Final Report

1 October 2011 – 30 September 2013

Project Title: A Retrospective Analysis of Spatial and Temporal Patterns of Growth and Abundance of Juvenile Anadromous Fishes in the Maryland Chesapeake Bay

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SYNOPSIS

Recruitment success of anadromous fishes (striped bass, white perch and alosines) in Maryland tributaries to Chesapeake Bay varies dramatically from year to year. Additionally, the tributaries and their watersheds differ in the degree of human development and impact that may affect reproductive success and productivity of anadromous fishes. In this project we undertook a retrospective analysis of data on abundance, sizes, growth rates, and production of young-of-the-year (YOY) anadromous fishes based on data from the Maryland Department of Natural Resources (DNR) Juvenile Striped Bass Seine Survey that has been conducted since 1959. Additionally, data on taxable structures located within three watersheds (Choptank, Nanticoke, and Patuxent rivers) were analyzed as a proxy for level of human activity and anthropogenic stress to evaluate potential effects of watershed development on growth, distribution, and abundance of YOY anadromous fishes. Significant increases in the combined-taxa abundance and biomass of YOY anadromous fishes were detected in the subestuaries that were sampled over the full time course of the DNR surveys. Abundances of the YOY alosines group declined significantly in the Choptank River but increased in the Potomac River, attributable to increasing numbers of YOY American shad in the Potomac. Significant negative temporal trends in mean lengths were detected for some YOY anadromous fish taxa. Despite the apparent trends in abundance and biomass, only a few of the trends in net production of anadromous fishes were judged to be significant. Shifts in spatial distribution of some YOY anadromous fishes occurred during the 53-yr time series, with observed shifts in centers of abundance being primarily down-estuary in some tributaries. Principal components analyses identified correlations and temporal patterns among water quality parameters, freshwater flow, anadromous fish abundances and their centers of abundance.

Research initiated in this project is being continued under funding from Maryland DNR via the Atlantic States Marine Fisheries Commission. Analyses on a suite of biotic and abiotic variables to identify and evaluate sources of interannual variability in abundance, sizes, and growth rates of YOY anadromous fishes are being conducted in the continuing research.

INTRODUCTION AND BACKGROUND

This is the Final Report for NOAA Grant NA11NMF4570219. The research was conducted in response to a NOAA Chesapeake Bay Office RFP priority requesting retrospective analyses of long-term monitoring data to develop resource management products. The project was initiated on 1 October 2011 and was funded for a single year. A one-year no-cost extension was granted that extended the project to 30 September 2013. This research is continuing under a contract from Maryland Department of Natural Resources (Contract Number K00B3400024) via the Atlantic States Marine Fisheries Commission for the period 16 July 2012 to 15 July 2014.

Anadromous fishes, including striped bass, white perch, and alosines (American shad, hickory shad, alewife, and blueback herring) are ecologically and economically important in Chesapeake Bay. Recruitment success of many anadromous fishes exhibits more than 10-fold inter-annual variability in the Bay. While the recruitment levels of these fishes are correlated among Maryland's Chesapeake Bay tributaries (Kraus and Secor 2005; Wood and Austin 2009), the contribution of YOY recruits by each tributary depends on numerous factors in addition to watershed size or areal extent of available habitat. Watersheds of each of the tributaries have experienced different land use patterns and nutrient loading regimes that can affect carrying capacity and production potential (Carlisle et al. 2013).

The proximity of many of the spawning and nursery grounds in Maryland to urbanized areas makes these species especially sensitive to anthropogenic influences (Schaaf et al. 1993; Uphoff 2008). Analyses conducted by the Maryland Department of Natural Resources (DNR) indicated negative relationships between the area of impervious surface (IS) within a watershed, dissolved oxygen concentrations, and abundance of juvenile anadromous fishes in several small Chesapeake Bay and Potomac River tributaries (McGinty et al. 2006; Uphoff 2008; Uphoff et al. 2011). Furthermore, the occurrences of white perch and yellow perch eggs, larvae, and adults were diminished in the Bush River watershed in 2006 (IS coverage = 13%) relative to 1973 (IS coverage = 9%) (Uphoff et al. 2007). Relationships among long-term trends in nutrients and dissolved oxygen (Hagy et al. 2004; Kemp et al. 2005; Testa et al. 2008; Prasad et al. 2010; Williams et al. 2010) and changes in land use and agricultural practices in Chesapeake watersheds and the Bay have been documented (Cronin and Vann 2003; Kemp et al. 2005; McGinty et al. 2006; Uphoff et al. 2011; Williams et al. 2010). The research conducted by DNR on watersheds differing in IS coverage was limited to data collected during a 3-year period. We evaluated relationships among long-term trends in abundance, growth, and production of young-of-the-year (YOY) anadromous fishes that may facilitate management decisions on allocation of restoration efforts and protective regulations.

OBJECTIVES

- Quantify differences and trends in abundance, size, and growth rate among YOY anadromous fishes in Maryland's upper Chesapeake Bay and tributaries.

- Document shifts in distributions of YOY anadromous fishes in Maryland's upper Chesapeake Bay and tributaries and relate to human habitation/land-use.

- Compare the historical abundance of zooplankton and benthic prey organisms for YOY anadromous fishes across tributaries and quantify temporal trends.

- Evaluate relationships between YOY fish, their zooplankton/benthos prey, environmental variables, and land use metrics.

METHODS AND APPROACHES

Monitoring Data

The Maryland Department of Natural Resources Juvenile Striped Bass Seine Survey (*http://www.dnr.state.md.us/fisheries/juvindex/)* has collected, enumerated, and measured YOY anadromous fishes in the Maryland tributaries of the Bay since 1957 (Figure 1). The systems sampled since initiation of the survey include the Potomac River, the Choptank River, the Nanticoke River, and the head of the Bay. The Patuxent River has been sampled since 1983. There are multiple permanent and auxiliary sampling sites in each system. Each site is sampled once each month in July, August, and September using a 30.5-m x 1.24-m bag-less beach seine of untreated 6.4-mm bar mesh. The time series is sufficiently long to capture shifts in abundance that appear to be related to changes in freshwater flow patterns, other environmental variables, and adult spawning stock biomasses. These data were analyzed to compare trends and differences in abundance, growth rates and biomass across tributaries under varying environmental conditions. With the exception of the Choptank River, only the sites sampled continuously in each tributary since the beginning of the survey were used in the analyses. In the Choptank River, only one site was sampled continuously since the beginning of the survey. However, replacement sites were selected in close proximity to the original sites and these were assumed to be representative of the respective regions of the Choptank River.

The Chesapeake Bay Program (CBP) has monitored water quality, species composition and abundance of mesozooplankton (through 2002), and the species composition and abundance of benthic organisms at fixed stations in Maryland since 1984 (Figure 1). Additional water quality data collected by the Chesapeake Bay

Institute dating back to 1949 are available. These data are being analyzed in the continuation phase of the project (with MD DNR and ASMFC support) to evaluate the potential of each tributary to support YOY anadromous fishes and to compare trends and patterns in the seine survey data.

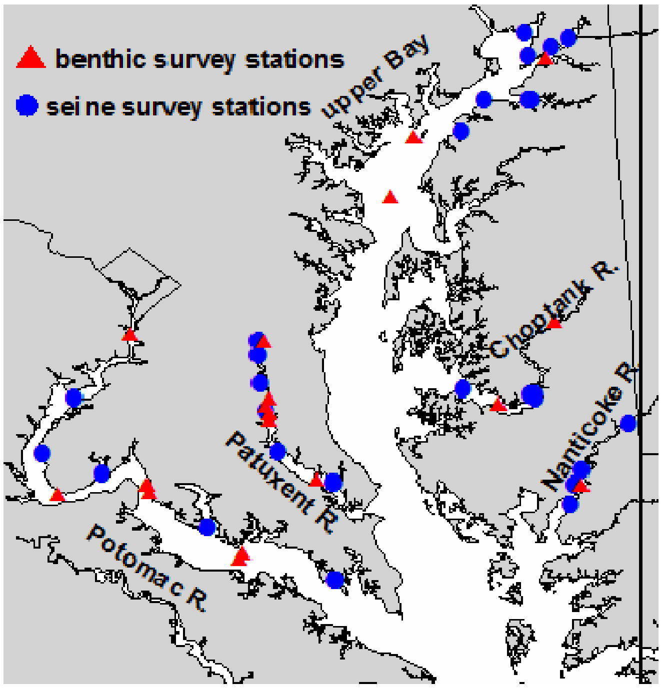

Figure 1. Map of the Maryland portion of Chesapeake Bay and tributaries. Sampling sites included in the analyses described in this report are represented by symbols. The sites are seine-sampling sites from the Maryland DNR Striped Bass Juvenile Index Survey (http://www.dnr.state.md.us/ fisheries/juvindex/)

Data on taxable structures from the Maryland State Department of Assessment and Taxation (SDAT) were incorporated into an analysis that examines anthropogenic alteration of the watershed and its relationship to abundance and growth of YOY anadromous fishes, shifts in water quality, and changes in land-use. The taxable structures data were selected for analysis because SDAT has collected data annually on the number and foundation footprint area of structures in each Maryland county since 1950. Additionally, area occupied by taxable structures has been reported to be strongly, positively correlated with estimates of impervious surface coverage (J. Uphoff, unpublished data).

Analyses

Annual mean abundance (number per 100 m^2) and biomass (grams wet weight per 100 m^2) estimates were calculated for alewife (*Alosa pseudoharengus*), blueback herring (*Alosa aestivalis)*, American shad (*Alosa sapidissima*), striped bass (*Morone saxatilis*), and white perch (*Morone americana*). Area swept by the MD DNR seine in a deployment was estimated using a quarter circle sweep or an approximately-trapezoidal sweep depending on the fraction of the seine's length that was deployed in a seine set (Martino and Houde 2012). The density (number per square meter) of each species was estimated for each sampling site during the survey each year, and the annual mean density was then calculated for each tributary (upper Chesapeake Bay, Choptank River, Nanticoke River, Patuxent River, and Potomac River). Length-to-wet-weight conversions were used to obtain a relative biomass estimate for each species at each sampling site. The number of years in the biomass time series differs for each species. Striped bass was the only species for which length was measured from the beginning of the seine survey (1957). White perch lengths were recorded since 1971 and the lengths of the alosines (alewife, American shad, and blueback herring) since 1991. Abundance and biomass for each species were estimated using only the survey sites at which a species occurred at least twice since the beginning of the survey. Prior to analysis, one-half of the minimum, non-zero abundance or biomass estimate for each tributary-species combination was added to all zero-catch sites in the tributary to allow inclusion of zero abundance values in a log-transformed data analysis. Trends in the transformed abundance and biomass data were identified and quantified using linear regression.

Trends in the sizes of YOY anadromous fishes over the survey years were quantified by examining median total lengths in September. Median lengths, rather than mean lengths, were analyzed because medians tend to be less sensitive to outliers. The analysis of growth rates was based on differences in median length of fish between the August and September surveys.

An index of net production of each species from August to September was calculated for each tributary by subtracting the mean relative biomass estimated in August from the mean relative biomass in September and then dividing by the number of days between the two sampling events.

