CHESAPEAKE BAY WATER QUALITY MONITORING PROGRAM

LONG-TERM BENTHIC MONITORING AND ASSESSMENT COMPONENT LEVEL I COMPREHENSIVE REPORT

JULY 1984 - DECEMBER 2010 (VOLUME 1)

Prepared for

Maryland Department of Natural Resources
Resource Assessment Service
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FOREWORD

This document, Chesapeake Bay Water Quality Monitoring Program: Long-Term Benthic Monitoring and Assessment Component, Level I Comprehensive Report (July 1984-December 2010), was prepared by Versar, Inc., at the request of Mr. Tom Parham of the Maryland Department of Natural Resources under Contract # RAT5/10-297 between Versar, Inc., and Maryland DNR. The report assesses the status of Chesapeake Bay benthic communities in 2010 and evaluates their responses to changes in water quality.

ACKNOWLEDGEMENTS

We are grateful to the State of Maryland's Environmental Trust Fund which partially funded this work. The benthic studies discussed in this report were conducted from the University of Maryland's and Maryland DNR research vessels and we appreciate the efforts of their captains and crew. We thank Nancy Mountford and Tim Morris of Cove Corporation who identified benthos in many of the historical samples and provided current taxonomic and autoecological information. We also thank those at Versar whose efforts helped produce this report: the field crew who collected samples, including Katherine Dillow, David Wong, and Lay Nwe; the laboratory technicians for processing samples, Dawn Hendrickson, Lay Nwe, and Charles Tonkin; Suzanne Arcuri and Michael Winnell for taxonomic identifications; Allison Brindley for GIS support; Dr. Don Strebel for web-page development; and Sherian George and Gail Lucas for document production. Jodi Dew-Baxter managed and analyzed the data.

We appreciate the efforts of Dr. Daniel M. Dauer, Mike Lane, and Anthony (Bud) Rodi of Old Dominion University who coordinate the activities of the Virginia Benthic Monitoring Program. Mike Lane contributed to data analysis for this report.

EXECUTIVE SUMMARY

Benthic macroinvertebrates have been an important component of the State of Maryland's Chesapeake Bay water quality monitoring program since the program's inception in 1984. Benthos integrate temporally variable environmental conditions and the effects of multiple types of environmental stress. They are sensitive indicators of environmental status. Information on the condition of the benthic community provides a direct measure of the effectiveness of management actions. The long-term benthic monitoring program contributes information to the Chesapeake Bay Health and Restoration reports, and to the water quality characterization and list of impaired waters under the Clean Water Act. This report is one in a series of Level-One Annual Reports that summarize data up to the current sampling year. Benthic community condition and trends in the Chesapeake Bay are assessed for 2010 and compared to results from previous years.

Sampling Design and Methods

Maryland's long-term benthic monitoring program currently contains two elements: a fixed-site monitoring effort directed at identifying temporal trends and a probability-based sampling effort intended to assess the areal extent of degraded benthic community condition. Benthic community condition is assessed using a benthic index of biotic integrity (B-IBI), which evaluates the ecological condition of a sample by comparing values of key benthic community attributes to reference values expected under non-degraded conditions in similar habitat types. These reference values are the benthic community restoration goals for the Chesapeake Bay. Application of the B-IBI is limited to samples collected in summer, defined as July 15 through September 30.

Twenty-seven fixed sites are sampled once a year in late August or September. Three replicate sediment samples for benthos are collected at each fixed site with sampling gear used since 1984. These sites are part of a more extensive suite of sites that were sampled previously at various times and locations. The current suite of fixed sites was also sampled each May through 2008, when spring sampling was discontinued. The probability-based sampling design is stratified simple random. It was established in 1994. Twenty-five random sites are allocated annually to each of six strata in the Maryland portion of the Chesapeake Bay. A similar stratification scheme has been used by the Commonwealth of Virginia since 1996, permitting annual estimates of benthic condition for the entire Chesapeake Bay. The largest portion of the Chesapeake Bay, the mainstem, is divided into three strata, and five strata consist of the major tributaries (Patuxent, Potomac, Rappahannock, York, and James rivers). Two additional strata include the remaining smaller tributaries of the Maryland western and eastern shores, respectively. The strata sampled represent the entire tidal region of the Chesapeake Bay from freshwater to polyhaline zones. Probability sites are sampled once a year in late August or September. One sample is collected at each probability site using a Young grab with a surface sampling area of 440 cm^2 to a depth of 10 cm in the sediment.

All samples are sieved on a 0.5-mm screen and preserved in the field. At each site, temperature, conductivity, salinity, dissolved oxygen concentration, and pH of the water column are measured at various depths, and silt-clay percent, total organic carbon, total inorganic carbon, and total nitrogen are measured from sediment samples processed in the laboratory.

Trends in Fixed Site Benthic Condition

Statistically significant B-IBI trends ($p<0.1$) were detected at 10 of the 27 sites currently monitored for trends. Trends in benthic community condition declined at 8 sites (significantly decreasing B-IBI trend) and improved at 2 sites. Four trends disappeared in 2010 and 4 trends emerged a new. All of the new trends were declining trends, and all of the trends that were significant through 2009 but disappeared in 2010 were improving trends. Thus changes in trend direction and magnitude in 2010 indicated generally degrading benthic conditions in Chesapeake Bay.

Sites with improving condition were located in the mainstem of the Bay (Station 26) and the Back River (Station 203). Sites with declining condition were located in Baltimore Harbor (Station 22), Curtis Creek (Station 202), Patuxent River at Holland Cliff (Station 77), Patuxent River at Broomes Island (Station 71), tidal fresh Potomac River (Station 36), mesohaline Potomac River at Morgantown (Stations 43 and 44), and Nanticoke River (Station 62). The most important changes in 2010 were the appearance of new degrading B-IBI trends, reversing conditions in the Potomac River at Morgantown (Station 44), and the disappearance of previously improving benthic condition trends in the Choptank River (Station 64), North Beach (Station 15), Bear Creek (Station 201), and Elk River (Station 29). These changes were reflected in a general decline in benthic community status at a majority of the fixed sites. Major effects of hypoxia in the last few years were suggested by a decline in abundance and species numbers at sites in the mainstem and lower reaches of tributaries since 2005, and, on average, lower abundance values and species numbers for the 1998-2010 time period.

Benthic organisms respond to long-term patterns in water quality parameters, such as dissolved oxygen concentrations, water column chlorophyll, total nitrogen, sediment loading, and organic loading, in addition to natural fluctuations in salinity and temperature. Improving trends likely reflect undergoing basin-wide changes resulting from management actions. Degrading trends reflect the cumulative impacts of nutrient loading and hypoxia in regions with significant problems that do not yet respond to pollution abatement.

Baywide Benthic Community Condition

The area with degraded benthos (failing the B-IBI goals) increased in the Maryland portion of the Bay from 58% in 2009 to 67% in 2010, encompassing 4,182 ± 287 Km^2 of tidal bottom remaining to be restored. Chesapeake Bay wide, the area with degraded benthos increased from 44% to 53%, and encompassed an estimated 6,176 ± 492 km^2 of bay bottom remaining to be restored. The extent of degradation, however, was not as high as in the 2005-2008 period, and the extent of the severely degraded condition remained unchanged. In 2010, the Patuxent River, Maryland mid-Bay mainstem, and Maryland Western Tributaries continued to be among the Maryland strata in poorest condition. Statistically significant increasing trends in percent area degraded were detected in the Patuxent River and the Maryland Eastern Tributaries over the 1995-2010 time series. In Virginia, percent degraded area increased in the Rappahannock River, York River, and Virginia mainstem, but declined in the James River. A statistically significant increasing trend in percent area degraded was detected in the Rappahannock River over the 1996-2010 time series.

The increased degradation observed in Chesapeake Bay in 2010 was associated with high river flow. Flow was higher than average in winter (December-January) and early spring (March), and lower that average in late spring and summer. In March, a pulse in river flow coincided with heavy rainfall and large amounts of snow melt in the Chesapeake Bay. High spring flows in the Bay's tributaries are thought to be responsible for high nutrient and sediment runoff, factors that usually lead to earlier and spatially more extensive water column stratification within the Bay, more extensive hypoxia, and greater benthic community degradation. Particularly large pulses in river flow bring sudden increases in nutrient and sediment loads into Chesapeake Bay. A marked declined in abundance and species numbers in 2005, continuing through 2008, coincided with large pulse events every year since 2005. The exception was 2009. Below average Susquehanna River flow in 2009 resulted in bay-wide improvements in benthic condition.

Mean abundance, mean species numbers, mean B-IBI, and percent area degraded, among other metrics, were significantly associated with high standard deviations (S.D.) of spring flow, reflecting pulse events. At the fixed sites, relationships between benthic measures and the S.D. of spring flow were significant only for the lower Patuxent River Station 71. It is suggested that several recent consecutive years of rain events and high spring flow may have had a compounded effect on benthic communities not obvious from more isolated events in the earlier 1980s and 1990s. In addition, a shift in hypoxia from mid to early summer since 1998 coincided with, on average, lower abundance and species numbers at some of the fixed sites. Results in the last few years suggest worsening conditions in Chesapeake Bay that coincide with an increasing incidence of pulses in river flow and earlier hypoxic events. These factors, which may be related to decadal cycles or climate change, may override attempts to restore the Chesapeake Bay through reductions of point and non-point nutrient and sediment loads, so that greater and more sustained restoration efforts may be needed.

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1.0 INTRODUCTION

1.1 BACKGROUND

Monitoring is a necessary part of environmental management because it provides the means for assessing the effectiveness of previous management actions and the information necessary to focus future actions (NRC 1990). Towards these ends, the State of Maryland has maintained a water quality monitoring program for Chesapeake Bay since 1984. The goals of the program are to:

- quantify the types and extent of water quality problems (i.e., characterize the "state-of-the-bay");
- determine the response of key water quality measures to pollution abatement and resource management actions;
- identify processes and mechanisms controlling the bay's water quality;
- define linkages between water quality and living resources;
- contribute information to the Chesapeake Bay Health and Restoration reports; and
- contribute information to the Water Quality Characterization Report (305b report) and the List of Impaired Waters (303d list).

The program includes elements to measure water quality, sediment quality, phytoplankton, and benthic macroinvertebrates (i.e., those invertebrates retained on a 0.5-mm mesh sieve). The monitoring program includes assessments of biota because the condition of biological indicators integrates temporally variable environmental conditions and the effects of multiple types of environmental stress. In addition, most environmental regulations and contaminant control measures are designed to protect biological resources; therefore, information about the condition of biological resources provides a direct measure of the effectiveness of management actions.

The Maryland program uses benthic macroinvertebrates as biological indicators because they are reliable and sensitive indicators of habitat quality in aquatic environments. Most benthic organisms have limited mobility and cannot avoid changes in environmental conditions (Gray 1979). Benthos live in bottom sediments, where exposure to contaminants and oxygen stress is most frequent. Benthic assemblages include diverse taxa representing a variety of sizes, modes of reproduction, feeding guilds, life history characteristics, and physiological tolerances to environmental conditions; therefore, they respond to and integrate natural and anthropogenic changes in environmental conditions in a variety of ways (Pearson and Rosenberg 1978; Warwick 1986; Dauer 1993; Wilson and Jeffrey 1994).

Benthic organisms are also important secondary producers, providing key linkages between primary producers and higher trophic levels (Virnstein 1977; Holland et al. 1980, 1989; Baird and Ulanowicz 1989; Diaz and Schaffner 1990). Benthic invertebrates are among the most important components of estuarine ecosystems and may represent the largest standing stock of organic carbon in estuaries (Frithsen 1989). Many benthic organisms, such as clams, are economically important. Others, such as polychaete annelids and small crustaceans, contribute significantly to the diets of economically important bottom feeding juvenile and adult fishes, such as spot and croaker (Homer and Boynton 1978; Homer et al. 1980).

The Chesapeake Bay Program's decision to adopt benthic community restoration goals (Ranasinghe et al. 1994 updated by Weisberg et al. 1997) enhanced use of benthic macroinvertebrates as a monitoring tool. Based largely on data collected as part of Maryland's monitoring effort, these goals describe the characteristics of benthic assemblages expected at sites exposed to little environmental stress. The restoration goals provide a quantitative benchmark against which to measure the health of sampled assemblages and ultimately the Chesapeake Bay. Submerged aquatic vegetation (Dennison et al. 1993) and benthic macroinvertebrates are the only biological communities for which such quantitative goals have been established in Chesapeake Bay. Restoration goals for phytoplankton and zooplankton are under development.

A variety of anthropogenic stresses affect benthic macroinvertebrate communities in Chesapeake Bay. These include toxic contamination, organic enrichment, and low dissolved oxygen. While toxic contamination is generally restricted to urban and industrial areas typically associated with ports, low dissolved oxygen (hypoxia) is the more widespread problem, encompassing an area of about 600 million m^2 mainly along the deep mainstem of the bay and at the mouth of the major Chesapeake Bay tributaries (Flemer et al. 1983). Organic enrichment, associated with excess phytoplankton growth and decay, is also a major problem in some regions of the Bay.

A variety of factors contribute to the development and spatial variation of hypoxia in the Chesapeake Bay. Freshwater inflow, salinity, temperature, wind stress, and tidal circulation are primary factors in the development of hypoxia (Holland et al. 1987; Tuttle et al. 1987; Boicourt 1992). The development of vertical salinity gradients during the spring freshwater run off leads to water column density stratification. The establishment of a pycnocline, in association with periods of calm and warm weather, restricts water exchange between the surface and the bottom layers of the estuary, where oxygen consumption is large. This process is especially manifested along the Maryland mid-bay and Potomac River deep troughs. The formation or the disruption of the pycnocline is probably the most important process determining the intensity and extent of hypoxia (Seliger et al. 1985; Boicourt 1992), albeit not the only one. Biological processes contribute significantly to deep water oxygen depletion in Chesapeake Bay (Officer et al.

1984). Benthic metabolic rates increase during spring and early summer, leading to an increase of the rate of oxygen consumption in bottom waters. This depends in part on the amount of organic carbon available for the benthos, which is derived to a large extent from seasonal phytoplankton blooms (Officer et al. 1984). Anthropogenic nutrient inputs to the Chesapeake Bay further stimulate phytoplankton growth, which results in increased deposition of organic matter to the sediments and a concomitant increase in the chemical and biological oxygen demand (Malone 1987). Winter to spring accumulation of phytoplankton biomass has been linked to depletion of bottom water oxygen in the Chesapeake Bay (Malone et al. 1988; Boynton and Kemp 2000).

The effects of hypoxia on benthic organisms vary as a function of the severity, spatial extent, and duration of the low dissolved oxygen event. Oxygen concentrations down to about 2 mg l^{-1} do not appear to significantly affect benthic organisms, although incipient community effects have been measured at 3 mg l^{-1} (Diaz and Rosenberg 1995; Ritter and Montagna 1999). Hypoxia brings about structural and organizational changes in the community, and may lead to hypoxia resistant communities. With an increase in the frequency of hypoxic events, benthic populations become dominated by fewer and short-lived species, and their overall productivity is decreased (Diaz and Rosenberg 1995). Major reductions in species number and abundance in the Chesapeake Bay have been attributed to hypoxia (Dauer et al. 1992, Llansó 1992). These reductions become larger both spatially and temporally as the severity and duration of hypoxic events increase. As hypoxia becomes persistent, mass mortality of benthic organisms often occurs with almost complete elimination of the macrofauna.

Hypoxia has also major impacts on the survival and behavior of a variety of benthic organisms and their predators (Diaz and Rosenberg 1995). Many infaunal species respond to low oxygen by migrating toward the sediment surface, thus potentially increasing their availability to demersal predators. On the other hand, reduction or elimination of the benthos following severe hypoxic or anoxic (absence of oxygen) events result in a reduction of food for demersal fish species and crabs. Therefore, the structural changes and species replacements that occur in communities affected by hypoxia may alter the food supply of important ecological and economical fish species in Chesapeake Bay. Given that dissolved oxygen stress and nutrient run-off are critical factors in the health of the resources of the Chesapeake Bay region, monitoring that evaluates benthic condition and tracks changes over time helps Chesapeake Bay managers assess the effectiveness of nutrient reduction efforts and the status of the biological resources of one of the largest and most productive estuaries in the nation.

1.2 OBJECTIVES OF THIS REPORT

This report is part of a series of Level I Comprehensive reports produced annually by the Long-Term Benthic Monitoring and Assessment Component (LTB) of the Maryland Chesapeake Bay Water Quality Monitoring Program. Level I reports summarize data from the latest sampling year and provide a limited examination of how conditions in the latest year differ from conditions in previous years of the study, as well as how data from this year contribute to describing trends in the Bay's condition.

The report reflects the maturity of the current program's focus and design. Approaches introduced when the new program design was implemented in 1995 continue to be extended, developed, and better defined. The level of detail in which changes are examined at the fixed stations sampled for trend analysis continues to increase. For example, we have reported on how species contribute to changes in condition and discussed results in relation to changes in water quality. The Chesapeake Bay Benthic Index of Biotic Integrity (B-IBI) is applied to each sampling site, from tidal freshwater to polyhaline habitats, and thus provides a uniform measure of ecological condition across the estuarine gradient. In describing baywide benthic community condition, estimates of degraded condition are presented for all subregions of the Bay, and community measures that contribute to restoration goal failure are used to diagnose the causes of failure.

The continued presentation of estimates of Bay area meeting the Chesapeake Bay Program's benthic community restoration goals, rather than Maryland estimates only, reflects improved coordination and unification of objectives among the Maryland and Virginia benthic monitoring programs. The sampling design and methods in both states are compatible and complementary.

In addition to the improvements in technical content, we have enhanced electronic production and transmittal of data. Data and program information are available to the research community and the general public through the Chesapeake Bay Benthic Monitoring Program Home Page on the World-Wide-Web at http://www.baybenthos.versar.com. Expansion of the website continues, with new program information, data, and documents being added every year. The 2010 data, as well as the data from previous years, can be downloaded from this website. The Benthic Monitoring Program Home Page represents the culmination of collaborative efforts between Versar, Maryland DNR, and the Chesapeake Information Management System (CIMS). The activities that Versar undertakes as a partner of CIMS were recorded in a Memorandum of Agreement signed October 28, 1999.

1.3 ORGANIZATION OF REPORT

This report has two volumes. Volume 1 is organized into five major sections and three appendices. Section 1 is this introduction. Section 2 presents the field, laboratory, and data analysis methods used to collect, process, and evaluate the LTB samples. Section 3 presents the results of analyses conducted for 2010, and consists of two assessments: an assessment of trends in benthic community condition at the fixed sites sampled annually by LTB in the Maryland Chesapeake Bay, and an assessment of the area of the Bay that meets the Chesapeake Bay Benthic Community Restoration Goals. Section 4 discusses the results and evaluates status and trends relative to recent changes in water quality. Section 5 is the literature cited in the report. Appendix A amplifies information presented in Table 3-2 by providing p-values and rates of change for the 1985-2010 fixed site trend analysis. Appendices B and C present the B-IBI values for the 2010 fixed and random sampling components, respectively. Finally, Volume 2 consists of the benthic, sedimentary, and hydrographic data appendices.

2.0 METHODS

2.1 SAMPLING DESIGN

The LTB sampling program contains two primary elements: a fixed site monitoring effort directed at identifying trends in benthic condition and a probability-based sampling effort intended to estimate the area of the Maryland Chesapeake Bay with benthic communities meeting the Chesapeake Bay Program's benthic community restoration goals (Ranasinghe et al. 1994, updated by Weisberg et al. 1997; Alden et al. 2002). The sampling design for each of these elements is described below.

2.1.1 Fixed Site Sampling

The fixed site element of the program involves sampling at 27 sites, 23 of which have been sampled since the program's inception in 1984, 2 since 1989, and 2 since 1995 (Figure 2-1). Sites are defined by geography (within 1 km from a fixed location), and by specific depth and substrate criteria (Table 2-1).

The 2010 fixed site sampling continues trend measurements, which began with the program's initiation in 1984. In the first five years of the program, from July 1984 to June 1989, 70 fixed stations were sampled 8 to 10 times per year. On each visit, three benthic samples were collected at each site and processed. Locations of the 70 fixed sites are shown in Figure 2-2.

In the second five years of the program, from July 1989 to June 1994, fixed site sampling was continued at 29 sites and a stratified random sampling element was added. Samples were collected at random from approximately 25 km^2 small areas surrounding these sites (Figure 2-3) to assess the representativeness of the fixed locations. Sites 06, 47, 62, and 77, which are part of the current design, were not sampled during this five-year period. Stratum boundaries were delineated on the basis of environmental factors that are important in controlling benthic community distributions: salinity regime, sediment type, and bottom depth (Holland et al. 1989). In addition, four new areas were established in regions of the Bay targeted for management actions to abate pollution: the Patuxent River, Choptank River, and two areas in Baltimore Harbor. Each area was sampled four to six times each year.

From July 1994 through 2008, three replicate samples were collected in spring and summer at most of the current suite of 27 sites (Stations 203 and 204 were added in 1995, Table 2-1, Figure 2-1). This sampling regime was selected as being most cost effective after analysis of the first 10 years of data jointly with the Virginia Benthic Monitoring Program (Alden et al. 1997). Starting in 2009, spring sampling was eliminated due to budgetary constraints.

