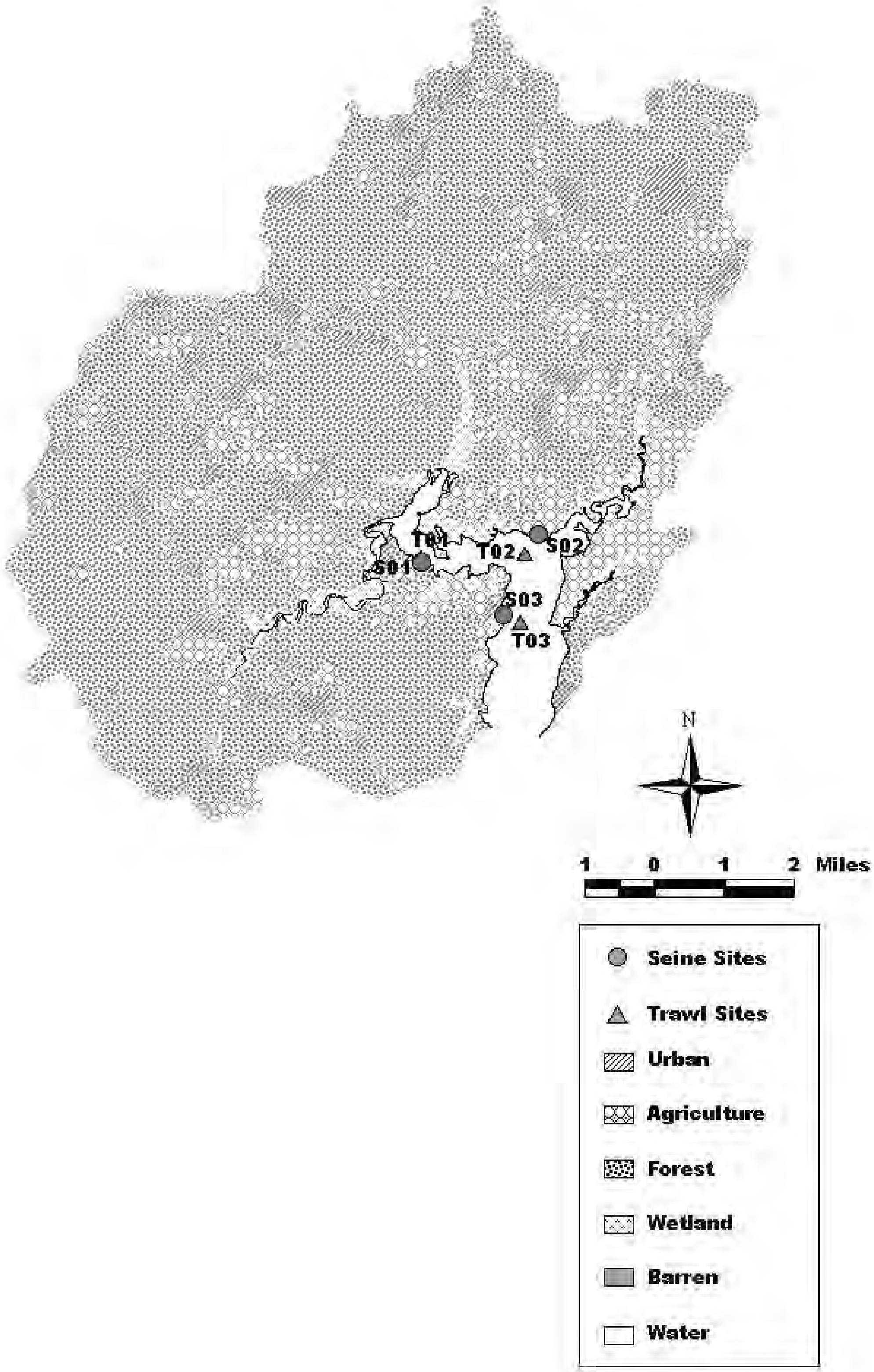


Figure 36. Distribution of temperature data for rivers sampled in 2008. Data include nearshore and offshore water column integrated data. The highlighted area indicates temperatures that are outside of the mean highest acceptable temperature for all target species combined. (Dark bar is the median, gray box represents the upper 75th percentile and the lower 25th percentile, black bars indicate the upper 95th and lower 5th percentiles, dark boxes indicate outliers.)