Patterns or trends over years in the spatial distribution of each species were evaluated by estimating the center of abundance of each species in each system for the entire seine survey time series. The center of abundance was calculated as a weighted mean location (distance from the mouth of each tributary to each survey sampling site), with the location weighted by the abundance of each species collected at each site.

A principal components analysis was conducted to examine and evaluate relationships among fish density for each species with respect to their centers of abundance, freshwater flow, water quality variables, and the number of taxable structures in each watershed. Monthly mean freshwater discharge data for the Susquehanna, Choptank, Nanticoke, Patuxent, and Potomac rivers were retrieved from the United States Geological Survey (USGS) National Water Information Survey (USGS 2012). Water quality data, including water temperature, salinity, pH, dissolved oxygen (DO), chlorophyll *a*, dissolved nitrate + nitrite, and dissolved phosphate, collected from 1985 to 2010, the first and last available full years of data, were downloaded from the Chesapeake Bay Program (CBP) website (*http://www.chesapeakebay.net/data/downloads/cbp_water_quality_database_1984_present*). These variables were chosen because they provide biologically relevant information about environmental conditions within each tributary and because there were few missing observations (less than 10%). Mean values for each water quality variable and the flow data from each tributary were calculated for spring (March, April, May) and summer (June, July, and August) because conditions during these two seasons strongly influence the survival and growth of anadromous fish larvae and juveniles (North and Houde 2001, 2003, 2006; Martino and Houde 2010, 2012). Data on taxable structures were available only for the Choptank, Nanticoke, and Patuxent river watersheds.

PROGRESS

Abundance and biomass

There were several significant trends in the abundance of anadromous fishes included in the analysis. Herein, we first report on the abundances and biomasses of combined groups of taxa and species and then on the individual species. Striped bass and white perch data were combined into a moronid group while the data for American shad and the river herrings were combined into an alosine group. Finally, the data for all five species were combined into an anadromous group.

<u>Abundance</u>

Combined Groups

While there were periods of below-average abundance (i.e., density) for each of the groups from 1957 to approximately 1960, and again in the 1980s, the abundances of YOY anadromous fishes, most notably the moronid group, tended to exhibit positive trends since the beginning of the time series, which is consistent with patterns reported by Martino and Houde (2012) for striped bass and Wood and Austin (2009) for a suite of species. Conversely, with the exception of the Potomac River where YOY alosine abundances increased, alosine abundances were declining throughout the time series (Figure 2). The trends in abundance were fairly consistent among tributaries and within species groups, although slopes often were not statistically different from zero (Table 1). Alosine abundance was more variable than the moronid or anadromous groups because of frequent extreme high and low catches. Trends in the anadromous group abundance appear to be mostly driven by the moronid group, with absolute abundance scaled upwards by large alosine catches. Negative trends in abundance across groups within the Choptank River may be a consequence of the spatial distribution of survey sites in this tributary, which included only one site in the tidal fresh region. This site was excluded from our analysis because it was not sampled until 1984.

Table 1. Abundance of YOY anadromous fish groups in Chesapeake Bay. Slope, intercept, r^2 (%), and regression p-value estimates for the trends in mean annual abundance ($\log_{10}$ number per 100 m^2) of alosines (American shad, alewife, blueback herring), moronids (striped bass and white perch), and all anadromous species combined. Significant p-values ($p \leq 0.05$) are in bold.

System	Group	Slope	Intercept	r^2	p-value
Head of Bay	Alosines	-0.0005	1.67	0.01	0.9437
Choptank	Alosines	**-0.0120**	23.66	9.34	**0.0208**
Nanticoke	Alosines	-0.0031	6.62	0.48	0.6078
Patuxent	Alosines	-0.0057	11.10	0.81	0.6293
Potomac	Alosines	**0.0157**	-30.32	14.84	**0.0031**
Head of Bay	Moronids	0.0040	-7.07	2.90	0.2052
Choptank	Moronids	-0.0034	7.68	0.88	0.4889
Nanticoke	Moronids	**0.0079**	-14.62	8.66	**0.0263**
Patuxent	Moronids	0.0080	-15.17	1.75	0.4786
Potomac	Moronids	0.0049	-8.72	5.08	0.0920
Head of Bay	Anadromous	0.0038	-5.90	1.30	0.3987
Choptank	Anadromous	-0.0015	4.30	0.14	0.7791
Nanticoke	Anadromous	**0.0083**	-14.92	7.90	**0.0342**
Patuxent	Anadromous	0.0042	-7.10	0.47	0.7129
Potomac	Anadromous	**0.0127**	-23.47	22.16	**0.0002**

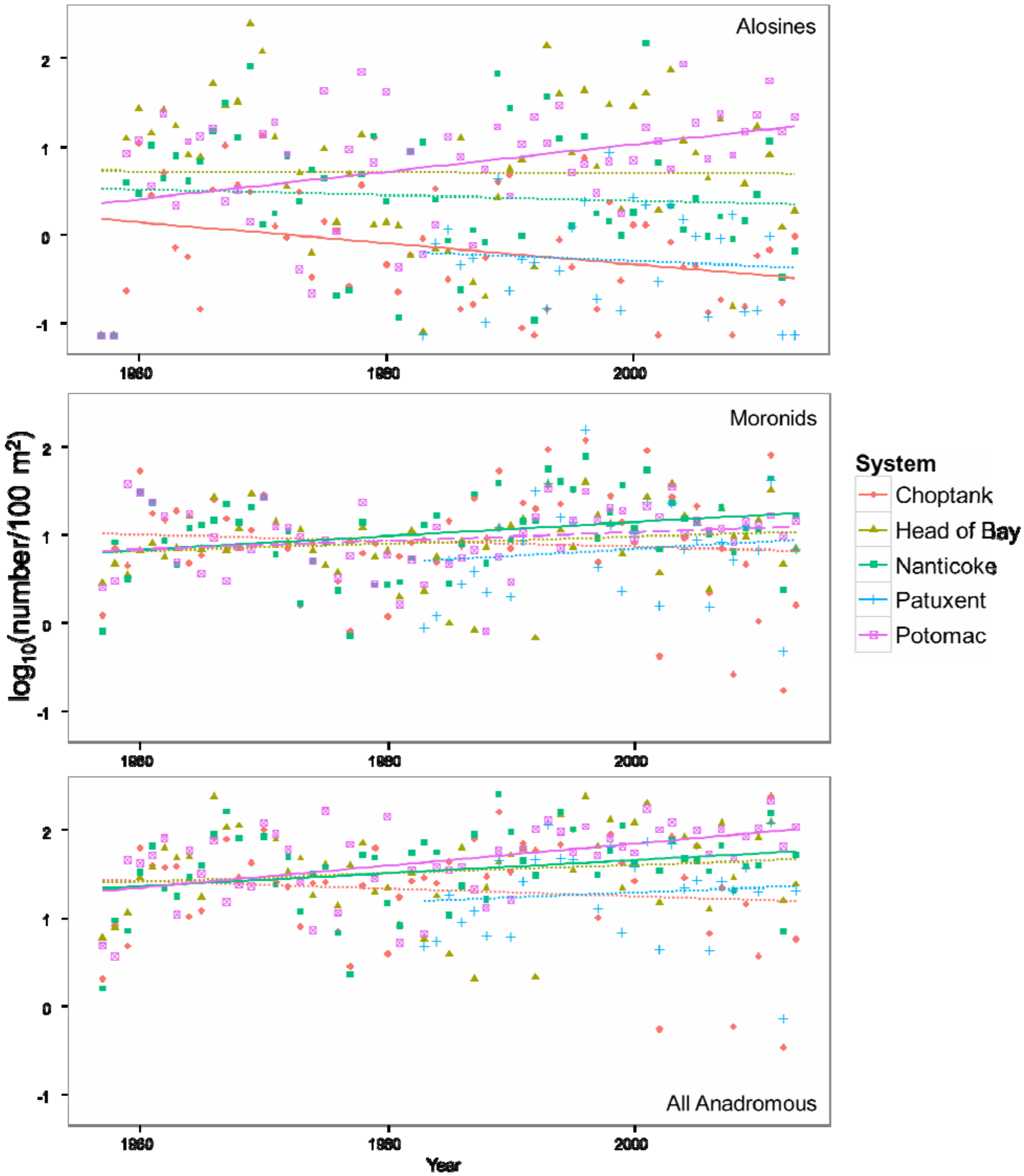

Figure 2. Trends in log_{10}- transformed density (i.e., abundance) of young-of-the-year moronids, alosines, and all anadromous species combined. Solid lines represent regressions with p-values ≤ 0.05. Dashed lines indicate regressions are near significant at 0.05 < p ≤ 0.10. Dotted lines indicate regressions with p > 0.10.

Abundance

Species-specific

The significant, positive trend in Potomac River alosine abundance (Table 1) reflects a concurrent significant increase in Potomac River YOY American shad abundance over the time series (Table 2; Figure 3). Similarly, decreasing trends in alosine-group abundance follow decreasing trends in the constituent species across the systems investigated (Table 2). Except in the Head of Bay, YOY alewife decreased across systems, although the trend was only significant within the Choptank. YOY blueback herring was the most variable in abundance of the alosines investigated, differing three orders of magnitude among years. Bluebacks declined significantly in the Choptank River but not in the other systems (Table 2; Figure 3).

YOY white perch exhibited the most significant abundance trends. With the exception of the Choptank, in which a slight, but not significant, negative trend was observed, trends in abundance were positive and comparatively large (Table 2; Figure 4).Trends in YOY striped bass abundance were consistently flat, with little evidence of any significant, long-term change in abundance in these systems.

Table 2. Abundance of YOY anadromous fishes in Chesapeake Bay. Slope, intercept, r^2 (%), and regression p-value estimates for the trends in mean annual abundance (log_{10} number per 100 m^2) of American shad, alewife, blueback herring, striped bass, and white perch. Significant p-values ($p \leq 0.05$) are in bold.