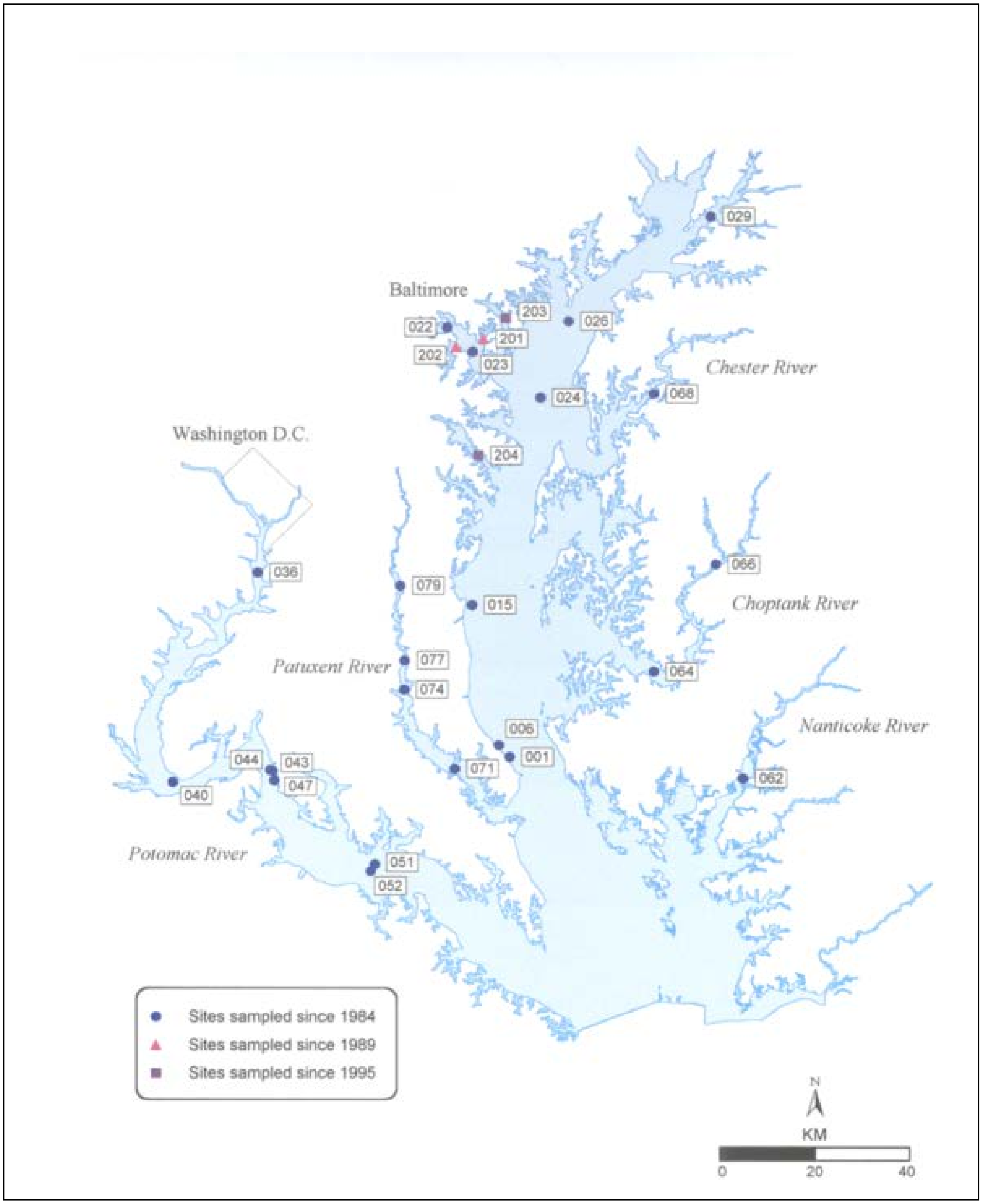

Figure 2-1. Fixed sites sampled in 2010.

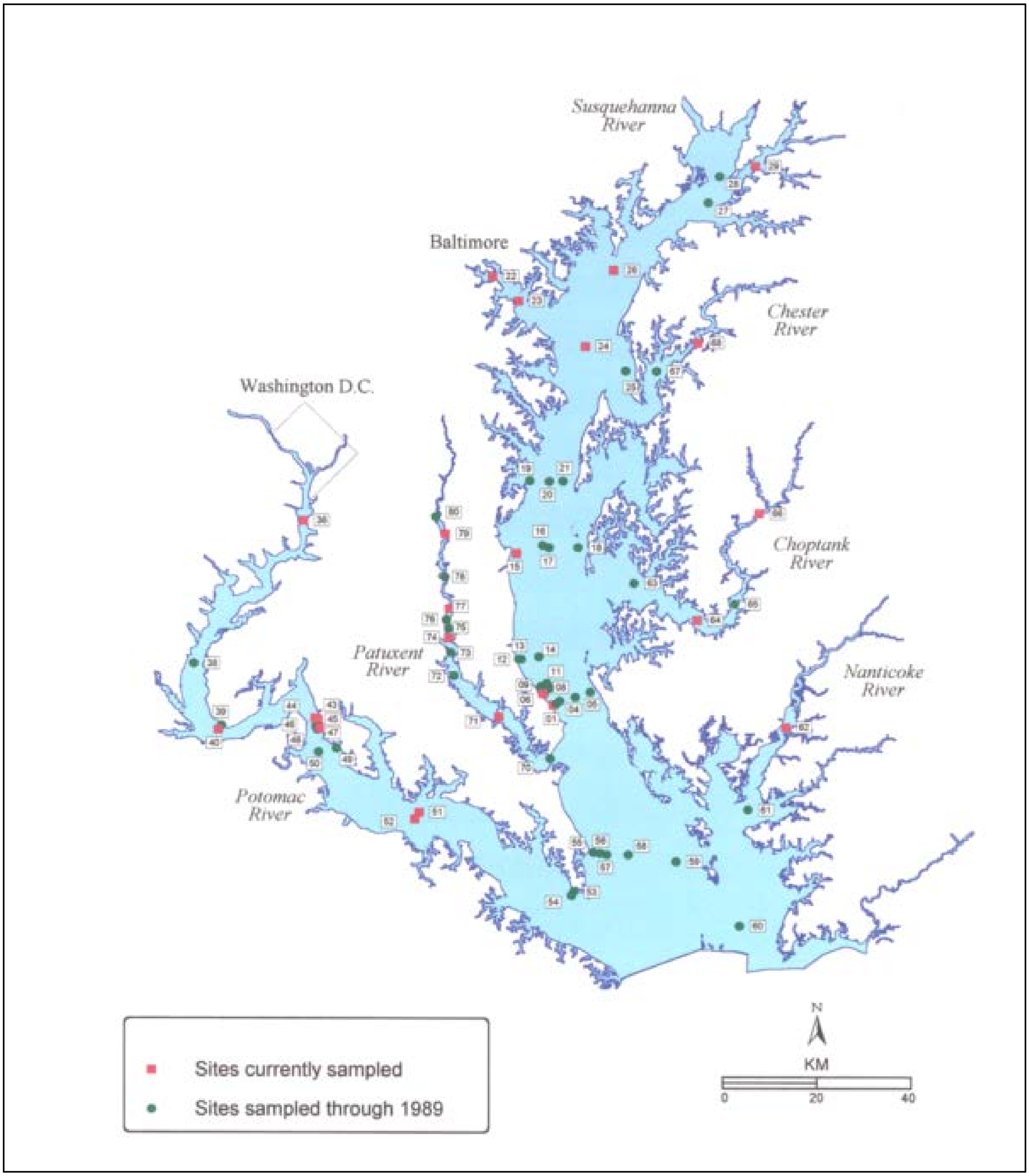

Figure 2-2. Fixed sites sampled from 1984 to 1989; some of these sites are part of the current design.

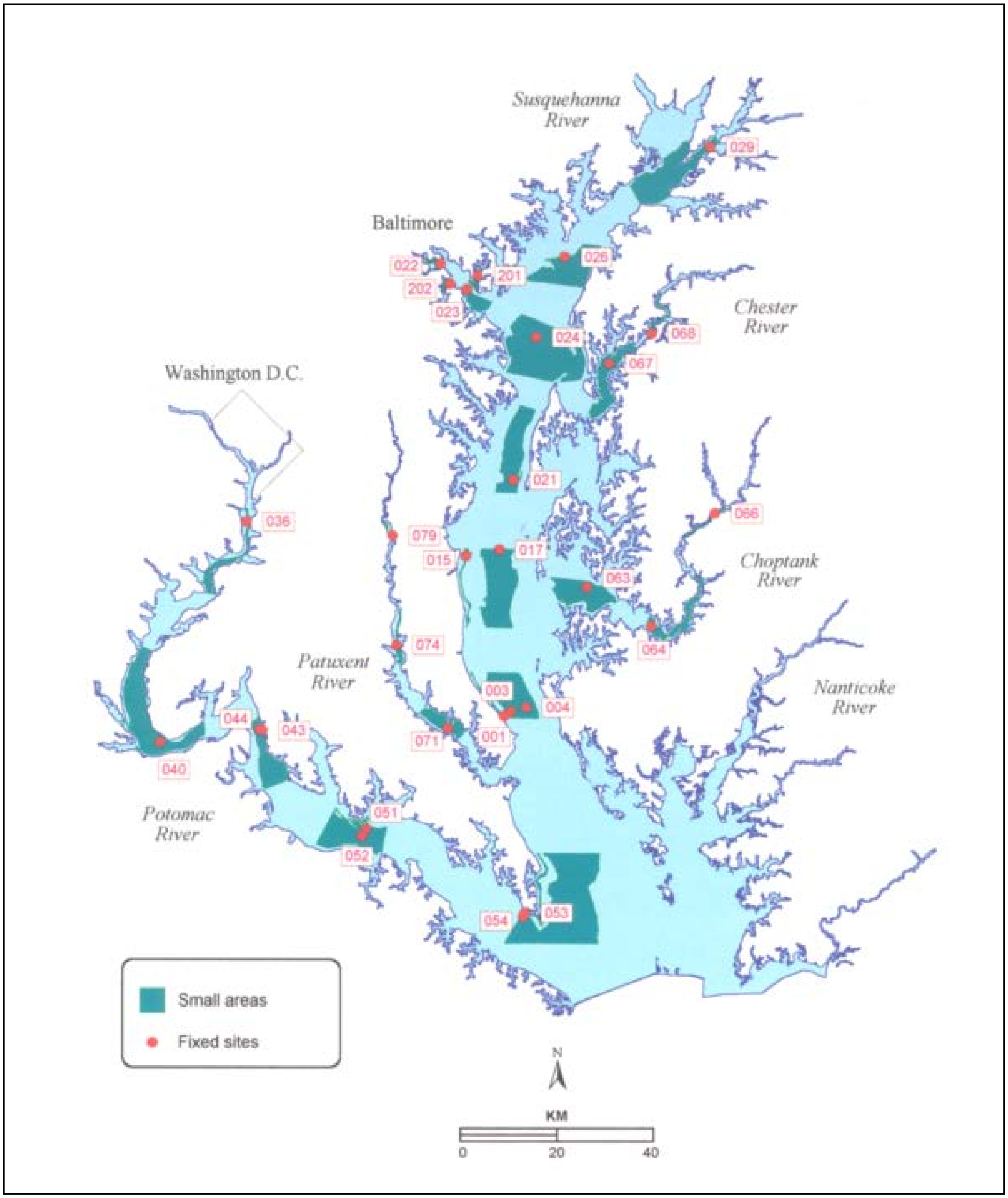

Figure 2-3. Small areas and fixed sites sampled from 1989 to 1994.

Table 2-1. Location, habitat type (Table 5, Weisberg et al. 1997), sampling gear, and habitat criteria for fixed sites. *Station 022 relocated across the channel during the 2010 field season because of construction at the old site.

Stratum	Sub-Estuary	Habitat	Station	Latitude (WGS84)	Longitude (WGS84)	Sampling Gear	Habitat Criteria		
							Depth (m)	Siltclay (%)	Distance (km)
Potomac River	Potomac River	Tidal Freshwater	036	38.769788	-77.037534	WildCo Box Corer	<=5	>=40	1.0
		Oligohaline	040	38.357466	-77.230537	WildCo Box Corer	6.5-10	>=80	1.0
		Low Mesohaline	043	38.384479	-76.988329	Modified Box Corer	<=5	<=30	1.0
		Low Mesohaline	047	38.363825	-76.983737	Modified Box Corer	<=5	<=30	0.5
		Low Mesohaline	044	38.385633	-76.995698	WildCo Box Corer	11-17	>=75	1.0
		High Mesohaline Sand	051	38.205355	-76.738622	Modified Box Corer	<=5	<=20	1.0
		High Mesohaline Mud	052	38.192304	-76.747689	WildCo Box Corer	9-13	>=60	1.0
Patuxent River	Patuxent River	Tidal Freshwater	079	38.750457	-76.689023	WildCo Box Corer	<=6	>=50	1.0
		Low Mesohaline	077	38.604461	-76.675020	WildCo Box Corer	<=5	>=50	1.0
		Low Mesohaline	074	38.548962	-76.676186	WildCo Box Corer	<=5	>=50	0.5
		High Mesohaline Mud	071	38.395132	-76.548847	WildCo Box Corer	12-18	>=70	1.0

Table 2-1. (Continued)

Stratum	Sub-Estuary	Habitat	Station	Latitude (WGS84)	Longitude (WGS84)	Sampling Gear	Habitat Criteria		
							Depth (m)	**Siltclay (%)**	**Distance (km)**
Upper Western Tributaries	Patapsco River	Low Mesohaline	023	39.208283	-76.523354	WildCo Box Corer	4-7	>=50	1.0
	Middle Branch	Low Mesohaline	022*	39.258082	-76.59512	WildCo Box Corer	2-6	>=40	1.0
	Bear Creek	Low Mesohaline	201	39.234167	-76.497501	WildCo Box Corer	2-4.5	>=70	1.0
	Curtis Bay	Low Mesohaline	202	39.217839	-76.564171	WildCo Box Corer	5-8	>=60	1.0
	Back River	Oligohaline	203	39.275005	-76.444508	Young-Grab	1.5-2.5	>=80	1.0
	Severn River	High Mesohaline Mud	204	39.006954	-76.504955	Young-Grab	5-7.5	>=50	1.0
Eastern Tributaries	Chester River	Low Mesohaline	068	39.132509	-76.078780	WildCo Box Corer	4-8	>=70	1.0
	Choptank River	Oligohaline	066	38.801455	-75.921827	WildCo Box Corer	<=5	>=60	1.0
		High Mesohaline Mud	064	38.590459	-76.069331	WildCo Box Corer	7-11	>=70	1.0
	Nanticoke River	Low Mesohaline	062	38.383960	-75.849990	Petite Ponar Grab	5-8	>=75	1.0

Table 2-1. (Continued)

Stratum	Sub-Estuary	Habitat	Station	Latitude (WGS84)	Longitude (WGS84)	Sampling Gear	Habitat Criteria		
							Depth (m)	**Siltclay (%)**	**Distance (km)**
Upper Bay	Elk River	Oligohaline	029	39.479505	-75.944836	WildCo Box Corer	3-7	>=40	1.0
	Mainstem	Low Mesohaline	026	39.271450	-76.290013	WildCo Box Corer	2-5	>=70	1.0
		High Mesohaline Mud	024	39.122004	-76.355673	WildCo Box Corer	5-8	>=80	1.0
Mid Bay	Mainstem	High Mesohaline Sand	015	38.715126	-76.513679	Modified Box Corer	<=5	<=10	1.0
		High Mesohaline Sand	001	38.419001	-76.418385	Modified Box Corer	<=5	<=20	1.0
		High Mesohaline Sand	006	38.442000	-76.444261	Modified Box Corer	<=5	<=20	0.5

2.1.2 Probability-based Sampling

The second sampling element, which was instituted in 1994, was probability-based summer sampling designed to estimate the area of the Maryland Chesapeake Bay and its tributaries that meet the Chesapeake Bay benthic community restoration goals (Ranasinghe et al. 1994, updated by Weisberg et al. 1997; Alden et al. 2002). Different probability sample allocation strategies were used in 1994 than in later years. In 1994, the design was intended to estimate impaired area for the Maryland Bay and one sub-region, while in later years the design targeted five additional sub-regions as well.

The 1994 sample allocation scheme was designed to produce estimates for the Maryland Bay and the Potomac River. The Maryland Bay was divided into three strata with samples allocated unequally among them (Table 2-2); sampling intensity in the Potomac was increased to permit estimation of degraded area with adequate confidence, while mainstem and other tributary and embayment samples were allocated in proportion to their area.

Table 2-2. Allocation of probability-based baywide samples, 1994

Stratum	Area		Number of Samples
	km^2	%	
Maryland Mainstem (including Tangier and Pocomoke Sounds)	3,611	55.5	27
Potomac River	1,850	28.4	28
Other tributaries and embayments	1,050	16.1	11

In subsequent years, the stratification scheme was designed to produce an annual estimate for the Maryland Bay and six subdivisions. Samples were allocated equally among strata (Figure 2-4, Table 2-3). According to this allocation, a fresh new set of sampling sites were selected each year. Figure 2-5 shows the locations of the probability-based Maryland sampling sites for 2010. Regions of the Maryland mainstem deeper than 12 m were not included in sampling strata because these areas are subjected to summer anoxia and have consistently been found to be azoic.

A similar stratification scheme has been used by the Commonwealth of Virginia since 1996, permitting annual estimates for the extent of area meeting the benthic community restoration goals for the entire Chesapeake Bay (Table 2-3, Figure 2-6). These samples were collected and processed, and the data analyzed by the Virginia Chesapeake Bay Benthic Monitoring Program.

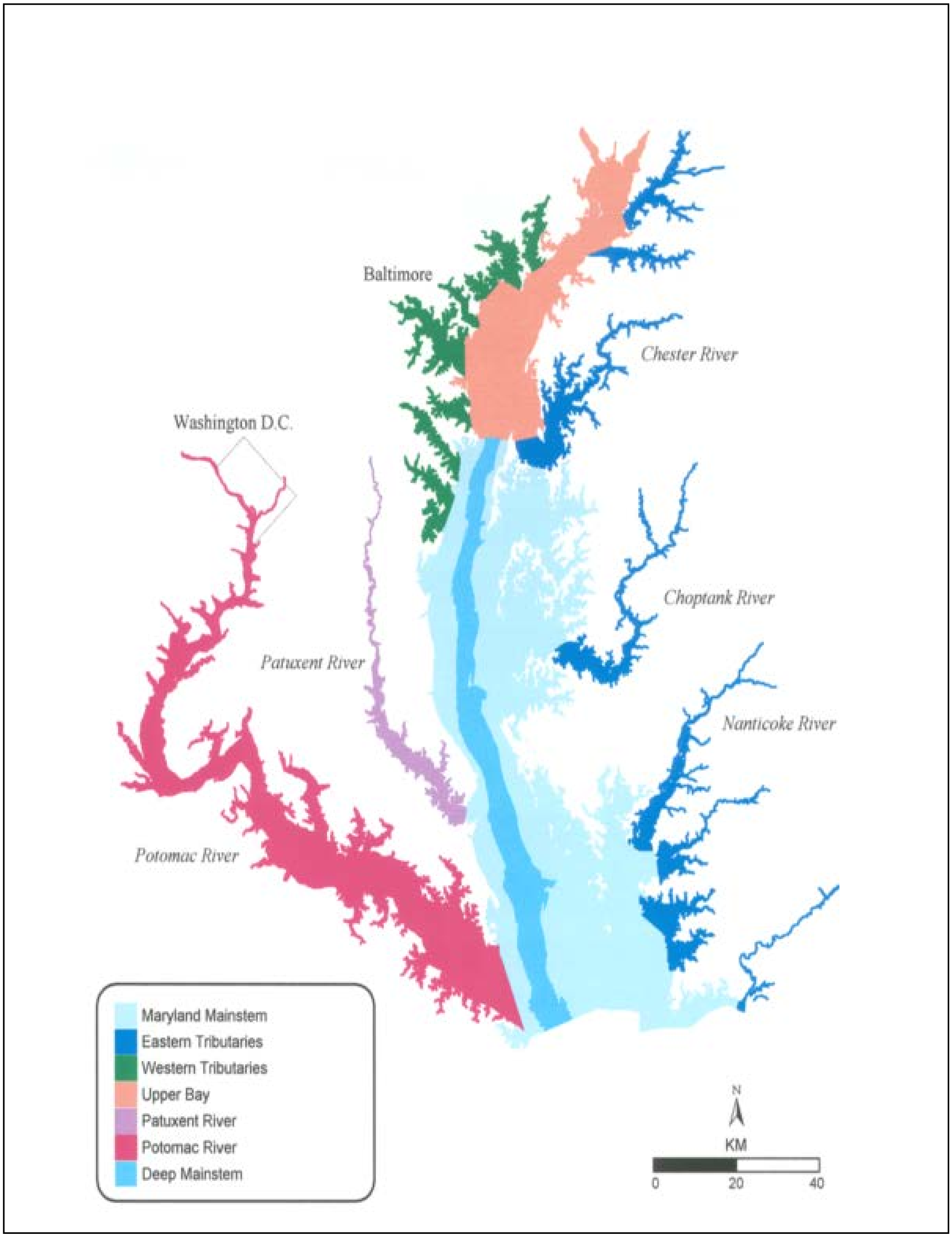

Figure 2-4. Maryland baywide sampling strata in and after 1995

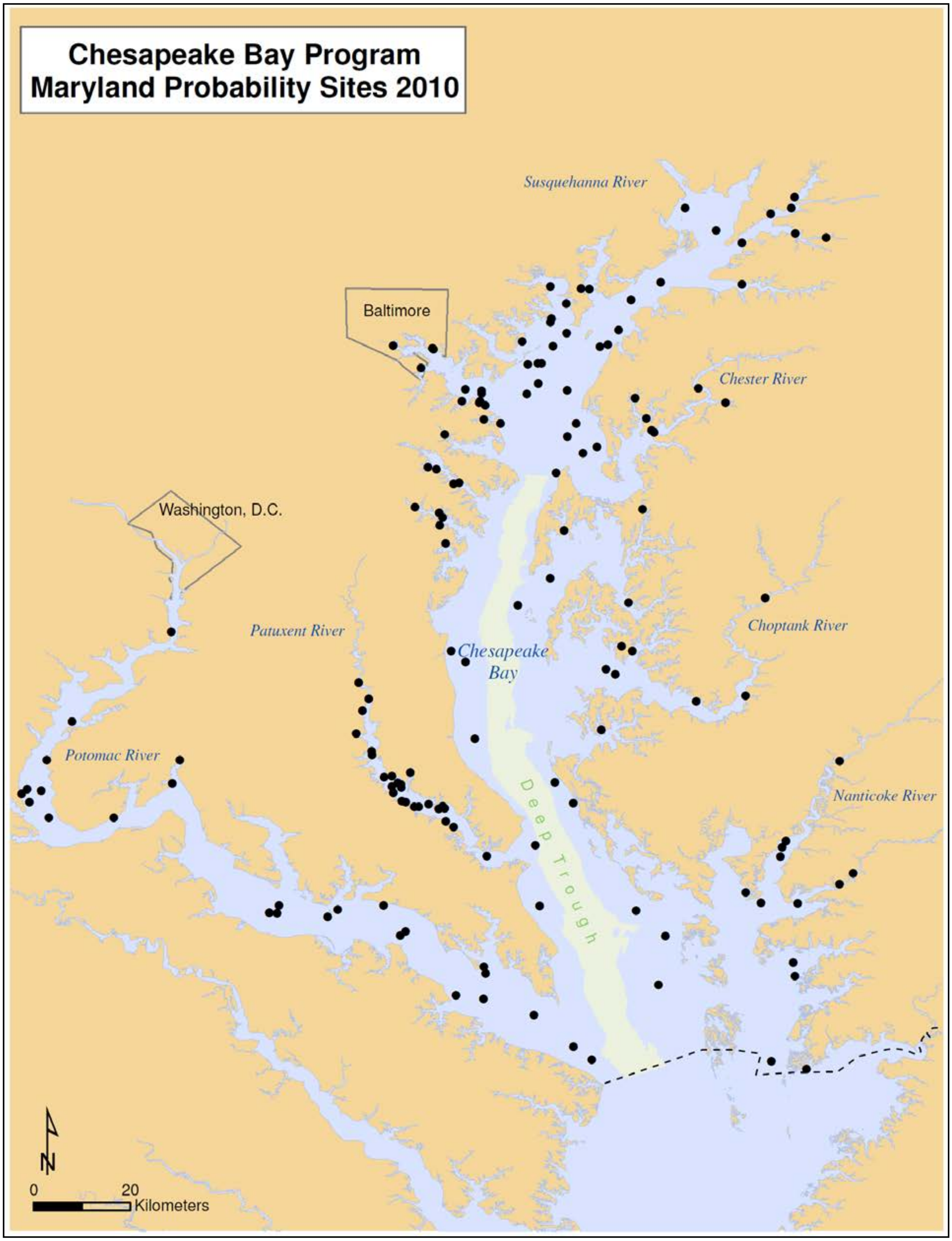

Figure 2-5. Maryland probability-based sampling sites for 2010

Table 2-3. Allocation of probability-based baywide samples, in and after 1995. Maryland areas exclude 676 km^2 of mainstem habitat deeper than 12 m. Virginia strata were sampled by the Virginia Chesapeake Bay Benthic Monitoring Program commencing in 1996.