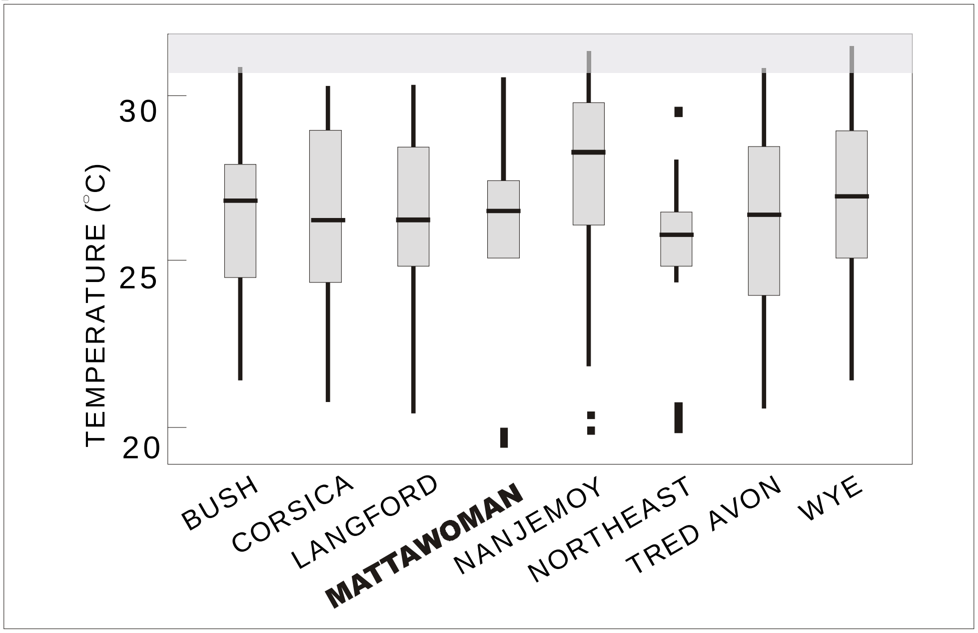


Figure 37. Distribution of dissolved oxygen data for rivers sampled in 2008. Data include nearshore and offshore water column integrated data. The highlighted area indicate dissolved oxygen concentrations below the 5.0 mg/L threshold. (Dark bar is the median, gray box represents the upper 75th percentile and the lower 25th percentile, black bars indicate the upper 95th and lower 5th percentiles, dark boxes indicate outliers.)

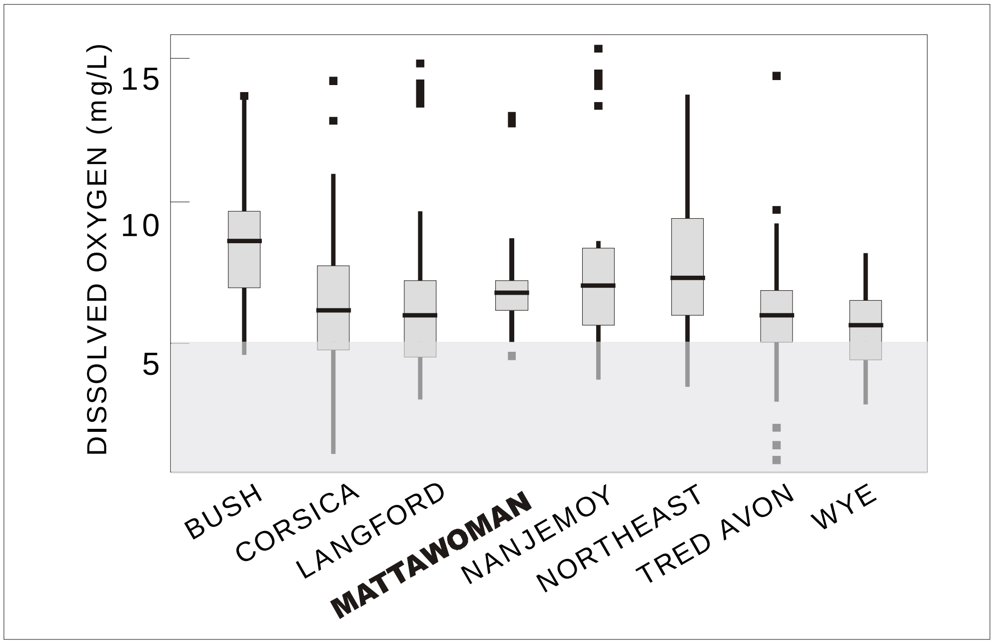


Figure 38. Distribution of salinity data for rivers sampled in 2008. Data include nearshore and offshore water column integrated data. (Dark bar is the median, gray box represents the upper 75th percentile and the lower 25th percentile, black bars indicate the upper 95th and lower 5th percentiles, dark boxes indicate outliers.) Horizontal line indicates salinity maximum for non-marine target species.

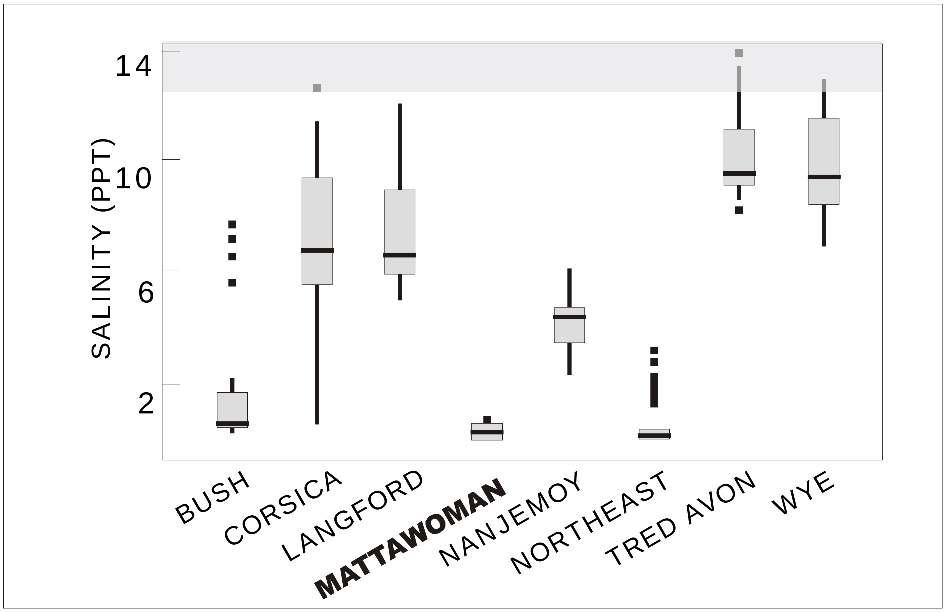


Figure 39. Distribution of bottom dissolved oxygen for rivers sampled in 2008. The gray shaded area represents concentrations below the 5.0 mg/l criteria. (Dark bar is the median, gray box represents the upper 75th percentile and the lower 25th percentile, black bars indicate the upper 95th and lower 5th percentiles, dark boxes indicate outliers.)

