Interim Assessment of Yellow Perch *Perca flavescens* Habitat and Population Dynamics in Severn River, a Suburbanized Chesapeake Bay Sub-estuary

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Abstract

The Severn River, located on the Chesapeake Bay's western shore within the rapidly developing Baltimore-Washington D.C. corridor, has been closed to yellow perch harvest since 1989 in response to largely unknown, but assumed detrimental habitat conditions. During 2001-2003, we assessed yellow perch habitat in the heavily developed Severn River watershed (17% impervious surface or IS) by combining stock assessment (larvae-adults), experimental stocking (larvae-juveniles), and water quality monitoring (temperature, salinity, dissolved oxygen). We contrasted yellow perch population and water quality characteristics in Severn River with developed reference systems (10-20% IS), relatively undeveloped reference systems (≈ 2% IS), and historic Severn River data from periods of lesser development. Hatching success of Severn River eggs was extremely low and larval relative abundance was very low during 2001-2003. Wild juveniles were not caught in summer during 2001, were present at very low levels in 2002, and were better represented during 2003. Hatchery juveniles were common after stocking during 2002-2003. Adult yellow perch did not exhibit excessive non-harvest related mortality or decreased growth. At this time, depressed egg and larval viability appear to be critical factors suppressing the resident population. Two significant habitat quality issues potentially impacting yellow perch population dynamics were described in our study of Severn River – possible salinity intrusion into the upper tidal spawning area and larval nurseries due to landscape changes, and poor summer dissolved oxygen (DO) throughout juvenile and adult habitat. Frequent violations of salinity requirements were observed for larvae (93% of measurements) and dissolved oxygen violations were common for juveniles and adults in summer (≈5% at the surface, 20-40% at mid-depth, 70-80% at the bottom). Based on our study, dissolved oxygen conditions unsuitable for yellow perch survival were common in urbanized watersheds and uncommon in less urbanized systems. Other issues, such as contaminants, exist that were not covered in the habitat variables we evaluated. If poor egg and larval viability observed in the Severn River is now normal, then the river's population may be entirely dependent upon immigration of good Head-of-Bay year-classes.

Introduction

Commercial harvest of yellow perch *Perca flavescens* throughout the Chesapeake Bay began to decline during the mid-1960s and reached its nadir during 1976-1982 (Yellow Perch Workgroup 2002). Declines in yellow perch sport fishing participation in the Severn, South, and Magothy rivers, as well as many rural rivers, became evident in the early1980s (O'Dell 1987). This decline of yellow perch was similar to that exhibited by other anadromous fishes in Maryland. Complete moratoria were imposed on striped bass, American shad, and hickory shad in the 1980s (Jensen 1993) and, in 1989, nine watersheds were closed to commercial fishing for yellow perch and six of these were also closed to recreational fishing, although catch-and-release angling was permitted (Yellow Perch Workgroup 2002). The Severn River, located on the Bay's western shore (Figure 1), was included in the yellow perch recreational harvest closure (Yellow Perch Workgroup 2002).

One operational hypothesis for the decline of yellow perch in Severn River was that development in the watershed caused water quality to deteriorate and this deterioration decreased recruitment success (O'Dell 1987; Land Ethics et al. 1995). Severn River's watershed is located in the rapidly developing Washington D.C.- Baltimore, Maryland metropolitan corridor and passes through Annapolis, Maryland. Many of the homes built during the early 1900s were summer cottages, but by the 1950's, many homes were built for year-round residence (MDDNR 1983). The Anne Arundel County Department of

Planning and Code Enforcement estimated that county's population increased by approximately 100,000 people per decade between 1950 (starting at ≈100,000) and 2000. Housing development within the Severn River watershed rapidly increased with the population (Maryland Department of Planning or MDP 1997).

Urbanization and industrial development contribute significantly to contaminant loads, eutrophication, and physical degradation of coastal areas (Pearce 1991). In 1994, land in urban development was the largest single land use in the Severn River watershed and 17% of the watershed was in impervious cover (MDDNR 2002). Research in freshwater streams has revealed a strong relationship between impervious cover and degradation of stream quality (Capiella and Brown 2001). As little as 10% watershed impervious cover can result in degraded stream conditions such as altered hydrology, elevated temperatures, eutrophication, and increased contaminants (Capiella and Brown 2001). Limburg and Schmidt (1990) noted a negative relationship and a significant threshold for declining anadromous fish spawning success in Hudson River, New York, watersheds in response to urbanization. Habitat degradation in the best recruitment areas of the Baltic Sea due to human activities (agriculture, forestry, industry, and settlement) has been implicated in the decline of estuarine populations of European perch *Perca fluviatilis* (Ljunggren et al. 2003).

The Severn River Commission (1995) identified increases in sedimentation, eutrophication, organic and inorganic contaminants, and water temperatures and depressed dissolved oxygen levels as urban-related threats to living resources in the watershed. During 1989-1991, mean summer dissolved oxygen levels in the Severn River were among the lowest estimated for five urbanized watersheds and three rural watersheds (Carmichael et al. 1992).

Anecdotal reports from anglers suggested an increase in yellow perch in Severn River since 1997. In 2001, the Maryland Department of Natural Resources (MDDNR) began a five-year assessment of yellow perch in the Severn. With foreknowledge of extensive urban development in the Severn River watershed, we explored the link between land development, water quality, and stock status of yellow perch. We collected information on every life stage of yellow perch (eggs, larvae, young-of-year, or adults) through a combination of field sampling, hatchery culture, and stocking. Life history information was coupled with water quality data to gain insight on factors threatening sustainability of yellow perch in the Severn River and to determine whether habitat deterioration precludes reopening a recreational fishery. We compared indicators of stock status to historic data and geographic reference populations (unfished or lightly fished stocks and rural or suburbanized watersheds). This ecosystem-based assessment is an action item in the *Maryland Tidewater Yellow Perch Fishery Management Plan* (Yellow Perch Workgroup 2002).

Fish populations react to stressors in varied, but often, predictable ways (Colby 1984). We developed four hypotheses to explain the perceived suppression of yellow perch survival in Severn River, one that supported overfishing and three that were habitat related. The three habitat related hypotheses focused on conditions that could be attributed to observations of decreased survival of specific yellow perch life stages. Absence of suppressed survival at any life stage would indicate that yellow perch population dynamics in Severn River were not compromised by exploitation or habitat conditions.

To accept exploitation as a cause of a suppressed population of yellow perch in the Severn River, adult annual instantaneous total mortality rate estimates (Z) should be well in excess of annual instantaneous natural mortality (M), and size or age distributions should not be dominated by larger, older fish (Colby 1984; Barry and Tegner 1989). Adverse habitat conditions should be absent or occur sporadically.

The first habitat related hypothesis described a temperature-dissolved oxygen (DO)-salinity squeeze, similar to the temperature-DO hypotheses developed by Coutant (1985) and Price et al. (1985) for striped bass *Morone saxatilis* in reservoirs and Chesapeake Bay, respectively. With this hypothesis, adult yellow perch during summer must constantly compromise their habitat requirements to survive in a degraded environment.

That is, bottom dissolved oxygen similar to levels reported by Carmichael et al. (1992) may be too low, forcing yellow perch to seek warmer surface waters or more saline waters with lower temperatures and stressful salinity. This constant shifting into different stressful environments could manifest itself as decreased adult survival (adult fish kills). Low dissolved oxygen and stressful water temperatures caused large die-offs of yellow perch in Head-of-Bay and western shore tributaries during 1999 (C. Poukish, Maryland Department of Environment, personal communication; Yellow Perch Workgroup 2002). Hypoxia may act as an endocrine disruptor that poses a significant threat to the reproductive success of fish and extensive low DO could lower egg, larval, and juvenile survival (Rudolf et al. 2003). Therefore, evidence of unbalanced habitat requirements (extensive areas and periods of unsuitable DO conditions), coupled with decreased survival of adults, eggs, and/or larvae would support this hypothesis. A second variant of this habitat squeeze could result from an imbalance in these three factors for eggs and larvae during the critical spawning and nursery period (March-April).

Contaminants (second habitat hypothesis) can reduce reproductive success through inhibition of oocyte development, inhibition of spawning, reduced egg weight, and low viability of offspring (Varanasi 1992). During egg development (oogenesis), diverse lipophilic contaminants are transferred from maternal tissues of fish to their eggs (Longwell et al. 1996). Contaminant-laden yolk material of the egg is then used during development of the embryo and larva. These maternal contaminants may contribute significantly to the occurrence and increased mortality of abnormal embryos and larvae (Longwell et al. 1996; Westin et al. 1985). Maternal effects may be biomagnified by contaminants in the water column in some environments (Longwell et al. 1992). Larvae are more sensitive to contaminants within the water column (usually metals) than eggs (Peterson et al. 1982), while toxicity of inorganic contaminants to striped bass larvae and juveniles decreased with age (Buckler et al. 1987). In the absence of the two habitat squeezes described above, depressed egg and larval survival would support, but not prove, the contaminant hypothesis.

Sedimentation (habitat hypothesis 3) would be most likely to smother eggs (Piavis 1991). Successful hatching of eggs from Severn River in a "clean" environment (hatchery), observations of smothered eggs *in situ*, and an absence of larvae and juveniles would support this hypothesis as the main factor in Severn River yellow perch year-class success.

Study Site

The Severn River watershed encompasses 175.7 km^2 (43,415.5 acres) on Maryland's western shore of the Chesapeake Bay (Figure 1) entirely within Anne Arundel County (Land Ethics et al. 1995). The river has approximately 19 linear km (12 miles) of navigable water and receives the majority of its freshwater input from Severn Run, although the river has at least 40 smaller tributaries and coves flanking it. Water varies from fresh to mesohaline (Muncy 1962). Although this watershed is within the coastal plain, it is on the eastern edge of the Piedmont Province, and topography is varied (M. Rabenhorst, University of Maryland, personal communication). In 1994, 47% of the watershed was classified as urban and agriculture comprised only 10-11% of the watershed land use (MDP 1997; MDDNR 2002).

Salinities in Severn River are low because of its proximity to Susquehanna River and are greatly influenced by periods of dry weather (Dowagiallo 1989). Average monthly salinities at Annapolis during 1951-1980 were lowest during May (6.7‰, range 4.3-11.0‰) and highest during November (12.7‰, range 6.2-16.2‰; Dowagiallo 1989).

Management of fish, especially yellow perch, has been of interest in Severn River for at least 120 years. The Maryland General Assembly of 1888 adopted an 1884 Anne Arundel County law that limited commercial gear allowed during spring in the Severn River to haul seines only (Poe 1888). A yellow perch hatchery operated sporadically in the Severn River from 1901-1955 to supplement wild stocks (Muncy 1959). Property owners along the Severn River concerned about depleted sportfish stocks successfully lobbied the state legislature to prohibit commercial fishing gear in the river in 1929 (Denmead 1927). The Severn River supported a quality yellow perch recreational fishery for many decades afterwards. A survey of issues of *Fishing in Maryland* published during 1964-1969, 1980-1981, 1985-1994, and 1997 (other issues were not available) indicated that the total number of citation yellow perch (356 mm or 14 inch minimum length) from Severn River ranked third statewide even though citations were no longer issued after its fishery was closed in 1989 (D. Weinrich, MDDNR, personal communication). Most yellow perch harvest by anglers in the Severn River occurred during late summer and fall, with some harvest during the late winter spawning run (Mansueti 1960; Muncy 1962).

Two tagging studies (Mansueti 1960; Muncy 1962) conducted during the 1950s described the distribution of adult yellow perch in the Severn River. Adult yellow perch ascended the upper tidal Severn River, a few downstream tributaries, and lower fluvial Severn Run (above river kilometer or Rkm 17.5; a location is identified by Rkm which is measured upstream from a line drawn between Greenbury Point and Chinks Point, Rkm 0.0, at the Severn River's mouth) to spawn in late winter. In mid-April, following spawning, they began to disperse downstream. During summer, there was widespread movement toward the mouth where salinities ranged from 6-10$^{o}/_{oo}$. Yellow perch moved in fall to the mid-river area where salinities ranged from 4-8$^{o}/_{oo}$. These movements suggested the Severn River contained a resident population that rarely left the river (Mansueti 1960; Muncy 1962).

Larvae were consistently present in ichthyoplankton collections within and slightly downstream of the spawning area and in several downstream tributaries (O'Dell 1987).

Juvenile yellow perch could be found throughout the Severn River (O'Dell 1987), but were usually found between Rkm 10 and 18 in salinities of $9.5^{o}/_{oo}$ or less (Muncy 1962). Greatest numbers were collected between Rkm 16 and 17 in 5-7 $^{o}/_{oo}$ (Muncy 1962). Muncy (1962) described yellow perch juveniles as scarce in 1955, absent in 1956, and abundant during 1957-1959. When Muncy (1962) described juveniles as having been abundant, several hundred could be collected from Severn River by seining during June-August. Effort was generally not reported by Muncy (1962), but during 1959, catches averaged nearly 4 juveniles per haul in 40 seine hauls. Juveniles can be difficult to collect by seining during summer (J. Uphoff, MDDNR, personal observation), so these catches indicated substantial abundances of young-of-year. In 1978, the average juvenile catch per seine haul was 1.2 (O'Dell 1987). Juveniles were either absent in seine surveys or catches were in the single digits during 1986-1992 (O'Dell 1987; International Science and Technology, Inc. 1988; Greening et al. 1989; Carmichael et al. 1992; Piavis et al. 1993).