System	Species	Slope	Intercept	r^2	p-value
Head of Bay	Alewife	0.0000	-0.18	0.00	0.9917
Choptank	Alewife	**-0.0117**	22.67	13.79	**0.0045**
Nanticoke	Alewife	-0.0024	4.30	0.99	0.4607
Patuxent	Alewife	-0.0128	24.80	6.27	0.1742
Potomac	Alewife	-0.0056	10.68	2.96	0.2008
Head of Bay	Blueback herring	0.0046	-8.69	0.68	0.5431
Choptank	Blueback herring	**-0.0125**	24.39	12.72	**0.0065**
Nanticoke	Blueback herring	-0.0013	2.80	0.09	0.8258
Patuxent	Blueback herring	-0.0081	15.52	1.64	0.4922
Potomac	Blueback herring	0.0031	-5.79	0.47	0.6123
Head of Bay	American shad	0.0013	-3.15	0.17	0.7642
Choptank	American shad	-0.0146	27.74	10.64	0.0902
Nanticoke	American shad	**-0.0061**	11.21	15.10	**0.0028**
Patuxent	American shad	0.0225	-45.51	10.82	0.0708
Potomac	American shad	**0.0265**	-52.89	36.89	**<0.0001**
Head of Bay	Striped bass	-0.0044	8.77	3.45	0.1664
Choptank	Striped bass	0.0059	-11.61	3.02	0.1959
Nanticoke	Striped bass	0.0010	-2.05	0.19	0.7459
Patuxent	Striped bass	0.0116	-23.02	3.21	0.3349
Potomac	Striped bass	0.0052	-10.24	5.43	0.0811
Head of Bay	White perch	**0.0143**	-27.91	20.92	**0.0003**
Choptank	White perch	-0.0077	15.59	3.25	0.1800
Nanticoke	White perch	**0.0129**	-24.92	14.53	**0.0034**
Patuxent	White perch	0.0226	-44.55	11.49	0.0623
Potomac	White perch	**0.0081**	-15.58	8.24	**0.0304**

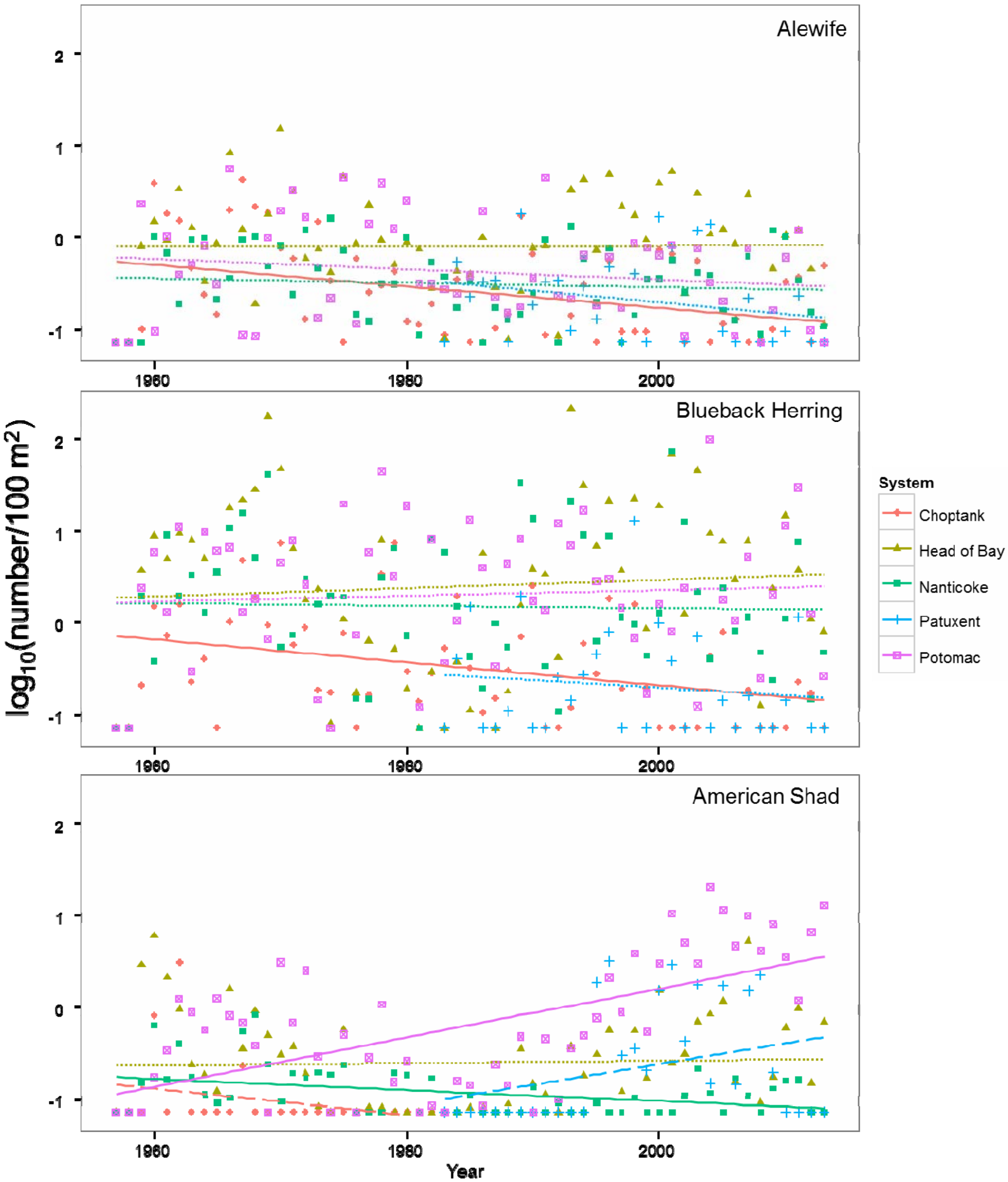

Figure 3. Trends in log_{10} - transformed density (i.e., abundance) of young-of-the-year alosines (alewife, blueback herring, and American shad). Solid lines represent regressions with p-values ≤ 0.05. Dashed lines indicate regressions are near significant at 0.05 < p ≤ 0.10. Dotted lines indicate regressions with p > 0.10.

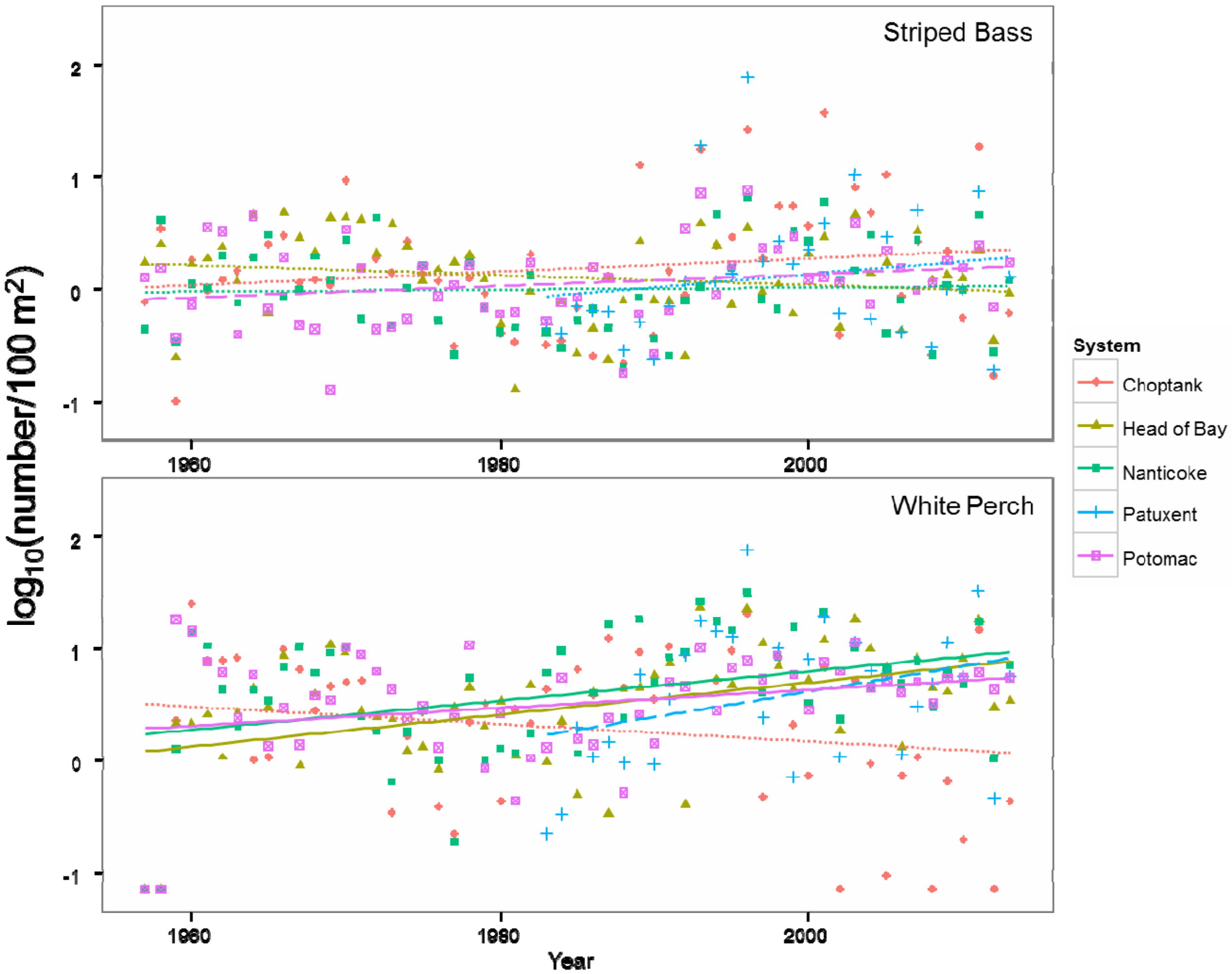

Figure 4. Trends in log_{10} - transformed density (i.e., abundance) of young-of-the-year moronids (striped bass and white perch). Solid lines represent regressions with p-values ≤ 0.05. Dashed lines indicate regressions are near significant at 0.05 < p ≤ 0.10. Dotted lines indicate regressions with p > 0.10.

<u>Biomass</u>

Combined Groups

With the exception of the Patuxent River, which had the shortest duration in the DNR survey, there were significant, positive trends in the biomass of YOY moronids. Biomass of YOY alosines, which could only be estimated since 1990, exhibited no significant trends in any of the systems (Figure 5, Table 3). No slopes of the trends in biomass for the combined YOY alosine or anadromous fishes differed significantly from zero in any of the systems for the period 1990 to present. There were fewer significant trends in the biomass data than in the abundance data, primarily because of the shorter period of data availability on fish sizes in the survey.

Table 3. Biomass of YOY anadromous fish groups in Chesapeake Bay. Slope, intercept, r^2 (%), and regression p-value estimates for the trends in mean annual biomass (log_{10} grams wet weight per 100 m^2) of alosines (American shad, alewife, blueback herring), moronids (striped bass and white perch), and all anadromous species combined. Significant p-values ($p \le 0.05$) are in bold.