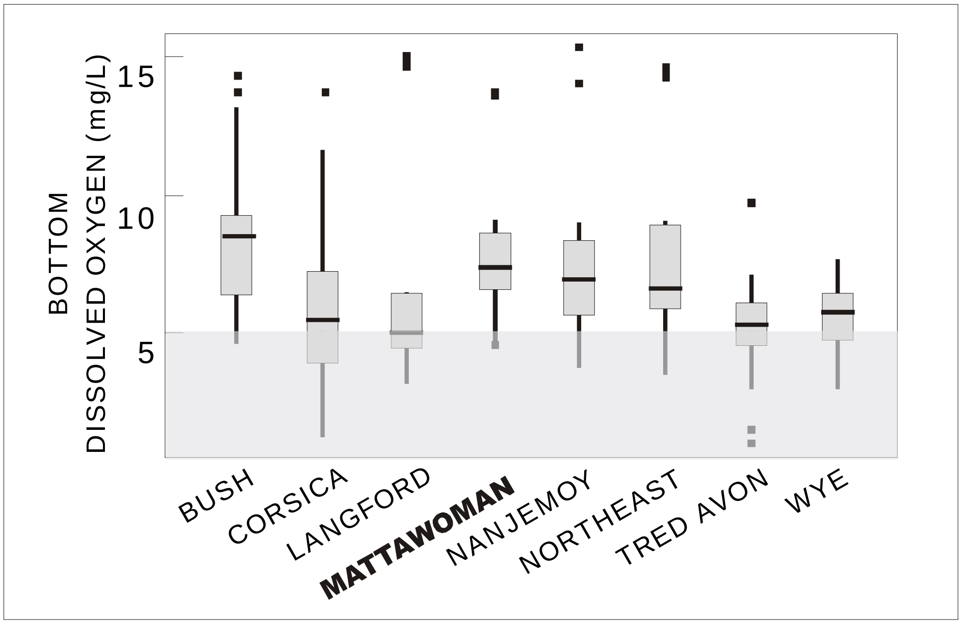


Figure 40. Mean bottom dissolved oxygen versus impervious surface for all brackish and tidal fresh systems during 2003-2008.

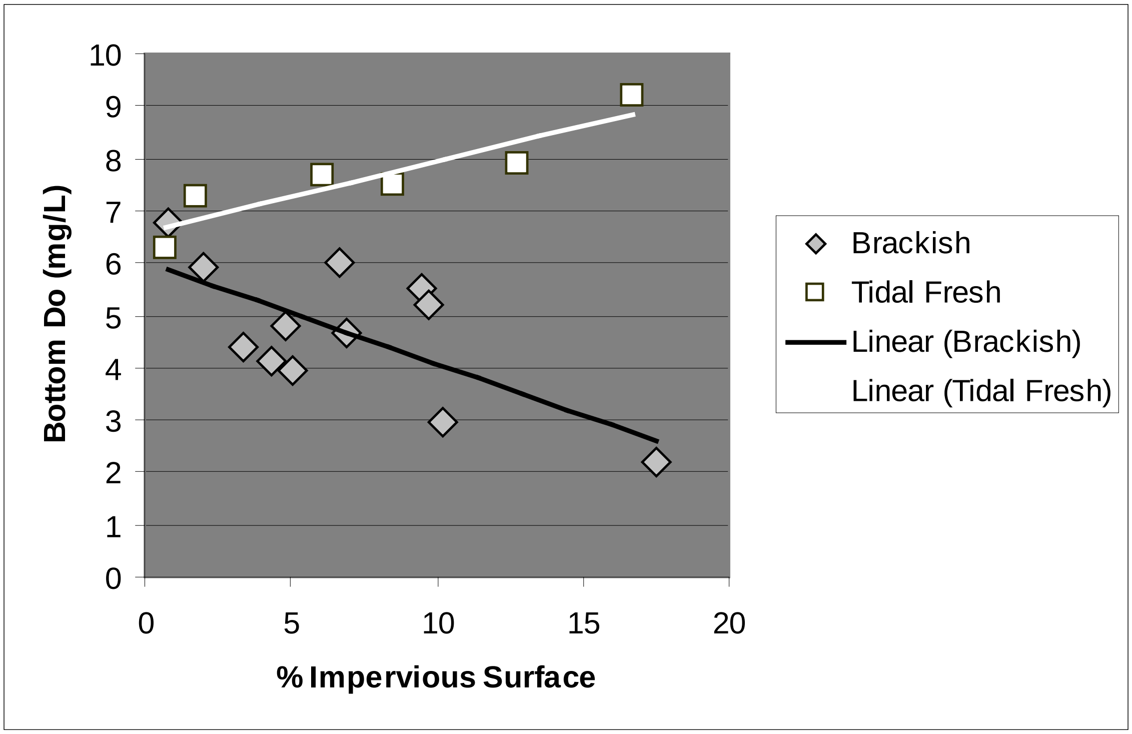


Figure 41. Distribution of bottom dissolved by percent impervious cover for tidal fresh rivers sampled during 2006-2008. (Dark bar is the median, gray box represents the upper 75th percentile and the lower 25th percentile, black bars indicate the upper 95th and lower 5th percentiles, dark boxes indicate outliers.) The shaded area indicates the 5.0 mg/L habitat criteria is not achieved.