Data for Severn River yellow perch were limited, but suggested this population began to decline in the 1960s (Land Ethics et *al*. 1995). During the spring of 1958, Muncy (1962) collected over 5,487 adult yellow perch in Severn Run using a trap-net stretched bank-to-bank. In 1986, O'Dell (1987) set a fyke net approximately 274 m upstream of Muncy's (1962) sample site and caught 57 yellow perch. O'Dell (1987) observed a decrease in abundance of smaller, presumably younger, yellow perch in the spawning runs between 1978-1986 and attributed this decline to reduced numbers of spawners. Fyke nets set in this area during 1987 and 1988 caught 164 and 230 adults, respectively (International Science and Technology, Inc. 1988; Greening et al. 1989); most yellow perch in these studies were large (greater than 229 mm or 9 inches). Length-at-age estimates indicated that growth in Severn River was much more rapid than Mattawoman Creek (a Potomac River tidal tributary considered a relatively unstressed system; Greening et al. 1989 Carmichael et al. 1992).

Two other adult yellow perch populations were contrasted with the Severn River in this analysis. The Choptank and Nanticoke rivers on Maryland's Eastern Shore of the

Chesapeake Bay (Figure 1) represented systems with limited development and light (recreational only) or no fishing pressure (closed to all harvest), respectively (Piavis and Uphoff 1999). The Nanticoke and Choptank rivers are located on the outer coastal plain where changes in elevation are minimal. Agriculture was a dominant land use, covering 38% of the Nanticoke River watershed and 60% of the Choptank River watershed within Maryland in 1994; urban areas represented 8% and 3% of the watersheds, respectively (Table 1; MDP 1997).

Water quality data gathered since 1989 from the South, Magothy, and Wicomico (Potomac River tributary; all references in this report to Wicomico River refer to this tributary) rivers by Carmichael et al. (1992) were summarized and compared with Severn River (Figure 1). These systems represented small watersheds that exhibited similar salinity gradients and topography as the Severn River, but with varying degrees of development (2-20% impervious surface; Table 1).

Additional juvenile data were collected from South River during 2002-2003 to monitor stocked fish. Juvenile monitoring was initiated in Magothy and Wicomico rivers during 2003 as part of a new federal aid project to develop linkages between impervious surface, habitat quality, and fish production (Rickabaugh et al. 2004). These data were contrasted with Severn River.

Methods

Hatchery Procedures and Analysis

Yellow perch larvae and juveniles were produced in 2002 and 2003 from tank spawning of brood fish and culture of egg chains collected from the wild. Egg chains were manually collected in buckets at the headwaters of the Wye (40 chains) and Wicomico (Potomac River tributary; 65 chains) rivers. Yellow perch brood stock for tank spawning were collected from fyke nets used to monitor anadromous fishes in the Patuxent, Severn, Choptank and Nanticoke rivers (Piavis et al. 2004).

Injections of synthetic analogs (LHRHa) of gonadotropin-releasing hormone (GnRHa) were used to stimulate pituitary release of endogenous gonadotropin, which induced gonadal maturation, ovulation, and spawning (Mylonas et. al. 1995). A compassionate exemption from an Investigational New Animal Drug Permit (INAD #8061-03-3) obtained from the U.S. Food and Drug Administration in conjunction with the U.S. Fish & Wildlife Service (USFWS) allowed the experimental use of this drug. Doses of 25 to 50 µg/kg body weight were suitable. LHRHa pellets were manufactured in the laboratory at Manning Hatchery using techniques developed by Lee et al. (1986). Powdered LHRHa (1.0 mg) was mixed

with alcohol (0.5 ml), cholesterol (380 mg), and cocoa butter (20 mg). The mixture was dried at 37ºC for one hour. A form was constructed by drilling 4 mm holes into 6 mm thick Plexiglas. The paste was hammered into the Plexiglas form. After compaction, pellets were popped out of the mold and stored in cell trays. Cell trays were labeled and frozen in plastic bags with Dri-Rite ® desiccant. Implants were stored in the hatchery freezer and transported to the field in coolers with ice packs.

Brood fish were placed in circular flow 3,785 L tanks at $5^{o}/_{oo}$ salinity and transported to Manning Hatchery (Brandywine, Maryland). Dissolved oxygen was continuously monitored and regulated (>7 mg/L), and salinity was maintained at $2\text{-}3^{o}/_{oo}$. Males and females received an intramuscular implant of LHRHa in the dorsal musculature. Implants were administered through a spring-loaded 11-gauge syringe. Adults were netted into 3.05 m diameter natural spawn tank systems. A sex ratio of 3:2 male:female was generally maintained. One-fourth of the water was changed each day to maintain water quality. Eggs were collected from spawning tanks each day after fish spawned naturally.

Eggs were placed in modified McDonald hatching jars supplied with approximately 2 L/min water flow. Eggs were exposed to a 600:1 prophylactic formalin treatment for approximately 20 minutes in the morning and afternoon to control fungus. Once eggs began hatching, jars were placed on 1.5 m circular flow-through larval tanks and water was flowed at approximately 2 L/min. Larvae flowed into tanks after hatch.

Prior to stocking, larvae were counted volumetrically. A columnar sample of water was collected with a 25 mm diameter PVC tube at random locations in the larval tank. Larvae were counted in this sample and the total number of larvae in the tank was estimated by extrapolation to the total tank volume.

All stocked fish during 2002-2003 had their otoliths marked by oxytetracycline (OTC; INAD #9197) immersion as larvae to identify a recaptured fish as hatchery origin. Yellow perch that were stocked into study tributaries as larvae received a double mark and early juveniles received a single mark. Yellow perch stocked as late juveniles received a single larval OTC immersion mark and a single juvenile immersion mark at approximately 75 days. Larval marks were produced by immersion in a 500 mg/L buffered OTC bath for 6-12 hours. Dissolved oxygen was monitored and regulated (>5 mg/L) by a carbon air stone connected to a liquid oxygen system.

All water used at Manning Hatchery for OTC marking was softened (Culligan® ion exchange system). Effective marking can only take place in water with hardness below 20 mg/L and hardness at Manning Hatchery routinely exceeds 200 mg/L. Marks were verified by viewing with a fluorescent microscope.

Marked larvae ready for stocking were placed into boxes originally designed for shipping tropical fish. These containers consisted of an outer shell cardboard box, an inner foam box, and a double thickness plastic bag. Holding tanks were drawn down to crowd larvae. These larvae were scooped out and placed into shipping bags with a salinity of approximately $1^{o}/_{oo}$ to ease stress. Each bag was filled with oxygen and sealed with electrician's tape. Boxes were driven to the stocking river and the bags were placed in the water long enough to acclimate temperature. The bags were then opened and river water was slowly introduced to acclimate larvae to river water quality. Bags were then emptied into flowing water, if possible, to minimize predation.

Fish intended for early juvenile stocking were given larval immersion marks and stocked into hatchery ponds at 3-6 days of age. Mirant Mid-Atlantic (formerly Potomac Electric Power Company or PEPCO) provided grow-out facilities and manpower. Larvae were cultured in Mirant hatchery ponds at Chalk Point, Maryland, and at Cedarville State Fish Hatchery (Brandywine, Maryland) ponds. Fish were removed from ponds after 30-45 days. At this time, fish were either stocked as early juveniles or brought into the hatchery for intensive culture to late juvenile size (~75 days). Juveniles were transported in 3-5 $^{o}/_{oo}$ salinity with DO at saturation to ease stress. Early or late juveniles were transported in various sized fish hauling tanks and directly released through a 15cm hose from the transport trailer into the river.

Larval and juvenile yellow perch were collected (see *Stock Assessment*, below) and later examined for OTC marks on their otoliths to determine the extent of hatchery contribution

in Severn and South Rivers. Specimens were placed on ice immediately after collection and frozen upon return to the lab. Samples were later thawed and measured (TL, mm). Sagittal otoliths were removed and mounted on slides with Crystalbond® 509 (Aremco Products, Ossining, NY). Larval otoliths were read directly, while juvenile otoliths were lightly ground on 600 grit silicon carbide wet sandpaper before being viewed under 400x magnification under epifluorescent light at 50 watts with a Zeiss Axioskop 20 microscope. The presence and location of fluorescent marks was recorded.

Stock Assessment

Conical plankton nets were used to collect larvae. Nets were 0.5-m in diameter, 1-m long, and had 0.5 mm mesh. Five minute stationary plankton samples were taken in fluvial waters of Severn Run during 2001-2002. Plankton nets were towed for 5 min at about 2.8 km per hour adjacent to our fyke nets (see below) for up to 2-3 days each week in the upper estuary during April of 2001-2003 (Figure 2).

Young-of-year (juvenile) yellow perch distribution in Severn River was monitored during 2001-2003 (Figure 2). Juveniles were sampled weekly in May to mid-June with 3.2-mm delta mesh 7.6-15.2 m (25-50ft) x 1.2 m (4ft) fry seines. From late June through October, seine sampling was bi-weekly using a 6.4-mm square mesh 30.5 m (100 ft) x 1.2 m (4 ft) seine; additional collections were made in Magothy, South, and Wicomico rivers during 2003 (Rickabaugh et al. 2004). Subsamples of juveniles were retained during 2002 and 2003 to determine the fraction of juveniles of wild and hatchery origin (described previously).

Juvenile yellow perch were collected weekly during May-July, 2002, with a 7.6-15.2 m long and 1.2 m wide 3.2-mm delta mesh fry seine in the South River. A minimum of ten sites, located in the upper-third of South River, were sampled. Several sampling trips encompassed the entire river but yellow perch were never observed downstream of the upper region. These collections were used to construct population and survival estimates (see below).

Larval and juvenile yellow perch relative abundance in Severn River was assessed as presence–absence (Mangel and Smith 1990) rather than using counts of larvae or juveniles in samples because high numbers of zero catches were expected and encountered. 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. The proportion of tows with yellow perch juveniles was determined separately for fry seine (F_p; mid-May through mid-June) and 30.5 m net collections (J_p; July-October). Wild and hatchery larvae or juvenile estimates were made separately when possible. Confidence intervals (95%) were constructed using the normal distribution to approximate the binomial distribution (Uphoff 1997).

Yellow perch larval presence-absence in the tidal Severn River was compared to a record of L_p developed from historic data collected in the tidal Nanticoke (1965-1971) and Choptank rivers (1986-1990 and 1998-2003). Collections in the Choptank and Nanticoke rivers targeted striped bass eggs and larvae, but yellow perch were also common (Uphoff 1991; 1997). 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 in the same manner used for striped bass eggs (Uphoff 1997). 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. Survey designs are described in Uphoff (1997).

Estimates of juvenile abundance, mortality and survival during 2002 were derived from ratios of marked and unmarked juveniles. Larval survival to juvenile stocking was calculated as

$$S_1 = (R_{12})\, M_2 \,/\, (M_1)\, R_{22};$$

where M_1 is the number of fish marked at the start of the first interval; M_2 is the number of fish marked at the start of the second interval; R_{12} is recaptures of first interval marked fish in the second interval; R_{22} is recaptures of second interval marked fish in the second interval; and S_1 is the survival rate during interval one (from the time of marking in interval one to time of marking in interval two; Ricker 1975). The variance was estimated as

$$S_1 = S_1^2 \{(1/R_{12}) + (1/R_{22}) - (1/M_1) - (1/M_2)\}$$ (Ricker 1975).

Instantaneous mortality (Z) for an interval (in days) was derived from survival estimates: $-ln\ S_1$.

Abundance of juvenile yellow perch at the time early juveniles were stocked was calculated by Chapman's modification to the Peterson estimate (Ricker 1975):

$$N = \{(C+1)\ (M+1)\} / (R + 1)$$

where N is the population estimate, M is the number of marked fish stocked, C is the number of fish examined for tags (total recaptures) and R is the number of marked fish that were recaptured.

Calculation of 95% confidences limits of abundance (N^*) were based on the Poisson distribution approximation (Ricker 1975)

$$N^* = \{(C+1)\ (M+1)\} / (R_1 + 1);$$ where

$$R_1 = (R + 1.92) \pm (1.96 \bullet (R + 1)^{0.5}).$$

Adult yellow perch were sampled during their late winter 2001-2003 spawning runs with four fyke nets located at Rkms 17.5 (opposite Ben Oaks), 16.0 (Arden on Severn), 13.8 (Plum Creek , south side of river), and 13.7 (mouth of Forked Creek, north side of river; Figure 2). Fyke nets were constructed with 64 mm stretch-mesh bodies, 15.2-30.5 m hedging (depending on water depth), and 7.6 m wings with 76 mm stretch-mesh. These fyke nets were fished 3 days per week, from the third week of February through the second week of April. In 2003, fyke nets were not set until the second week of March due to ice in the river.

A representative subsample of yellow perch from each fyke net catch was sexed by gonad expression and measured (TL) to the nearest mm (Piavis et al. 2004). All remaining perch were counted. A non-random subsample was sacrificed for otolith removal and age determination. Sacrificed fish were also measured. All otoliths were immersed in glycerin and read whole. The outer edge of an otolith was counted as an age mark because fish were collected just prior to annulus formation (Piavis et al. 2004).

Severn River length-frequency distributions were compiled from fyke net collections made during 2001-2003. These distributions were compared to historic (1958, 1987, and1988) and geographic (Choptank and Nanticoke rivers during 2001-2003) reference length-frequencies using relative stock densities (RSDs; Gablehouse 1984). Relative stock densities assign fish into five length categories; stock (140-215 mm), quality (216-254 mm), preferred (255-317 mm), memorable (318-404 mm), and trophy (> 405 mm; Gablehouse 1984; Piavis et al. 2004). These length categories were standardized percentages of the all-tackle world record yellow perch (Gablehouse 1984; Piavis et al. 2004). Incremental RSD was calculated as number of fish in a length class divided by number of fish greater than or equal to minimum stock length and expressed as a percentage by multiplying by 100 (Gablehouse 1984).