System	Group	Slope	Intercept	r^2	p-value
Head of Bay	Alosines	-0.0040	9.06	0.09	0.8997
Choptank	Alosines	0.0158	-32.01	2.12	0.5284
Nanticoke	Alosines	0.0254	-50.43	3.67	0.4053
Patuxent	Alosines	0.0023	-4.30	0.07	0.9063
Potomac	Alosines	0.0179	-34.74	5.65	0.2997
Head of Bay	Moronids	**0.0182**	-34.96	31.66	**0.0001**
Choptank	Moronids	**0.0185**	-35.49	11.44	**0.0306**
Nanticoke	Moronids	**0.0216**	-41.76	28.33	**0.0004**
Patuxent	Moronids	0.0141	-26.80	5.27	0.2310
Potomac	Moronids	**0.0181**	-34.97	26.42	**0.0006**
Head of Bay	Anadromous	0.0064	-10.68	0.66	0.7256
Choptank	Anadromous	-0.0501	102.27	15.20	0.0807
Nanticoke	Anadromous	-0.0140	30.01	4.79	0.3408
Patuxent	Anadromous	-0.0155	32.55	3.68	0.4046
Potomac	Anadromous	0.0003	1.55	0.00	0.9759

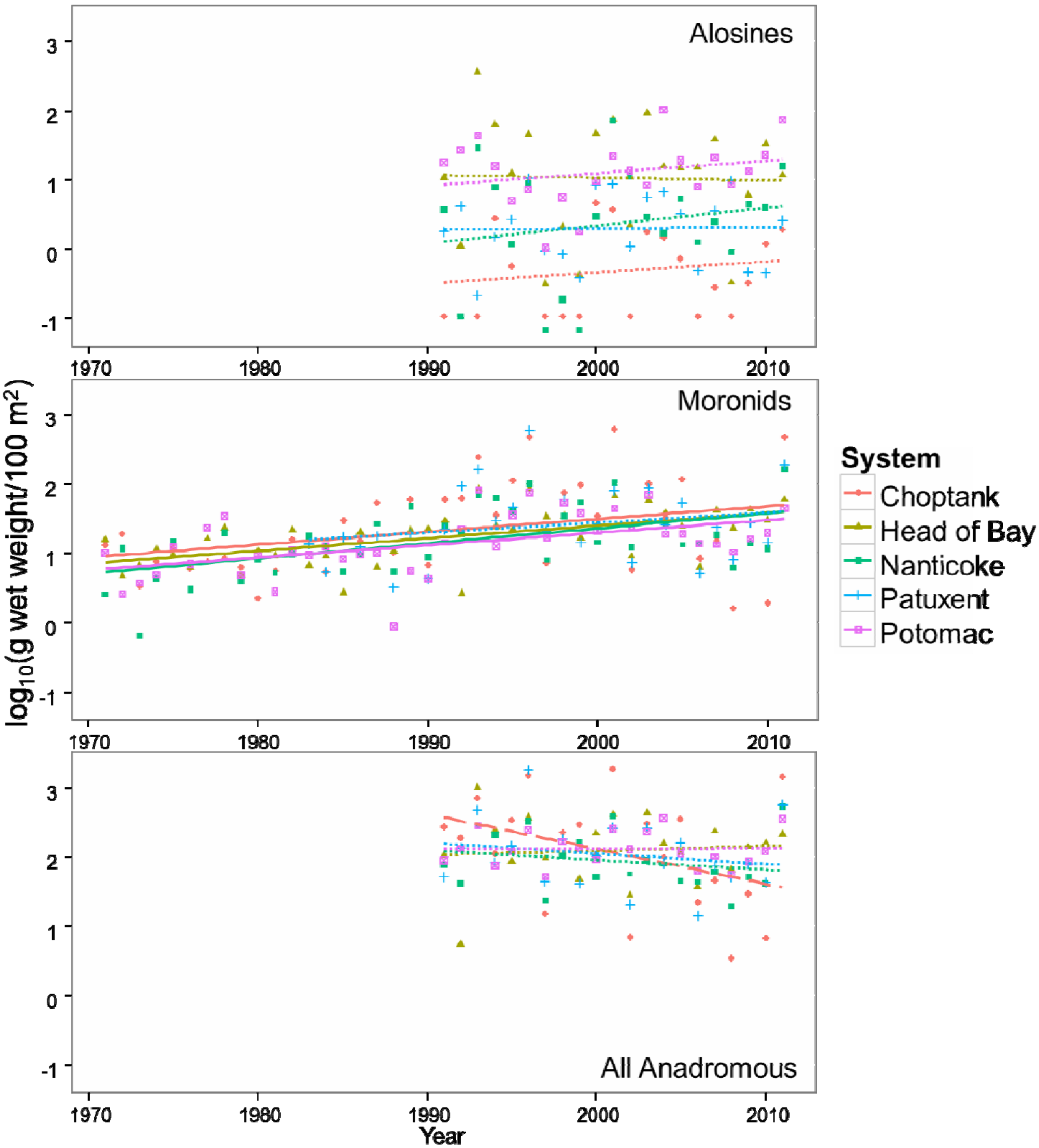

Figure 5. Trends in $\log_{10}$-transformed biomass of young-of-the-year moronids, alosines, and all anadromous species combined. Solid lines represent regressions with p-values ≤ 0.05. Dashed lines indicate regressions are near significant at 0.05 < p ≤ 0.10. Dotted lines are regressions with p > 0.10.

Biomass

Species-specific

YOY American shad had significant positive trends in biomass within the Nanticoke and Potomac Rivers (Figure 6, Table 4). There were, however, no significant trends in biomass in any of the systems for YOY alewife or blueback herring. YOY white perch had strongly significant positive trends in biomass in all systems except the Choptank River. The slopes for the significant trends were similar, ranging from 0.0260-0.0284 $\log_{10}$ grams wet weight 100 m^{-2} $year^{-1}$ (Figure 7, Table 4). Conversely, slopes of the trends in YOY striped bass biomass over the time series were near-zero and not significant, indicating that the trends in white perch biomass drove the observed biomass trends in the combined moronid group.

Table 4. Biomass of YOY anadromous fishes in Chesapeake Bay. Slope, intercept, r^2 (%), and regression p-value estimates for the trends in mean annual biomass ($\log_{10}$ grams wet weight per 100 m^2) of American shad, alewife, blueback herring, striped bass, and white perch. Significant p-values ($p \le 0.05$) are in bold.

System	Species	Slope	Intercept	r^2	p-value
Head of Bay	Alewife	0.0029	-5.29	0.06	0.9162
Choptank	Alewife	0.0104	-21.16	2.08	0.5325
Nanticoke	Alewife	0.0070	-14.26	0.62	0.7342
Patuxent	Alewife	-0.0206	41.13	4.85	0.3375
Potomac	Alewife	0.0022	-4.60	0.06	0.9169
Head of Bay	Blueback herring	-0.0045	9.83	0.07	0.9122
Choptank	Blueback herring	-0.0018	2.98	0.05	0.9267
Nanticoke	Blueback herring	0.0126	-25.14	0.68	0.7231
Patuxent	Blueback herring	-0.0041	7.68	0.32	0.8073
Potomac	Blueback herring	0.0101	-19.93	0.34	0.8022
Head of Bay	American shad	0.0326	-65.23	17.11	0.0623
Nanticoke	American shad	**0.0366**	-73.58	36.76	**0.0036**
Patuxent	American shad	0.0197	-39.32	3.17	0.4399
Potomac	American shad	**0.0779**	-155.28	51.12	**0.0003**
Head of Bay	Striped bass	-0.0056	11.84	4.67	0.1165
Choptank	Striped bass	0.0083	-15.47	3.17	0.1978
Nanticoke	Striped bass	-0.0064	13.31	4.45	0.1294
Patuxent	Striped bass	0.0150	-29.06	4.18	0.2876
Potomac	Striped bass	0.0003	-0.02	0.01	0.9388
Head of Bay	White perch	**0.0284**	-55.50	33.95	**0.0001**
Choptank	White perch	0.0010	-1.43	0.02	0.9350
Nanticoke	White perch	**0.0284**	-55.52	30.37	**0.0002**
Patuxent	White perch	**0.0262**	-51.12	15.10	**0.0372**
Potomac	White perch	**0.0260**	-51.06	27.68	**0.0004**

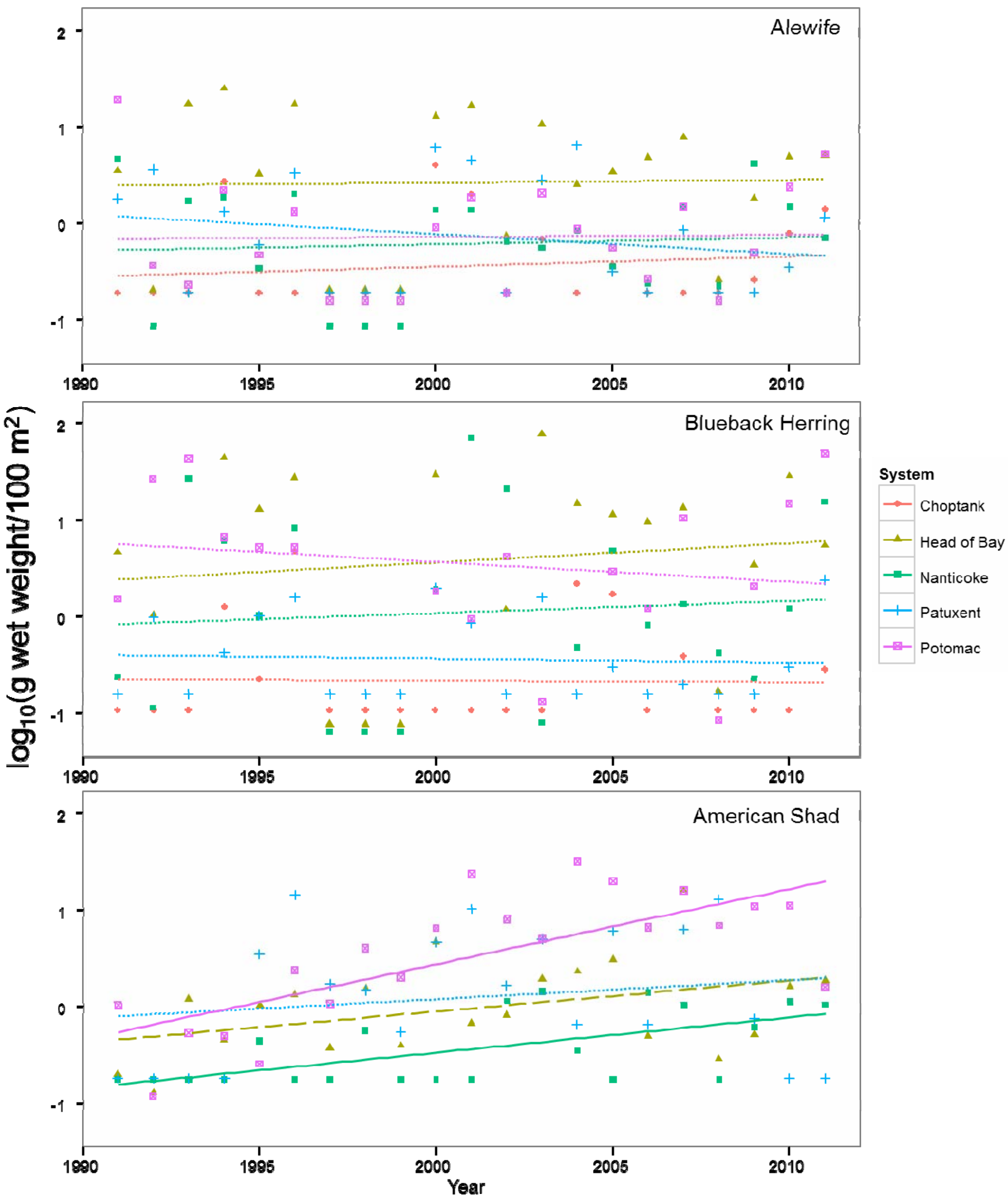

Figure 6. Trends in $\log_{10}$ - transformed biomass of young-of-the-year alosines (alewife, blueback herring, and American shad) for the period 1990 to present. Solid lines represent regressions with p-values ≤ 0.05. Dashed lines indicate regressions are near significant at 0.05 < p ≤ 0.10. Dotted lines are regressions with p > 0.10.