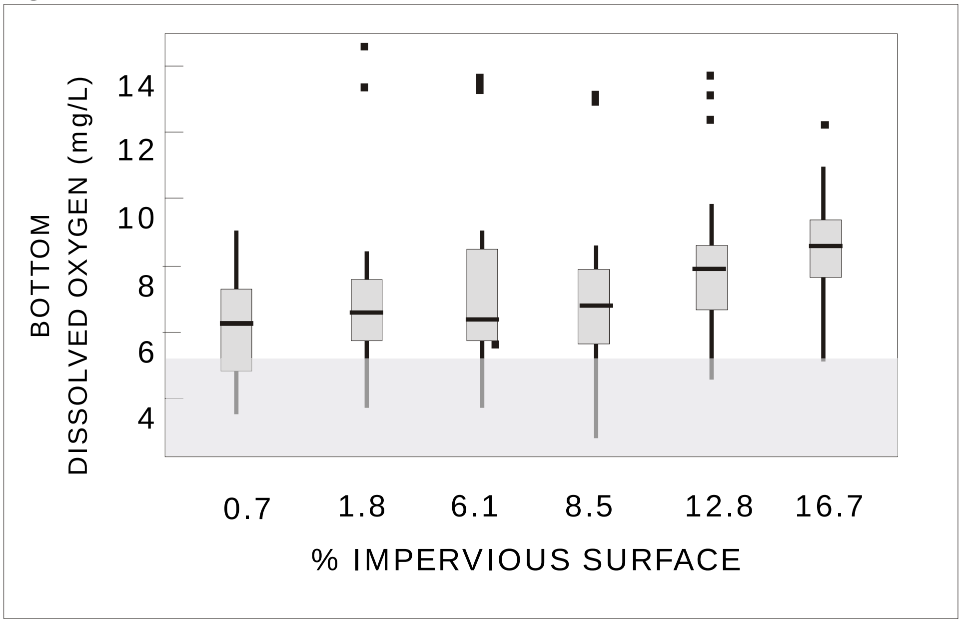


Figure 42. Distribution of secchi depth by impervious surface in tidal fresh rivers sampled in 2006-2008. The gray shaded area represents concentrations below the 5.0 mg/l criteria. (Dark bar is the median, gray box represents the upper 75th percentile and the lower 25th percentile, black bars indicate the upper 95th and lower 5th percentiles, dark boxes indicate outliers.)

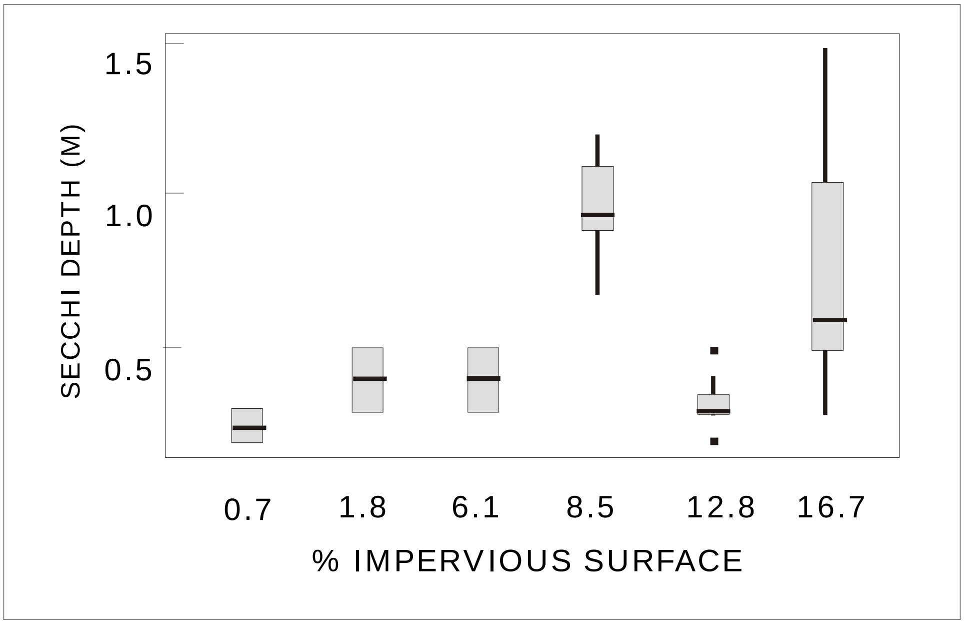


Figure 43a. Proportion of target species present in the trawl, in tidal fresh tributaries versus percentage of impervious surface.