A population's length-frequency distribution results from its recent history of recruitment, mortality, and growth (Barry and Tegner 1990). Historic Severn River length-frequencies graphs were converted to RSD distributions; 1958 RSDs were recreated from Figures 3 and 4 in Muncy (1962), while 1987 and 1988 RSDs were recreated from Figures 3.3 in International Science and Technology, Inc. (1988) and Greening et al. (1989), respectively. The 1958 RSDs were based on catches made with a 1.2 m trap net, comprised of 25-mm bar mesh, with one 46 m wing and one 15 m wing that was set to block Severn Run entirely near Rkm 19. The 1987-1988 RSDs were calculated from a single 25 mm stretch-mesh Maine fyke net with square Dakota mouth openings fitted with 50 mm mesh wings set to block the width of Severn Run near the location used by Muncy (1962; International Science and Technology, Inc. 1988; Greening et al. 1989). Identical fyke nets were used in the Severn and Choptank rivers during 2001-2003, so direct comparisons of RSDs were made between these rivers. Fyke net samples taken from Nanticoke River were not directly comparable to Severn or Choptank rivers because they were obtained from commercial fishers who used larger mesh (100 mm stretch-mesh hedging and 81 mm stretch-mesh hoop nets; J. Mowrer, MDDNR, personal communication). We truncated the Severn River RSD distributions by basing them on quality length and greater fish when making comparisons with Nanticoke River.

Inferences about differences in growth among the Severn, Nanticoke, and Choptank rivers were based on non-parametric comparisons of ranks of mean length-at-age because of greatly uneven sample sizes and inconsistent presence among years and systems. Estimates of mean length-at-age represented by fewer than four fish were not included in the comparison. Ages younger than 4-years were excluded from analysis to minimize bias that could have been introduced by including only fast growing young fish from the Nanticoke River that would have been caught by the larger webbing. During any given year (2001-2003) when sufficient samples of yellow perch existed for all three rivers, mean lengths-at-age were ranked. These ranks were compiled into a frequency table to compare how often each system ranked first, second, or third for each age present.

Instantaneous total mortality rates (Z) for each survey year in the Severn and Choptank rivers were estimated from the ratios of ln-transformed catch per unit effort (CPUE) of pooled age classes between years, that is,

$$Z = \ln U_{t+1\ a5+} / \ln U_{t\ a4+},$$

where $U_{t+1\ a5+}$ is the catch per effort of ages 5 and older (a5+) in the next year t+1 and U_{ta4+} is the catch per fyke net of ages 4 and older (a4+) yellow perch in year t. These estimates were made for 2001-2002 and 2002-2003; they were based on the span of time containing

95% of catches. Exceptions to this procedure were made for the Choptank River because of an exceptionally large CPUE in 2001 and Nanticoke River because of larger mesh used by commercial fishers there. The estimate of Z in the Choptank River for 2002 was based on $[(\ln U_{t+2\ a6+}) / \ln U_{t\ a4+}] / 2$; where the numerator represents CPUE in 2000 and the denominator represents 2002 CPUE. Estimates of Z in the Nanticoke River were based on $Z = \ln U_{t+1\ a6+} / \ln U_{t\ a5+}$ (notations are as above). An estimate of Z was not made for the Nanticoke River in 2003 because ice precluded reliable sampling of yellow perch there.

Water Quality Sampling and Analysis

Water temperature (ºC), salinity (‰), and dissolved oxygen (DO, mg/L), were measured using Yellow Springs Incorporated Model 85 meters at surface, mid-depth, and bottom during winter-summer. At shallow sites (< 2 m), mid-depth samples were sometimes omitted.

During 2001, water quality measurements were concurrent with fish collections in upper Severn River (Figure 3). During 2002, temperature, dissolved oxygen, and salinity were gathered throughout Severn River (Figure 4) to determine the extent of suitable habitat for yellow perch in summer when conditions were expected to have been at their worst. During 2003, temperature, dissolved oxygen, and salinity monitoring was conducted concurrently with fish collections at four stations within the upper one-half of Severn River (Figure 5; Rickabaugh et al. 2004).

To describe diurnal fluctuations, two continuous monitoring Hydrolabs™ were deployed at (approximately) Rkms 14 and 17 in September of 2001(Figure 3) and at Rkms 18 and 10 during early May through December, 2002 (Figure 4). These instruments continuously recorded surface (0.5 m in 2001 and 1.0 m in 2002) temperature, dissolved oxygen, and salinity for a 48-hour period.

Dissolved oxygen, salinity, and temperature data collected from surface and bottom during 2001-2003 were compared to requirements of larvae, juveniles and adult yellow perch (Table 2; Piavis 1991) to determine the extent and duration of suitable habitat for yellow perch in the Severn River. These comparisons were limited to the expected duration of a life stage and location of its habitat. A negative impact was inferred from any measurement not meeting the habitat requirements and the suitability of each parameter was indicated by the percentage of measurements not meeting the requirement. During 2003, collections from South, Magothy, and Wicomico rivers were analyzed in the same manner. Due to time constraints, 2001 water quality data collected during July-October in Severn River were not summarized by depth category (surface, mid-depth, bottom.

Larval yellow perch habitat in the estuarine portion of Severn River was determined from the distribution of larval presence in O'Dell (1987) and the span of stations where larvae were present during 2001-2003. Juvenile yellow perch habitat was bounded between Rkm 10 and 18 (Muncy 1962).

Adult habitat suitability during 2002 was judged from water quality data, habitat requirements, and an expected adult spatial distribution. Location of tags returned by anglers during 1958-1961, described by Figure 5 in Muncy (1962), were used to estimate expected spatial distribution. Returns (N = 121) were grouped into 2-Rkm segments and the percentage of recaptures within a segment was considered an indicator of use. The distribution of angling pressure and catch was unknown, but it was likely that tag returns were related more to season than fishing intensity (Muncy 1962). Fishing pressure was greatest during summer and tag returns were greater during June, October, and November (Mansueti 1960; Muncy 1962).

During July-September, 2003, biweekly surface, mid-depth, and bottom salinity, water temperature, and DO measurements were made concurrently with mid-channel trawl samples in Severn, South, Magothy, and Wicomico rivers. This monitoring was conducted as part of a new Fisheries Service federal aid project designed to develop impervious surface fisheries management reference points (Rickabaugh et al. 2004). Four to five stations were located longitudinally within the upper two-thirds of each of these rivers. The areas sampled were selected to minimize influence of mainstem Bay water on tributary water quality (Rickabaugh et al. 2004). Station locations within Severn River

approximated the bounds of the juvenile yellow perch nursery and were assumed to represent juvenile habitat in the other rivers.

Long-term monitoring data collected by MDDNR were compiled and examined to determine historic trends in the extent and duration of suitable habitat for yellow perch in the Severn River. Temperature, dissolved oxygen, and salinity were recorded at five stations along the longitudinal axis of the Severn River monthly during July-September, 1989–1993, 1995, and 2002 (Figure 5; Carmichael et al. 1992; M. McGinty, MDDNR, personal communication). Data were recorded at surface, middle, and bottom depths, using a Hydrolab™ Surveyor III. Box and whisker plots of bottom DO for each of the five Severn River sites were contrasted with data from Magothy, South, and Wicomico rivers to explore differences among the different levels of development. Wicomico River was considered by Carmichael et al. (1992) to be a reference system for the developed Severn, Magothy, and South River watersheds. Bottom DO was chosen because its sensitivity to urbanization (Limburg and Schmidt 1990) and sensitivity of species richness in bottom trawls to DO (Carmichael et al. 1992).

Results

Broodstock were collected from the Severn, Choptank, Patuxent and Nanticoke rivers during 2002-2003 (Table 3). Severn River broodstock (N = 320 during 2002-2003) were induced to spawn each year but viable eggs were not produced in sufficient quantity for hatchery production. The majority of the Severn River broodstock expelled chains, but eggs exhibited signs of atresia (regression during development). Nearly 100% of fish from tributaries other than Severn River that were induced to spawn produced egg chains with viable, fertilized embryos; therefore, out-of-basin adults were the source of larvae and juveniles that were stocked into Severn River.

Yellow perch stocked as larvae (≈250,000-420,000) were released in Severn Run (≈Rkm 20) during 2002 and in tidal Severn River (≈Rkm 18.2) during 2003. Early juveniles (≈110,000-203,000) were released both years in the tidal Severn River near Rkm 18.2 (Table 4). Similar numbers were released in South River. Late juveniles (≈15,000-20,000 at ≈75 days old) were stocked in both rivers in 2003 (Table 4). Samples analyzed from each group of larval or juvenile marked fish indicated that all fish stocked were successfully marked.

Relative abundance of larval yellow perch in the tidal Severn River was low compared to historic estimates of L_p in the Choptank and Nanticoke Rivers (Figure 6). Estimates of L_p in the tidal Severn River (L_p = 0.16, SD = 0.05) were based on pooled 2001-2003 data; data were pooled to compensate for low annual sample sizes (N = 20 in 2001; 32 in 2002, and 9 in 2003). Mean L_p in the tidal Severn River was lower than 15 estimates made between 1965 and 2003 in the tidal Nanticoke and Choptank rivers. Wild larvae were present in 2 tows in 2001. Larvae of unknown origin were present in 4 tows during 2002. Wild larvae were present in 4 of 9 tows during 2003 while hatchery larvae were present in 6 of 9. Based on 95% confidence interval overlap, L_p in Choptank River during 2000 and 2001, and Nanticoke River during 1967 and 1971 were not significantly different than Severn River. In the Choptank and Nanticoke rivers, L_p ranged between 0.2 and 1.0; values of L_p in these two systems were above 0.6 nearly as frequently as below (7 instances above versus 8 below; Figure 6).

Estimates of L_p in Severn River were based on collections during April 6-19, 2001; April 1-24, 2002; and April 7-14, 2003. Starting dates for estimating L_p in Choptank and Nanticoke rivers ranged between March 30 and April 16, but starting dates during the first or early in the second week of April were typical. End dates in these two rivers fell between April 16 and May 9, but usually occurred during the last week of April through the first week of May.

Larvae were only collected in fluvial or near fluvial tidal waters in Severn River during 2001 (Rkm 18.5-20.8) and 2002 (Rkm 18.1-19.8); these were both dry years. The distribution of larval yellow perch shifted downstream in 2003 (a wet year) and they were caught in the estuarine portion of Severn River between Rkm 14.0 and 18.1; the former Rkm was considered the lower boundary of the larval nursery in subsequent water quality analysis. O'Dell (1987) reported a lower boundary at about Rkm 15.

In Severn River, estimated survival of stocked larval yellow perch was 0.0703 over 30 days during 2002. Daily mortality of larvae stocked into Severn River to the time of juvenile stocking was 8.8% (Z = 0.088, SE = 0.023). In South River, survival of stocked larvae to juvenile stocking was lower than Severn River - 0.0094 for the 28-day period. Daily mortality of larval yellow perch stocked in South River was 16.7% (Z = 0.167, SE = 0.011) over 28-days.

Relative abundance of yellow perch juveniles in Severn River fry seine collections made during mid-May through mid-June, 2001-2003, did not differ significantly among years based on 95% confidence interval overlap (Table 5). Estimates of F_p ranged between 0.38 and 0.46 (Table 5). Larvae and juvenile yellow perch were stocked in Severn River during 2002-2003, but not 2001.

There were marked differences in relative abundance of late juveniles (July-October collections) in Severn River during 2001-2003 (Table 6). Late juvenile yellow perch were absent in seine collections during 2001, but were present at statistically similar relative abundance during 2002-2003 (J_p = 0.21 and 0.38, respectively; Table 6). Confidence intervals (95%) of J_p overlapped between 2002 and 2003, but did not overlap 0 (J_p in 2001). During 2003, estimates of J_p in the South (0.61, SD = 0.09) and Magothy (0.57, SD = 0.09) were similar (95% CI's overlapped) to Severn River, but stocking did not occur in Magothy River. The proportion of hauls with juvenile yellow perch was low (0.07, SD = 0.05) in Wicomico River during 2003.

In May of each year, juvenile yellow perch in Severn River were distributed between Rkm 16 and 18.8. Juvenile yellow perch caught in July and August 2001-2003 seine hauls were distributed between Rkm 7.5 and 18.0.

Based on mark and recapture estimates, there were about twice as many yellow perch juveniles in Severn River than in South River during 2002; however, population estimates of wild juveniles were similar. The estimated population of juveniles in Severn River was 222,998 fish (95% CI = 197,488-251,806). Four percent of Severn River juveniles were of wild origin (9,880 juveniles, 95% CI = 8,749-11,156), 82% were stocked as juveniles (183,480, 95% CI = 162,491-207,182), and 14% were stocked as larvae (26,639, 95% CI = 26,248-33,468). An estimated 124,668 yellow perch juveniles (95% CI = 101,432-153,232) were present in South River during 2002. Approximately 8% (9,875 juveniles, 95% CI = 8,034-12,137) were of wild origin, 89% (111,090, 95% CI = 90,385-136,544) were stocked as juveniles, and 3% (3,703, 95% CI = 3,013-4,551) were stocked as larvae.

During 2003, stocked yellow perch comprised 70% of juveniles in collections made during July-October in Severn River (Table 6). All hatchery fish originated from juvenile stockings. A limited sample of juveniles (N=11) was inspected from Magothy River; six of these fish were of hatchery origin (four were stocked as larvae and two as juveniles) even though none were stocked there. The origin of the stocked juveniles (Severn or South River) in Magothy River was unknown. Data were not available from the South River.