State	Stratum	Area			Number of Samples
		km^2	State %	Bay %	
Maryland	Deep Mainstem	676	10.8	5.8	0
	Mid Bay Mainstem	2,552	40.9	22.0	25
	Eastern Tributaries	534	8.6	4.6	25
	Western Tributaries	292	4.7	2.5	25
	Upper Bay Mainstem	785	12.6	6.8	25
	Patuxent River	128	2.0	1.1	25
	Potomac River*	1,276	20.4	11.0	25
	TOTAL	6,243	100.0	53.8	150
Virginia	Mainstem	4,120	76.8	35.5	25
	Rappahannock River	372	6.9	3.2	25
	York River	187	3.5	1.6	25
	James River	684	12.8	5.9	25
	TOTAL	5,363	100.0	46.2	100

*Excludes Virginia tidal creeks and district of Columbia waters

2.2 SAMPLE COLLECTION

2.2.1 Station Location

From July 1984 to June 1996, stations were located using Loran-C. After June 1996 stations were located using a differential Global Positioning System. The WGS84 coordinate system (undistinguishable in practice from NAD83) is currently used.

2.2.2 Water Column Measurements

Water column vertical profiles of temperature, conductivity, salinity, dissolved oxygen concentration (DO), and pH were measured at each site. Oxidation reduction potential (ORP) was measured prior to 1996. For fixed sites, profiles consisted of water quality measurements at 1 m intervals from surface to bottom at sites 7 m deep or less, and at 3 m intervals, with additional measurements at 1.5 m intervals in the vicinity of the pycnocline, at sites deeper than 7 m. Surface and bottom measurements were made at all other sampling sites. Table 2-4 lists the measurement methods used.

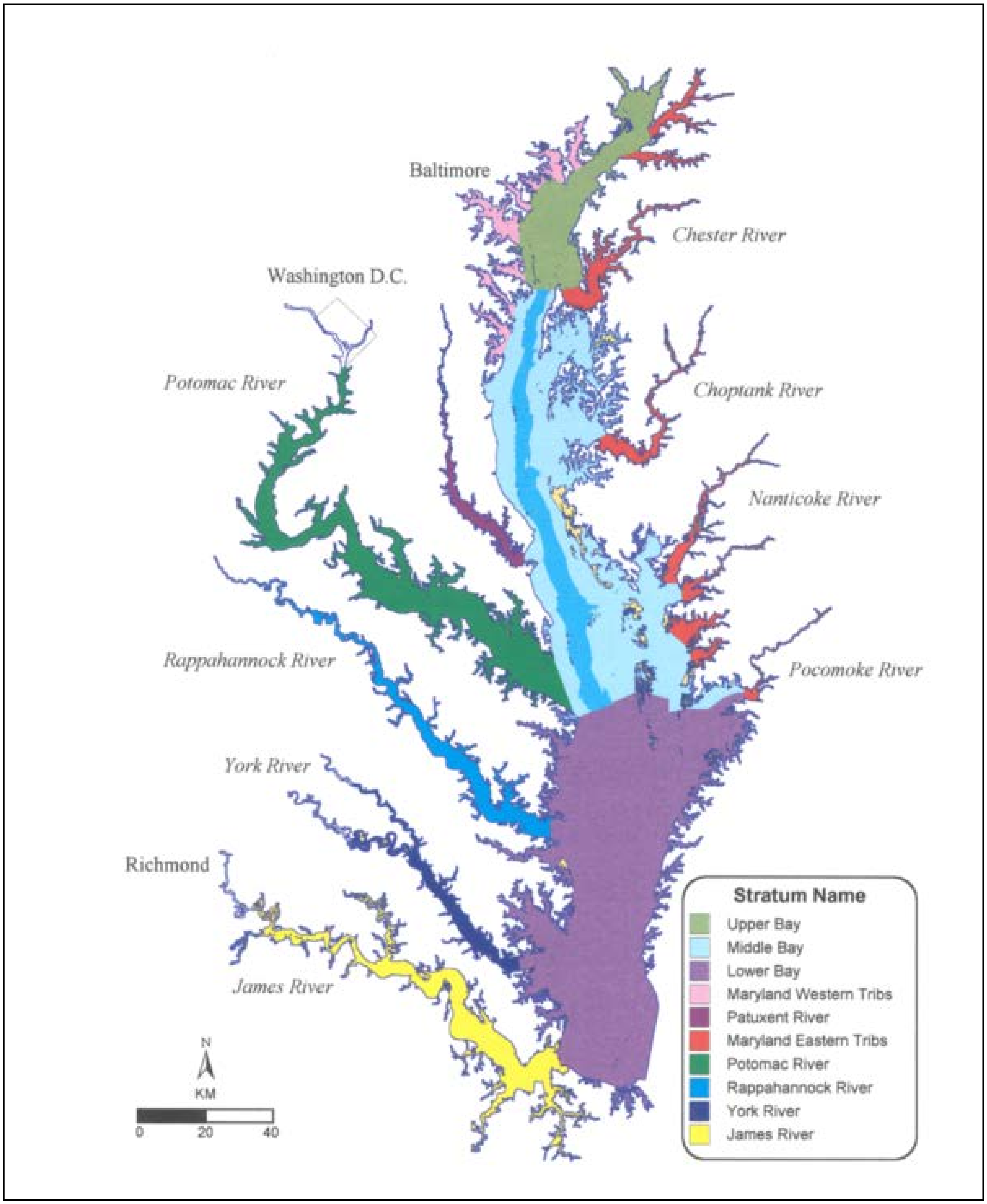

Figure 2-6. Chesapeake Bay stratification scheme

Table 2-4. Methods used to measure water quality parameters

Parameter	Period	Method
Temperature	July 1984 to November 1984	Thermistor attached to Beckman Model RS5-3 salinometer
	December 1984 to December 1995	Thermistor attached to Hydrolab Surveyor II
	January 1996 to present	Thermistor attached to YSI-6600 Sonde or Hydrolab DataSonde 4a
Salinity and Conductivity	July to November 1984	Beckman Model RS5-3 salinometer toroidal conductivity cell with thermistor temperature compensation
	December 1984 to December 1995	Hydrolab Surveyor II nickel six-pin electrode-salt water cell block combination with automatic temperature compensation
	January 1996 to present	YSI-6600 four nickel electrode cell, or Hydrolab DataSonde 4a four graphite electrode cell (open-cell design), with automatic temperature compensation
Dissolved Oxygen	July to November 1984	YSI Model 57 or Model 58 Oxygen Meter with automatic temperature and manual salinity compensation
	December 1984 to December 1995	Hydrolab Surveyor II membrane design probe with automatic temperature and salinity compensation
	January 1996 to present	YSI-6600 Rapid Pulse, or Hydrolab DataSonde 4a, membrane-design DO sensor with automatic temperature and salinity compensation
pH	July to November 1984	Orion analog pH meter with Ross glass combination electrode manually compensated for temperature
	December 1984 to December 1995	Hydrolab Surveyor II glass pH electrode and Lazaran reference electrode automatically compensated for temperature
	January 1996 to present	YSI-6600 combined pH and gel reference sensor, or Hydrolab DataSonde 4a pH and glass bulb reference sensors, automatically compensated for temperature
Oxidation Reduction Potential	December 1984 to December 1995	Hydrolab Surveyor II platinum banded glass ORP electrode

2.2.3 Benthic Samples

Samples were collected using four kinds of gear depending on the program element and habitat type. For the fixed site element (Table 2-1), a hand-operated box corer ("modified box corer"), which samples a 250 cm^2 area to a depth of 25 cm, was used in the nearshore shallow sandy habitats of the mainstem bay and tributaries. A Wildco box corer, which samples an area of 225 cm^2 to a depth of 23 cm, was used in shallow muddy or deep-water (> 5 m) habitats in the mainstem bay and tributaries. A Petite Ponar Grab, which samples 250 cm^2 to a depth of 7 cm, was used at the fixed site in the Nanticoke River to be consistent with previous sampling in the 1980s. At the two fixed sites first sampled in 1995 and at all probability-based sampling sites, a Young Grab, which samples an area of 440 cm^2 to a depth of 10 cm, was used.

Sample volume and penetration depth were measured for all samples; Wildco and hand-operated box cores penetrating less than 15 cm, and Young and Petite Ponar grabs penetrating less than 7 cm into the sediment were rejected and the site was re-sampled.

In the field, samples were sieved through a 0.5-mm screen using an elutriative process. Organisms and detritus retained on the screen were transferred into labeled jars and preserved in a 10% formaldehyde solution stained with Rose Bengal (a vital stain that aids in separating organisms from sediments and detritus).

Two surface-sediment sub-samples of approximately 120 ml each were collected for grain-size, carbon, and nitrogen analysis from an additional grab sample at each site. Surface sediment samples were frozen until they were processed in the laboratory.

2.3 LABORATORY PROCESSING

Organisms were sorted from detritus under dissecting microscopes, identified to the lowest practical taxonomic level (most often species), and counted. Oligochaetes and chironomids were mounted on slides and examined under a compound microscope for genus and species identification.

Ash-free dry weight biomass was determined by three comparable techniques during the sampling period. For samples collected from July 1984 to June 1985, biomass was directly measured using an analytical balance for major organism groups (e.g., polychaetes, molluscs, and crustaceans). Ash-free dry weight biomass was determined by drying the organisms to a constant weight at 60 °C and ashing in a muffle furnace at 500 °C for four hours. For samples collected between July 1985 and August 1993, a regression relationship between ash-free dry weight biomass and size of morphometric characters was defined for 22 species (Ranasinghe et al. 1993). The biomass of the 22 selected species was estimated from these regression relationships. These taxa (Table 2-5) were selected because they accounted for more than 85% of the abundance (Holland et al. 1988). After August 1993, ash-free dry weight biomass was measured directly for each species by drying the organisms to a constant weight at 60 °C and ashing in a muffle furnace at 500 °C for four hours and re-weighing (ash weight). The difference between the dry weight and the ash weight is the ash-free dry weight. Bivalves were crushed to open the shells and expose the animal to drying and ashing (shells included).

Table 2-5. Taxa for which biomass was estimated in samples collected between 1985 and 1993.

Polychaeta	**Mollusca**
Eteone heteropoda *Glycinde solitaria* *Heteromastus filiformis* *Marenzelleria viridis* *Neanthes succinea* *Paraprionospio pinnata* *Streblospio benedicti*	*Acteocina canaliculata* *Corbicula fluminea* *Gemma gemma* *Haminoe solitaria* *Macoma balthica* *Macoma mitchelli* *Mulinia lateralis* *Mya arenaria* *Rangia cuneata* *Tagelus plebeius*
Crustacea	
Cyathura polita *Gammarus* spp. *Leptocheirus plumulosus*	
Miscellaneous	
Carinoma tremaphoros *Micrura leidyi*	

Silt-clay composition and carbon and nitrogen content were determined for one of the two sediment sub-samples collected at each sampling site. The other sample was archived for quality assurance purposes (Scott et al. 1988). Sand and silt-clay particles were separated by wet-sieving through a 63-μm, stainless steel sieve and weighed using the procedures described in the Versar, Inc., Laboratory Standard Operating Procedures (Versar 1999). Carbon and nitrogen content of dried sediments was determined using an elemental analyzer. Sediment carbon content was measured with a Perkin-Elmer Model 240B analyzer from 1984 to 1988, and an Exeter Analytical Inc., Model CE-440 analyzer in and after 1995. The results from both instruments are comparable. Samples are combusted at high temperature (975 °C) and the carbon dioxide and nitrogen produced are measured by thermal conductivity detection. Prior to combustion, each sample is homogenized and oven-dried. No acid is applied.

2.4 DATA ANALYSIS

Analyses for the fixed site and probability-based elements of LTB were both performed in the context of the Chesapeake Bay Program's benthic community restoration goals and the Benthic Index of Biotic Integrity (B-IBI) by which goal attainment is measured. The B-IBI, the Chesapeake Bay benthic community restoration goals, and statistical analysis methods for the two LTB elements are described below.

2.4.1 The B-IBI and the Chesapeake Bay Benthic Community Restoration Goals

The B-IBI is a multiple-attribute index developed to identify the degree to which a benthic assemblage meets the Chesapeake Bay Program's benthic community restoration goals (Ranasinghe et al. 1994, updated by Weisberg et al. 1997; Alden et al. 2002). The B-IBI provides a means for comparing relative condition of benthic invertebrate assemblages across habitat types. It also provides a validated mechanism for integrating several benthic community attributes indicative of habitat "health" into a single number that measures overall benthic community condition.

The B-IBI is scaled from 1 to 5, and sites with values of 3 or more are considered to meet the restoration goals. The index is calculated by scoring each of several attributes as either 5, 3, or 1 depending on whether the value of the attribute at a site approximates, deviates slightly from, or deviates strongly from values found at the best reference sites in similar habitats, and then averaging these scores across attributes. The criteria for assigning these scores are numeric and depend on habitat. Data from seasons for which the B-IBI has not been developed were not used for B-IBI based assessment.

Benthic community condition was classified into four levels based on the B-IBI. Values less than or equal to 2.0 were classified as severely degraded; values from 2.0 to 2.6 were classified as degraded; values greater than 2.6 but less than 3.0 were classified as marginal; and values of 3.0 or more were classified as meeting the goals. Values in the marginal category do not meet the restoration goals, but they differ from the goals within the range of measurement error typically recorded between replicate samples.

2.4.2 Fixed Site Trend Analysis

Trends in condition at the fixed sites were identified using the nonparametric technique of van Belle and Hughes (1984). This procedure is based on the Mann-Kendall statistic and consists of a sign test comparing each value with all values measured in subsequent periods. The ratio of the Mann-Kendall statistic to its variance provides a normal deviate that is tested for significance. Alpha was set to 0.1 for these tests because of the low power for trend detection for biological data. An estimate of the magnitude of each significant trend was obtained using Sen's (1968) procedure which is closely related to the Mann-Kendall test. Sen's procedure identifies the median slope among all slopes between each value and all values measured in subsequent periods.

2.4.3 Probability-Based Estimation

The Maryland Bay was divided into three strata (Bay Mainstem, Potomac River, other tributaries and embayments) in 1994 (Table 2-2). It was divided into six strata in and after 1995 (Figure 2-4, Table 2-3). The Virginia Bay was divided into four strata, beginning in 1996 (Figure 2-6, Table 2-3).

To estimate the amount of area in the entire Bay that failed to meet the Chesapeake Bay benthic community restoration goals (P), we defined for every site *i* in stratum *h* a variable y_{hi} that had a value of 1 if the benthic community met the goals, and 0 otherwise. For each stratum, the estimated proportion of area meeting the goals, p_h, and its variance were calculated as the mean of the y_{hi}'s and its variance, as follows:

$$p_h = \overline{y}_h = \sum_{i=1}^{n_h} \frac{y_{hi}}{n_h} \quad (1)$$

and

$$\operatorname{var}(p_h) = s_h^2 = \sum_{i=1}^{n_h} \frac{\left(y_{hi} - \overline{y}_h\right)^2}{n_h - 1} \quad (2)$$

Estimates for strata were combined to achieve a statewide estimate as:

$$\hat{P}_{ps} = \overline{y}_{ps} = \sum_{h=1}^{6} W_h \overline{y}_h \quad (3)$$

where the weighting factor $W_h = A_h/A$; A_h is the total area of the *h*th stratum, and A is the combined area of all strata. The variance of (3) was estimated as:

$$\operatorname{var}\left(\hat{P}_{ps}\right) = \operatorname{var}\left(\overline{y}_{ps}\right) = \sum_{h=1}^{6} W_h^2 s_h^2 / n_h \quad (4)$$

The standard error for individual strata is estimated as the square root of (2), and for the combined strata, as the square root of (4).

3.0 RESULTS

3.1 TRENDS IN FIXED SITE BENTHIC CONDITION

Trend analysis is conducted on 27 fixed sites located throughout the Bay and its tributaries to assess whether benthic community condition is changing. Through 2008 the sites were sampled yearly in the spring and summer but the trend analysis is performed on the summer data only in order to apply the B-IBI (Weisberg et al. 1997; Alden et al. 2002). B-IBI calculations and trend analysis methods are described in Section 2.4.

The B-IBI is the primary measure used in trend analysis because it integrates several benthic community attributes into a measure of overall condition. It provides context for interpretation of observed trends because status has been calibrated to reference conditions. Significant trends that result in a change of status (sites that previously met the Chesapeake Bay benthic community restoration goals which now fail, or vice versa) are of greater management interest than trends which do not result in a change. As a first step in identifying causes of changes in condition, trends on individual attributes are identified and examined.

Table 3-1 presents trends in benthic community condition from 1985 to the present. Although the Maryland benthic monitoring component began sampling in 1984, data collected in the first year of our program were excluded from analysis to facilitate comparison of results with other components of the monitoring program. Several components of the Maryland program as well as the Virginia Benthic Monitoring Program did not start sampling until 1985. Twenty six-year (1985-2010) trends are presented for 23 of the 27 trend sites, 22-year trends are presented for two sites in Baltimore Harbor (Stations 201 and 202) first sampled in 1989, and 16-year trends are presented for two western shore tributaries (Back River Station 203, and Severn River Station 204) first sampled in 1995. Trend site locations are shown in Figure 2-1.

Statistically significant B-IBI trends ($p<0.1$) were detected at 10 of the 27 sites (Table 3-1). These are the same number of trends that were reported for 2009, but four trends disappeared in 2010 and four trends emerged as new. Trends in benthic community condition declined at 8 sites (significantly decreasing B-IBI trend) and improved at 2 sites. All of the new trends were declining trends, and all of the trends that were significant through 2009 but disappeared in 2010 were improving trends. Therefore, changes in trend direction and magnitude in 2010 indicated generally degrading benthic conditions in Chesapeake Bay.

Sites with improving condition (Table 3-1) were located in the Bay main stem (Station 26) and the Back River (Station 203). Sites with declining condition (Table 3-1) were located in Baltimore Harbor (Station 22), Curtis Creek (Station 202), Patuxent River at Holland Cliff (Station 77), Patuxent River at Broomes Island (Station 71), tidal fresh Potomac River (Station 36), mesohaline Potomac River at Morgantown (Stations 43 and 44), and Nanticoke River (Station 62).

The most important changes in 2010 were the appearance of new degrading B-IBI trends, reversing conditions in the Potomac River at Morgantown (Station 44), and the disappearance of previously improving benthic condition trends in the Choptank River (Station 64), North Beach (Station 15), Bear Creek (Station 201), and Elk River (Station 29). These changes were reflected in a general decline in benthic community status. Seven sites showed moderate to strong declines in B-IBI scores using the last three years of data, while only one site showed an increase and the rest remained about the same. The current condition at the fixed sites (Table 3-1 shaded areas) declined from meeting the goals to marginal in the Patapsco River (Station 23), from marginal to degraded in the Back River (Station 203), and from degraded to severely degraded in North Beach (Station 15), lower Potomac River (Station 51), and Bear Creek (Station 201). Note that the Back River (Station 203) shows an improving B-IBI trend but that the current condition at the site and the strength of the B-IBI trend have declined. Only the condition of the oligohaline Potomac River (Station 40) improved, from failing to meeting the goals. Currently, 10 sites meet the goals and 17 sites fail the goals.