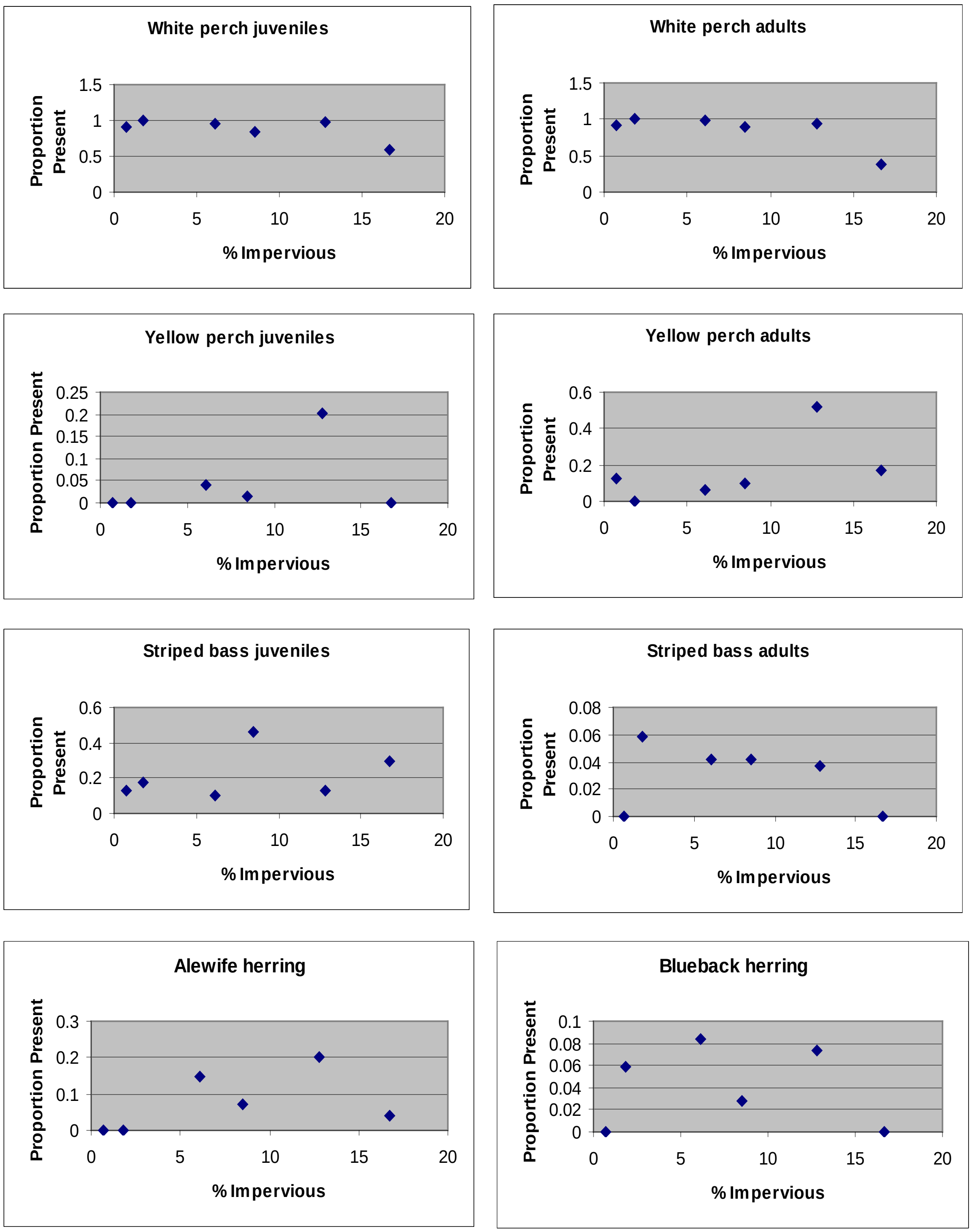


Figure 43b. Proportion of target species present in tidal fresh tributaries, in the trawl versus percentage of impervious surface.