Estimates of total annual instantaneous mortality rate (Z) of adult yellow perch in Severn River equaled 0.30 during 2001-2002 and 0.25 during 2002-2003. These estimates were close to the estimate of Z during 2001-2002 in the Nanticoke River, 0.26; this river was also closed to fishing. These estimates of Z are close to estimates of M (0.25) used in Chesapeake Bay yellow perch stock assessments (Piavis and Uphoff 1999). Estimates of Z in the exploited Choptank River equaled 0.53 and 0.60 during 2000-2002 and 2002-2003, respectively.

Severn River mean length-at-age fell between estimates made for Nanticoke River (overall highest) and Choptank River (overall lowest). Criteria for comparisons were met for ages 5 and 7 during 2001, 4-7 during 2002, and age 7 during 2003. Nanticoke River yellow perch ranked highest in mean length at age in 10 of 11 comparisons and second once. Severn River ranked first on one occasion, second on eight, and third twice. Choptank River

ranked lowest in mean length at age on nine occasions, second on two, and never ranked first.

Relative stock densities indicated that large yellow perch (255-318 mm or preferred-memorable category) have been well represented throughout the available years (Figure 7). The preferred-memorable category was predominant in 1958, 1987-1988, and 2002-2003; the smaller quality-preferred yellow perch (216-255 mm) were predominant during 2001. Stock-quality yellow perch proportions were higher during 1958 and 1987-1988 than during 2001-2003 (Figure 7).

Relative stock densities in Severn, Choptank and Nanticoke Rivers indicated differences in population dynamics among systems. Severn River RSDs during 2001-2003 were shifted towards larger fish, while Choptank River RSDs were shifted towards small fish and exhibited an exponential decline as RSD categories progressed (Figure 8). RSD distributions in Severn and Nanticoke Rivers were similar in magnitude, but exhibited opposite trends during 2001-2003 (Figure 9). Larger yellow perch increased proportionally over time in Severn River, while they decreased in the Nanticoke River (Figure 9).

Water Quality

Water quality station depths varied between 1 and 6 meters. Depth generally increased with downstream distance.

The estuarine larval nursery (between Rkm's 14 and 18) during 2001-2003 was characterized by frequent violations of the salinity criterion, occasional violations of the temperature criterion, and DO that was always above the minimum required (Table 7). Salinity violations occurred in 93% of measurements and excessive temperatures were found 7% of the time. Salinity violations were spread evenly among years. A sharp surface salinity gradient was present in the Severn River between Rkm 18 and 18.5. In the dry springs of 2001 and 2002, the difference was as much as 5.5$^{o}/_{oo}$ to 7.5$^{o}/_{oo.}$ In 2003, a wet spring, the surface salinity difference between Rkm 18 and 18.5 was 2$^{o}/_{oo.}$ Temperature violations did not occur during 2002 (Table 7).

Habitat violations were infrequent during fry seining (concurrent collections during May-June, 2002-2003; N = 72 and 234, respectively). Temperature violations were not noted during 2002, while about 6% of DO measurements were below suggested requirements. During 2003, temperature violations occurred about 3% of the time and DO violations were present in about 12% of measurements.

Dissolved oxygen was of greatest concern during July-September, 2001. The distance over which these measurements were made approximated the juvenile nursery. About 64% of measurements were made at the surface. Violations of habitat requirements occurred in 66% of DO measurements (N = 509), 14% (N = 509) of salinity measurements, and 2% of temperature measurements (N = 535). The quartiles of all measurements of DO were 2.9mg/L, 25th percentile; 4.1 mg /L, 50th percentile; and 5.7 mg/L, 75th percentile. Minimum and maximum DO was 0.02 and 15.9 mg/L, respectively.

Fifty to 87 water quality stations were visited per month during May-September, 2002, in Severn River (Table 8). Measurements were not made above Rkm 16. These intensive water quality collections in Severn River indicated deterioration of juvenile and adult yellow perch habitat (DO, salinity, and temperature) as summer progressed, except between Rkms 2 and 4 where habitat violations were not detected (Table 9). Surface measurements of habitat parameters were generally suitable within the juvenile nursery (Rkm 10 and above) during May-July, although temperature violations rose to 7-18% during July (Table 9). By August, DO below the criterion occurred in 60-80% of surface measurements in the 2-km segments within the nursery; temperature and salinity were within habitat requirements. In September 2002, 17-54% of surface DO and 40-46% of salinity measurements were out-of-bounds between Rkm's 10 and 14.

Habitat requirement violations for juvenile yellow perch in Severn River were much more severe in bottom measurements during 2002 (Table 10). Only the uppermost 2-km segment did not have bottom dissolved oxygen violations in May, while 15-25% of measurements in the remaining segments were below the criterion. After May, bottom temperature violations were never of consequence, salinity was not of concern until September, but 75% of bottom DO measurements made during July-September were below the criterion. By August-September, 2002 there was little suitable bottom habitat for juvenile yellow perch in the nursery (Table 10).

Adult habitat in Severn River, was located upstream of Rkm 2 (Figure 10). Habitat that held about 77% of adults coincided with the juvenile nursery, according to the distribution in Muncy (1962; Figure 10). Trends in violations of the three water quality parameters during May-September, 2002 differed little between adults and juveniles (Tables 9 and 10). Dissolved oxygen violations were most pervasive, occurring 32% of the time at the surface and 76% of the time at the bottom during July-September. Surface and bottom DO between Rkm's 2 and 4 was often at suitable levels during summer, in marked contrast to the rest of the river. This area would have held less than 5% of adult yellow perch in the late 1950s (Muncy 1962). Yellow perch in this segment of acceptable DO would have experienced excessive salinity by September 2002 (Tables 9 and 10). The quartiles of all measurements of DO were 4.1mg/L, 25th percentile; 5.8 mg/L 50th percentile; and 6.7 mg/L, 75th percentile. Minimum and maximum DO were 0.5 and 10.4 mg/L, respectively.

Low oxygen conditions at 1.0 m depth occurred frequently at the two continuous monitoring stations during 2002 in Severn River. Dissolved oxygen at Ben Oaks (≈ Rkm 17) was below the 5.0 mg/l criterion 49% of the time (Figure 11). Dissolved oxygen concentrations at the Sherwood Forest station (≈ Rkm 10) fell below the criterion 11.5% of the time. These deficits were most common in the summer months in both locations. Dissolved oxygen deficits occurred throughout May–November at Ben Oaks, but did not occur prior to June or after October at Sherwood Forest (Figure 11)

During July-October, 2003 (a wet or high rainfall year), salinity violations did not occur in Severn River and only a single instance of excessive temperatures was noted (N = 118). Dissolved oxygen violations increased from surface measurements (7.1%, SD = 3.4%), to mid-depth (21.4%, SD = 7.7%), to bottom (89.3%, SD = 6.8%) within a region approximating the juvenile nursery (Table 11). Temperature and salinity violations were not detected in South and Magothy rivers. Based on 95% CI overlap, the percentages of surface, mid-depth, and bottom DO violations were not different among the Severn, South, and Magothy rivers. The same DO conditions occurred in these rivers even though impervious surface coverage varied between 10% and 20%. Temperature and salinity violations were also rare in the less developed Wicomico River. Dissolved oxygen violations were much less prevalent; surface DO violations were similar to the

Severn River at the surface, but were much lower at mid-depth (6% in Wicomico River versus 42% in Severn River) and bottom (26% in Wicomico River versus 85% in Severn River; Table 11).

Box and whisker plots of historic bottom DO measurements indicated the same general pattern of decreasing DO with upstream distance in the high impervious surface systems (Magothy, Severn, and South rivers; Figure 12). There was little apparent difference in this trend when impervious surface varied between 10% and 20% of the watershed. The worst conditions occurred in the upper half of the suburbanized tributaries where over 80% of juvenile yellow perch were collected in these rivers during 2003. Bottom DO improved with upstream distance in the less developed Wicomico River (Figure 12).

Discussion

At this time, depressed egg and larval viability appear to be critical factors suppressing the resident populations of the suburbanized watersheds on Maryland's western shore. Two significant habitat quality issues potentially impacting yellow perch population dynamics were described in our study of Severn River – salinity intrusion into the upper tidal spawning area and larval nurseries, and poor summer DO throughout juvenile and adult habitat. Other issues exist that were not covered in the habitat variables we evaluated.

These negative attributes best supported the first habitat hypothesis about how fish populations react to habitat-related stress. In the absence of exploitation, it seems reasonable to attribute declining fortunes of yellow perch in suburbanized estuaries to deterioration of water quality associated with development. Yellow perch appeared to have been subjected to an oxygen-temperature squeeze similar to that suggested for striped bass in Chesapeake Bay (Price et *al*. 1985, Coutant 1985) with an added dimension of salinity. Yellow perch in Severn River during summer must constantly compromise their habitat requirements to survive in a degraded environment. This constant shifting of adults into different stressful environments may have manifested itself as decreased egg and, possibly, larval-juvenile viability in the following spring. Evidence of unmet habitat requirements (large areas of inadequate DO), coupled with decreased survival of eggs, and/or larvae supported this hypothesis. The second variant of this habitat squeeze for eggs and larvae was also present during the critical spawning and nursery period (March-April). Salinity intrusion may have reduced the area available as spawning and nursery grounds or had directly fatal consequences to eggs and larvae.

Severn River broodstock were induced to spawn during 2002-2003 but did not produce enough viable eggs to support a system-specific hatchery effort. Yellow perch collected from the Choptank River, Patuxent River and Nanticoke River successfully spawned in captivity during 2002-2003. Hatching success of yellow perch eggs contained in floating screen-bottom boxes in the fluvial Severn River during hatchery operations in Maryland's tidal waters during 1901-1955 varied from 60-98%, while average hatching success between slightly brackish and freshwater varied from 42% to 65% (Muncy 1962). Unsuccessful hatching of eggs in an environment free of sediment implies that other factors besides sedimentation are contributing to poor egg survival. However it does not eliminate the possibility that sedimentation could impact hatch rates when viable eggs are present.

During 2002, potential yellow perch broodstock were collected from Severn River in $14^{o}/_{oo}$ salinity and acclimated to $1^{o}/_{oo}$ (B. Richardson, MDDNR, personal communication). Many females released their eggs within six days and these eggs did not develop. Those yellow

perch that held their eggs for six days or more developed normally. About 10% of the brood stock collected from the Severn River spawned viable eggs. This is very low egg viability in comparison to the Choptank, Nanticoke and Patuxent rivers, where an estimated 90% of brood stock produced viable eggs (B. Richardson, MDDNR, personal communication). In fish eggs at the extremes of salinity, embryo malformation occurs, development is aborted, and the egg capsule swells in size up to 20% (Bunn et al. 2000).

Poor hatching success in Severn River during 2001-2003 was supported by meager relative abundance of wild larval yellow perch. The vast majority of larvae observed in presence-absence sampling were postlarvae, so their low presence could have indicated poor hatching of eggs or survival of prolarvae. Hatchery larvae may have been present in 2002 collections but pooled 2001-2003 L_p was still low compared to the Choptank and Nanticoke time-series. Our estimates of L_p in Severn River during 2001-2003 may have been biased by unequal annual sample sizes among years.

Our judgement of poor L_p in Severn River during 2001-2003 was based upon comparisons with rural Eastern Shore systems because a Severn River time-series did not exist. Dovel (1967) reported sparse collections of yellow perch larvae in Magothy River during 1965-1966 and attributed them to a small spawning population, poor hatching success, or poor larval survival. Muncy (1962) indicated that yellow perch juveniles were scarce in Severn River during 1955-1956 and abundant in 1958-1959. These sparse collections at the beginning of suburban development suggested that our expectation of comparability with our rural Eastern Shore reference systems could have been unrealistic. Yellow perch population dynamics in these western shore tributaries may have been as dominated by “boom and bust” dynamics in the past as they appear to be now.

Excessive mortality of postlarvae in suburbanized watersheds was not indicated by estimates of mortality rates of stocked larvae. During 2002, mortality rates of hatchery postlarvae stocked into South and Severn rivers (daily Z = 0.17 and 0.09, respectively) fell within the range estimated by Uphoff (1991) in the Choptank River during 1980-1985 (0.06-0.22). South River mortality estimates could be considered high while Severn River would be low. The migration of yellow perch juveniles stocked as larvae into Magothy River, where they were not released, indicated that mortality estimates for Severn and South rivers were positively biased. This movement from a stocked system would be considered mortality in the tagging model. Daily instantaneous mortality rates of yellow perch postlarvae in Choptank River were measured as logarithmic decay of weekly catch per effort in larval trawls (Uphoff 1991). Extensive mortality of juveniles in Severn River after mid-June, 2001, may have been indicated by their complete absence in samples during July-October. Stocking of early juveniles during 2002-2003 and the likelihood of spillover of juveniles from Head-of-Bay (see below) clouds our ability to interpret changes in relative abundance between fry and late juvenile collections during the latter two years.

Salinity within Severn River’s estuarine nursery was nearly always too high for eggs and larvae during spring 2001-2003. Muncy (1962) and O’Dell’s (1987) descriptions of upper Severn River salinity suggested that the nursery was less brackish in the 1950s through the 1970s than at present, although Sanderson’s 1950 cruise did not. Sanderson (1950) conducted a salinity cruise on March 11, 1950 and measured a rise in salinity with downstream distance similar to what we observed between Rkm’s 18.7 (Severn Run, 0 $^{o}/_{oo}$) and 17.7 (Indian Landing, 5.4 $^{o}/_{oo}$). Muncy (1962) reported salinities between 0.5 and 2.4$^{o}/_{oo}$ over this same distance during yellow perch egg hatching experiments in 1958. Most yellow perch spawning in 1958 occurred in waters of 2.5$^{o}/_{oo}$ or less above Indian Landing and in Severn Run (Muncy 1962). In April 1978, salinity at Indian Landing was 1.2 $^{o}/_{oo}$ (J. Mowrer, MDDNR, personal communication). During 2001-2003, the estuarine larval nursery (between Rkm’s 14 and 18) was characterized by frequent violations of the salinity criterion of 2$^{o}/_{oo}$ without an annual pattern even though conditions went from extremely dry (2001-2002) to extremely wet (2003).