Trends in community attributes that are components of the B-IBI are presented in Table 3-2 (mesohaline stations), Table 3-3 (oligohaline and tidal freshwater stations), and Appendix A. Sites with decreasing B-IBI trends had negative (declining trends below restorative thresholds) in abundance, biomass, or both, and usually in one other component of the B-IBI (Table 3-2). Several sites with no B-IBI trends also exhibited statistically significant declining trends in abundance and number of species, indicating a general tendency in the Chesapeake Bay toward low index scores despite the baywide improvements observed in 2009. Figures 3-1 through 3-27 show patterns in abundance, biomass, number of species, and B-IBI at the fixed sites. The first thing to notice in these figures is that, on average, abundance was lower during the 1998-2010 period than during the 1984-1997 period in the Maryland mainstem (Stations 01, 06, 15, 24 and 26), Patapsco River (Stations 22, 23), Elk River (Station 29), mesohaline Potomac River (Stations 43, 47, 51 and 52), and lower Patuxent River (Stations 71), but not in the upper Potomac River (Stations 36 and 40), Nanticoke River (Station 62), Choptank River (Stations 64 and 66), Chester River (Station 68), and upper Patuxent River (Stations 74, 77, and 79). The upper Potomac and Patuxent rivers and the eastern shore tributaries failed to show this general pattern, suggesting that different types of stresses affect the upper and lower reaches of tributaries. The second thing to notice is the very low abundance values in the last 6 years of monitoring at most of the fixed sites. These very low values have been circled in Figure 3-1 but similar circles can be made in the other figures. Species numbers also showed declines at many of the fixed sites, with the exception of Station 79 in the upper Patuxent River, which showed an increase in species numbers (Figure 3-23).

The upper reaches of the tidal Potomac (Figure 3-9) and Patuxent (Figure 3-23) rivers did not show declines in abundance. These systems are eutrophic and tend to show variable abundance and biomass values above restorative thresholds. The mid Nanticoke (Figure 3-16) and Chester (Figure 3-19) rivers exhibited similar patterns. The Chester and upper Patuxent rivers had abundance, biomass, or B-IBI values in the good range whereas the Nanticoke and upper Potomac rivers showed declining conditions. The patterns at these sites contrast with those of the higher salinity sites, which show depauperate conditions more typical of hypoxic waters.

Table 3-1. Summer trends in benthic community condition, 1985-2010. Trends were identified using the van Belle and Hughes (1984) procedure. Current mean B-IBI and condition are based on 2008-2010 values. Initial mean B-IBI and condition are based on 1985-1987 values, except where noted. NS: not significant; (a): 1989-1991 initial condition; (b): 1995-1997 initial condition. Shaded areas highlight changes in condition or trend direction over those reported for 2009.

Station	Trend Significance	Median Slope (B-IBI units/yr)	Current Condition (2008-2010)	Initial Condition (1985-1987 unless otherwise noted)
Potomac River				
36	$p < 0.05$	–0.02	2.44 (Degraded)	3.14 (Meets Goal)
40	NS	0.00	3.09 (Meets Goal)	2.80 (Marginal)
43	$p < 0.05$	–0.00	3.18 (Meets Goal)	3.76 (Meets Goal)
44	$p < 0.1$	–0.02	2.60 (Degraded)	2.80 (Marginal)
47	NS	0.00	3.93 (Meets Goal)	3.89 (Meets Goal)
51	NS	0.00	1.96 (Severely Degraded)	2.43 (Degraded)
52	NS	0.00	1.33 (Severely Degraded)	1.37 (Severely Degraded)
Patuxent River				
71	$p < 0.001$	–0.03	1.3 (Severely Degraded)	2.52 (Degraded)
74	NS	0.00	3.58 (Meets Goal)	3.78 (Meets Goal)
77	$p < 0.01$	–0.04	2.64 (Degraded)	3.76 (Meets Goal)
79	NS	0.00	3.11 (Meets Goal)	2.75 (Marginal)
Choptank River				
64	NS	0.02	3.15 (Meets Goal)	2.78 (Marginal)
66	NS	0.00	2.95 (Marginal)	2.60 (Degraded)
Maryland Mainstem				
01	NS	0.00	2.78 (Marginal)	2.93 (Marginal)
06	NS	0.00	2.67 (Marginal)	2.56 (Degraded)
15	NS	0.00	1.96 (Severely Degraded)	2.22 (Degraded)
24	NS	0.00	3.33 (Meets Goal)	3.04 (Meets Goal)
26	$p < 0.01$	0.02	3.80 (Meets Goal)	3.16 (Meets Goal)
Maryland Western Shore Tributaries				
22	$p < 0.001$	–0.04	1.33 (Severely Degraded)	2.08 (Degraded)
23	NS	0.00	2.96 (Marginal)	2.49 (Degraded)
201	NS	0.00	1.76 (Severely Degraded)	1.10 (Severely Degraded) (a)
202	$p < 0.05$	–0.00	1.0 (Severely Degraded)	1.40 (Severely Degraded) (a)
203	$p < 0.05$	0.05	2.56 (Degraded)	2.08 (Degraded) (b)
204	NS	–0.03	3.44 (Meets Goal)	3.67 (Meets Goal) (b)
Maryland Eastern Shore Tributaries				
29	NS	0.00	2.40 (Degraded)	2.38 (Degraded)
62	$p < 0.001$	–0.04	2.42 (Degraded)	3.42 (Meets Goal)
68	NS	0.00	3.62 (Meets Goal)	3.51 (Meets Goal)

Table 3-2. Summer trends in benthic community attributes at mesohaline stations 1985-2010. Monotonic trends were identified using the van Belle and Hughes (1984) procedure. ⇑: Increasing trend; ⇓: Decreasing trend. *: $p< 0.1$; **: $p< 0.05$; ***: $p< 0.01$; shaded trend cells indicate increasing degradation; unshaded trend cells indicate unchanging or improving conditions; (a): trends based on 1989-2010 data; (b): trends based on 1995-2010 data; (c): attribute trend based on 1990-2010 data; (d): attributes are used in B-IBI calculations when species specific biomass is unavailable; NA: attribute is not part of the reported B-IBI. Blanks indicate no trend (not significant). See Appendix A for further detail.

Station	B-IBI	Abundance	Biomass	Shannon Diversity	Indicative Abundance	Sensitive Abundance	Indicative Biomass (c)	Sensitive Biomass (c)	Abundance Carnivore/ Omnivores
Potomac River									
43	⇓ **	⇓ ***	⇓ ***		⇑ ***	⇓ *** (d)	NA	⇓ ***	NA
44	⇓ *	⇓ ***	⇓ ***		⇓ *	(d)	NA		NA
47		⇓ ***	⇓ ***			⇓ *** (d)	NA	⇓ ***	NA
51		⇓ ***	⇓ ***		⇓ ***		NA	⇓ ***	
52		⇓ ***	⇓ ***	⇓ **	(d)	(d)			
Patuxent River									
71	⇓ ***	⇓ ***	⇓ ***	⇓ **	(d)	⇓ **(d)			
74			⇓ ***			⇓ **(d)	NA	⇓ ***	NA
77	⇓ ***		⇓ ***			⇓ * (d)	NA		NA
Choptank River									
64		⇓ **		⇑ **	(d)	⇑ ***(d)		⇓ *	⇑ ***
Maryland Mainstem									
01		⇓ ***			⇓ **		NA	NA	
06				⇓ **			NA	NA	⇓ **
15			⇓ *				NA	NA	
24		⇓ **		⇓ ***	⇓ ***(d)	⇑ ** (d)			⇑ ***
26	⇑ ***					(d)	NA		NA
Maryland Western Shore Tributaries									
22	⇓ ***	⇓ ***	⇓ ***	⇓ ***	⇑ ***	(d)	NA	⇓ **	NA
23		⇓ ***		⇓ **		⇑ *** (d)	NA	⇑ **	NA
201(a)						(d)	NA		NA
202(a)	⇓ **	⇓ ***				(d)	NA		NA
204(b)		⇓ **	⇓ **		(d)	(d)			
Maryland Eastern Shore Tributaries									
62	⇓ ***		⇓ ***	⇓ ***		⇓ *** (d)	NA	⇓ **	NA
68			⇑ ***	⇓ **		(d)	NA		NA

Table 3-3. Summer trends in benthic community attributes at oligohaline and tidal freshwater stations 1985-2010. Monotonic trends were identified using the van Belle and Hughes (1984) procedure. ⇑: Increasing trend; ⇓: Decreasing trend. *: $p < 0.1$; **: $p < 0.05$; ***: $p < 0.01$; shaded trend cells indicate increasing degradation; unshaded trend cells indicate unchanging or improving conditions; (a): trends based on 1995-2010 data; NA: attribute not calculated. Blanks indicate no trend (not significant). See Appendix A for further detail.

Station	B-IBI	Abundance	Tolerance Score	Freshwater Indicative Abundance	Oligohaline Indicative Abundance	Oligohaline Sensitive Abundance	Tanypodinae to Chironomidae Ratio	Abundance Deep Deposit Feeders	Abundance Carnivore/ Omnivores
Potomac River									
36	⇓ **		⇑ ***	⇑ ***	NA	NA	NA	⇑ ***	NA
40			⇓ ***	NA			⇓ **	NA	
Patuxent River									
79			⇓ **		NA	NA	NA		NA
Choptank River									
66			⇑ **	NA				NA	
Maryland Western Shore Tributaries									
203(a)	⇑ **		⇓ ***	NA			⇑ ***	NA	⇑ ***
Maryland Eastern Shore Tributaries									
29			⇓ *	NA	⇓ **			NA	⇑ ***

3-6

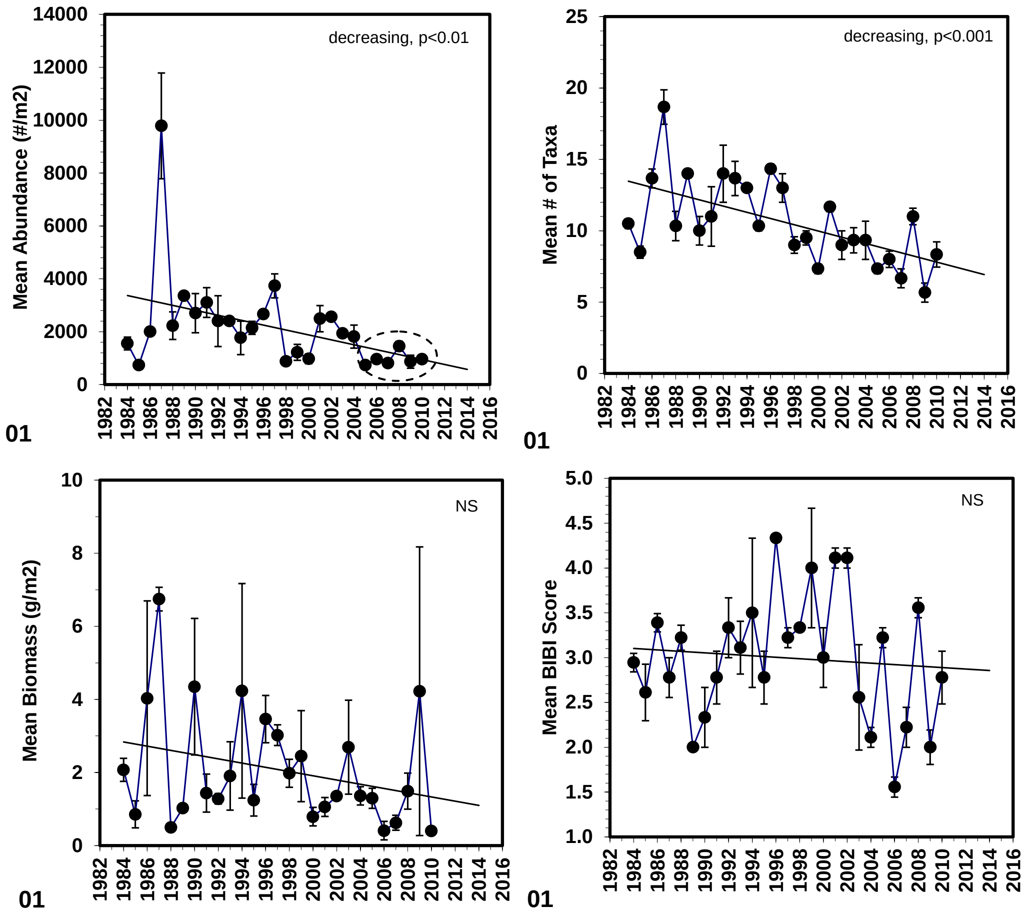

Figure 3-1. Trends in abundance, biomass, number of species, and B-IBI (mean ± 1 SE) at fixed sites. See text for details. Station 01 = Chesapeake Bay mainstem (≤ 5 m), Calvert Cliffs.

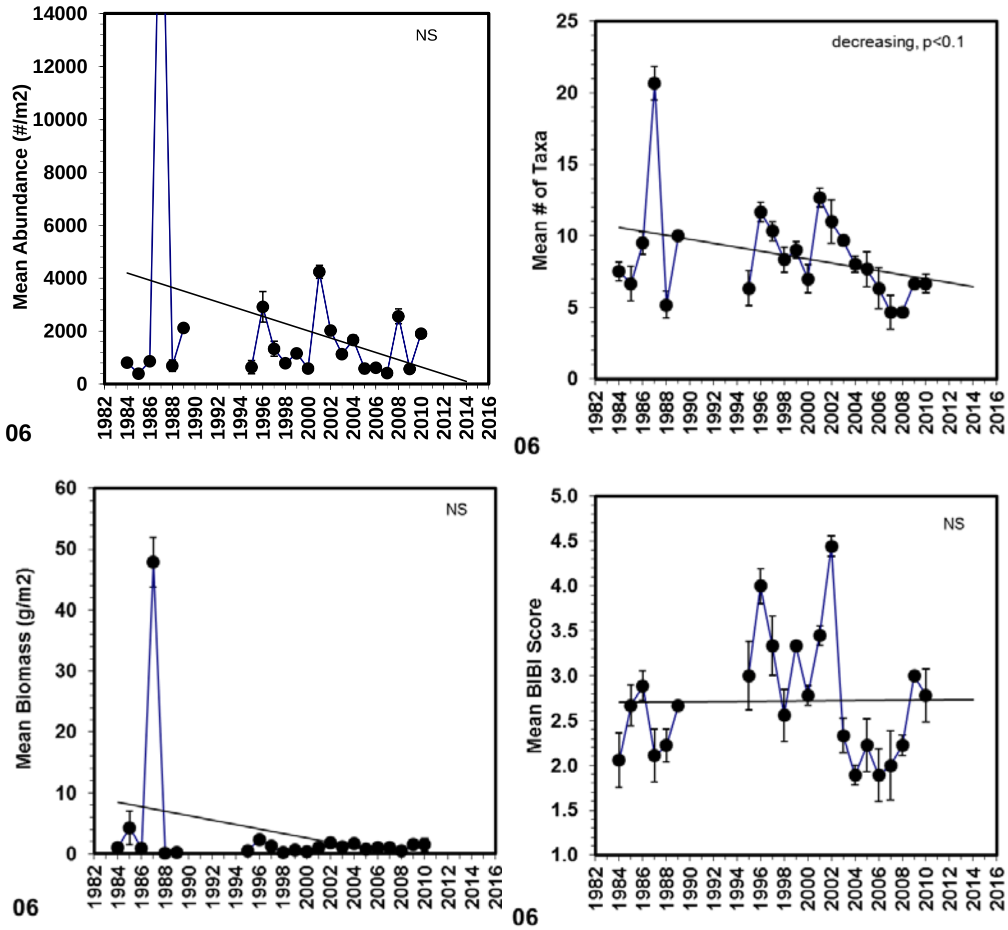

Figure 3-2. Trends in abundance, biomass, number of species, and B-IBI (mean ± 1 SE) at fixed sites. See text for details. Station 06 = Chesapeake mainstem (≤ 5 m), Calvert Cliffs.

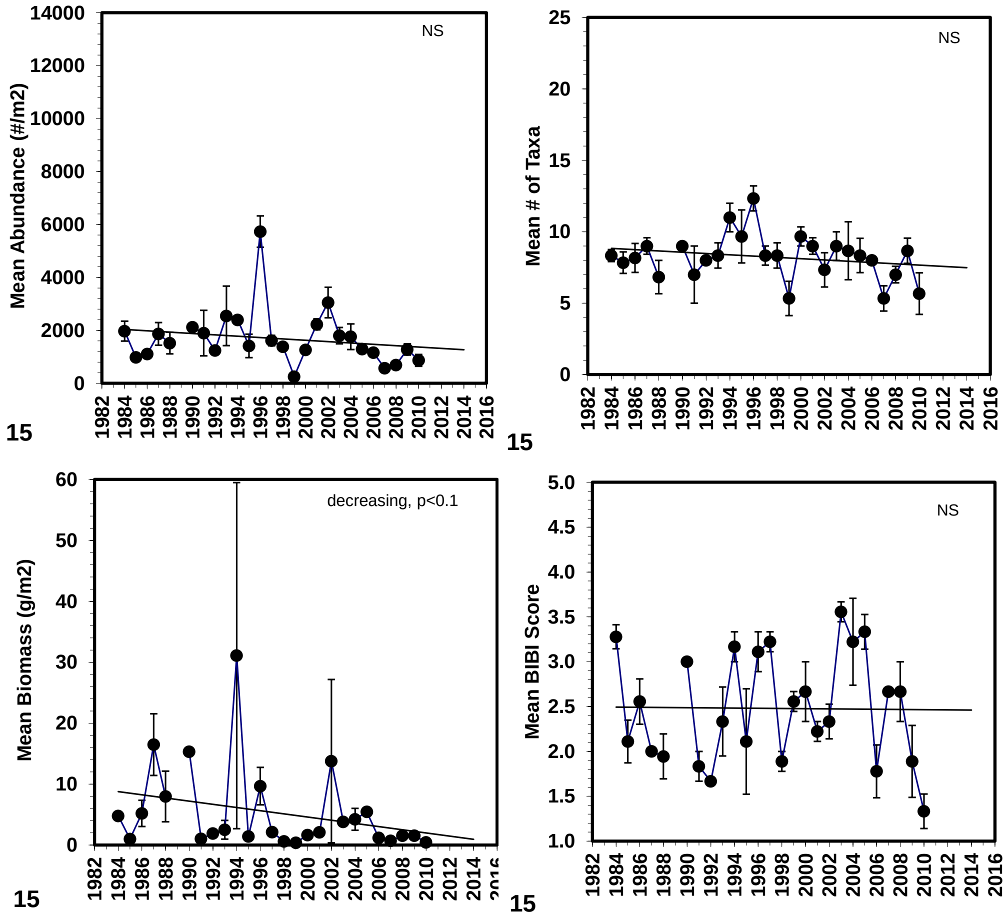

Figure 3-3. Trends in abundance, biomass, number of species, and B-IBI (mean ± 1 SE) at fixed sites. See text for details. Station 15 = Chesapeake mainstem (≤ 5 m), North Beach.

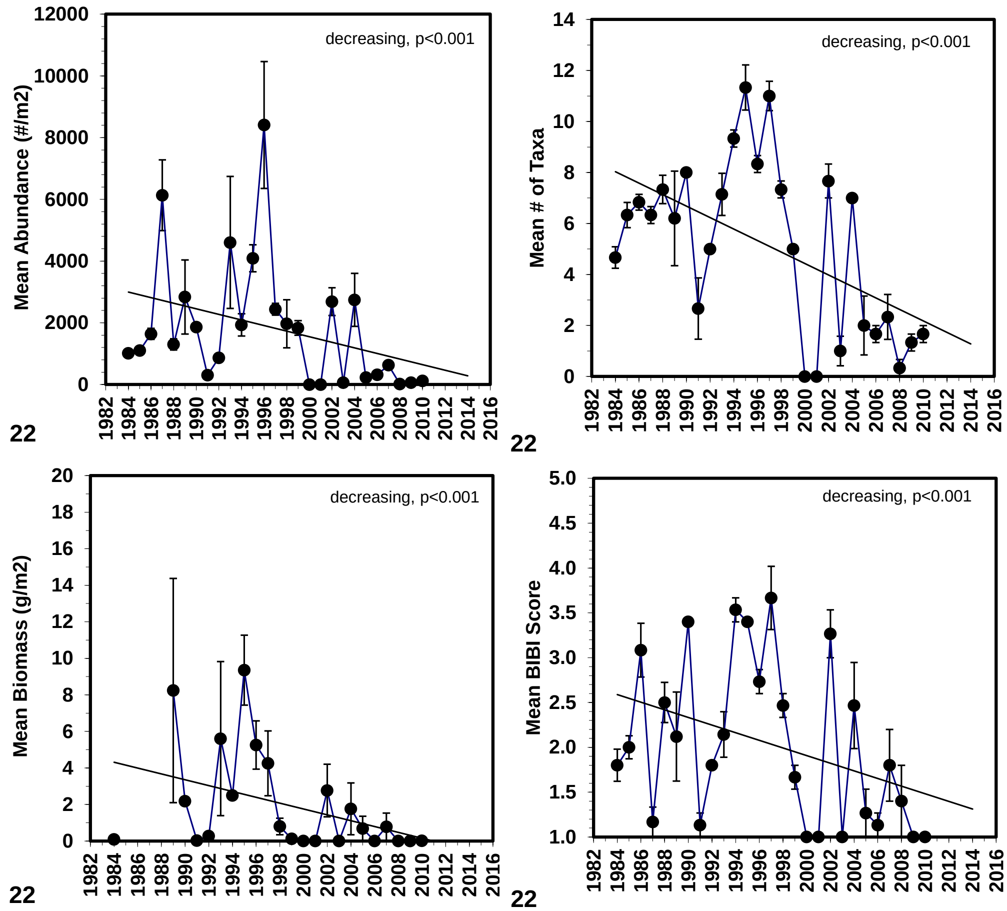

Figure 3-4. Trends in abundance, biomass, number of species, and B-IBI (mean ± 1 SE) at fixed sites. See text for details. Station 22 = Patapsco River estuary (2-6 m), Middle Branch.