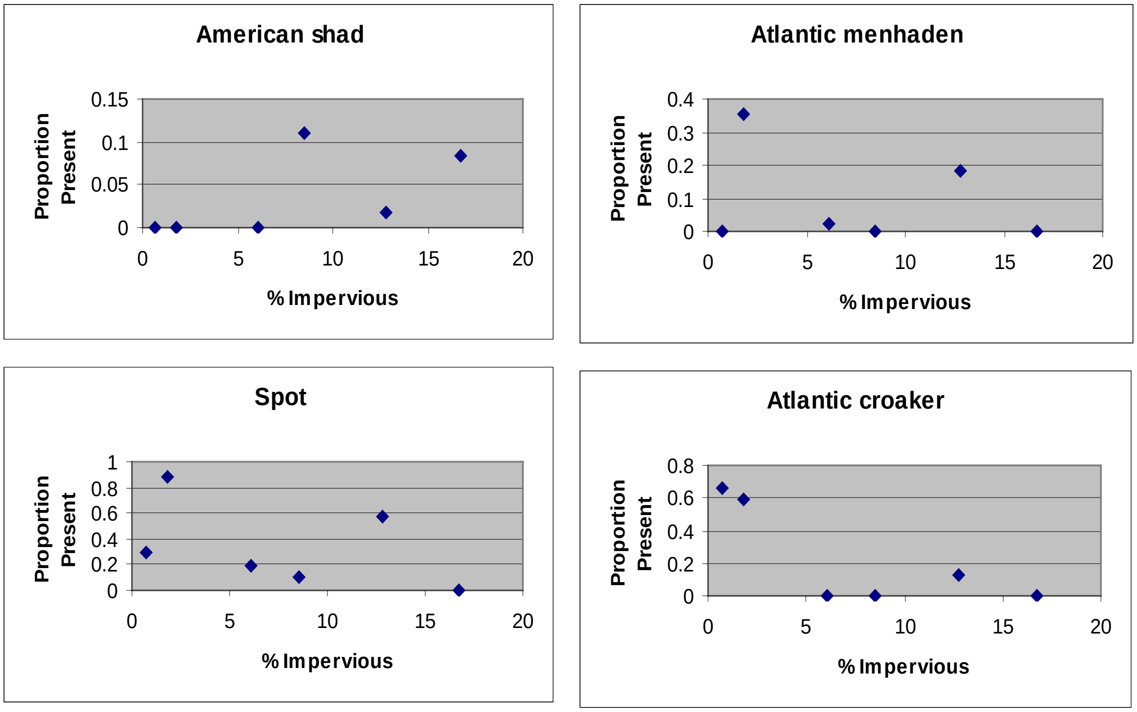


Figure 44a. Proportion of target species present in tidal fresh tributaries, in the seine versus percentage of impervious surface.

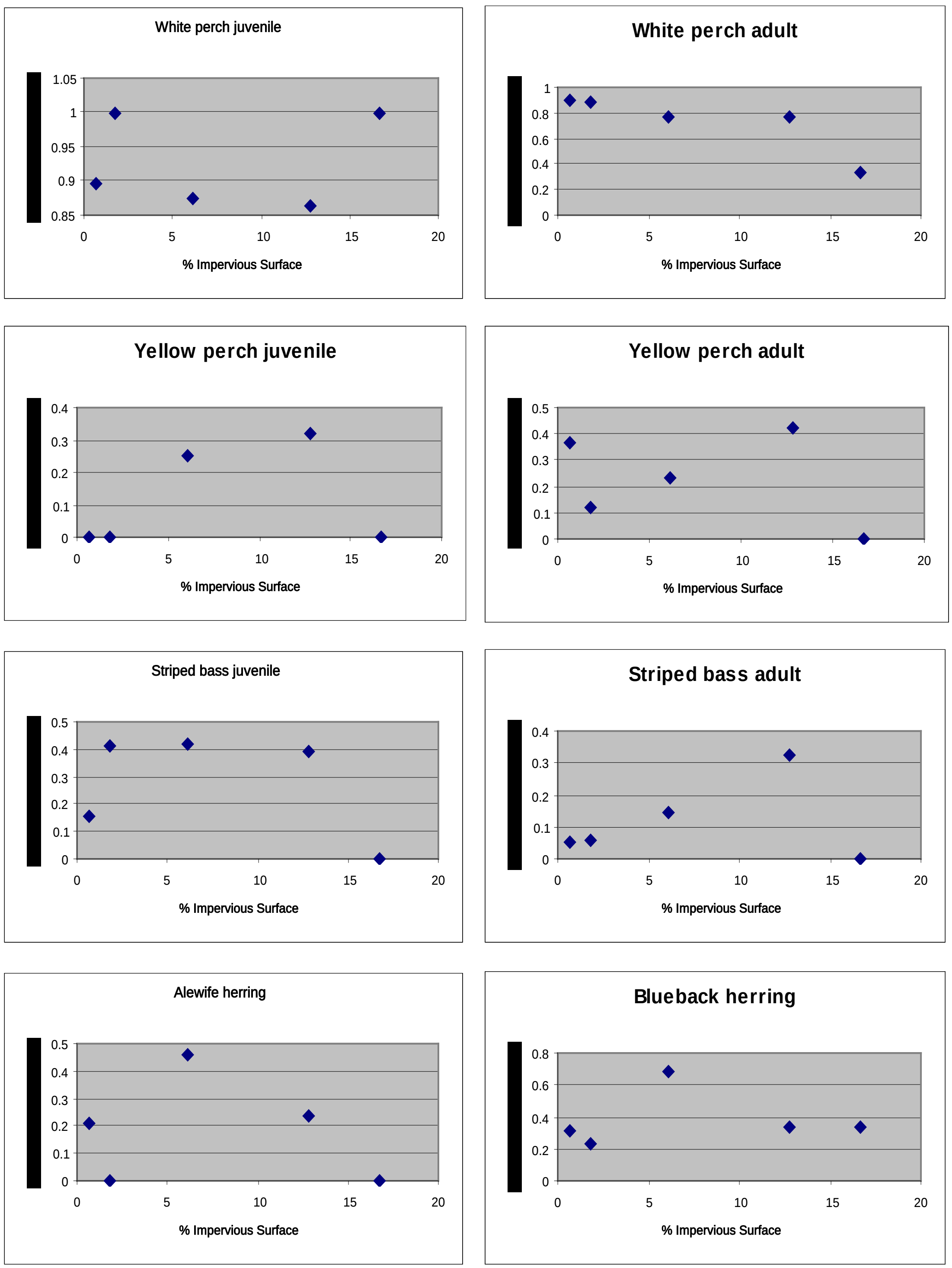


Figure 44b. Proportion of target species present in tidal fresh tributaries, in the seine versus percentage of impervious surface.