Mortality of yellow perch eggs and prolarvae in past experiments generally increased with salinity and was complete by 12‰ (Sanderson 1950; Victoria et al. 1992). Average mortalities of eggs placed in aquaria at about 15ºC containing Severn River water with mean salinities of 0.0‰, 5.5‰, and 11.7‰ were 33%, 54%, and 100% (Sanderson 1950).

Laboratory experiments with yellow perch eggs and prolarvae from Sassafras, Severn, and Wicomico rivers indicated complete mortality of both life stages at approximately 12‰ (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‰. Abnormal behavior of larvae held for about a week at 8‰ suggested that delayed mortality would occur. Severn River prolarvae generally grouped into the highest mortality group and Wicomico River typically displayed the lowest mortality regardless of salinity treatment (Victoria et al. 1992).

Distribution of yellow perch larvae in field collections indicated a lower salinity preference than exhibited in Victoria et al. (1992). Nearly 90% of yellow perch larvae (nearly all were postlarvae) collected in Choptank River were collected at $1^{o}/_{oo}$ salinity or less during 1980-1985 and the remainder were collected at salinities less than $8^{o}/_{oo}$ (Uphoff 1991). Approximately 85% of yellow perch larvae collected from Magothy and Patuxent rivers, and Head-of-Bay during1963-1967 were collected at salinity $l^{o}/_{oo}$ or less (Dovel 1971).

Reduction of the estuarine spawning area upstream of Indian Landing could have a large impact on the population if egg deposition were proportional to river area because this region is much broader than the fluvial spawning area. We have estimated that 49% of potential spawning area (estuarine and stream) could have been lost by assuming that (1) the downstream boundary of the historic spawning area described by Muncy (1962) was located at Rkm 17.7 and that (2) it is now bounded at our uppermost fyke net (≈Rkm 18.0).

As development increases, rainfall flows faster across the ground and more of it reaches fluvial streams rather than recharging groundwater (Cappiella and Brown 2001; Beach 2002). In natural settings, very little rainfall is converted to runoff and about half is infiltrated into underlying soils and the water table (Cappiella and Brown 2001). These pulses of runoff alter stream flow patterns and could be at the root of the suggested change in salinity at the head of the Severn River estuary. High volumes of light freshwater runoff may spread across the surface of heavier saline nursery waters rather than infiltrating slowly through bottom springs and groundwater seeps and mixing with saline waters.

During summer 2001-2003, poor DO conditions were common at all water depths in Severn River. These same conditions were present during 1989-1991 (Carmichael et al 1992). During summer, fish should have been restricted to waters less than 3 m and even these waters experienced pervasive inadequate DO.

We simply do not know what behavioral mechanisms allowed yellow perch to survive what appeared to be seriously compromised DO conditions within Severn River in summer. Cooler, deep-water may be needed by larger yellow perch to avoid high surface water temperatures, but low DO limited access to deep water within the Severn River proper. Larger yellow perch in lakes have preferred temperatures lower than small perch (Rudtam and Magnuson 1985). Widespread DO sampling within Severn River during 2002 indicated little likelihood that extensive refuges existed within the estuarine portion of the river considered to be adult habitat. Yellow perch may be able to tolerate existing conditions, escape them by migrating into Severn Run, or migrate towards the junction with the Bay where DO conditions improve.

Laboratory experiments indicated that juvenile yellow perch were adaptable to moderate and gradual diurnal fluctuations in DO at relatively low concentrations and that growth and survival may be poor indicators of low DO effects (Carlson et al. 1980). At mean constant DO concentrations of 3.5 mg/L, yellow perch juveniles consumed less food, but growth was not affected. At DO of 2 mg/L, less food was consumed and growth was reduced. Growth was not affected by fluctuations between 1.4 and 3.8 mg/L. Survival was unaffected by low DO exposure (Carlson et al. 1980).

Electrofishing of Severn Run above Rkm 22 (Dicus Mill Road) by the Maryland Biological Stream Survey (MBSS) during summer 1997 indicated yellow perch were present upstream as far as Rkm 28 (MBSS unpublished data). Severn Run may offer a refuge for some yellow perch because the forest canopy would provide shade and cool temperatures and flowing waters would provide oxygen.

Dissolved oxygen and salinity generally increase toward the mouth of Severn River. In years of high Susquehanna River flow such as 2003, adequate salinity and DO conditions could exist at the mouth of Severn River. In dryer years such as 2001-2002, Severn River yellow perch would need to trade-off better oxygen conditions with high salinity at the mouth of the river (see September in Table 10).

Downstream movement of adults towards the mouth of the Bay may be an exaggeration of normal migration suggested by studies of European perch *Perca fluviatilis* in coastal waters. European perch inhabit brackish coastal waters of the Baltic Sea in summer, while they usually winter in freshwater lagoons (Lozys 2003). Experiments with European perch indicated beneficial effects on growth at high temperatures when salinity was 2-5$^{o}/_{oo}$; growth was less in freshwater. The beneficial effect was most likely manifested under salinities close to their internal osmotic pressure. At lower water temperatures, beneficial effect dissipated and perch migrated back to freshwater (Lozys 2003). If similar beneficial effects of brackish water in summer exist for yellow perch, low DO may limit access to upper and mid-regions of Severn River with 2-5$^{o}/_{oo}$ salinity.

Depressed egg and larval viability observed during 2002-2003 may be an outcome of extensive exposure of adults to inadequate DO the previous summer. Ovaries of yellow perch are repopulated with new germs cells during late spring and summer after resorptive processes are complete (Ciereszko et al. 1997; Malison 2004). This is when poor DO conditions become common in Severn River and, if DO is linked to egg viability, these are likely the processes affected. Exposure of adult common carp *Cyprinus carpio* to hypoxia (1 mg/L oxygen) depressed reproductive processes such as gametogenesis, gonad maturation, gonad size, gamete quality, egg fertilization and hatching, and larval survival through endocrine disruption (Rudolph et al. 2003). These carp were exposed to hypoxia for 12 weeks and then were allowed to spawn under normal DO conditions (Rudolph et al. 2003).

Large negative impacts on estuarine DO were apparent in this study when impervious surface was as low as 10% of watershed area. Our rural reference system, Wicomico River, had approximately 2% impervious surface and did not exhibit extensive hypoxia in its upper reaches. A threshold for negative impacts on DO in suburbanized estuaries should exist between 2% and 10%. Beach (2002) proposed a 10% rule (10% impervious surface) as a threshold for serious degradation of aquatic resources in coastal areas based upon research in freshwater systems. Some researchers have found impacts in freshwater systems at impervious cover levels as low as 5% (Cappiella and Brown 2001). Based on the extent of DO violations observed at 10% impervious surface, it appears that the threshold for yellow perch in mesohaline estuarine tributaries could be closer to 5% than 10%.

Anthropogenic chemicals such as organochlorine pesticides (DDT, mirex) and industrial chemicals (PCBs) disrupt endocrine function associated with reproduction and are associated with depressed survival, malformation, and abnormal chromosome division of eggs and larvae (Longwell et al. 1992; Longwell et al 1996; Colborn and Thayer 2000; Rudolph et al. 2003). Yellow perch tissues from our suburbanized tributaries had not been tested for contaminants during 2001-2003. Organochlorine compounds were present in tissues of another semi-anadromous fish, white perch *Morone americanus*, in two of the surburbanized estuaries we investigated. Consumption advisories have been issued for white perch in South and Magothy rivers due to excessive concentrations of PCBs and organochlorine pesticides (Maryland Department of Environment www.mde.state.md.us).

Relative abundance of yellow perch juveniles in Severn River fry seine collections made during mid-May through mid-June did not differ significantly during 2001-2003. There were marked differences in relative abundance of later juveniles (July-October) in Severn River during 2001-2003. Late juvenile yellow perch were absent in seine collections during 2001 when stocking did not occur; juveniles disappeared between June and July, 2001. They were present at statistically similar, higher relative abundance during 2002-2003, but stocking occurred during both years. Wild juveniles were present during 2002-2003, but the proportion of wild fish was significantly higher during 2003.

It seems reasonable to conclude that three strong year-classes (1996, 1998, and 2003) appeared in Severn River during 1996-2003 based on adult and juvenile sampling. Age structure of spawning Severn River yellow perch during 2003 was dominated by two year-classes (out of eight identified year classes and a plus group), 1998 (≈26% of all) and 1996 (≈47%; Piavis et al. 2004). Wild yellow perch juveniles were abundant in the three suburbanized tributaries in 2003, whether the tributary was stocked or not.

Piavis and Uphoff (1999) suggested that yellow perch recruitment in Severn, South, and Magothy rivers was influenced by migration of early juveniles from Head-of-Bay. The spread of hatchery yellow perch from one or both stocked tributaries to Magothy River in 2003 indicated migration from one system to another was plausible. Adult biomass estimates (Piavis 2003; J. Uphoff, MDDNR, unpublished analysis) in Head-of-Bay have generally been high since the mid-1990s and have likely contributed to higher recruitment there. If poor egg and larval viability observed in the Severn River is now normal for the three suburbanized drainages, then recruitment in these systems (absent stocking) may be entirely dependent upon good Head-of-Bay year-classes, high Susquehanna River flow, and salinities at the mouth of the rivers low enough to allow free movement into them. The appearance of three strong year-classes in Severn River since 1996 coincided with Head-of-Bay yellow perch juvenile indices that were nearly three times the time-series (1979-2003) median, annual Susquehanna River flows above the median (1932-2003, at Marietta, Pennsylvania; J. Nantz, U. S. Geological Survey, personal communication), and 75% or more of the salinity measurements on the main-Bay just north of Severn River (Chesapeake Bay Program monitoring station CB3.3W) below $10^{o}/_{oo}$ (Table 12). When this combination occurred, strong year-classes were present in Severn River; when one element was missing, year-classes were weak or absent (Table 12).

Magothy River has been characterized as having a sharp gradient of salinity that was greatly influenced by the Susquehanna River (Mansueti 1960; Dovel 1971). Ranges of salinities are similar between Baltimore and Annapolis (Dowgiallo 1989) and this characterization should apply to the Severn and South rivers as well. At times during spring runoff, lighter, less saline surface waters from Head-of-Bay flow into Magothy River, creating a salinity pattern contrary to normal (Dovel 1971). Salinity at the mouth of the river may be less than upriver (Dovel 1971). This physical phenomenon should facilitate movement of young upper Bay yellow perch into these tributaries.

Historic data on Susquehanna River flow (J. Nantz, U.S. Geological Survey, personal communication), mean May salinity at Annapolis (Dowagiallo 1989), and qualitative descriptions of juvenile abundance in Severn River (Muncy 1962) during 1955-1958 do not confirm that the physical conditions thought to affect access by Head-of-Bay juveniles greatly influenced Severn River recruitment in the past. Muncy (1962) described yellow perch juveniles as scarce in Severn River during 1955-1956 and abundant during 1957-1958. Susquehanna River flows were below the median during 1955 and 1957 and May salinities were above average, while 1956 and 1958 conditions were their opposite. One “poor” and one “good” year-class were detected under both sets of conditions.

Stocked juveniles in Severn River may have precluded more extensive occupation by Head-of-Bay wild juveniles in 2003. Wild and stocked juveniles in Severn River competed with one another for a limited pool of environmental resources such as food and refuge from predators (Rose and Cowan 2000). Yellow perch stocked as larvae and early juveniles in our suburbanized tributaries occupy the rivers earlier than migrants from Head-of-Bay. Hatchery fish in general are typically more numerous, larger, and in some cases more aggressive than wild fish and these attributes can confer dominance status to them (Pearsons 2002). Hatchery produced salmon may compete with, prey upon, increase disease to, alter predator consumption of, and alter behavior of their wild counterparts (Pearsons 2002).

Adult total mortality rate estimates in Severn River were near natural mortality rates assumed for Chesapeake Bay yellow perch, while size or age distributions were dominated by larger, older fish. These factors indicated exploitation was not excessive (Colby 1984; Barry and Tegner 1989). This was comforting, since harvest had not been allowed since 1989. Neither excessive mortality nor reduced growth of adults was evident

in the suburbanized Severn River when compared to yellow perch from rural Eastern Shore watersheds. Estimates of Z of adult yellow perch in Severn River were similar to those estimated for the unfished Nanticoke River and were close to estimates of M used in Chesapeake Bay yellow perch stock assessments (Piavis and Uphoff 1999). Severn River mean length-at-age fell between estimates made for Nanticoke River (overall highest) and Choptank River (overall lowest). Relative stock densities in Severn, Choptank and Nanticoke Rivers during 2001-2003 indicated different dynamics in each system.

Relative stock densities indicated that large yellow perch (255-318 mm or preferred-memorable category) have been well represented in Severn River throughout the years for which we have data. O'Dell (1987), International Science and Technology, Inc. (1988), and Greening et al. (1989) interpreted the lower abundance of smaller, presumably younger, yellow perch in the spawning runs between 1978-1986 as an indication of reduced survival of young fish. The high representation of larger yellow perch in Muncy (1962) indicated it was an historic attribute of Severn River. Lesser representation of stock-quality yellow perch during 2001-2003 may have signified a large year-class (1996) passing through the population rather than recruitment failure in recent years.