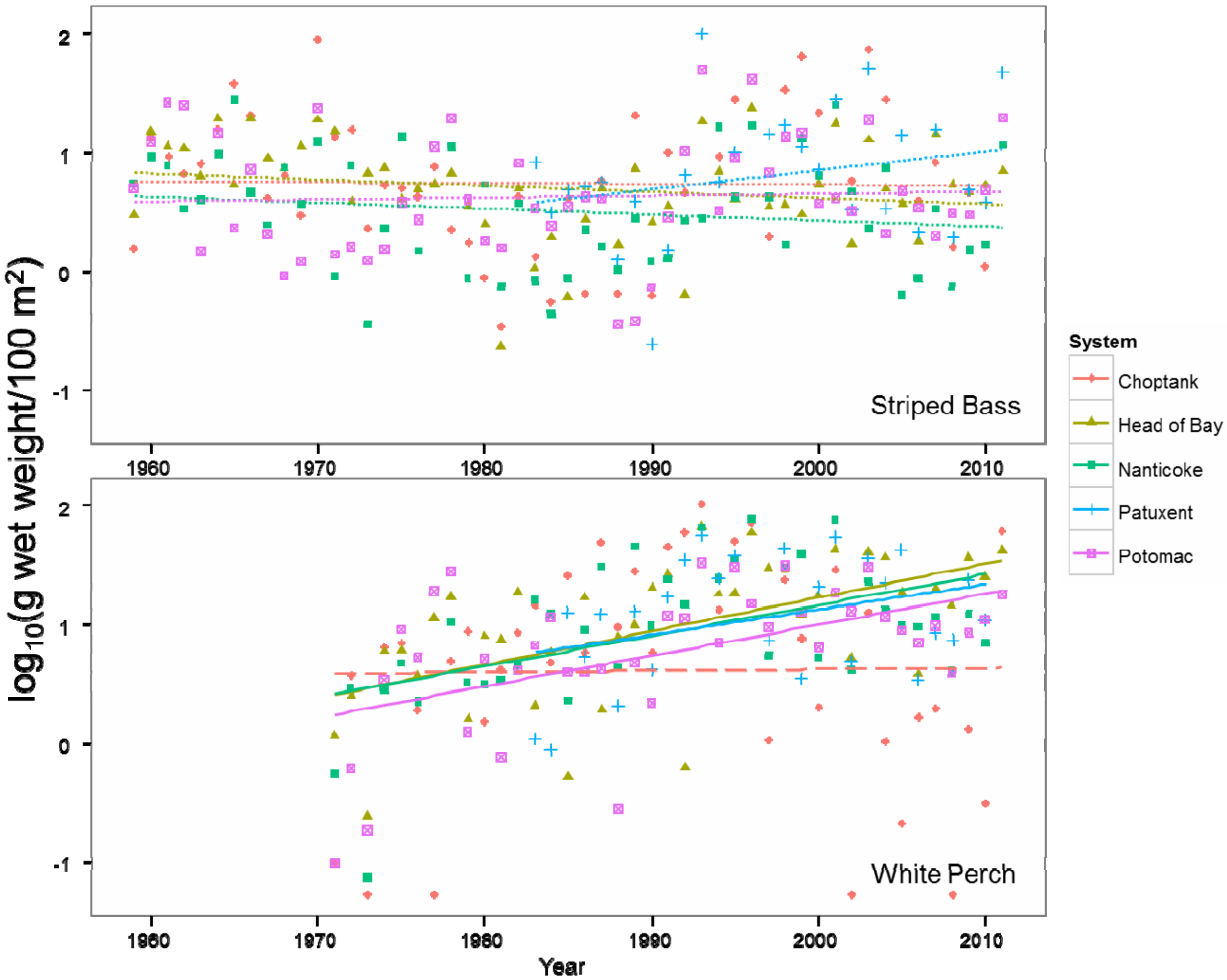

Figure 7. Trends in log_{10} - transformed biomass of young-of-the-year moronids (striped bass and white perch) for the periods 1957 to present (striped bass) and 1971 to present (white perch). Solid lines represent regressions with p-values ≤ 0.05. Dashed lines indicate regressions are near significant at 0.05 < p ≤ 0.10. Dotted lines indicate regressions with p > 0.10.

Length, growth, and production

Length

The analysis of median lengths in September indicated six significant negative trends (Figure 8, Table 5) and no significant positive trends in length over the survey period. Only YOY striped bass and American shad exhibited significant negative trends in more than one tributary. No significant trends in length were observed for YOY alewife or blueback herring.

Growth

There were no strong or consistent trends in growth rates of the YOY anadromous fishes. Only three close-to-significant trends in August-September growth rates were observed (Table 6). One (white perch, Potomac) was positive and two (white perch, Patuxent and American shad, Potomac) were negative. Trends in growth rates were more variable than trends in median length because too few individuals were collected (<5) in several survey years to provide robust estimates. Additionally, there were many years when small individuals continued to recruit (become available) to the seine gear in September, which resulted in lower or negative estimates of growth rates. We will conduct a modal length progression analysis in the continuation of this research that may provide better and more consistent growth rate estimates.

Table 5. Lengths of YOY anadromous fishes in Chesapeake Bay. Slope, intercept, r^2 (%), and regression p-value estimates for the trends in median length in September. Significant ($p \leq 0.05$) trends are in bold. Significant p-values ($p \leq 0.05$) are in bold.

Species	System	Slope	Intercept	r^2	p-value
Alewife	Head of Bay	-0.23	544.86	2.17	0.615
Alewife	Choptank	1.03	-1960.46	30.13	0.380
Alewife	Nanticoke	-0.63	1337.28	25.03	0.082
Alewife	Patuxent	-3.44	6972.49	76.22	0.127
Alewife	Potomac	-0.61	1304.77	19.95	0.145
American shad	Head of Bay	**-0.70**	1493.2	46.23	**0.011**
American shad	Patuxent	1.19	-2288.83	39.05	0.133
American shad	Potomac	**-0.81**	1709.25	30.20	**0.022**
Blueback herring	Head of Bay	-0.03	119.89	0.24	0.851
Blueback herring	Choptank	-0.12	306.79	5.30	0.496
Blueback herring	Nanticoke	0.16	-261.42	8.75	0.305
Blueback herring	Patuxent	-0.12	307.08	2.92	0.746
Blueback herring	Potomac	-0.02	110.02	0.34	0.835
Striped bass	Head of Bay	0.00	89.52	0.24	0.976
Striped bass	Choptank	**-0.38**	849.03	11.04	**0.036**
Striped bass	Nanticoke	**-0.34**	762.43	15.41	**0.007**
Striped bass	Patuxent	**-0.67**	1423.79	26.81	**0.005**
Striped bass	Potomac	-0.08	240.35	0.70	0.576
White perch	Head of Bay	-0.01	79.23	0.01	0.947
White perch	Choptank	0.12	-159.3	2.39	0.470
White perch	Nanticoke	0.00	55.12	0.00	0.976
White perch	Patuxent	**-0.49**	1054.3	17.99	**0.024**
White perch	Potomac	0.03	14.21	0.31	0.739

Figure 8. The six significant, negative trends in September median lengths of YOY anadromous fishes in tributaries and the head of Chesapeake Bay (see Table 5).

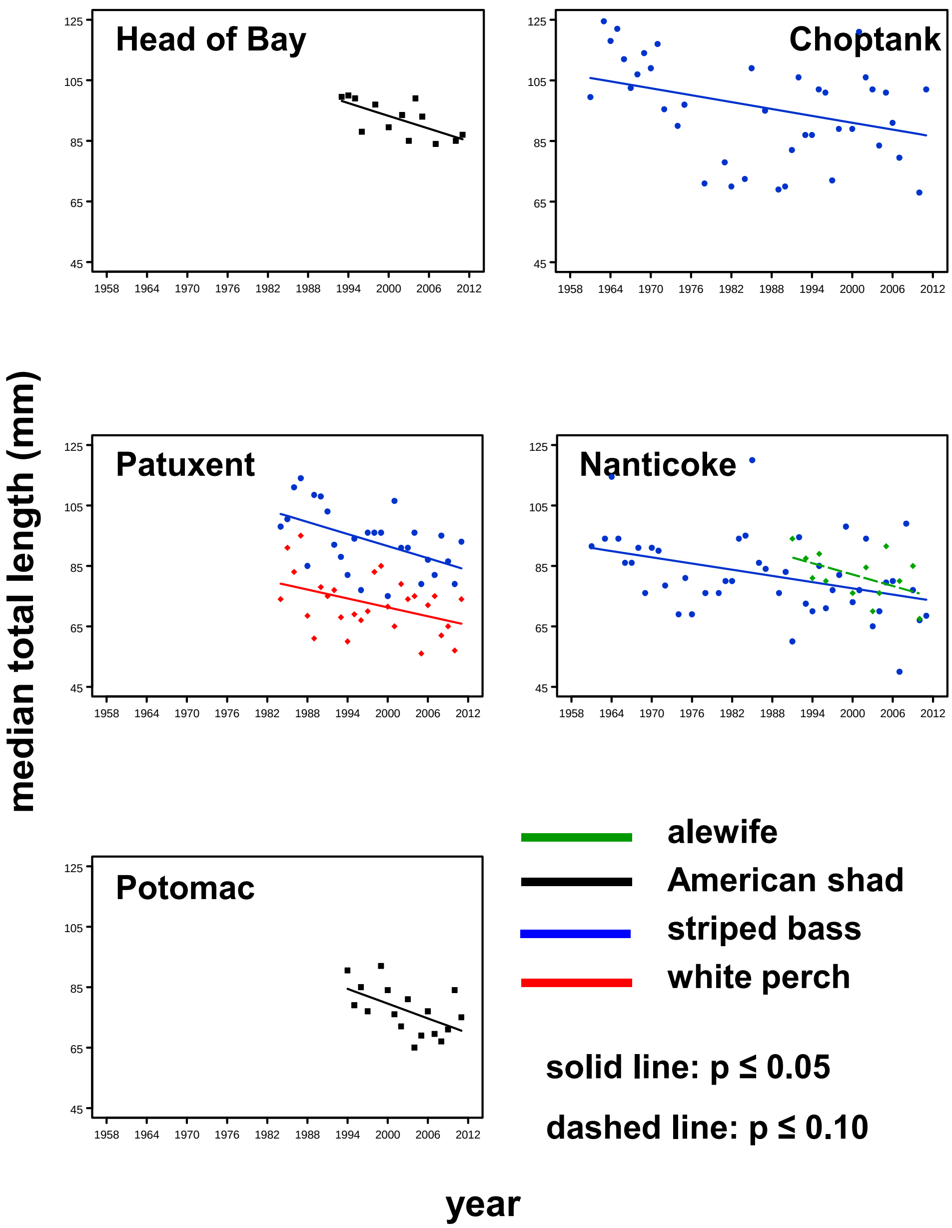

Table 6. Growth Rates of YOY anadromous fishes in Chesapeake Bay. Slope, intercept, r^2(%), and regression p-value estimates for the trends in growth rates (mm total length/d)from August to September) over the survey years. No trends were significant at the p ≤ 0.05 level, although three (Patuxent white perch and Potomac American shad and white perch) approached the significance level.