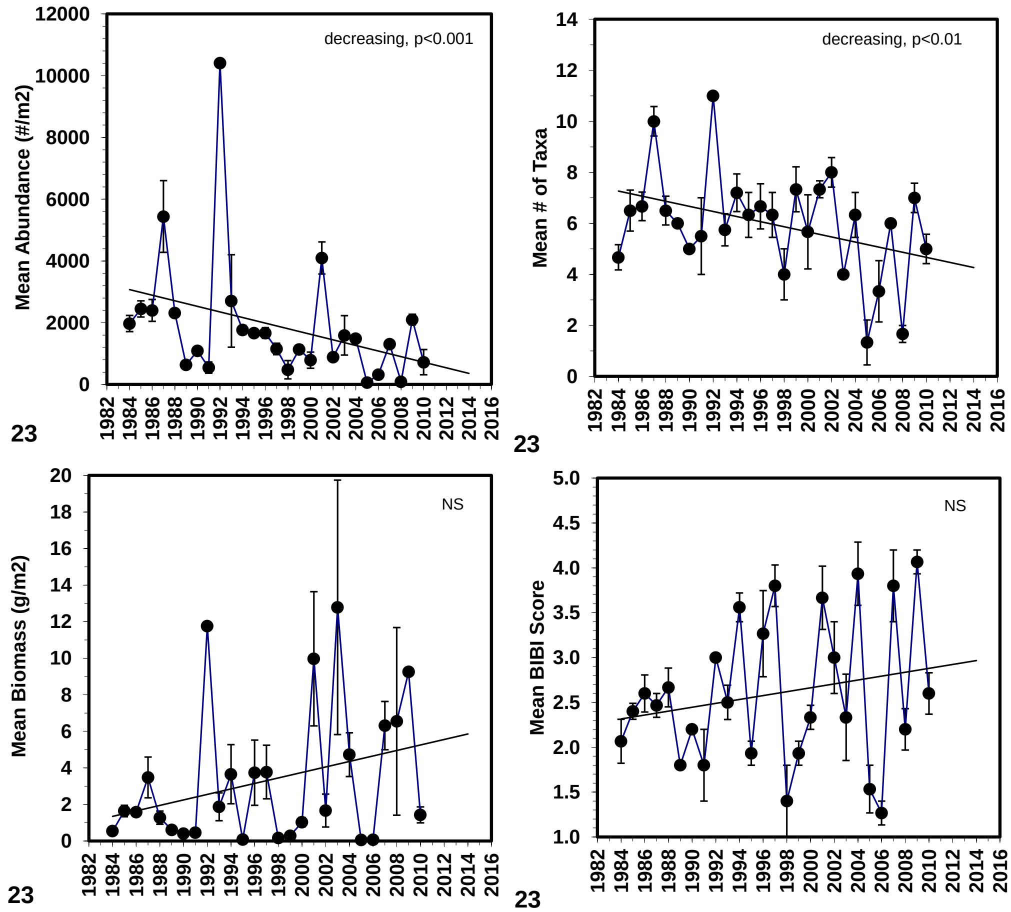

Figure 3-5. Trends in abundance, biomass, number of species, and B-IBI (mean ± 1 SE) at fixed sites. See text for details. Station 23 = Patapsco River estuary (4-7 m), main stem.

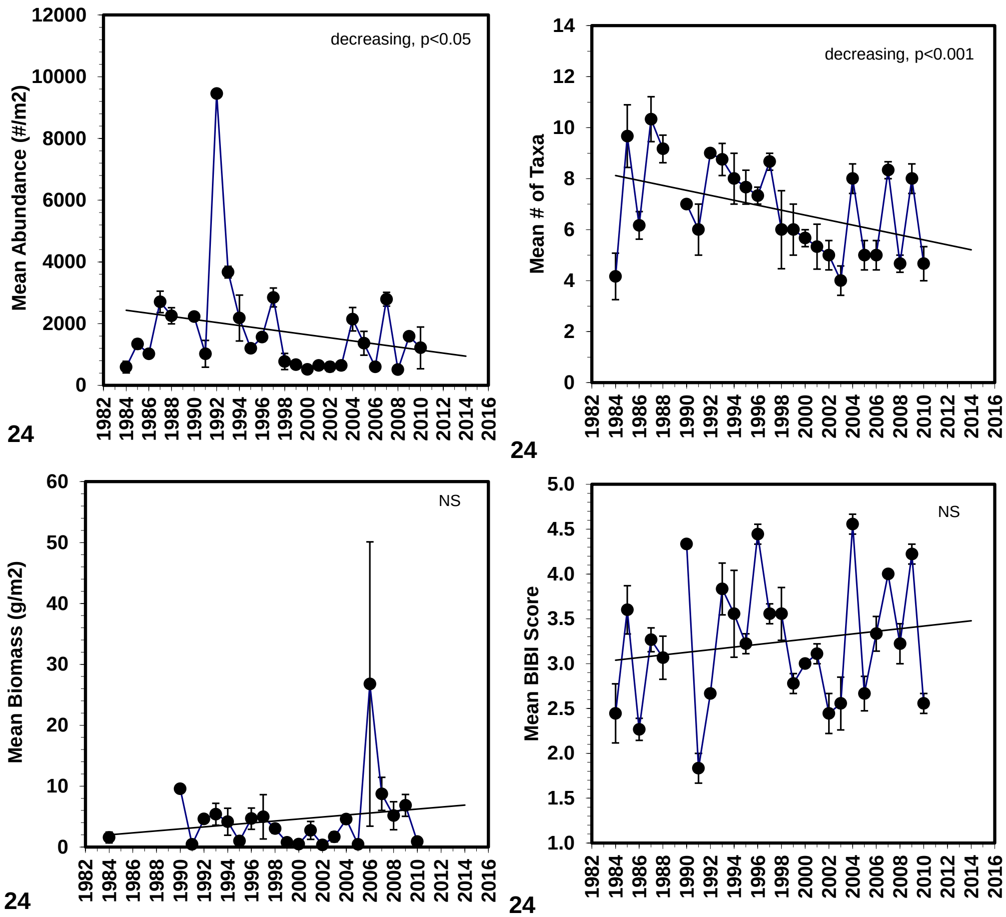

Figure 3-6. Trends in abundance, biomass, number of species, and B-IBI (mean ± 1 SE) at fixed sites. See text for details. Station 24 = Chesapeake Bay mainstem (5-8 m), near the mouth of the Patapsco River.

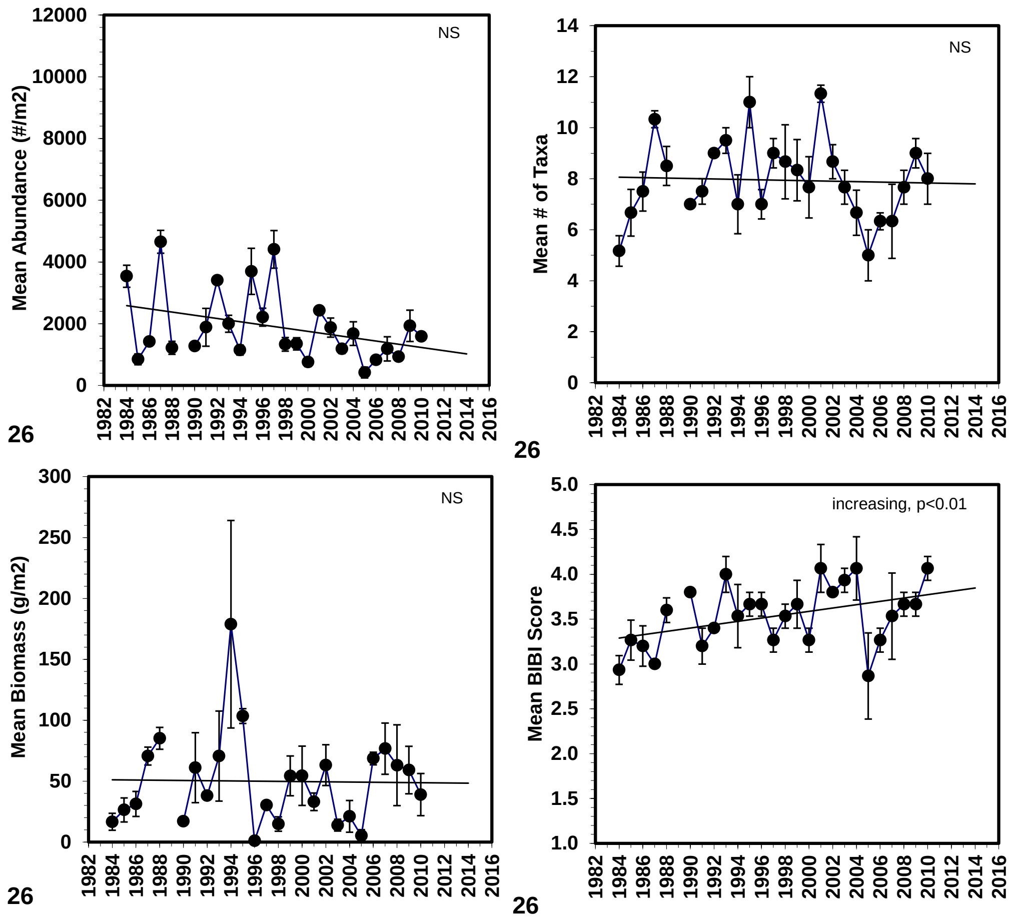

Figure 3-7. Trends in abundance, biomass, number of species, and B-IBI (mean ± 1 SE) at fixed sites. See text for details. Station 26 = Chesapeake Bay mainstem (2-5 m), near Pooles Island.

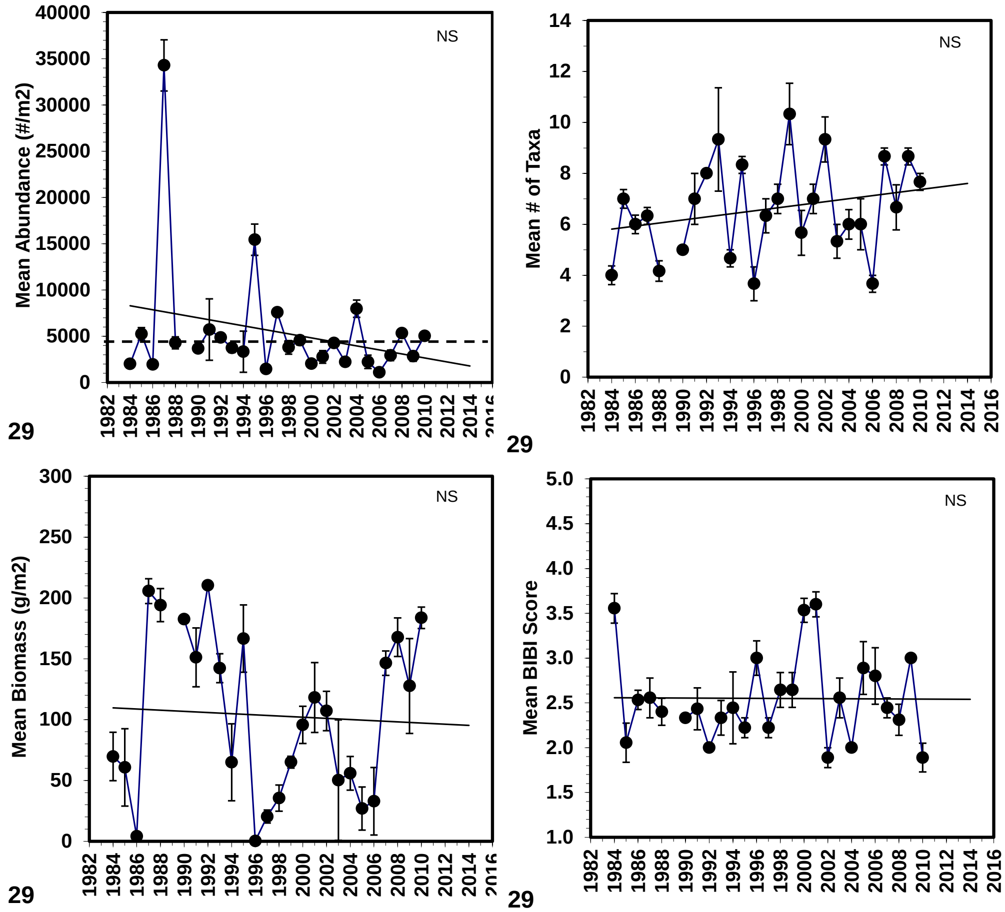

Figure 3-8. Trends in abundance, biomass, number of species, and B-IBI (mean ± 1 SE) at fixed sites. See text for details. Station 29 = Elk River. Dashed line: upper B-IBI threshold for abundance.

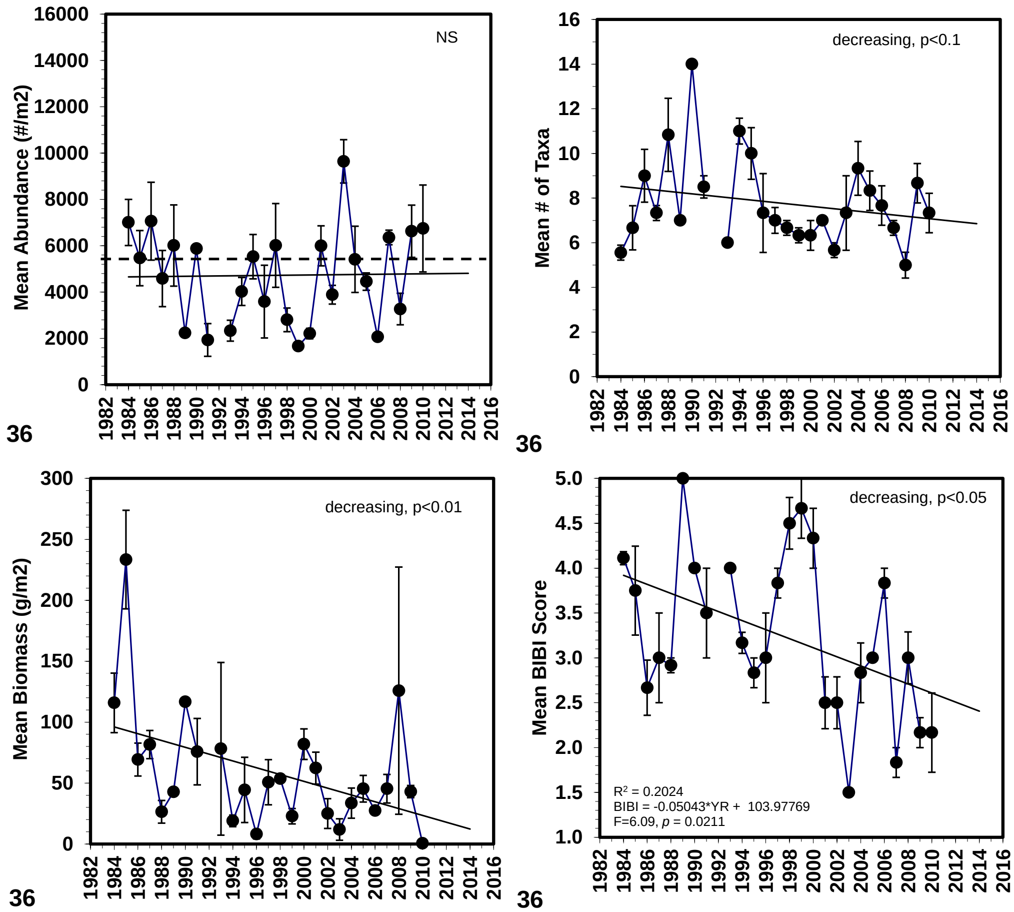

Figure 3-9. Trends in abundance, biomass, number of species, and B-IBI (mean ± 1 SE) at fixed sites. See text for details. Station 36 = Tidal fresh Potomac River tidal (≤ 5 m), Rosier Bluff. Dashed line: upper B-IBI threshold for abundance.

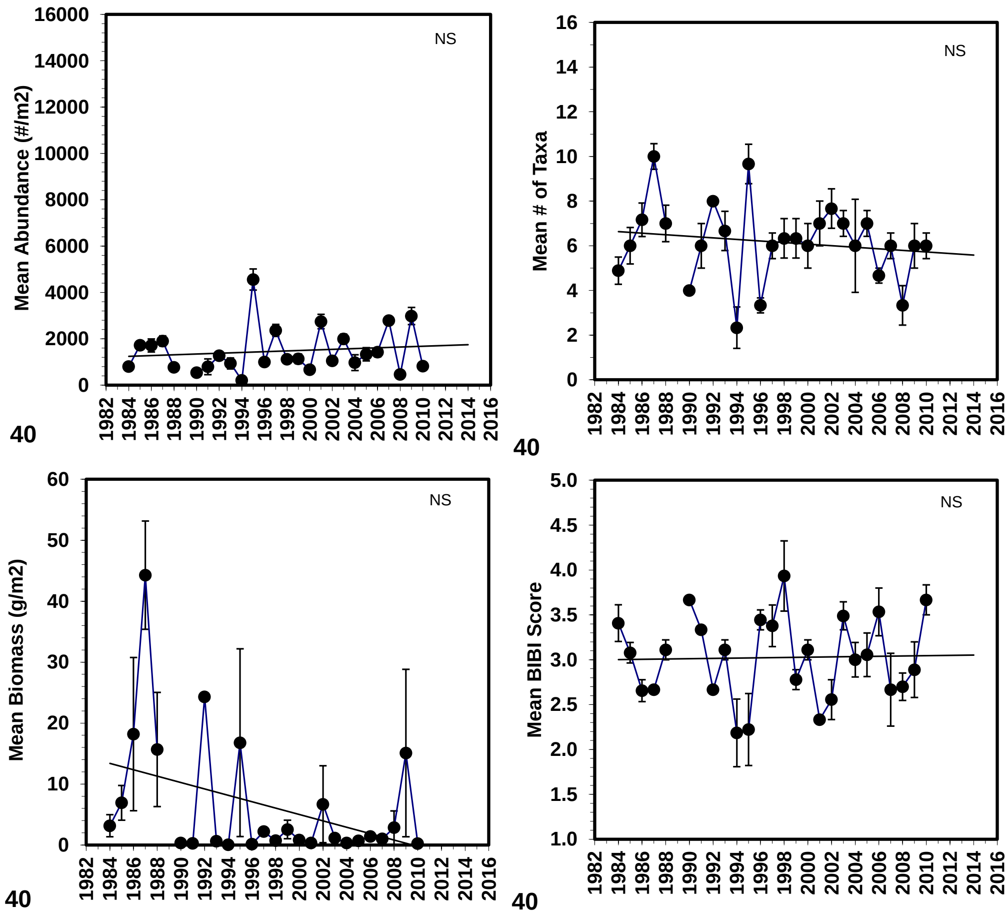

Figure 3-10. Trends in abundance, biomass, number of species, and B-IBI (mean ± 1 SE) at fixed sites. See text for details. Station 40 = Oligohaline Potomac River (6-10 m), Maryland Point.

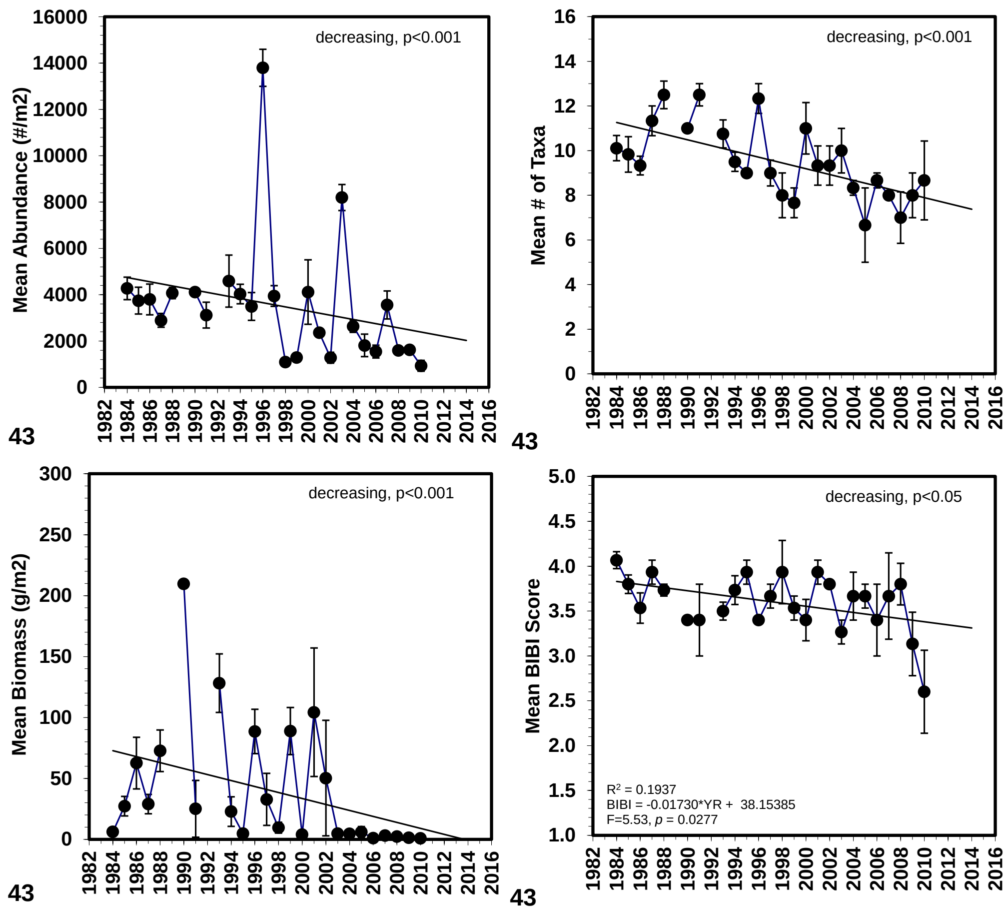

Figure 3-11. Trends in abundance, biomass, number of species, and B-IBI (mean ± 1 SE) at fixed sites. See text for details. Station 43 = Mesohaline Potomac River (≤5 m), Morgantown.