Angler harvest was considered insufficient by O'Dell (1987) to have caused the observed decrease in adult yellow perch abundance in the 1980s. Muncy (1962) estimated that the recreational harvest of yellow perch resulted in a modest exploitation rate of 14%. Low exploitation rates, coupled with a long absence of commercial exploitation suggested to O'Dell (1987) that reasons other than harvest pressure affected the Severn River yellow perch population. O'Dell (1987) suggested poor recruitment was due to changes in water quality associated with acid rain in spawning streams and urbanization (sedimentation of streams and decreased DO in the estuary).

Maryland DNR judges stock status of tidewater yellow perch populations with spawner biomass per recruit (SBR) analysis, an equilibrium model that characterizes the reproductive potential of a stock in terms of the spawner biomass (a surrogate for egg production) produced by a year-class over its lifetime under conditions of constant growth, mortality, and recruitment (Goodyear 1993; Piavis and Uphoff 1999). Spawner biomass per recruit links a harvest strategy to robustness of the stock to recruitment overfishing based on a measured or assumed (in the case of Chesapeake Bay yellow perch) stock-recruitment relationship (Goodyear 1993). Spawner biomass per recruit analysis indicated that yellow perch in the Bay would have had a fairly low overfishing threshold prior to 1989 because of an absence of size and bag limits and that exploitation rates higher than 18-26%, not far above that measured by Muncy (1962) in the late 1950s, could have been excessive (Uphoff and Piavis 1999). Habitat deterioration could have lowered the overfishing threshold and magnified the effect of even modest exploitation on spawning potential.

Spawner biomass per recruit analysis can be used to model the effects of habitat degradation on the sustainable level of fishing (Boreman 1997). Before completion of the five-year study of Severn River, we will develop a SBR model that incorporates our best estimate of the impact of habitat deterioration on subsequent survival of yellow perch recruits of Severn River origin. This model will enable us to determine whether a sustainable harvest strategy could be developed for yellow perch in suburbanized Bay tributaries.

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Table 1. Acreage and land use data for watersheds used in historic comparisons with Severn River water quality data. Land use designations and estimates were based on 1994 MDDNR estimates (MDDNR 2002)

River	Impervious Surface %	Urban %	Agriculture %	Forest %	Acreage
Severn	17.0	47.3	11.1	41.2	44,264
South	10.3	29.0	19.9	50.5	36,521
Magothy	20.2	61.1	6.0	32.8	22,641
Wicomico	2.0	7.4	37.2	51.0	49,364
Choptank	2.4	8	60	28.6	273,532
Nanticoke	1.2	3	38	43.1	110,464

Table 2. Habitat requirements for yellow perch at various life stages (Piavis 1991).

Yellow perch Life Stage	Temperature (°C)	Salinity (ppt)	Dissolved Oxygen (mg/L)
Egg	7 – 20	0 – 2	> 5.0
Larvae	10 – 30	0 – 2	> 5.0
Juvenile	10 – 30	0 – 13	> 5.0
Adult	6 – 30	0 – 13	> 5.0

Table 3. Yellow perch brood stock collection date and location, and distribution of collection by sex during 2002-03.

Date collected	Location collected	Females	Males
February 18, 2002	Patuxent River	6	3
February 26, 2002	Severn River	80	90
March 5, 2002	Severn River	33	35
March 5, 2003	Choptank River	38	55
March 11, 2003	Choptank/Nanticoke River	100	204
March 17, 2003	Severn River	20	40
March 19, 2003	Severn River	9	13

Table 4 . Number of larval and juvenile yellow perch stocked in target tributaries during 2002-2003.

River	Life stage	2002	2003
Severn	Larvae	420,000	287,200
Severn	Early juveniles	182,900	203,500
Severn	Late juveniles		15,500
South	Larvae	390,000	251,200
South	Early juveniles	110,000	135,000
South	Late juveniles		19,700

Table 5. Summary data for Severn River fry seine collections during May-June, 2001-2003. F_p = the proportion of fry seine hauls with juvenile yellow perch.

	2001	2002	2003
F_p	0.38	0.39	0.46
SD	0.12	0.06	0.08
Upper 95%	0.62	0.51	0.62
Lower 95%	0.16	0.27	0.29
N	16	72	35
Collection date range	5/24	5/8 – 6/18	5/17 – 6/17

Table 6. Summary statistics for July-October seine collections in Severn River during 2001-2003. J_p is the proportion of hauls with yellow perch juveniles.

	2001	2002[1]	2003
Hauls	46	62	34
J_p	0.00	0.21	0.38
SD	-	0.05	0.08
Number examined for hatchery marks		12	125
Number stocked as larvae in catch		1	0
Number stocked as juvenile in catch		11	87
Number wild juveniles in catch		0	38
Percent of catch from hatchery		96%	70%

1. 12 hauls were checked for hatchery contribution.

Table 7. Frequency of violations of larval water quality criteria during 2001-2003. A dash indicates data were not collected.

	2001	2002	2003
Larval collection dates	April 6-19	April 1-24	April 7-14
Total samples	20	29	9
Temperature violations	1	0	3
Salinity violations	20	28	6
Dissolved oxygen	-	0	0

Table 8. Number of water quality samples taken by month and 2-km segment during 2002 intensive sampling. Segments begin at the mouth of Severn River.

Segment	May	June	July	August	September
16-18	2	0	0	0	0
14-16	37	13	16	11	1
12-14	8	4	11	7	6
10-12	13	15	25	21	16
8-10	0	12	23	17	13
6-8	0	10	13	9	9
4-6	0	10	10	8	2
2-4	0	0	4	1	3
0-2	0	2	1	2	3

Table 9. Percent of failures of habitat requirements for surface measurements made within 2 km segments during May-September, 2002. Segments begin at the mouth of Severn River. ND = no data available.

May

Segment	Dissolved Oxygen		Temperature		Salinity	
	Juvenile	Adult	Juvenile	Adult	Juvenile	Adult
16-18	0	0	0	0	0	0
14-16	5	5	0	0	0	0
12-14	0	0	0	0	0	0
10-12	0	0	0	0	0	0
8-10	ND	ND	ND	ND	ND	ND
6-8	ND	ND	ND	ND	ND	ND
4-6	ND	ND	ND	ND	ND	ND
2-4	ND	ND	ND	ND	ND	ND
0-2	ND	ND	ND	ND	ND	ND

June

Segment	Dissolved Oxygen		Temperature		Salinity	
	Juvenile	Adult	Juvenile	Adult	Juvenile	Adult
16-18	ND	ND	ND	ND	ND	ND
14-16	0	0	15	15	0	0
12-14	0	0	0	0	0	0
10-12	7	7	0	0	0	0
8-10	25	25	0	0	0	0
6-8	20	20	0	0	0	0
4-6	0	0	0	0	0	0
2-4	ND	ND	ND	ND	ND	ND
0-2	0	0	0	0	0	0

Table 9. Continued.

July

Segment	Dissolved Oxygen		Temperature		Salinity	
	Juvenile	Adult	Juvenile	Adult	Juvenile	Adult
16-18	ND	ND	ND	ND	ND	ND
14-16	0	0	6.7	6.7	0	0
12-14	0	0	18.2	18.2	0	0
10-12	7	7	13.0	13.0	0	0
8-10	25	25	0	0	0	0
6-8	20	20	0	0	0	0
4-6	0	0	0	0	0	0
2-4	0	0	0	0	0	0
0-2	0	0	0	0	0	0

August

Segment	Dissolved Oxygen		Temperature		Salinity	
	Juvenile	Adult	Juvenile	Adult	Juvenile	Adult
16-18	ND	ND	ND	ND	ND	ND
14-16	64	64	0	0	0	0
12-14	57	57	0	0	0	0
10-12	62	62	0	0	0	0
8-10	77	77	0	0	0	0
6-8	56	56	0	0	0	0
4-6	62	62	0	0	0	0
2-4	0	0	0	0	0	0
0-2	100	100	0	0	0	0

September

Segment	Dissolved Oxygen		Temperature		Salinity	
	Juvenile	Adult	Juvenile	Adult	Juvenile	Adult
16-18	ND	ND	ND	ND	ND	ND
14-16	0	0	0	0	0	0
12-14	17	17	0	0	40	40
10-12	25	25	0	0	43	43
8-10	54	54	0	0	46	46
6-8	33	33	0	0	33	33
4-6	0	0	0	0	0	0
2-4	0	0	0	0	100	100
0-2	33	33	0	0	100	100

Table 10. Percent failures of habitat requirements for bottom measurements made within 2-km segments during May-September, 2002. Segments begin at the mouth of Severn River. ND = no data available.

May

Segment	Dissolved Oxygen		Temperature		Salinity	
	Juvenile	Adult	Juvenile	Adult	Juvenile	Adult
16-18	0	0	0	0	0	0
14-16	16	16	0	0	0	0
12-14	25	25	0	0	0	0
10-12	15	15	0	0	0	0
8-10	ND	ND	ND	ND	ND	ND
6-8	ND	ND	ND	ND	ND	ND
4-6	ND	ND	ND	ND	ND	ND
2-4	ND	ND	ND	ND	ND	ND
0-2	ND	ND	ND	ND	ND	ND

June

Segment	Dissolved Oxygen		Temperature		Salinity	
	Juvenile	Adult	Juvenile	Adult	Juvenile	Adult
16-18	ND	ND	ND	ND	ND	ND
14-16	8	8	0	0	0	0
12-14	50	50	0	0	0	0
10-12	27	27	0	0	0	0
8-10	50	50	0	0	0	0
6-8	70	70	0	0	0	0
4-6	50	50	0	0	0	0
2-4	ND	ND	ND	ND	ND	ND
0-2	50	50	0	0	0	0

July

Segment	Dissolved Oxygen		Temperature		Salinity	
	Juvenile	Adult	Juvenile	Adult	Juvenile	Adult
16-18	ND	ND	ND	ND	ND	ND
14-16	44	44	7	7	0	0
12-14	64	64	0	0	0	0
10-12	56	56	0	0	0	0
8-10	78	78	0	0	0	0
6-8	92	92	0	0	0	0
4-6	50	50	0	0	0	0
2-4	75	75	0	0	0	0
0-2	100	100	0	0	0	0

Table 10. Continued.

August

Segment	Dissolved Oxygen		Temperature		Salinity	
	Juvenile	Adult	Juvenile	Adult	Juvenile	Adult
16-18	ND	ND	ND	ND	ND	ND
14-16	73	73	0	0	0	0
12-14	86	86	0	0	29	29
10-12	95	95	5	5	10	10
8-10	82	82	0	0	0	0
6-8	89	89	0	0	11	11
4-6	75	75	0	0	0	0
2-4	0	0	0	0	0	0
0-2	100	100	0	0	0	0

September

Segment	Dissolved Oxygen		Temperature		Salinity	
	Juvenile	Adult	Juvenile	Adult	Juvenile	Adult
16-18	ND	ND	ND	ND	ND	ND
14-16	100	100	0	0	0	0
12-14	100	100	0	0	83	83
10-12	69	69	0	0	63	63
8-10	100	100	0	0	67	67
6-8	89	89	0	0	67	67
4-6	100	100	0	0	0	0
2-4	33	33	0	0	100	100
0-2	100	100	0	0	100	100

Table 11. Summary of dissolved oxygen violations (percent < 5 mg/l) of yellow perch habitat requirements during July-October, 2003 in Severn, South, Magothy and Wicomico rivers.

	Mean	SD	N
	Severn River		
Surface	6.4	3.1	62
Mid-depth	42.8	9.4	28
Bottom	85.2	6.8	28
	South River		
Surface	3.6	2.5	56
Mid-depth	35.7	9.0	28
Bottom	71.4	8.5	28
	Magothy River		
Surface	7.1	3.4	56
Mid-depth	21.4	7.7	28
Bottom	89.3	5.8	28
	Wicomico River		
Surface	5.4	3.0	56
Mid-depth	5.9	5.7	17
Bottom	26.1	9.2	23

Table 12. Head-of-Bay yellow perch juvenile index (JI), mean May-June Susquehanna River flow (cubic feet per second), categorization of salinity in main Bay just north of Severn River, proportion of haul seines with juvenile yellow perch (J_p), proportion of juvenile catch that were wild perch, and contribution to age structure of 2003 Severn River adult population . (Median Head-of-Bay JI was determined for the 1979-2003 time-series and median of Susquehanna River flow was for 1932-2003 at Marietta, Pennsylvania (J. Nantz., U.S. Geological Survey, personal communication).