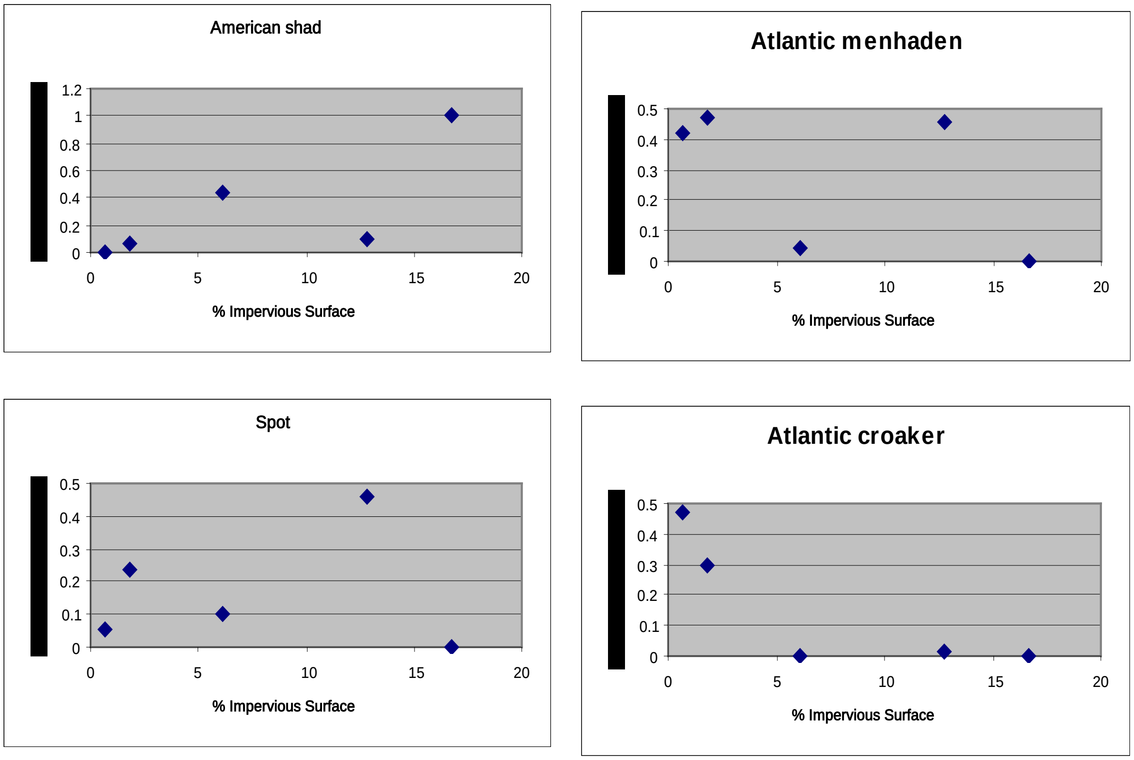


Figure 45. Distribution of bottom dissolved oxygen concentrations in Mattawoman Creek from 1989 to present. (Dark bar is the median, gray box represents the upper 75th percentile and the lower 25th percentile, black bars indicate the upper 95th and lower 5th percentiles, dark boxes indicate outliers.)

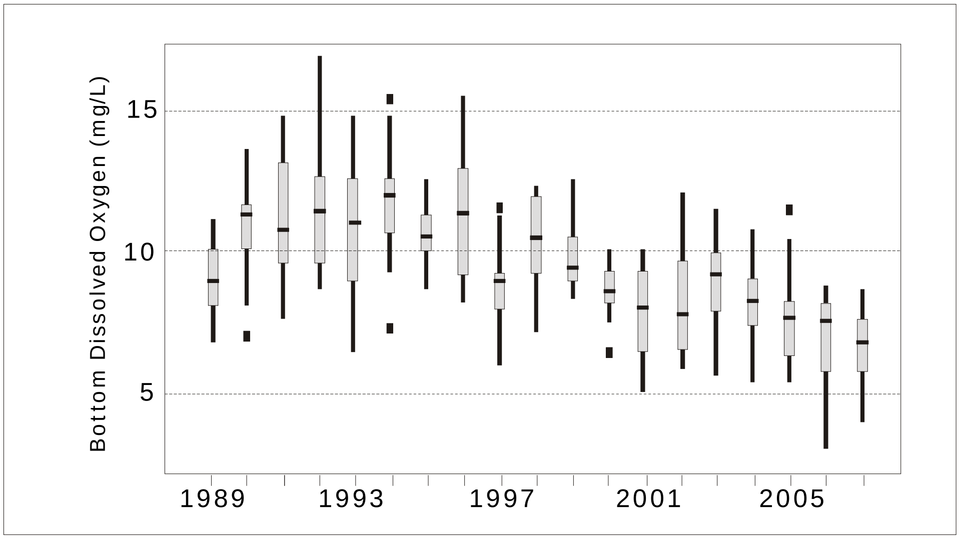


Figure 46. Distribution of bottom oxygen saturation in Mattawoman Creek, 1989 to present. (Dark bar is the median, gray box represents the upper 75th percentile and the lower 25th percentile, black bars indicate the upper 95th and lower 5th percentiles, dark boxes indicate outliers.)