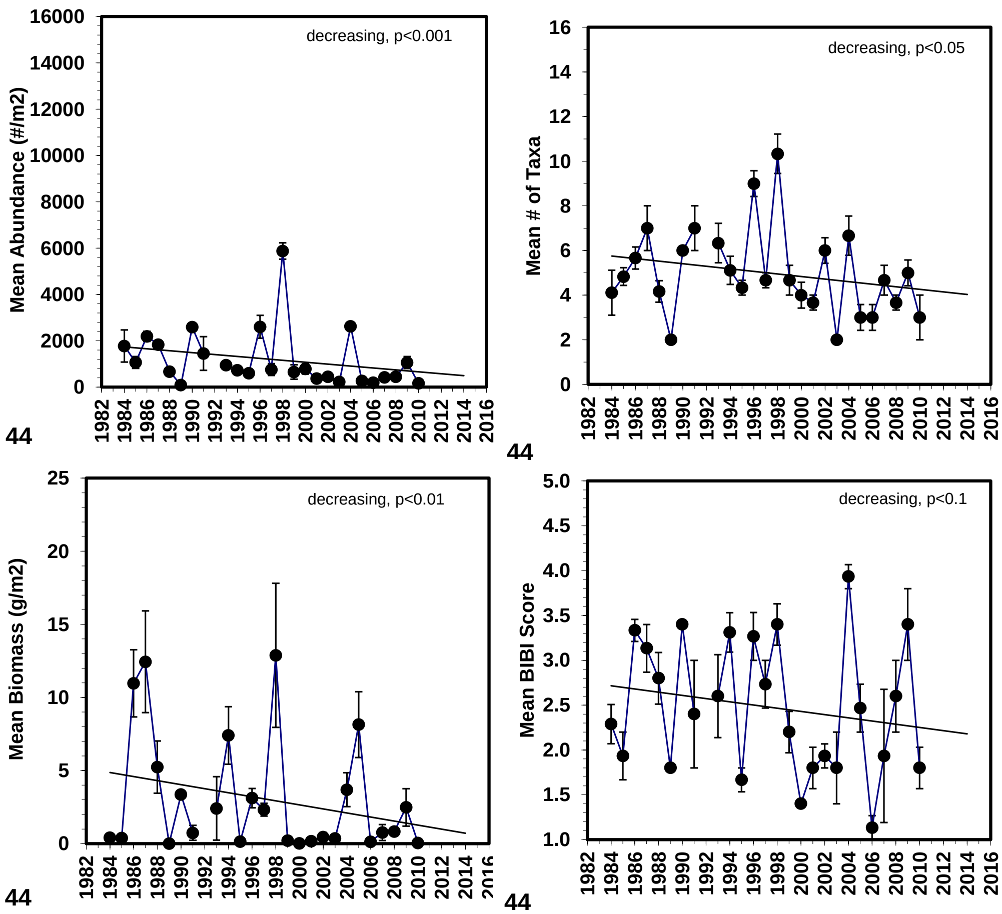

Figure 3-12. Trends in abundance, biomass, number of species, and B-IBI (mean ±1 SE) at fixed sites. See text for details. Station 44 = Mesohaline Potomac River (11-17 m), Morgantown.

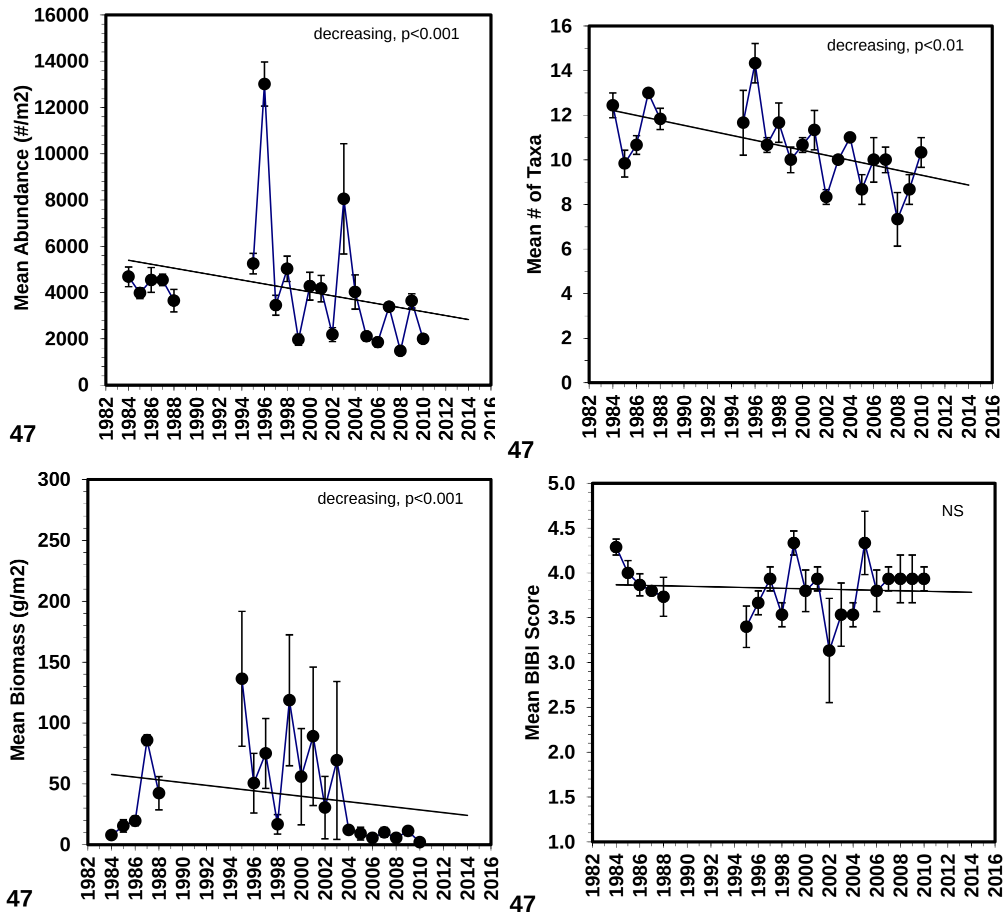

Figure 3-13. Trends in abundance, biomass, number of species, and B-IBI (mean ± 1 SE) at fixed sites. See text for details. Station 47 = Mesohaline Potomac River (≤5 m), Morgantown.

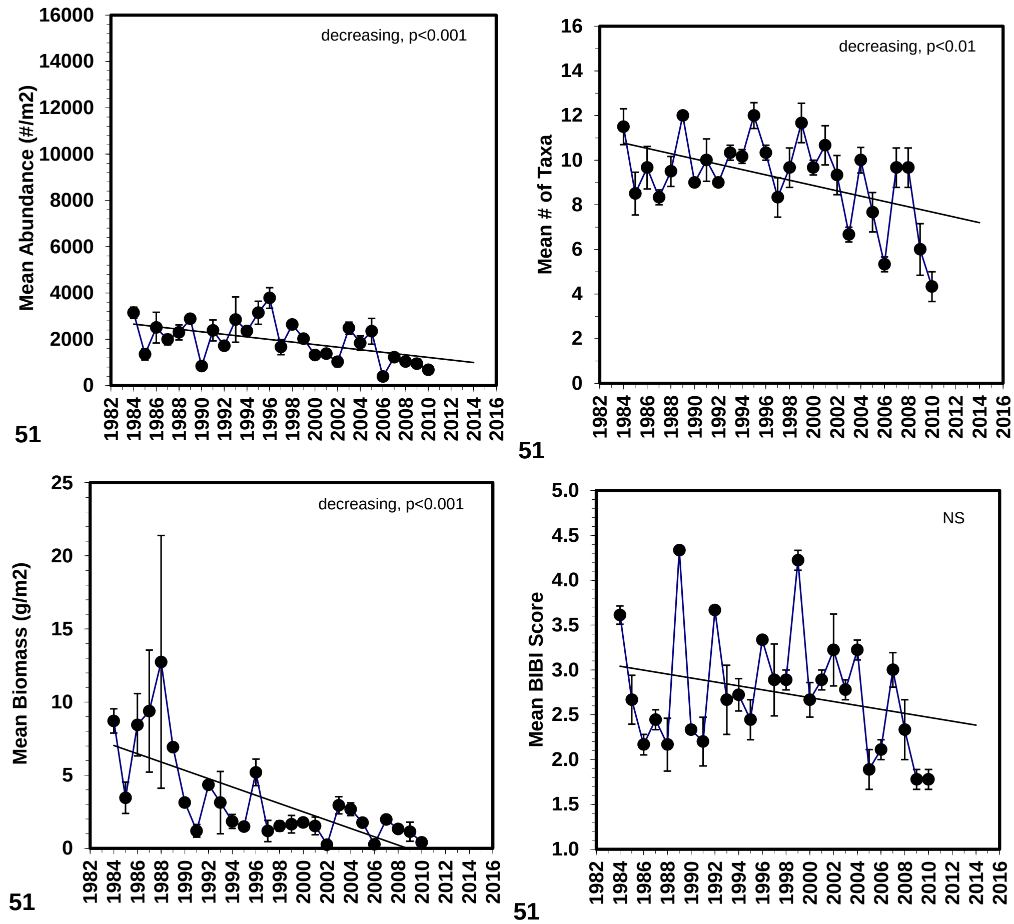

Figure 3-14. Trends in abundance, biomass, number of species, and B-IBI (mean ± 1 SE) at fixed sites. See text for details. Station 51 = Mesohaline Potomac River (≤5 m), St. Clements Island.

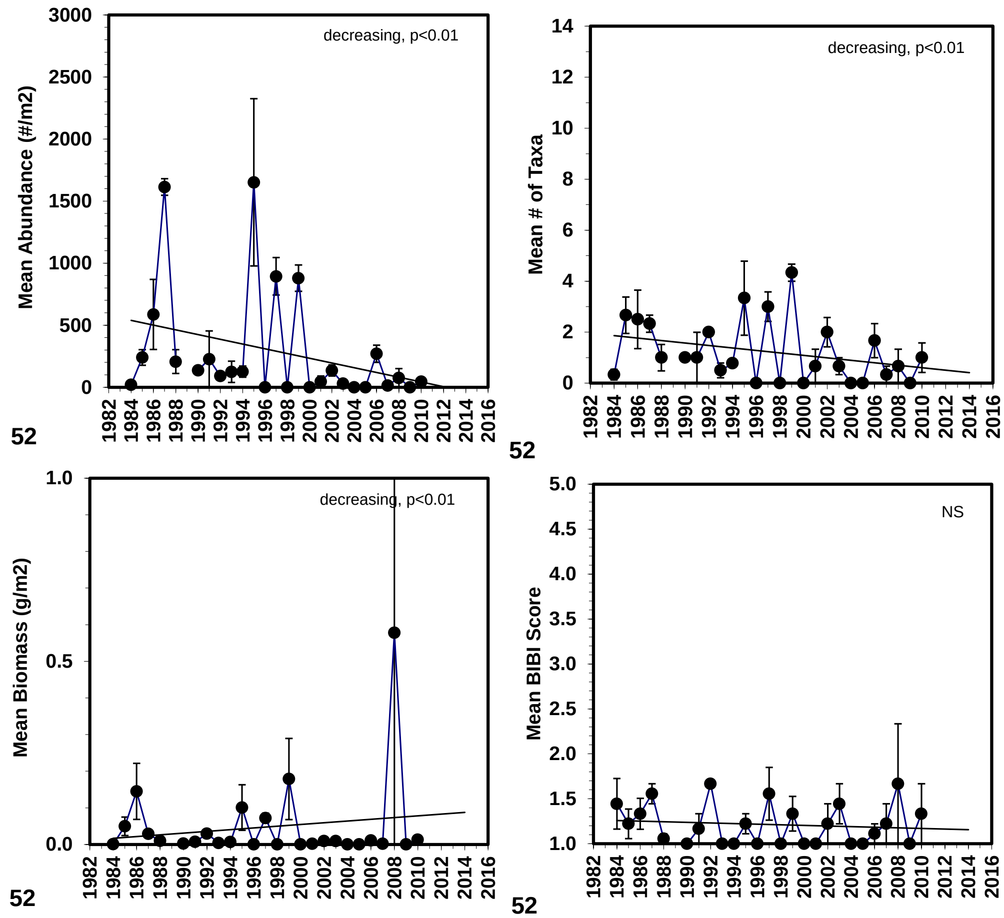

Figure 3-15. Trends in abundance, biomass, number of species, and B-IBI (mean ± 1 SE) at fixed sites. See text for details. Station 52 = Mesohaline Potomac River (9-13 m), St. Clements Island.

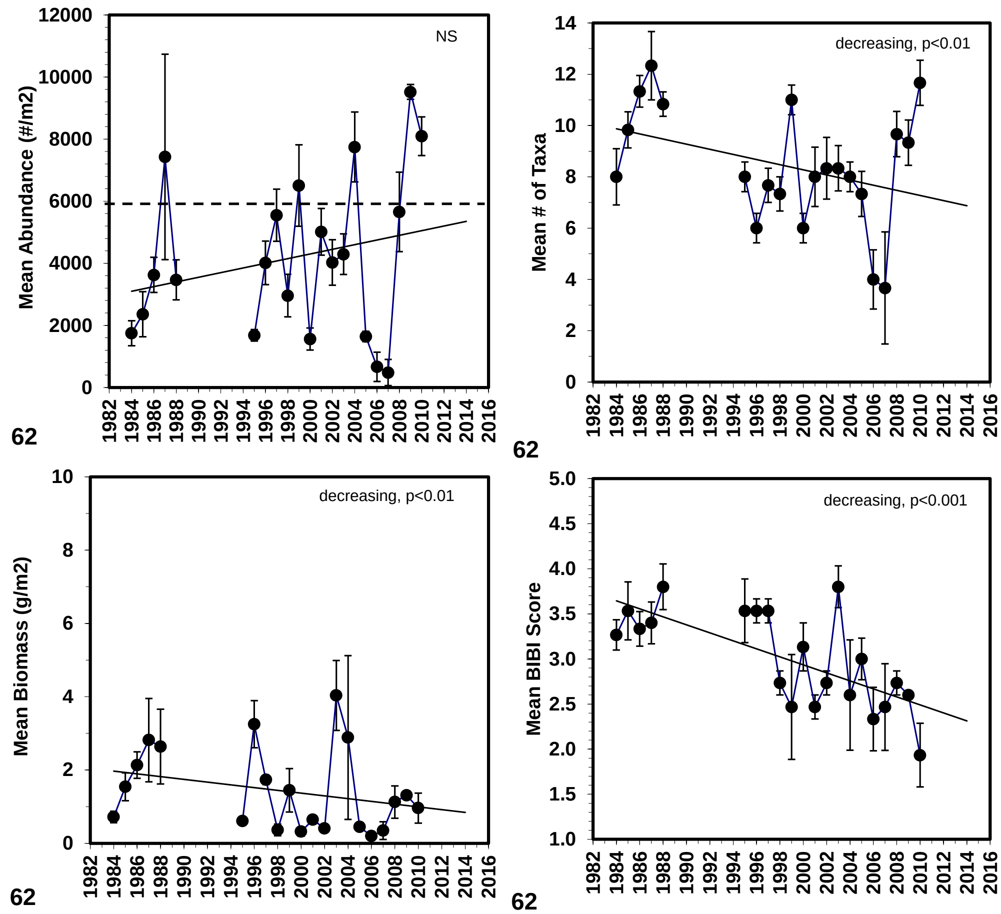

Figure 3-16. Trends in abundance, biomass, number of species, and B-IBI (mean ± 1 SE) at fixed sites. See text for details. Station 62 = Nanticoke River. Dashed line: upper B-IBI threshold for abundance.

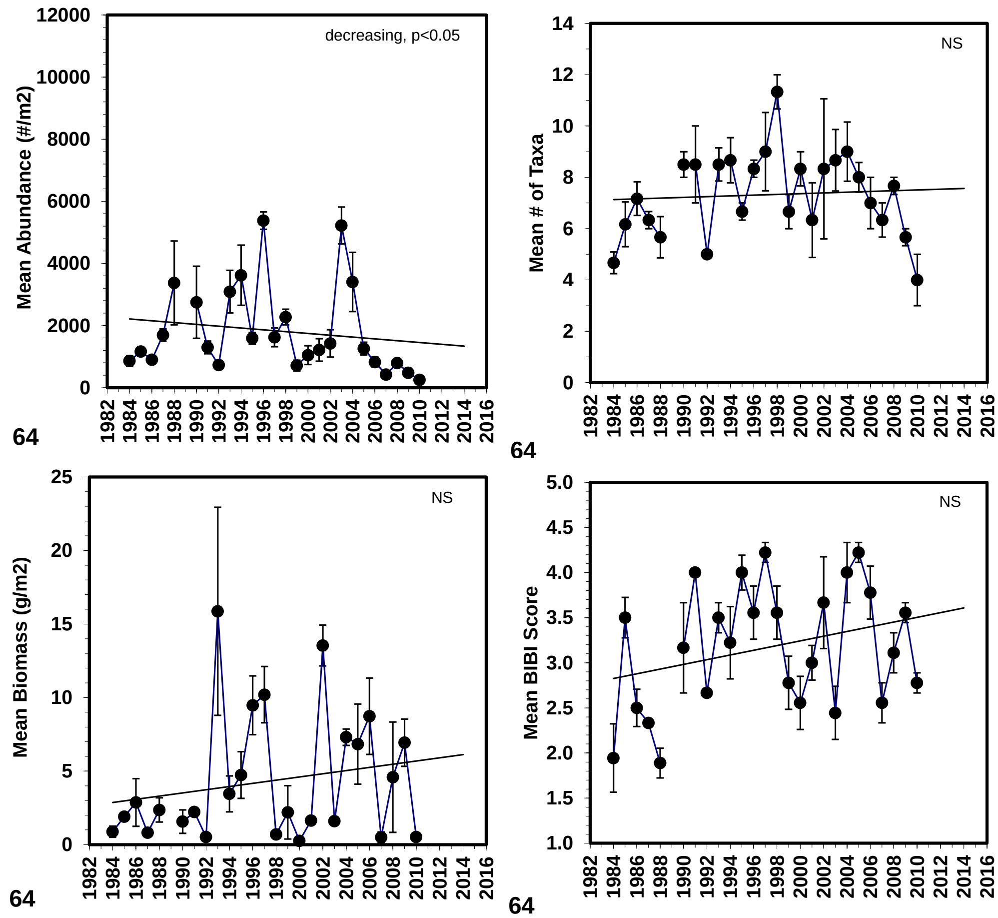

Figure 3-17. Trends in abundance, biomass, number of species, and B-IBI (mean ± 1 SE) at fixed sites. See text for details. Station 64 = Mesohaline Choptank River.

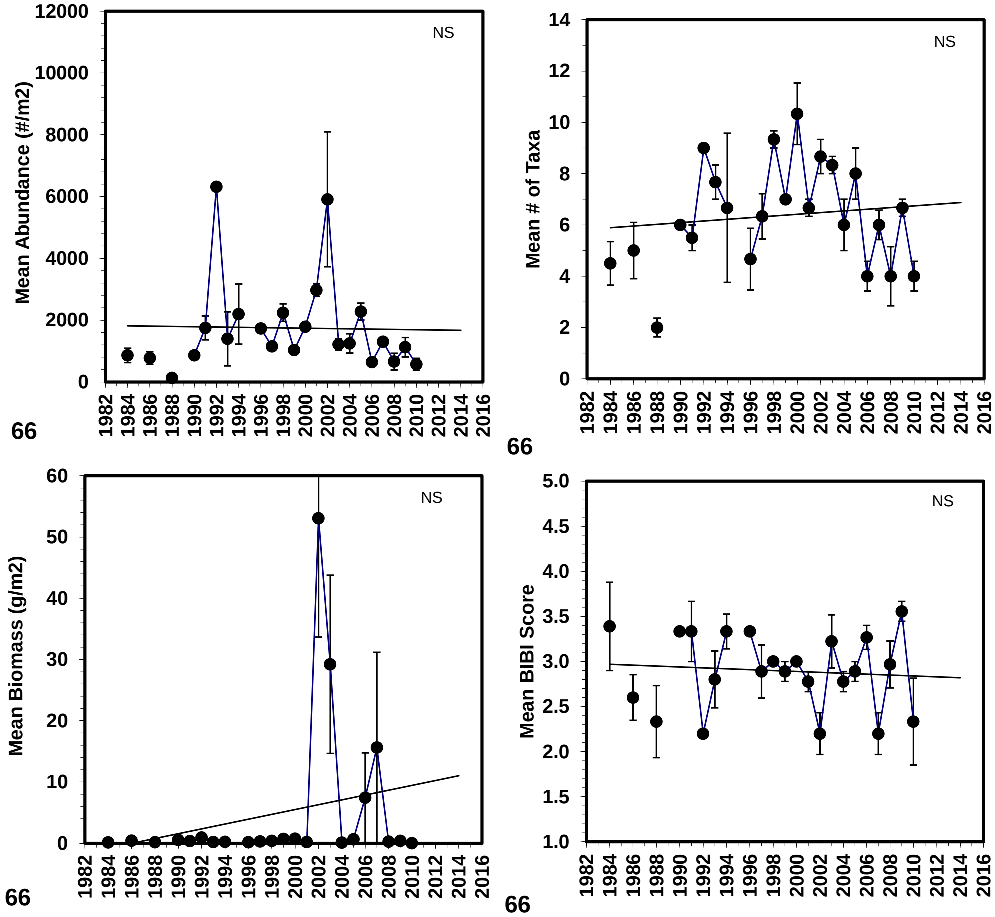

Figure 3-18. Trends in abundance, biomass, number of species, and B-IBI (mean ± 1 SE) at fixed sites. See text for details. Station 66 = Oligohaline Choptank River.