Year-class	Head-of-Bay JI index	Susquehanna River flow (cfs)	Salinity < $10^{o}/_{oo}$ 75% of time or more	J_p	Severn R. Proportion wild in seine catch	Severn R. 2003 proportion at age	Year-class interpretation
1996	0.93	63,560	Yes			0.47	Strong
1997	0.12	29,149	Yes			0.04	Poor
1998	0.54	42,320	Yes			0.26	Strong
1999	0.24	27,570	No			0.00	Poor
2000	0.54	36,040	No			0.028	Poor
2001	0.56	24,370	No	0	0	0.072	Poor
2002	0.00	27,320	No	0.21	0.04		Poor
2003	0.79	51,330	Yes	0.38	0.30		Strong
Median	0.15	36,980					

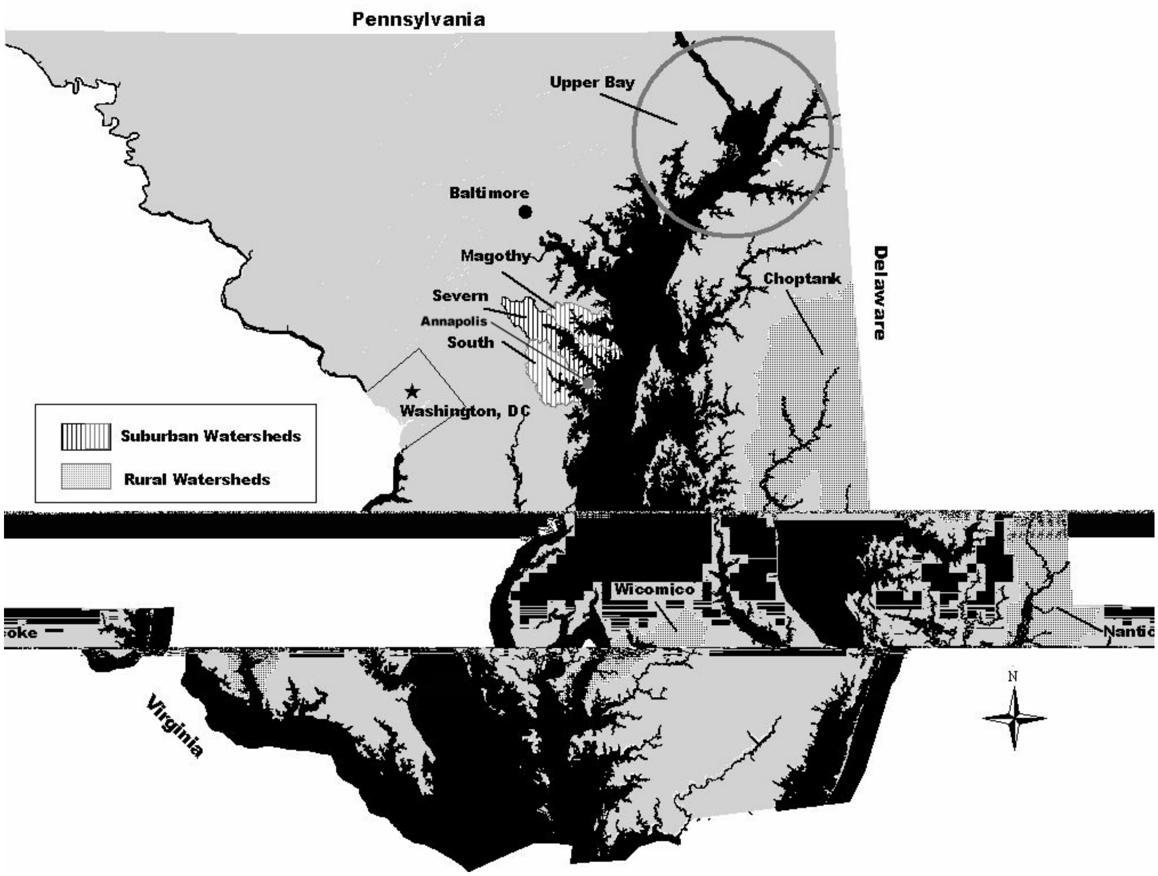

Figure 1. Severn River and other Chesapeake Bay tidal tributaries sampled. The Upper Bay was not sampled, but is highlighted as an area important to the Severn River's ecological dynamics.

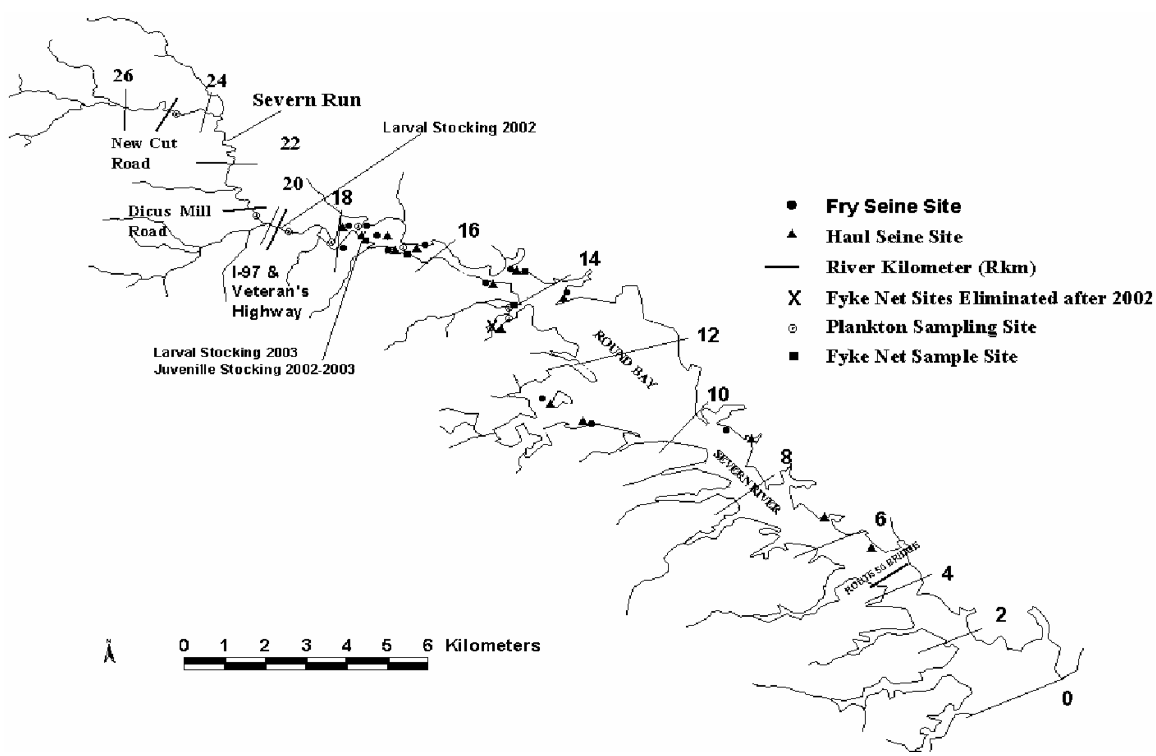

Figure 2. Severn River yellow perch stocking locations and sampling locations, 2001-2003.

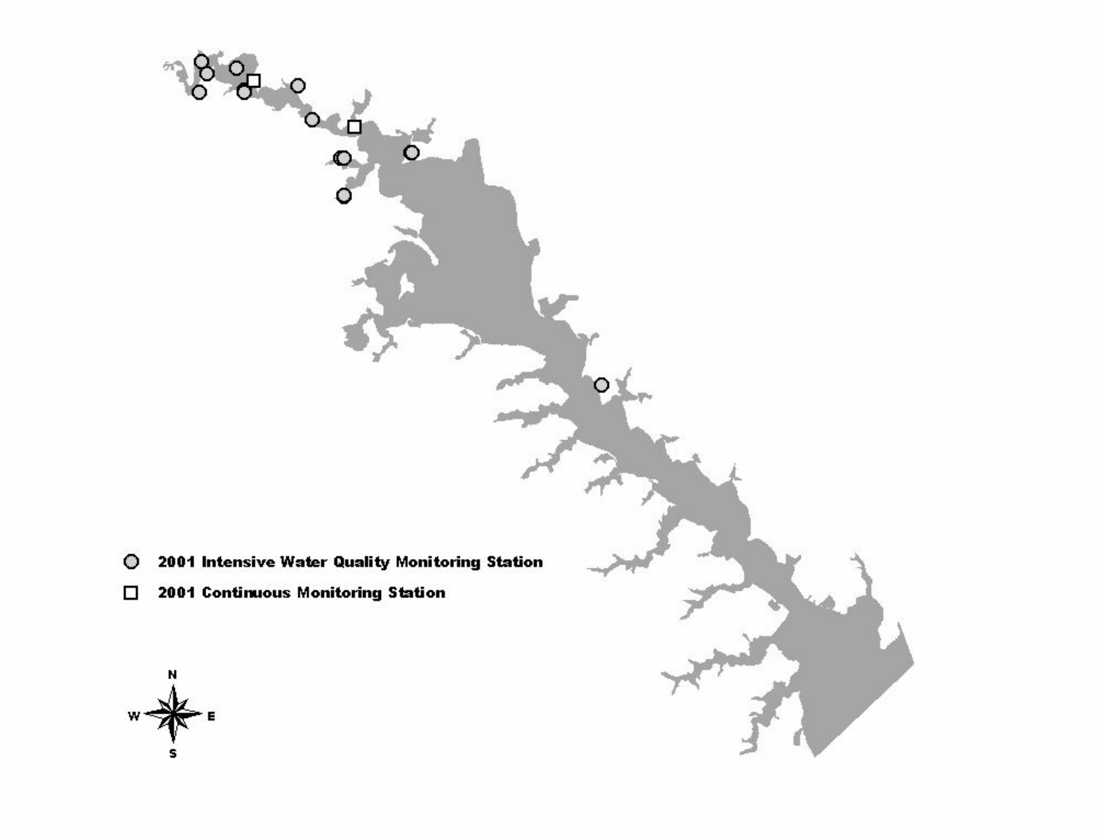

Figure 3. Water quality stations sampled in 2001.

Figure 4. Water quality stations sampled in 2002

Figure 5. Water quality stations sampled in 2003 and during surveys conducted in the late 1980s and 1990s.

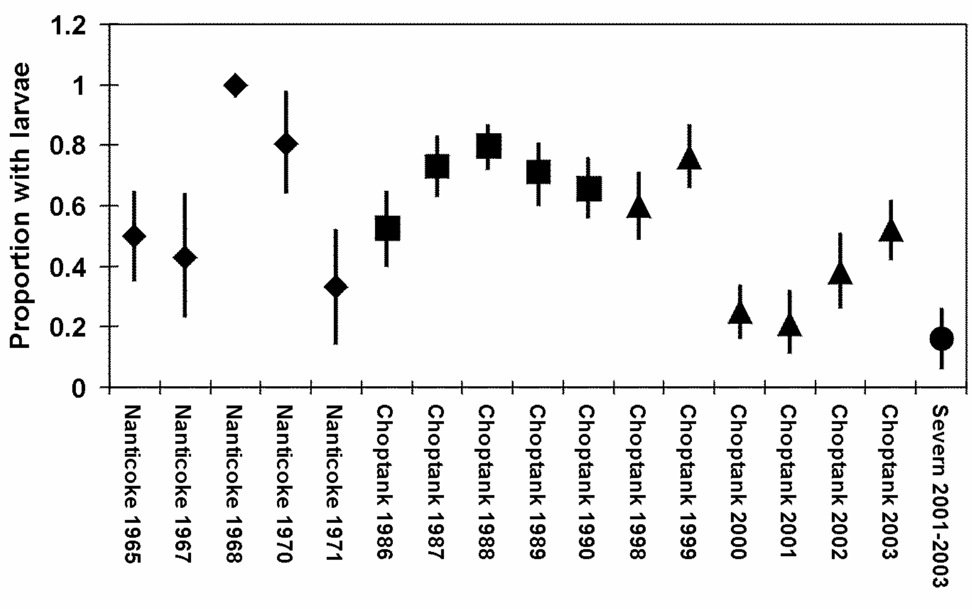

Figure 6. Proportion of plankton tows with yellow perch larvae and their 95% confidence intervals in the Severn (2001-2003 pooled), Nanticoke (1965-1971) and Choptank (1986-1989, and 2000-2003) rivers.

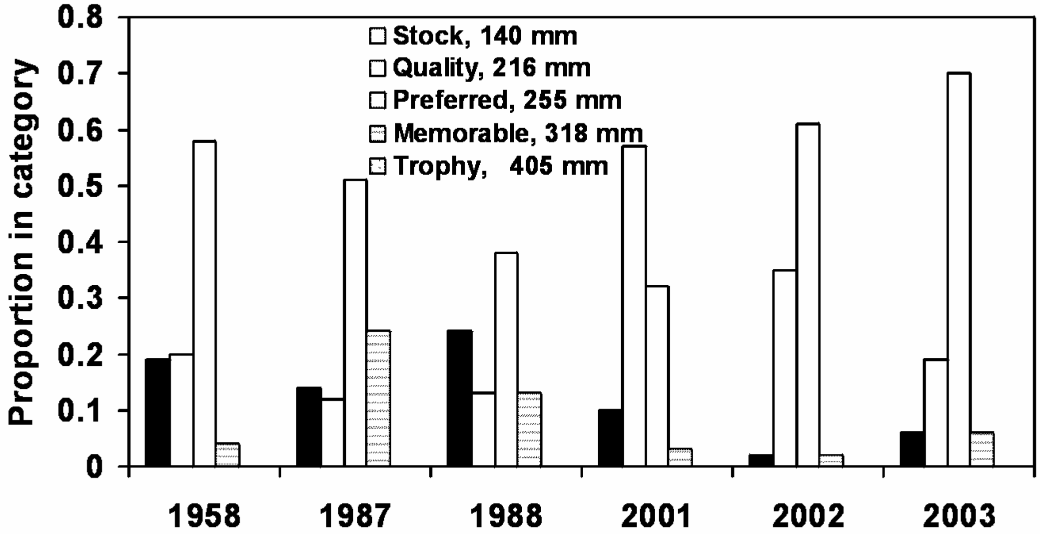

Figure 7. Relative stock densities of Severn River yellow perch during 1958, 1987-1988, and 2001-2003. Category labels refer to beginning of increment (i.e., stock = stock-quality interval) and length is the size at the beginning of the increment.