System	Species	Slope	Intercept	r^2	p-value
Head of Bay	Alewife	-0.0211	42.43	18.33	0.127
Head of Bay	American shad	-0.0065	13.42	6.01	0.443
Head of Bay	Blueback herring	-0.0005	0.99	0.02	0.954
Head of Bay	Striped bass	-0.0031	6.39	3.04	0.241
Head of Bay	White perch	-0.0020	4.24	1.34	0.484
Choptank	Blueback herring	-0.0031	6.26	5.98	0.526
Choptank	Striped bass	-0.0040	8.32	1.86	0.428
Choptank	White perch	0.0020	-3.76	2.22	0.498
Nanticoke	Alewife	-0.0091	18.42	13.01	0.306
Nanticoke	Blueback herring	-0.0111	22.29	15.02	0.239
Nanticoke	Striped bass	-0.0028	6.05	0.76	0.579
Nanticoke	White perch	0.0002	-0.26	0.03	0.924
Patuxent	American shad	-0.0243	48.94	27.49	0.227
Patuxent	Blueback herring	-0.0099	20.07	15.21	0.610
Patuxent	Striped bass	-0.0076	15.49	8.03	0.152
Patuxent	White perch	-0.0068	13.69	13.60	0.054
Potomac	Alewife	0.0044	-8.54	2.86	0.599
Potomac	American shad	-0.0094	19.05	22.99	0.052
Potomac	Blueback herring	-0.0053	10.78	4.79	0.452
Potomac	Striped bass	-0.0055	11.28	5.55	0.124
Potomac	White perch	0.0039	-7.48	13.28	0.052

Net Production

Estimating net production based on the changes in median sizes of YOY fish between August and September indicated a single significant trend (positive for blueback herring, Choptank River) for years in the survey where both abundance and sizes of YOY anadromous fishes were available (Table 7). The difficulties in estimating growth rates (see above paragraph) were magnified in the net production analysis.

Table 7. Net Production of YOY anadromous fishes in Chesapeake Bay. Slope, intercept, r^2 (%), and regression p-value estimates for the trends in net production (g wet weight/m^2/d) from August to September over the survey years. Too few American shad were collected in the Choptank River to estimate production. Significant ($p < 0.05$) trends are in bold.

System	Species	Slope	Intercept	r^2	p-value
Bay	Alewife	-0.00006	0.13	0.43	0.778
Bay	American shad	-0.00006	0.12	4.55	0.353
Bay	Blueback herring	0.00021	-0.41	0.21	0.844
Bay	Striped bass	-0.00002	0.05	0.75	0.553
Bay	White perch	0.00001	-0.03	0.14	0.814
Choptank	Alewife	-0.00002	0.03	0.50	0.766
Choptank	American shad	NA	NA	NA	NA
Choptank	Blueback herring	**0.00039**	-0.79	24.84	**0.022**
Choptank	Striped bass	0.00187	-3.69	4.52	0.147
Choptank	White perch	-0.00011	0.22	1.72	0.414
Nanticoke	Alewife	0.00003	0.05	2.62	0.484
Nanticoke	American shad	0.000004	-0.01	9.14	0.183
Nanticoke	Blueback herring	0.00061	1.22	4.50	0.356
Nanticoke	Striped bass	-0.00005	0.09	5.42	0.111
Nanticoke	White perch	0.00005	-0.10	1.05	0.524
Patuxent	Alewife	0.00002	-0.04	1.06	0.658
Patuxent	American shad	-0.00015	0.31	10.04	0.162
Patuxent	Blueback herring	-0.00002	0.03	9.96	0.164
Patuxent	Striped bass	-0.00007	0.15	1.21	0.570
Patuxent	White perch	-0.00003	0.07	0.25	0.798
Potomac	Alewife	-0.00008	0.16	12.30	0.119
Potomac	American shad	-0.00009	0.17	0.26	0.825
Potomac	Blueback herring	0.00095	-1.88	2.06	0.535
Potomac	Striped bass	-0.00010	0.28	7.14	0.066
Potomac	White perch	-0.00007	0.13	3.59	0.236

Centers of abundance

Eight of the eleven significant slopes of trends in the location of the center of abundance of YOY anadromous fishes indicated a down-estuary shift (Table 8). Alewife, in all systems with the exception of in the upper-Bay, experienced substantial down-estuary shifts of 0.16 to 0.60 km year^{-1} since the beginning of the survey. Shifts in the center of mass that occurred for other species were not consistent, though most up-estuary shifts were not statistically significant. All species had significant down-estuary shifts in the Choptank River, ranging from 0.45 to 0.75 km year^{-1}. Most trends in the upper Bay were up-bay. Since sites sampled by the DNR seine survey include only one or two stations in upper-Bay tributaries, the survey design may be inadequate to detect down-estuary shifts.

Table 8. Centers of Abundance of YOY anadromous fishes in Chesapeake Bay. Slope (river km year^{-1}), intercept, r^2 (%), and regression p-value estimates for trends during the survey years in the annual centers of abundance. Negative slopes indicate a down-estuary shift in the center of abundance, and positive slope values indicate an up-estuary shift. Significant ($p < 0.05$) trends are in bold.

System	Species	Slope	Intercept	r2	p-value
Head of Bay	Alewife	0.0614	178.50	2.10	0.2917
Choptank	Alewife	**-0.4505**	936.19	19.77	**0.0022**
Nanticoke	Alewife	**-0.1666**	364.25	8.17	**0.0420**
Patuxent	Alewife	**-0.6044**	1265.06	25.85	**0.0186**
Potomac	Alewife	**-0.4539**	1016.35	13.71	**0.0063**
Head of Bay	Blueback Herring	0.0631	176.91	1.33	0.4151
Choptank	Blueback Herring	**-0.5629**	1161.87	30.74	**0.0001**
Nanticoke	Blueback Herring	0.0239	-4.15	0.28	0.7026
Patuxent	Blueback Herring	-0.1079	280.35	2.76	0.5243
Potomac	Blueback Herring	**-0.3236**	775.21	17.70	**0.0015**
Head of Bay	American Shad	0.0290	246.99	1.01	0.5106
Nanticoke	American Shad	0.1176	-188.09	7.84	0.1145
Patuxent	American Shad	-0.2092	482.13	10.84	0.2307
Potomac	American Shad	-0.0449	225.17	0.78	0.5508
Head of Bay	Striped bass	-0.0228	341.91	0.43	0.6269
Choptank	Striped bass	**-0.4486**	925.96	30.33	**<0.0001**
Nanticoke	Striped bass	0.0055	18.62	0.02	0.9124
Patuxent	Striped bass	-0.0562	162.85	0.24	0.7955
Potomac	Striped bass	**0.3620**	-617.81	8.62	**0.0267**
Head of Bay	White perch	**0.1535**	-1.70	17.21	**0.0016**
Choptank	White perch	**-0.7541**	1542.72	57.74	**<0.0001**
Nanticoke	White perch	0.0445	-51.05	0.88	0.4952
Patuxent	White perch	-0.2216	497.88	6.84	0.1551
Potomac	White perch	**0.2858**	-449.54	7.91	**0.0376**

Principal components analyses

Some common patterns were detected by the principal components analyses (PCA). The first two principal components (PCs) captured between 39.6% and 46% of the variance (Figures 9-13). As expected, there were positive correlations in each tributary between freshwater flow and nutrients in both spring and summer. The abundances of YOY anadromous fishes were generally positively correlated with freshwater flow and loaded highly on PC1, indicating that freshwater flow and nutrients were important sources of variability in the data. Additionally, there were temporal trends in all five tributaries, due in part to the abundance trends of anadromous fishes during the survey period (described above). However, there also were some differences in the patterns among tributaries. The definitions of variables in the PCA are provided in Table 9.

Table 9. Definitions of the variable abbreviations in Figures 5-9.

Variable	Definition	Variable	Definition
am	Atlantic menhaden density	sp.chla	spring chlorophyll a
as	American shad density	sp.do	spring dissolved oxygen
aw	alewife density	sp.no23f	spring nitrite + nitrate
bb	blueback herring density	sp.ph	spring pH
sb	striped bass density	sp.po4	spring phosphate
wp	white perch density	sp.salt	spring salinity
amcent	Atlantic menhaden center of abundance	sp.temp	spring water temperature
ascent	American shad center of abundance	su.chla	summer chlorophyll a
awcent	alewife center of abundance	su.do	summer dissolved oxygen
bbcent	blueback herring center of abundance	su.no23f	summer nitrite + nitrate
sbcent	striped bass center of abundance	su.ph	summer pH
wpcent	white perch center of abundance	su.po4	summer phosphate
sp.flo	spring freshwater flow	su.salt	summer salinity
su.flo	summer freshwater flow	su.temp	summer water temperature
struct	taxable structure count		

Upper Bay

In the upper Bay, spring and summer flows, spring (N and P) and summer (N) nutrients, and YOY anadromous fish abundances were positively correlated and loaded highly on PC1 (Figure 9). However, the center of abundance for the alosines loaded on PC2, indicating that the centers of abundance for alosines were uncorrelated with their abundances. The center of abundance for striped bass also loaded on PC2 but was negatively correlated with the centers of abundance for the alosines. The center of abundance for white perch was negatively correlated with white perch abundance, suggesting that the center of abundance for white perch shifts down-estuary in years of higher abundance. The temporal trend for the upper Bay oriented along PC1, indicating that spring and summer flows, spring and summer nutrient levels, and abundances of YOY anadromous species generally increased from 1985 until 2003. Since 2004, PC1 scores have tended to shift back toward negative values similar to those in the late 1980s.

Choptank River

YOY striped bass and white perch abundances were positively correlated with spring and summer flows and spring (N and P) and summer (N) nutrient levels (Figure 10). However, alewife abundance was negatively correlated with those variables. The center of abundance for striped bass shifted down-estuary in years of higher striped bass abundance while the center of abundance of white perch tended to move up-estuary with increasing white perch abundance. The temporal trend for the Choptank River progressed from the lower left hand corner of Figure 10 to the upper right hand corner, toward conditions of higher summer nutrient levels, higher summer water temperature, and increasing numbers of taxable structures.