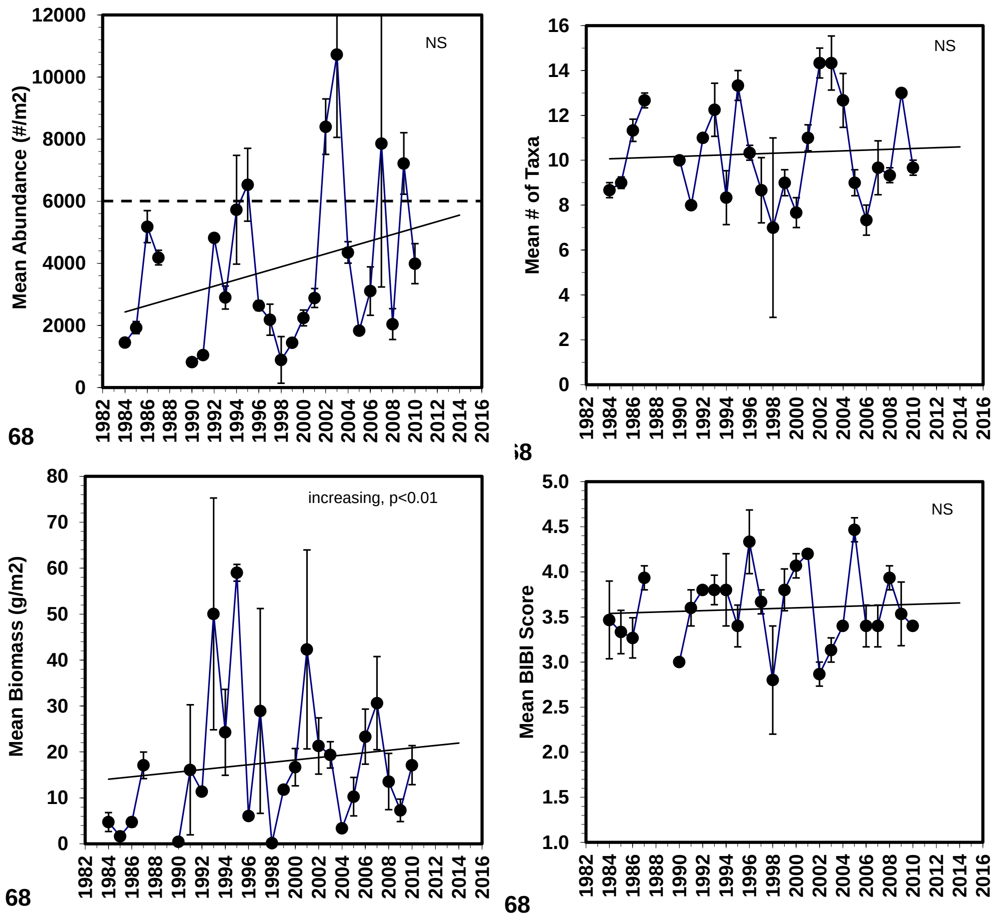

Figure 3-19. Trends in abundance, biomass, number of species, and B-IBI (mean ± 1 SE) at fixed sites. See text for details. Station 68 = Chester River. Dashed line: upper B-IBI threshold for abundance.

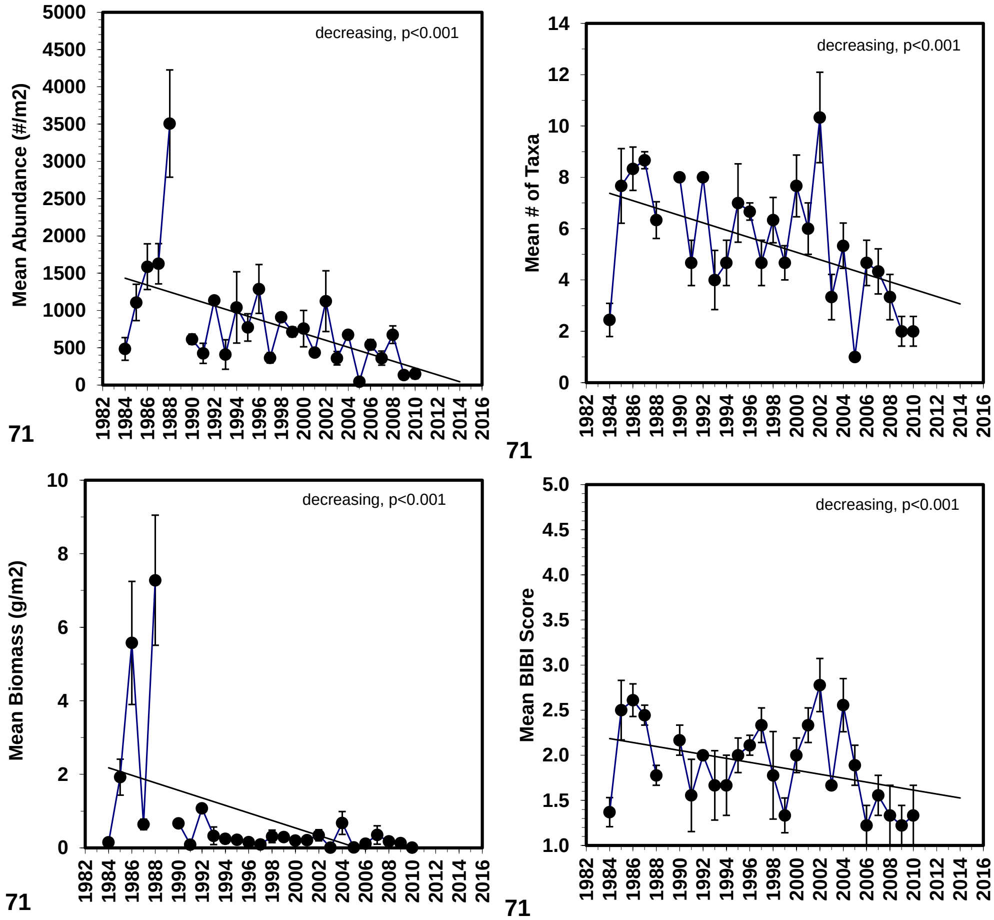

Figure 3-20. Trends in abundance, biomass, number of species, and B-IBI (mean ± 1 SE) at fixed sites. See text for details. Station 71 = Mesohaline Patuxent River (12-18 m), Broomes Island.

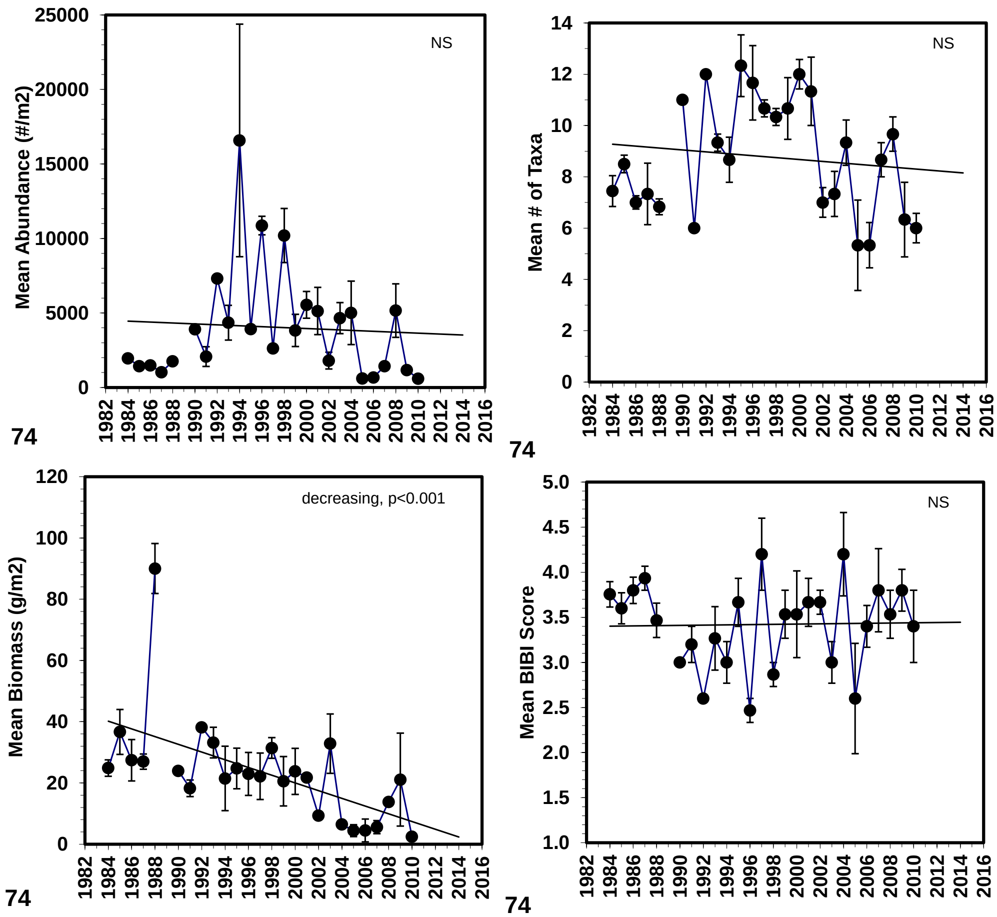

Figure 3-21. Trends in abundance, biomass, number of species, and B-IBI (mean ± 1 SE) at fixed sites. See text for details. Station 74 = Mesohaline Patuxent River (≤5 m), Chalk Point.

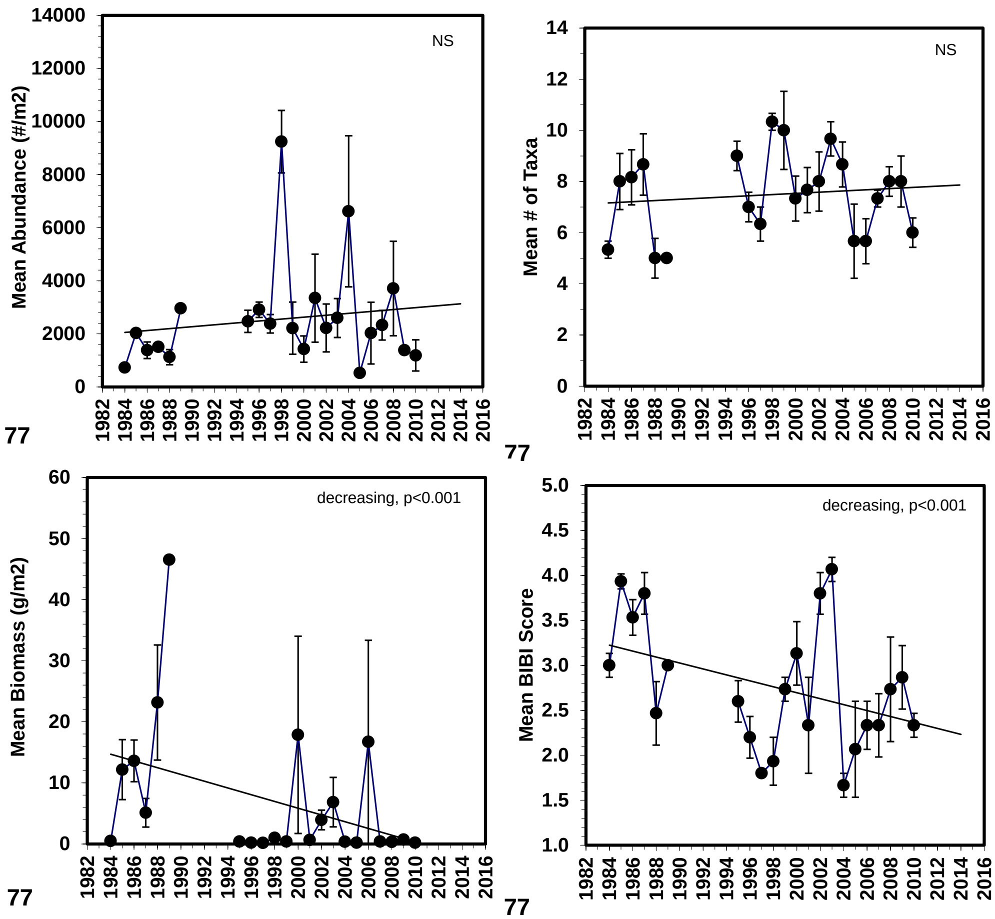

Figure 3-22. Trends in abundance, biomass, number of species, and B-IBI (mean ± 1 SE) at fixed sites. See text for details. Station 77 = Mesohaline Patuxent River (≤5 m), Holland Cliff.

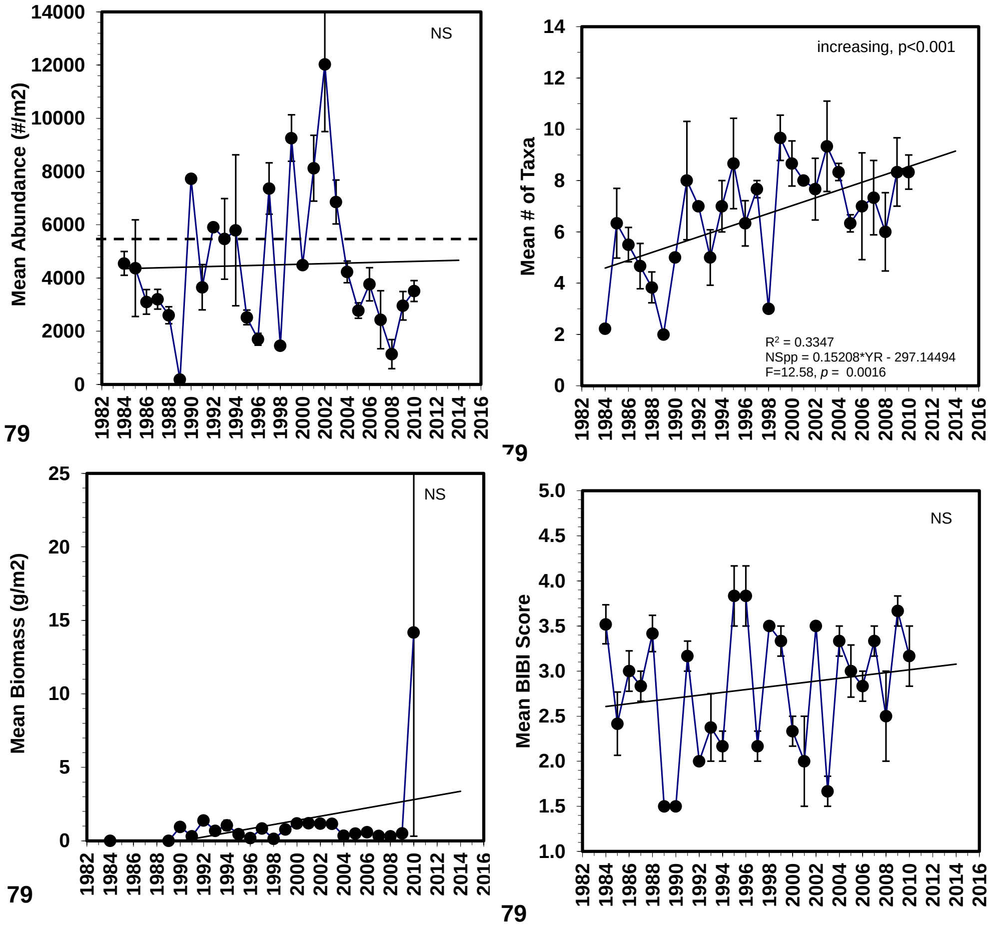

Figure 3-23. Trends in abundance, biomass, number of species, and B-IBI (mean ± 1 SE) at fixed sites. See text for details. Station 79 = Tidal fresh Patuxent River (≤6 m), Lyons Creek. Dashed line: upper B-IBI threshold for abundance.

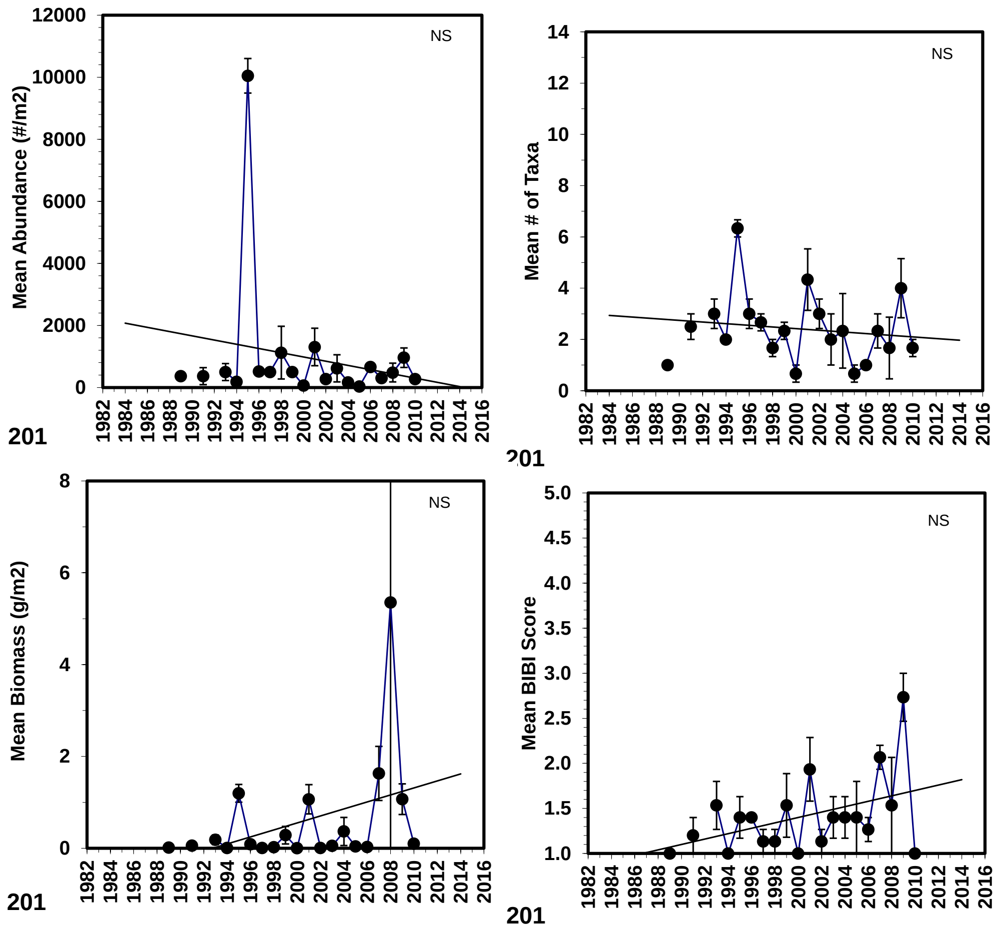

Figure 3-24. Trends in abundance, biomass, number of species, and B-IBI (mean ± 1 SE) at fixed sites. See text for details. Station 201 = Patapsco river estuary, Bear Creek.

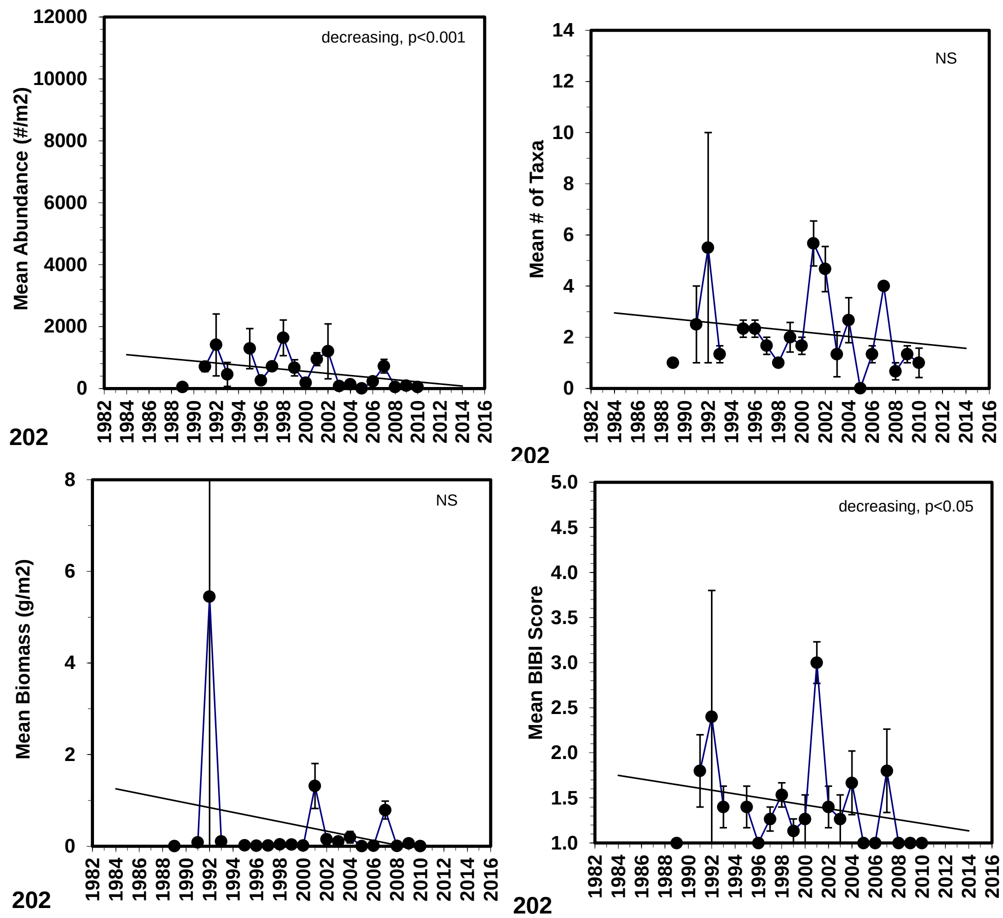

Figure 3-25. Trends in abundance, biomass, number of species, and B-IBI (mean ± 1 SE) at fixed sites. See text for details. Station 202 = Patapsco River estuary, Curtis Creek.

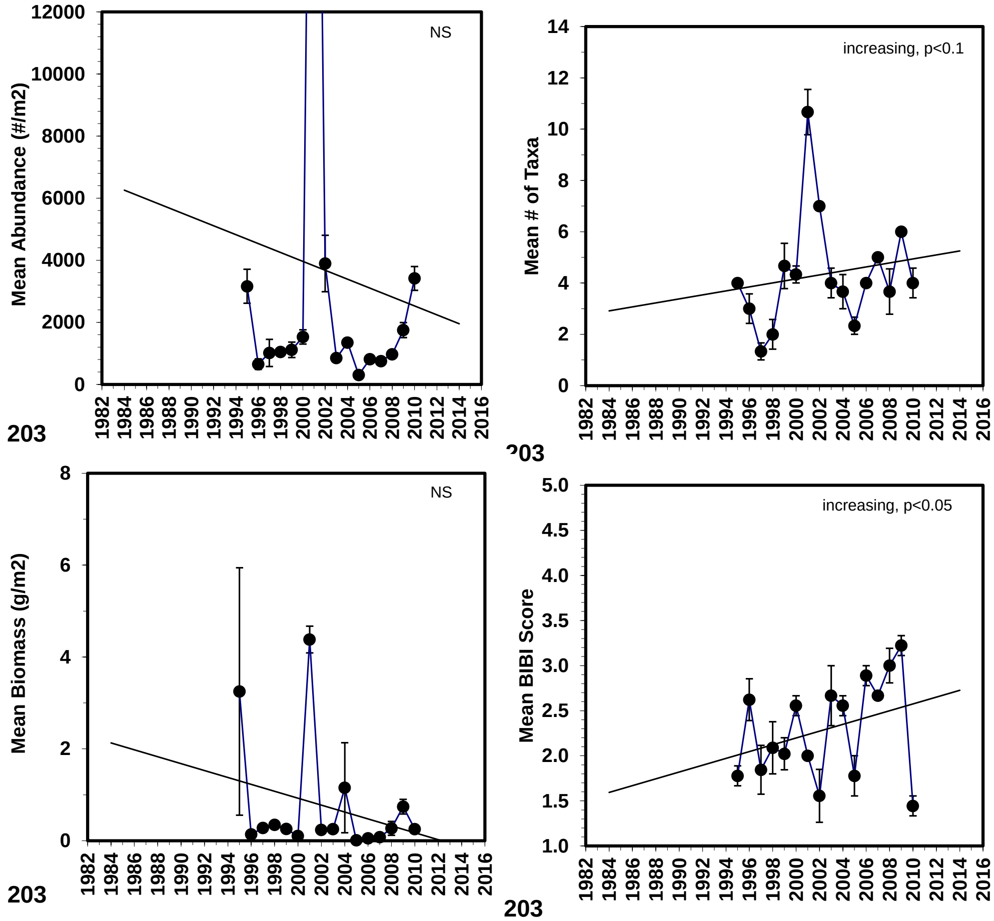

Figure 3-26. Trends in abundance, biomass, number of species, and B-IBI (mean ± 1 SE) at fixed sites. See text for details. Station 203 = Back River.