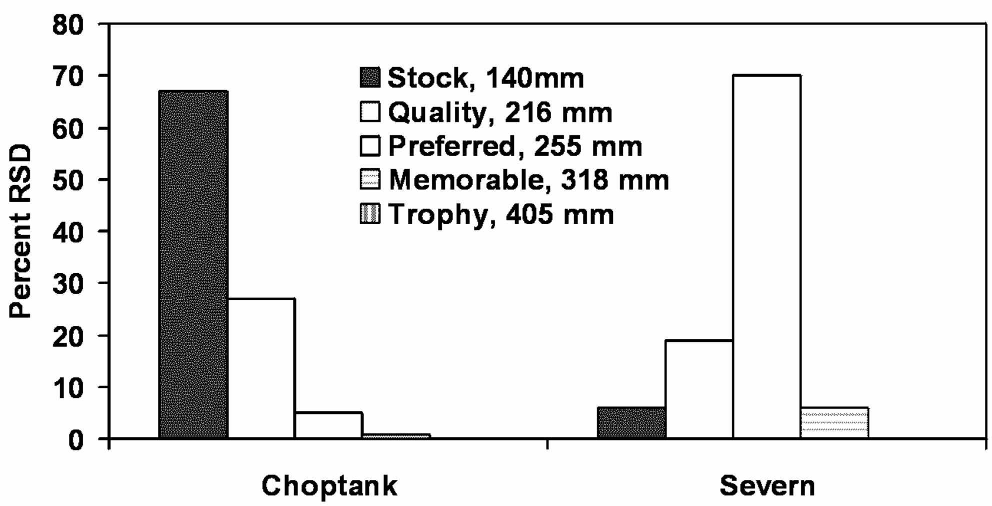

Figure 8. Relative stock densities of yellow perch in Severn and Choptank rivers during 2003. Category labels refer to beginning of increment (i.e., stock = stock-quality interval) and length is the size at the beginning of the increment.

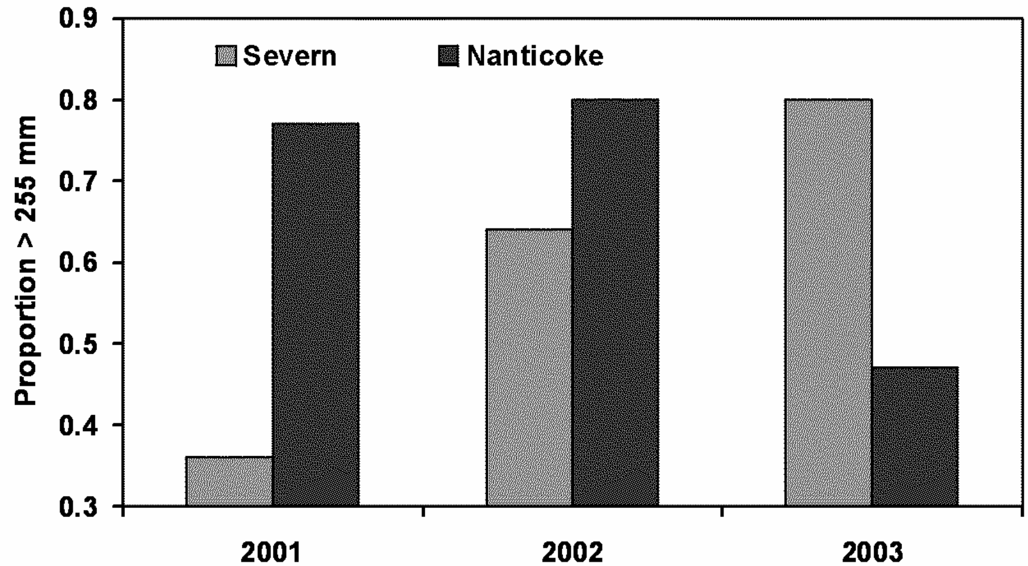

Figure 9. Severn and Nanticoke RSDs during 2001-2003. RSDs are based on proportion of quality RSD fish (216 mm +) that were in the preferred or above categories (> 255 mm).

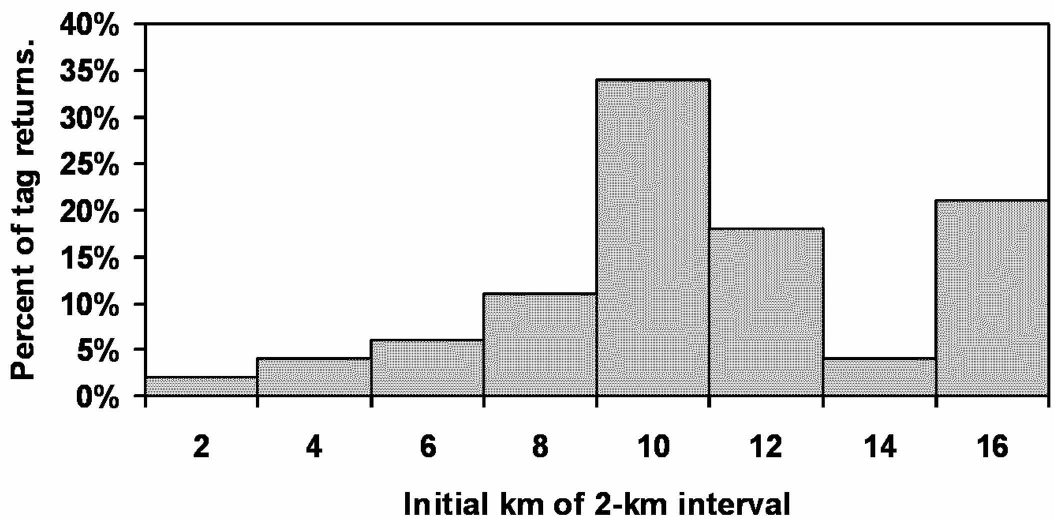

Figure 10. Distribution of Muncy (1962) tag returns grouped into 2-km intervals that begin at the mouth of Severn River. Number on x-axis refers to the beginning of the 2-km interval (i.e., 2 = area between km's 2 and 4).

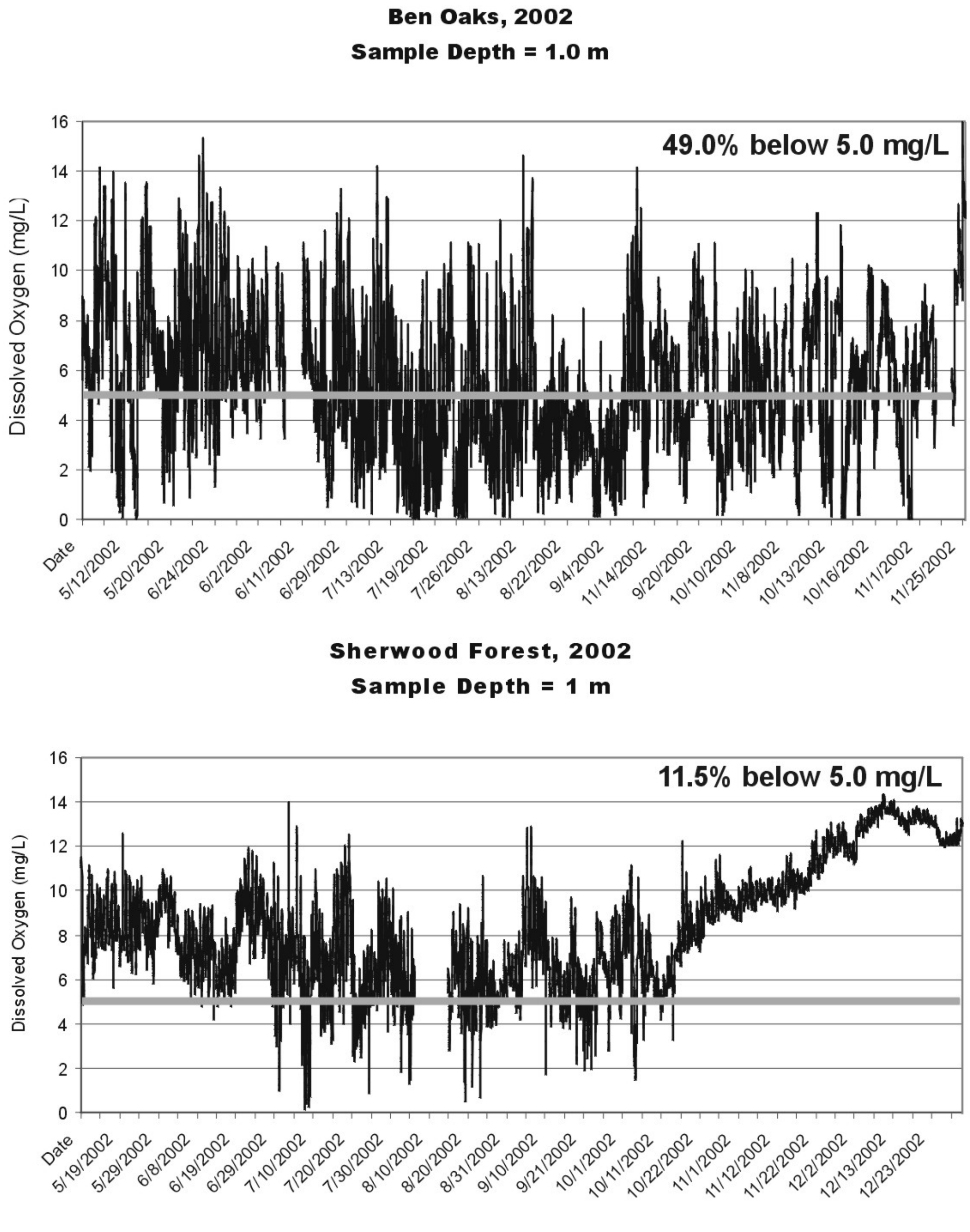

Figure 11. Continuous monitoring 24 hour dissolved oxygen profiles at Ben Oaks (Rkm 14) and Sherwood Forest (Rkm 10) during May-December 2002.

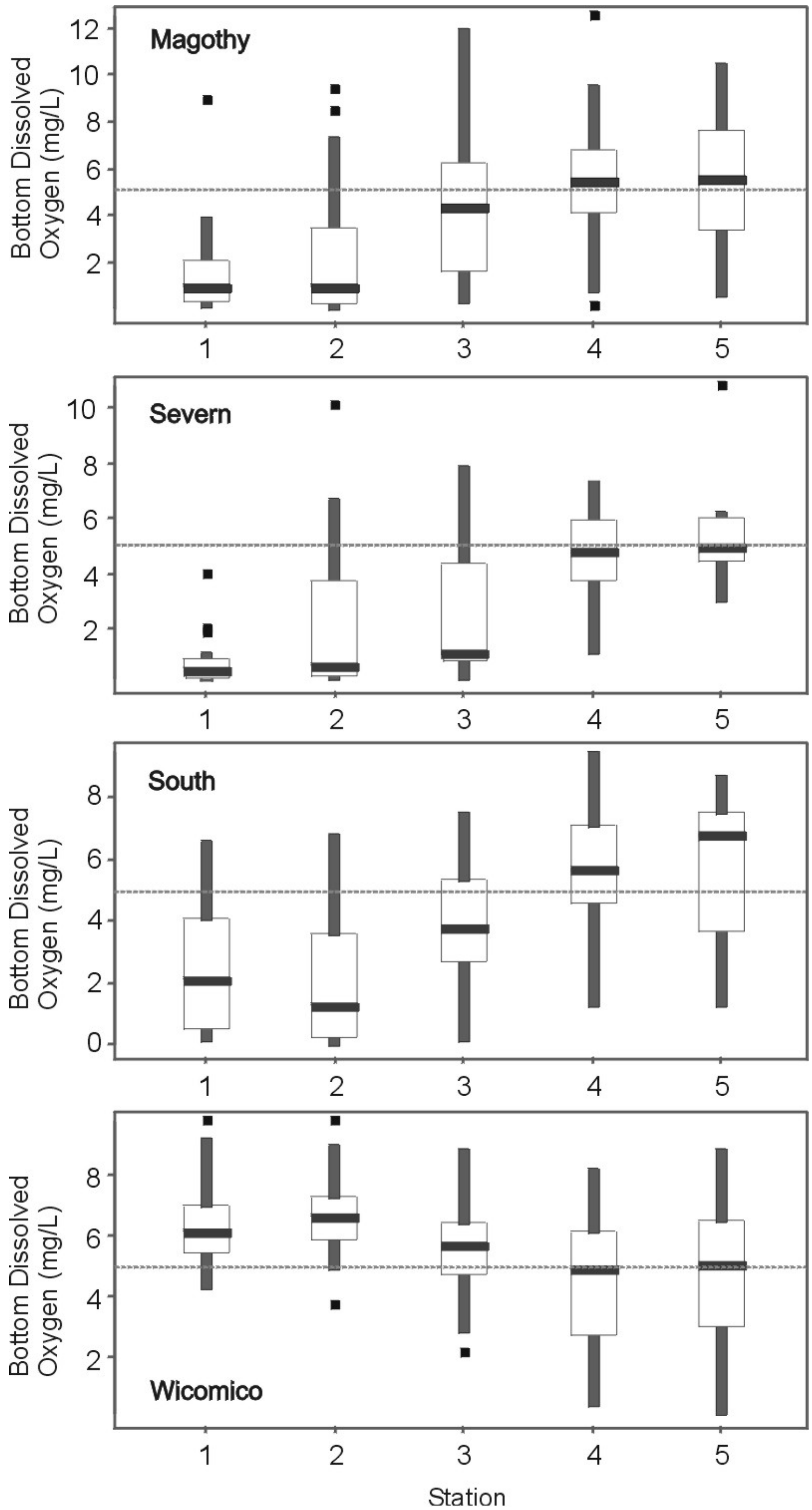

Figure 12. Historic distributions of bottom dissolved oxygen in suburban (Magothy, Severn and South Rivers) and rural (Wicomico River) watersheds. Lowest station number indicates upper most station and highest station number indicates station near the tributary mouth.