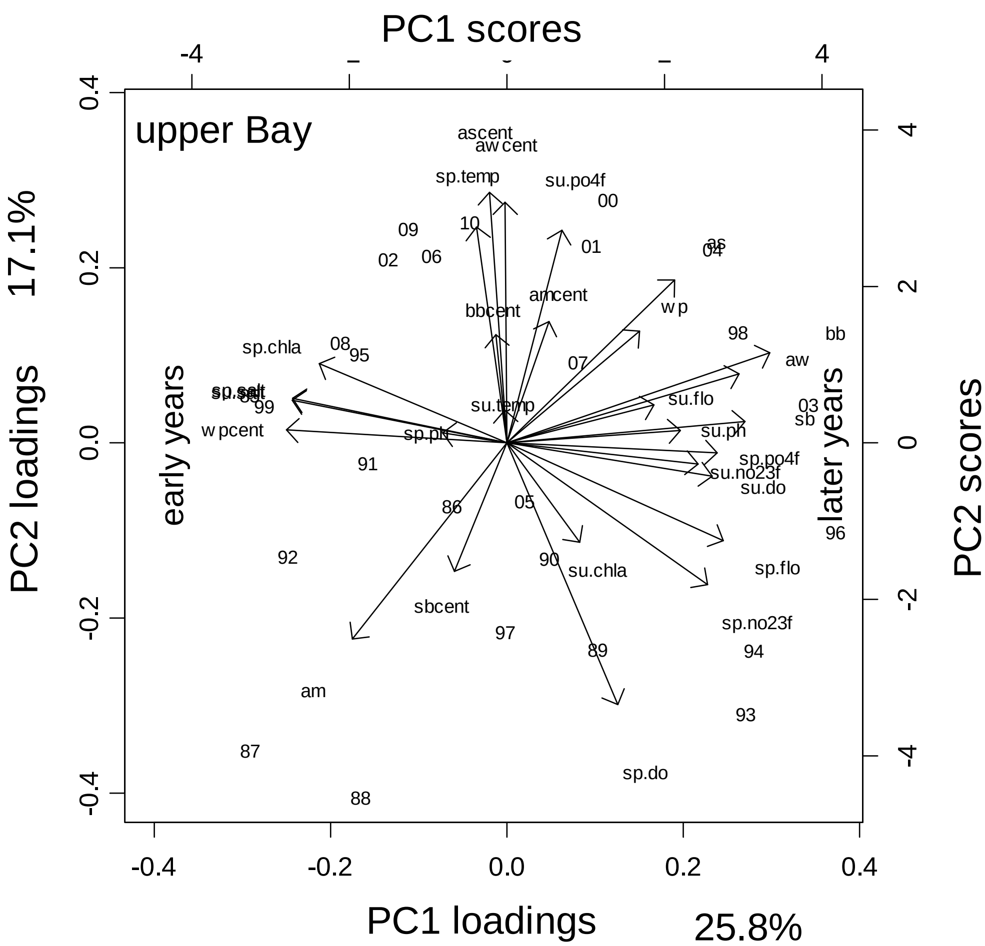

Figure 9. Principal components analysis biplot for the upper Chesapeake Bay. The numbers indicate the years of the observations. See Table 9 for abbreviations of variables.

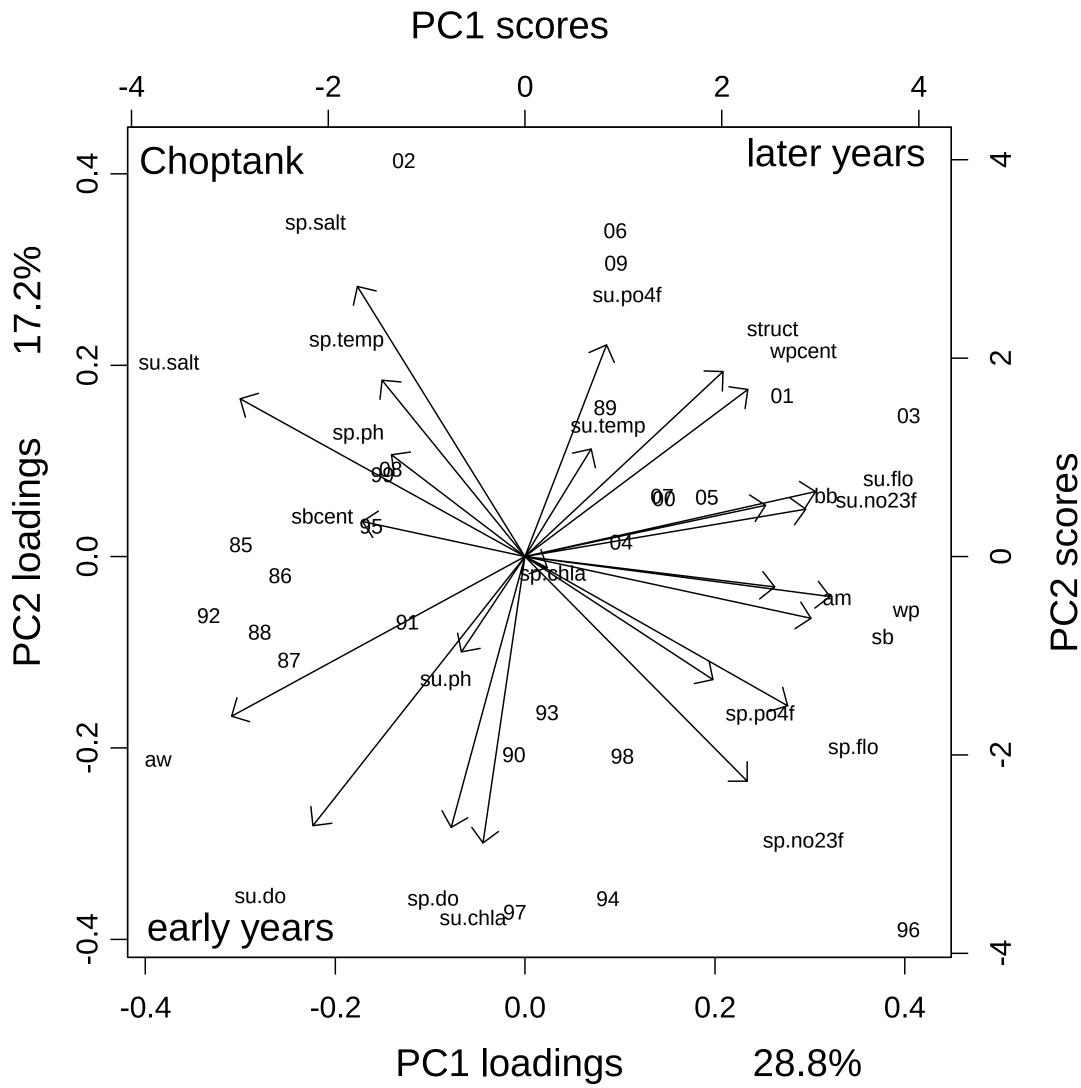

Figure 10. Principal components analysis biplot for the Choptank River. The numbers indicate the years of the observations. See Table 9 for abbreviations of variables.

<u>Nanticoke River</u>

The Nanticoke River exhibited fewer patterns than observed in the other tributaries (Figure 11). Flow and nutrients were correlated during each season, but abundances of YOY anadromous fishes were either uncorrelated or negatively correlated with flow and nutrients. The center of abundance for each species was negatively correlated with flow indicating down-estuary shifts with increased flow. The temporal pattern for the Nanticoke River was oriented from the upper left hand corner of Figure 11 to the lower right hand corner, which signified a shift from high summer DO and chlorophyll *a* levels toward higher summer flow levels, nutrient concentrations, and taxable structure counts.

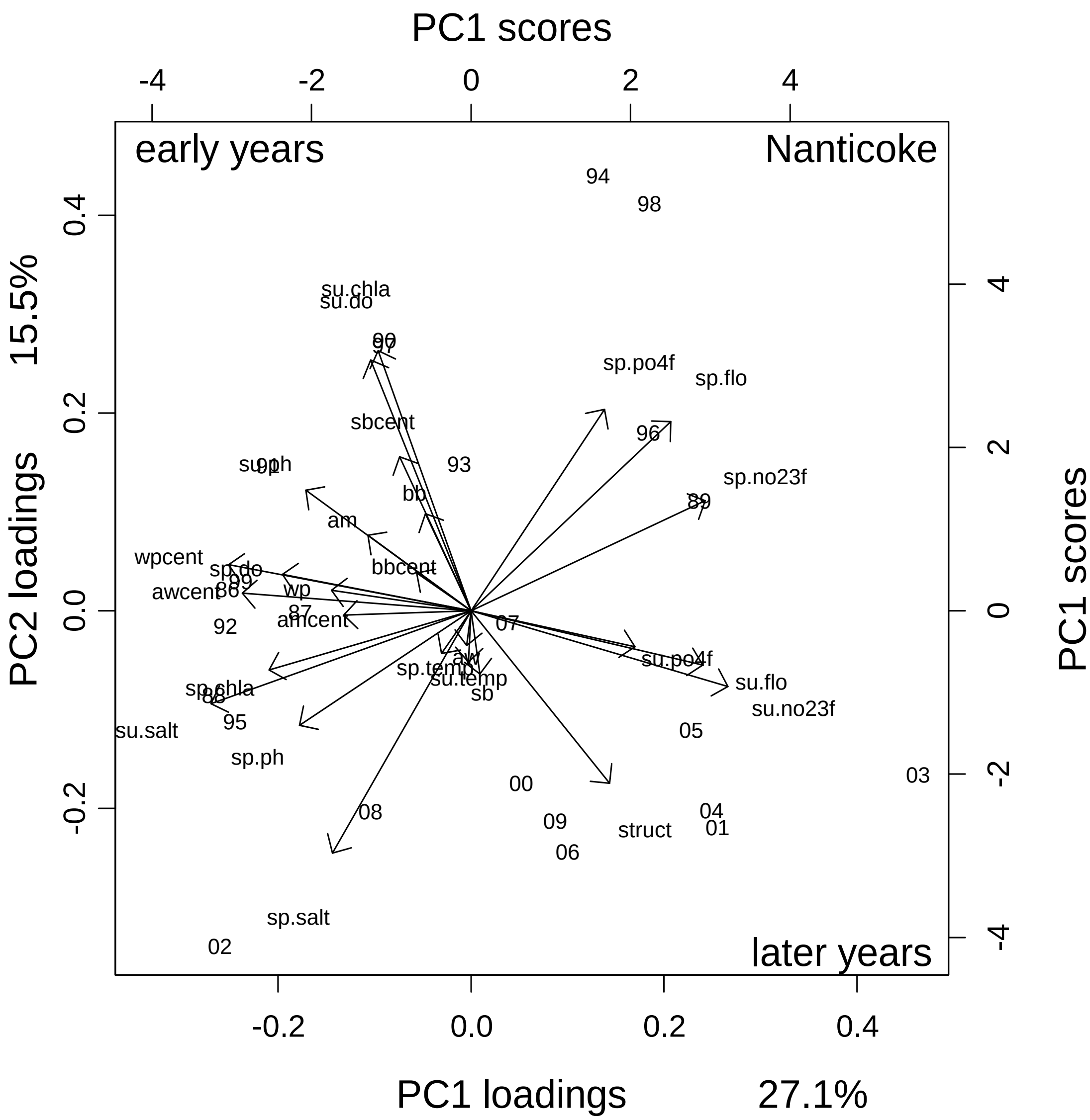

Figure 11. Principal component analysis biplot for the Nanticoke River. The numbers indicate the years of the observations. See Table 9 for abbreviations of variables.