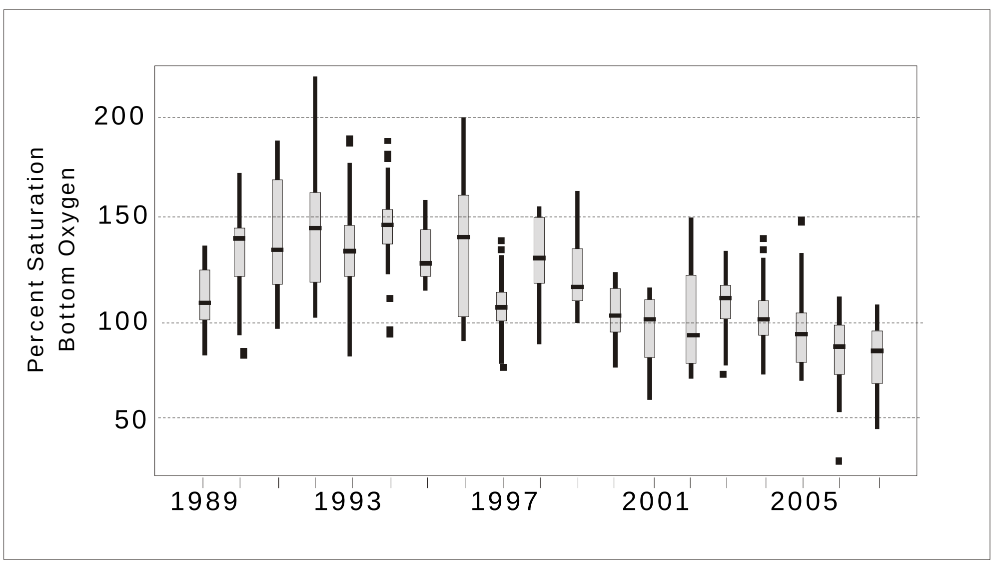
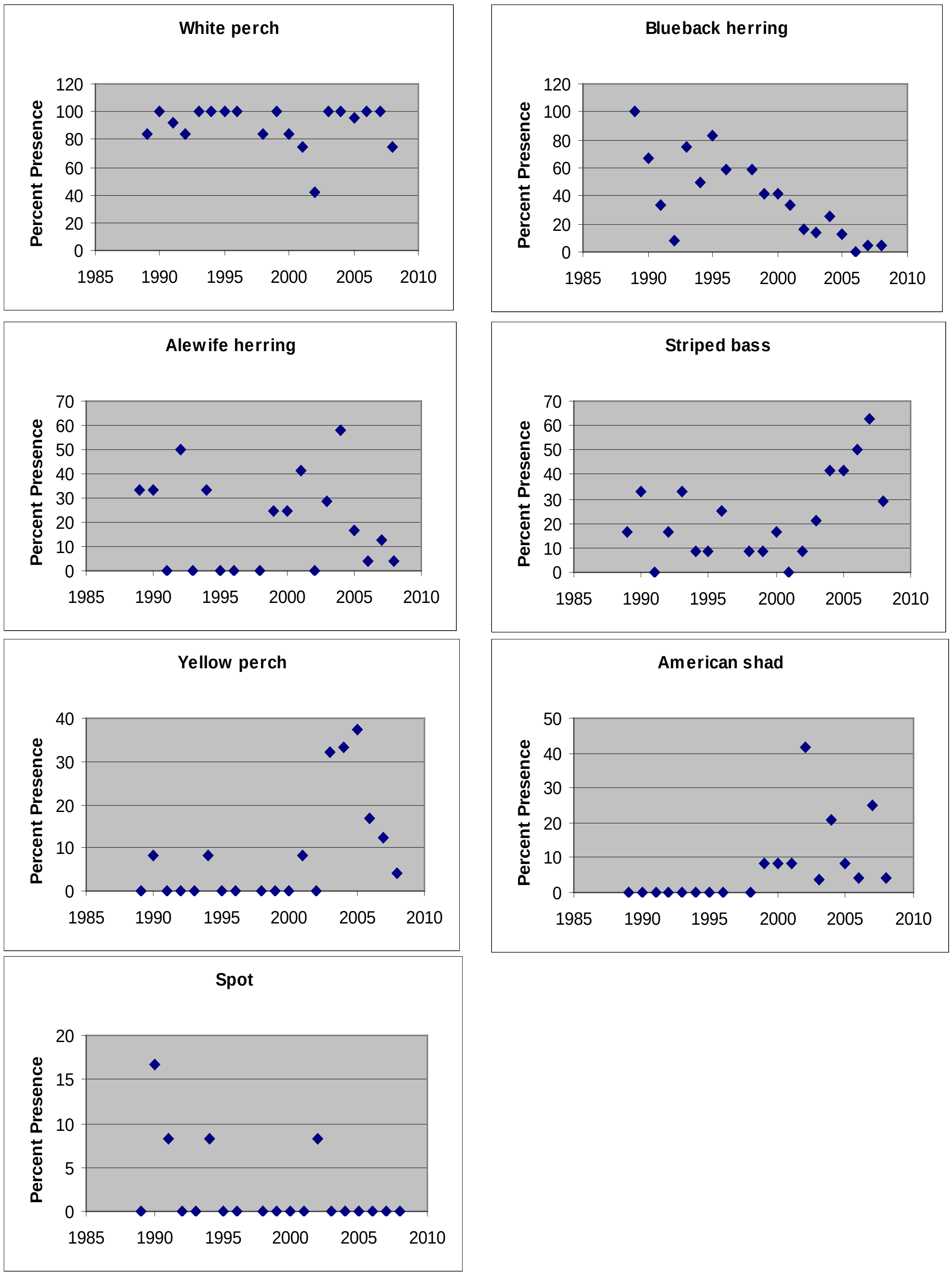


Figure 47. Percent presence of target species frequently captured in the trawl in Mattawoman Creek, from 1989 to present.



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