Patuxent River

Spring and summer flows were positively correlated with the abundances of YOY anadromous fishes (Figure 12). The centers of abundance for YOY white perch and striped bass were negatively correlated with abundances while centers of abundance for the YOY alosines were positively correlated with abundances, indicating that the distributions (centers of abundance) of moronids and alosines responded differently to increases in abundance. Unlike the other tributaries, nutrient levels in the Patuxent River were negatively correlated along the PC1 and PC2 axes. Additionally, the temporal pattern in the Patuxent River was oriented from the lower left hand corner to the upper right hand corner, indicating a reduction in spring and summer nutrients since the mid-1980s and an increase in taxable structures.

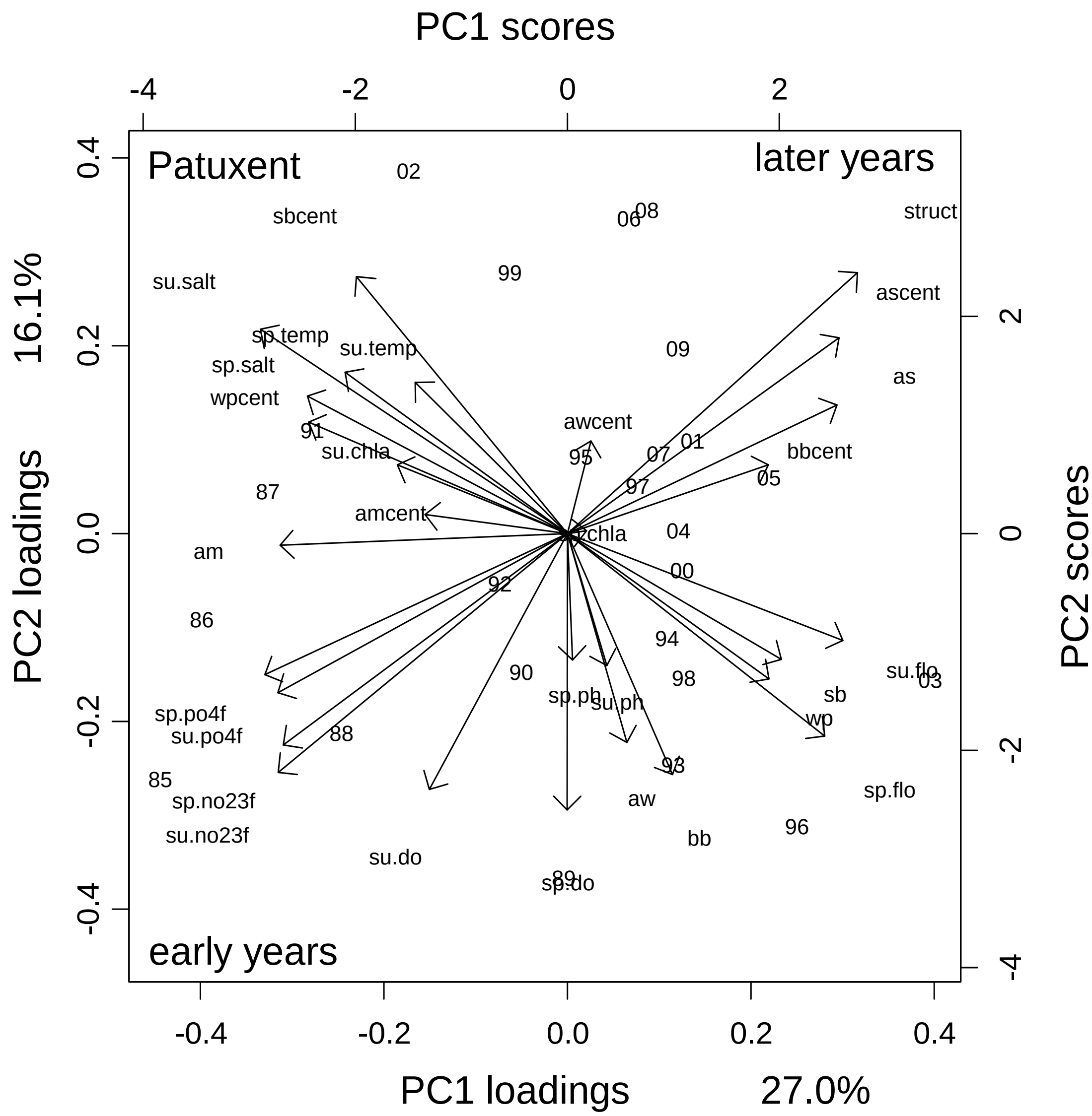

Figure 12. Principal components analysis biplot for the Patuxent River. The numbers indicate the years of the observations. See Table 9 for abbreviations of variables.

Potomac River

Nutrient variables could not be included in the Potomac River PCA because monitoring of nutrients was not conducted by the Chesapeake Bay Program until 1991. Abundances of all YOY anadromous fishes were positively correlated with spring and summer flows (Figure 13). YOY anadromous fish abundances were negatively correlated with their centers of abundance, which indicated that the centers of abundance shifted down-estuary in years of higher abundance. The temporal pattern was oriented along PC1 and reflected the increasing trend in abundance of YOY anadromous fishes.

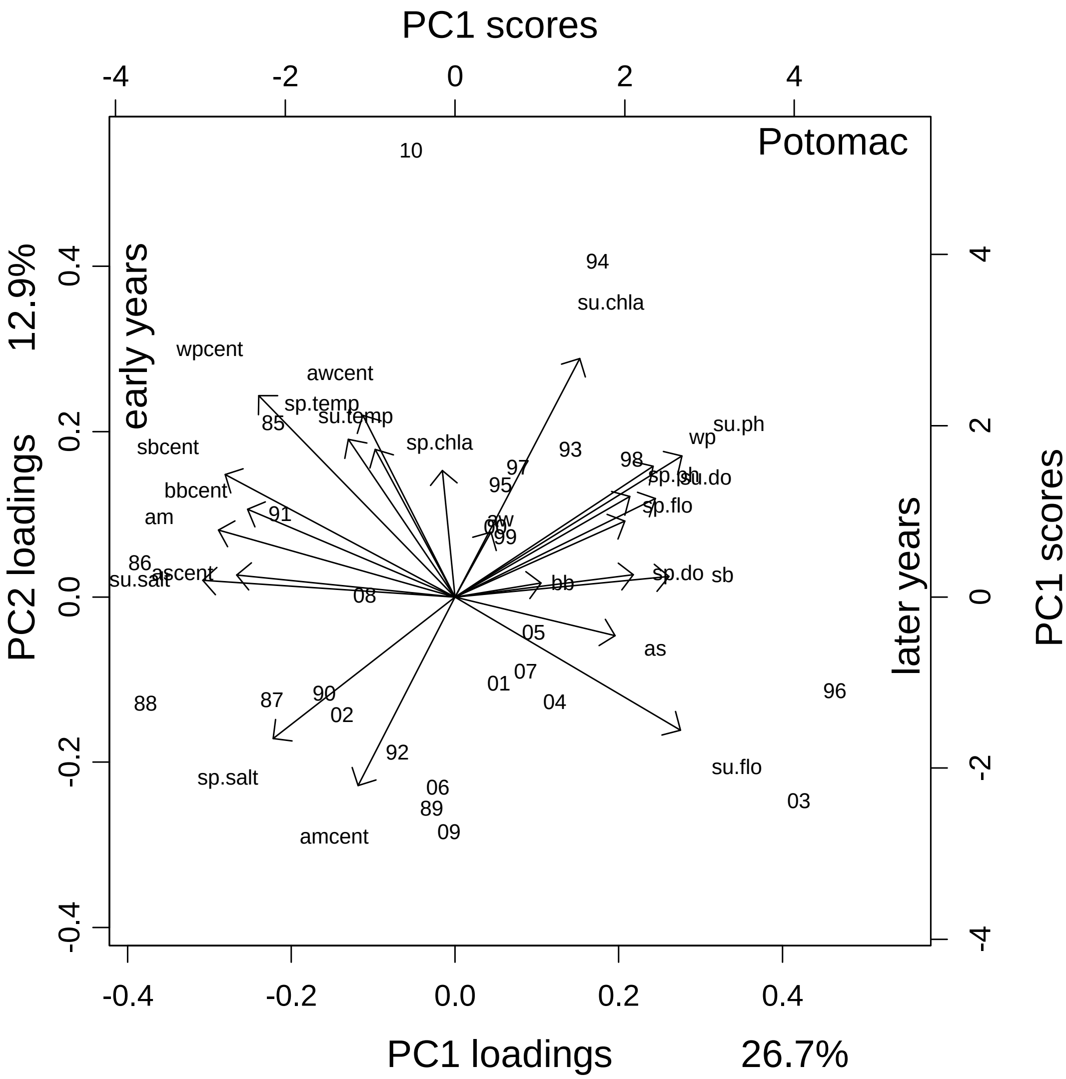

Figure 13. Principal components analysis biplot for the Potomac River. The numbers indicate the years of the observations. See Table 9 for abbreviations of variables.

Strategy and plan for remaining analyses

Analyses that we conducted with support from the NOAA Chesapeake Bay Office evaluated trends in abundance, biomass, length, growth, production, and spatial distribution of YOY anadromous fishes. Under the continuing contract from Maryland DNR and ASMFC, we are analyzing abundance trends and patterns of the YOY anadromous fishes and other species (e.g., Atlantic menhaden) to document inter-annual variability, analyze its causes, and evaluate effects of variability in abundance on sizes and growth rates of the YOY anadromous fishes. In an extension of analyses completed to date, abundances of YOY and age-1+ fish of all common species in the DNR seine survey will be included in our principal components analysis. Water quality, zooplankton prey abundance, and benthic prey abundance data from the Chesapeake Bay Program will be included in our multivariate analyses to identify and quantify drivers of interannual variability in growth and production of YOY anadromous fishes.

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PRODUCTS

A. Presentations (since October 2011)

Houde, E. D. and W. J. Connelly. 2012. A retrospective analysis of spatial and temporal patterns of growth and abundance of juvenile anadromous fishes in the Maryland Chesapeake Bay. NOAA Chesapeake Bay Office Fisheries Science Rollout Edgewater, MD. January, 2012.

Houde, E. D. 2012. Forage fishes and YOY anadromous fishes in Chesapeake Bay: causes of variability in abundance. Invited presentation. Fisheries Goal Implementation Team, Chesapeake Bay Program, Port Isobel, VA. 7 December 2012.

Lozano, C. and E. D. Houde. 2013. Offshore growth of Atlantic menhaden larvae before entering Chesapeake Bay. American Fisheries Society, Tidewater Chapter, Annual Meeting, Solomons, MD. 22 March 2013.

O'Brien, M. H. P., A. N. Atkinson and D. H. Secor. 2013. Preconditioning of summer juvenile fish assemblage by winter conditions in a temperate estuary. American Fisheries Society, Tidewater Chapter, Annual Meeting, Solomons, MD. 22 March 2013.

Personnel

The Principal Investigator is Dr. E. D. Houde. The principal scientist involved was Dr. W. J. Connelly, Assistant Research Scientist. Dr. Connelly left UMCES in October 2012 to take a new position with the Federal Energy Regulatory Commission. C. Lozano and M. O'Brien provided technical assistance.