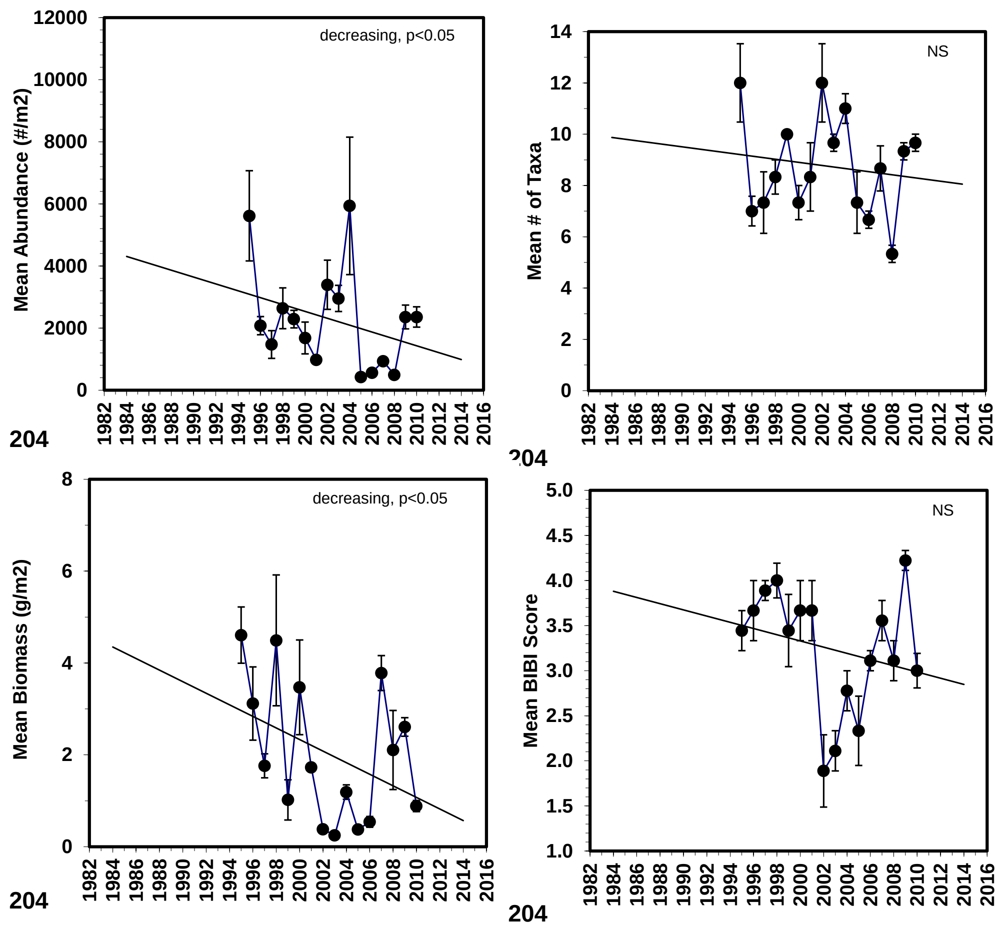

Figure 3-27. Trends in abundance, biomass, number of species, and B-IBI (mean ± 1 SE) at fixed sites. See text for details. Station 204 = Severn River.

3.2 BAYWIDE BOTTOM COMMUNITY CONDITION

The fixed site monitoring provides useful information about trends in the benthic community condition at 27 locations in the Maryland Bay but it does not provide an integrated assessment of the Bay's overall condition. The fixed sites were selected for trend monitoring because they are located in areas subject to management action and, therefore, are likely to undergo change. Because these sites were selected subjectively, there is no objective way of weighting them to obtain an unbiased estimate of Maryland baywide status.

An alternative approach for quantifying status of the bay, which was first adopted in the 1994 sampling program, is to use probability-based sampling to estimate the bottom area populated by benthos meeting the Chesapeake Bay benthic community restoration goals. Where the fixed site approach quantifies change at selected locations, the probability sampling approach quantifies the spatial extent of problems. While both approaches are valuable, developing and assessing the effectiveness of a Chesapeake Bay management strategy requires understanding the extent and distribution of problems throughout the Bay, instead of only assessing site-specific problems. Our probability-based sampling element is intended to provide that information, as well as a more widespread baseline data set for assessing the effects of unanticipated future contamination (e.g., oil or hazardous waste spills). Probability-based sampling information is also used for Chesapeake Bay aquatic life use support decisions under the Clean Water Act (Llansó et al. 2005b, 2009a).

Probability-based sampling has been employed previously by LTB, but the sampled area included only 16% of the Maryland Bay (Ranasinghe et al. 1994) which was insufficient to characterize the entire Bay. Probability-based sampling was also used in the Maryland Bay by the U.S. EPA Environmental Monitoring and Assessment Program (EMAP), and most recently by the U.S. EPA National Coastal Condition Assessment, but at a sampling density too low to develop precise condition estimates for the Maryland Bay. The 2010 sampling continues with efforts initiated in 1994 to develop area-based bottom condition statements for the Maryland Bay.

Estimates of tidal bottom area meeting the benthic community restoration goals are also included for the entire Chesapeake Bay. The estimates were enabled by including a probability-based sampling element in the Virginia Benthic Monitoring Program starting in 1996. The Virginia sampling is compatible and complementary to the Maryland effort and is part of a joint effort by the two programs to assess the extent of "healthy" tidal bottom baywide.

This section presents the results of the 2010 Maryland and Virginia probability-based sampling and provides seventeen years (1994-2010) of benthic community monitoring in tidal waters of the Maryland Chesapeake Bay. The analytical methods for estimating the areal extent of bay bottom meeting the restoration goals were presented in Section 2.0. The physical data associated with the benthic samples (bottom water salinity, temperature, dissolved oxygen, and sediment silt-clay and organic carbon content) can be found in the Appendices Section of this report (Volume 2). Only summer data (July 15-September 30) are used for the probability-based assessments.

Of the 150 Maryland samples collected with the probability-based design in 2010, 54 met and 96 failed the Chesapeake Bay benthic community restoration goals (Figure 3-28), a decrease in the number of samples meeting the goals relative to 2009. Of the 250 probability samples collected in the entire Chesapeake Bay in 2010, 102 met and 148 failed the restoration goals. The Virginia sampling results are presented in Figure 3-29. In terms of number of sites meeting the goals in Chesapeake Bay, fewer sites met the goals in 2010 (41%) than in 2009 (47%) but more sites met the goals in 2010 than in 2008 (39%) or 2007 (36%).

The area with degraded benthos in the Maryland Bay increased in 2010 (Maryland Tidal Waters, Figure 3-30 left panel), but the magnitude of the severely degraded condition remained largely unchanged (Figure 3-30 right panel). Results from the individual sites were weighted based on the area of the stratum represented by the site in the stratified sampling design to estimate the tidal Maryland area failing the restoration goals. In 2010, 67% (±5% SE) of the Maryland Bay was estimated to fail the restoration goals (Figure 3-30). In 2009, the estimate was 58% (±5% SE). Expressed as area, 4,182±287 km^2 of the Maryland tidal waters in Chesapeake Bay remained to be restored in 2010 (Table 3-4).

In 2010, the Patuxent River and the Maryland mid-Bay mainstem continued to be among the Maryland strata in poorest condition (Figures 3-31 and 3-33). However, the Maryland Western Tributaries exhibited a large increase in both percent degraded and percent severely degraded area in 2010, and this stratum was among the most degraded (Figures 3-31 and 3-33). There were also increases in degradation in the Potomac River, Maryland Eastern Tributaries, and the Upper Bay mainstem relative to 2009. In the Potomac River, the increase in degradation was in the upper portion of the river, above Morgantown. The lower Potomac, although typically exhibiting degraded conditions in more than 90% of its area, continued to show a decline in the severely degraded condition for the fourth consecutive year (Figure 3-31). Over the 1995-2010 time series, statistically significant increasing trends in percent area degraded were detected in the Patuxent River (ANOVA, p = 0.0003) and the Maryland Eastern Tributaries (ANOVA, p = 0.0058). Over the same time series, more than half of the tidal Potomac River (714-1,173 km^2, Table 3-4) failed the restoration goals each year, and a large portion of that area, ranging from 48% to 93% (510-867 km^2), was severely degraded.

In Virginia, percent area degraded increased in the Rappahannock River, York River, and the Virginia mainstem, and declined in the James River (Table 3-4, Figure 3-32). A statistically significant increasing trend in percent area degraded was detected in the Rappahannock River over the 1996-2010 time series (ANOVA, p = 0.0401). The improvements in the James River were substantial but not significant over the time series (Figure 3-32).

For the Chesapeake Bay, the estimate of degradation in 2010 increased relative to 2009, but it was not as high as for the 2005-2008 period (Figure 3-30 left panel). The extent of the severely degraded condition remained unchanged (Figure 3-30 right panel).

Weighting results from the 250 probability sites in Maryland and Virginia, 53% (±4%) or 6,176±492 km^2 of the tidal Chesapeake Bay was estimated to fail the restoration goals in 2010, and 52% of that area (3,199 km^2) was severely degraded (Table 3-4). There was no statistically significant change in percent area degraded over the time series (ANOVA, $p = 0.443$).

The increased degradation observed in Chesapeake Bay in 2010 coincided with higher river flows. Flow was higher than average in winter (December-January) and early spring (March) and lower than average in late spring and summer. In March a pulse in river flow coincided with heavy rainfall and large amounts of snow melt in the Chesapeake watershed. Pulse events bring sudden increases in nutrient and sediment loads into Chesapeake Bay resulting in greater benthic community degradation (See Section 3.4 of this report). Mean benthic abundance, mean biomass, and mean B-IBI scores were lower in 2010 than in 2009 in the Maryland Bay and baywide (Figures 3-34 and 3-35). On average, abundance, number of species, and B-IBI scores (but not biomass) were lower during the 2005-2010 period than in previous years. The exception was 2009, a year of below average spring flow. During the 2005-2010 period the number of sites scoring "1" for low abundance and low biomass (below restorative thresholds) increased substantially relative to previous years (Figures 3-34 and 3-35), and the increase was statistically significant for biomass.

In addition to percent area degraded, results can be summarized by the type of stress experienced by the benthic communities. Low abundance, low biomass, and the level of widespread failure in most metrics necessary to classify a site as severely degraded is usually expected on exposure to catastrophic events such as prolonged dissolved oxygen stress. Conversely, excess abundance and excess biomass are phenomena usually associated with eutrophic conditions and organic enrichment of the sediment in the absence of low dissolved oxygen stress. For the period 1996-2010, four strata (Potomac River, Patuxent River, Mid Bay mainstem, and Maryland Western Tributaries) had a large percentage (>70%) of sites failing the goals because of insufficient abundance or biomass of organisms relative to reference conditions (Table 3-5). These strata also had a high percentage (>60%) of failing sites classified as severely degraded (Table 3-5). These results contrast with those of Maryland Eastern Tributaries, James River, and York River strata, which had fewer depauperate sites but excess abundance, excess biomass, or both in >20% of the failing sites (Table 3-6).

Table 3-4. Estimated tidal area (km^2) failing to meet the Chesapeake Bay benthic community restoration goals in the Chesapeake Bay, Maryland, Virginia, and each of the 10 sampling strata. In this table, the area of the mainstem deep trough is included in the estimates for the severely degraded portion of Chesapeake Bay, Maryland tidal waters, and Maryland mid-bay mainstem.

Region	Year	Severely Degraded	Degraded	Marginal	Total Failing	% Failing
Chesapeake Bay	1996	3,080	1,388	1,056	5,524	47.6
	1997	2,941	2,072	877	5,890	50.7
	1998	3,771	1,689	1,271	6,731	58.0
	1999	3,164	1,660	1,020	5,844	50.3
	2000	2,704	1,538	1,474	5,715	49.2
	2001	3,123	1,187	1,749	6,060	52.2
	2002	3,424	1,584	1,170	6,178	53.2
	2003	3,351	2,537	964	6,852	59.0
	2004	2,902	1,940	650	5,492	47.3
	2005	4,664	1,550	614	6,828	58.8
	2006	4,336	1,779	756	6,871	59.2
	2007	4,120	1,529	1,064	6,713	57.8
	2008	3,474	1,555	1,759	6,788	58.5
	2009	3,164	898	1,032	5,094	43.9
	2010	3,199	1,492	1,485	6,177	53.2
Maryland Tidal Waters	1994	2,684	1,152	497	4,332	66.5
	1995	2,872	605	182	3,659	58.6
	1996	2,614	700	155	3,469	55.6
	1997	2,349	697	483	3,529	56.5
	1998	2,663	1,016	623	4,302	68.9
	1999	2,423	1,137	374	3,935	63.0
	2000	2,455	1,137	236	3,828	61.3
	2001	2,313	582	644	3,538	56.7
	2002	2,444	713	928	4,086	65.4
	2003	2,571	1,288	228	4,086	65.4
	2004	2,037	985	226	3,248	52.0
	2005	2,771	1,014	295	4,080	65.3
	2006	3,077	1,013	504	4,595	73.6
	2007	3,088	851	513	4,452	71.3
	2008	2,727	767	854	4,348	69.6
	2009	2,484	580	540	3,605	57.7
	2010	2,656	1,171	355	4,182	67.0

Table 3-4. (Continued)

Region	Year	Severely Degraded	Degraded	Marginal	Total Failing	% Failing
Virginia Tidal Waters	1996	466	688	901	2,055	38.3
	1997	592	1,375	394	2,361	44.0
	1998	1,107	673	648	2,429	45.3
	1999	741	523	646	1,909	35.6
	2000	249	401	1,238	1,888	35.2
	2001	810	606	1,106	2,522	47.0
	2002	980	871	242	2,092	39.0
	2003	780	1,249	736	2,766	51.6
	2004	866	955	424	2,245	41.9
	2005	1,893	536	319	2,748	51.2
	2006	1,259	765	252	2,276	42.4
	2007	1,031	678	552	2,261	42.2
	2008	747	788	905	2,440	45.5
	2009	680	318	491	1,489	27.8
	2010	543	321	1,130	1,994	37.2
Maryland Eastern Tributaries	1995	107	128	0	235	44.0
	1996	21	150	21	192	36.0
	1997	43	64	21	128	24.0
	1998	21	64	64	150	28.0
	1999	43	150	86	278	52.0
	2000	64	150	21	235	44.0
	2001	128	64	86	278	52.0
	2002	64	107	64	235	44.0
	2003	128	214	0	342	64.0
	2004	86	107	21	214	40.0
	2005	86	64	86	235	44.0
	2006	86	128	43	257	48.0
	2007	150	86	128	363	68.0
	2008	86	86	64	235	44.0
	2009	192	64	64	321	60.0
	2010	150	171	43	363	68.0

Table 3-4. (Continued)

Region	Year	Severely Degraded	Degraded	Marginal	Total Failing	% Failing
Maryland Mid Bay Mainstem	1995	1,799	204	102	2,106	65.2
	1996	1,595	306	102	2,004	62.1
	1997	1,493	306	306	2,106	65.2
	1998	1,799	204	408	2,412	74.7
	1999	1,391	715	102	2,208	68.4
	2000	1,493	510	204	2,208	68.4
	2001	1,289	102	408	1,799	55.7
	2002	1,595	204	613	2,412	74.7
	2003	1,289	613	204	2,106	65.2
	2004	983	510	204	1,697	52.6
	2005	1,595	613	204	2,412	74.7
	2006	1,697	613	306	2,616	81.0
	2007	1,799	510	306	2,616	81.0
	2008	1,799	306	613	2,718	84.2
	2009	1,595	204	408	2,208	68.4
	2010	1,697	510	204	2,412	74.7
Maryland Upper Bay Mainstem	1995	345	63	0	408	52.0
	1996	126	126	31	283	36.0
	1997	126	94	31	251	32.0
	1998	157	188	31	377	48.0
	1999	188	63	63	314	40.0
	2000	94	126	0	220	28.0
	2001	157	31	31	220	28.0
	2002	94	126	31	251	32.0
	2003	188	157	0	345	44.0
	2004	220	31	0	251	32.0
	2005	31	0	0	31	4.0
	2006	188	31	31	251	32.0
	2007	188	31	0	220	28.0
	2008	126	188	94	408	52.0
	2009	31	31	63	126	16.0
	2010	157	31	31	220	28.0

Table 3-4. (Continued)

Region	Year	Severely Degraded	Degraded	Marginal	Total Failing	% Failing
Maryland Upper Western Tributaries	1995	58	47	23	129	44.0
	1996	117	47	0	164	56.0
	1997	105	23	12	140	48.0
	1998	94	23	12	129	44.0
	1999	117	47	12	175	60.0
	2000	140	70	0	211	72.0
	2001	70	12	47	129	44.0
	2002	94	47	47	187	64.0
	2003	47	105	23	175	60.0
	2004	70	117	0	187	64.0
	2005	140	47	0	187	64.0
	2006	187	47	12	246	84.0
	2007	94	35	12	140	48.0
	2008	94	23	12	129	44.0
	2009	94	35	0	129	44.0
	2010	152	70	0	222	76.0
Patuxent River	1995	51	10	5	67	52.0
	1996	41	20	0	61	48.0
	1997	20	5	10	36	28.0
	1998	31	26	5	61	48.0
	1999	20	10	10	41	32.0
	2000	51	26	10	87	68.0
	2001	56	15	20	92	72.0
	2002	36	26	20	82	64.0
	2003	51	46	0	97	76.0
	2004	15	67	0	82	64.0
	2005	51	36	5	92	72.0
	2006	51	41	10	102	80.0
	2007	41	36	15	92	72.0
	2008	61	10	20	92	72.0
	2009	61	41	5	108	84.0
	2010	41	31	26	97	76.0

Table 3-4. (Continued)						
Region	**Year**	**Severely Degraded**	**Degraded**	**Marginal**	**Total Failing**	**% Failing**
Potomac River	1994	793	330	0	1,123	60.7
	1995	510	153	51	714	56.0
	1996	714	51	0	765	60.0
	1997	561	204	102	867	68.0
	1998	561	510	102	1,173	92.0
	1999	663	153	102	918	72.0
	2000	612	255	0	867	68.0
	2001	612	357	51	1,020	80.0
	2002	561	204	153	918	72.0
	2003	867	153	0	1,020	80.0
	2004	663	153	0	816	64.0
	2005	867	255	0	1,122	88.0
	2006	867	153	102	1,122	88.0
	2007	816	153	51	1,020	80.0
	2008	561	153	51	765	60.0
	2009	510	204	0	714	56.0
	2010	459	357	51	867	68.0
James River	1996	137	82	55	273	40.0
	1997	219	109	27	355	52.0
	1998	164	164	109	437	64.0
	1999	82	246	55	383	56.0
	2000	55	109	55	219	32.0
	2001	219	164	27	410	60.0
	2002	164	137	55	355	52.0
	2003	137	246	55	437	64.0
	2004	109	191	27	328	48.0
	2005	82	109	109	301	44.0
	2006	137	219	27	383	56.0
	2007	246	191	27	465	68.0
	2008	164	219	164	547	80.0
	2009	164	191	109	465	68.0
	2010	109	82	82	273	40.0

Table 3-4. (Continued)						
Region	**Year**	**Severely Degraded**	**Degraded**	**Marginal**	**Total Failing**	**% Failing**
Rappahannock River	1996	119	60	0	179	48.0
	1997	149	74	15	238	64.0
	1998	60	134	45	238	64.0
	1999	89	89	74	253	68.0
	2000	149	104	15	268	72.0
	2001	30	60	60	149	40.0
	2002	134	45	0	179	48.0
	2003	89	104	0	194	52.0
	2004	60	89	30	179	48.0
	2005	253	60	30	343	92.0
	2006	223	15	45	283	76.0
	2007	209	104	15	328	88.0
	2008	194	45	45	283	76.0
	2009	119	104	45	268	72.0
	2010	209	45	45	298	80.0
Virginia Mainstem	1996	165	494	824	1,483	36.0
	1997	165	1,154	330	1,648	40.0
	1998	824	330	494	1,648	40.0
	1999	494	165	494	1,154	28.0
	2000	0	165	1,154	1,318	32.0
	2001	494	330	989	1,813	44.0
	2002	659	659	165	1,483	36.0
	2003	494	824	659	1,977	48.0
	2004	659	659	330	1,648	40.0
	2005	1,483	330	165	1,977	48.0
	2006	824	494	165	1,483	36.0
	2007	494	330	494	1,318	32.0
	2008	330	494	659	1,483	36.0
	2009	330	0	330	659	16.0
	2010	165	165	989	1,318	32.0

Table 3-4. (Continued)						
Region	**Year**	**Severely Degraded**	**Degraded**	**Marginal**	**Total Failing**	**% Failing**
York River	1996	45	52	22	120	64.0
	1997	60	37	22	120	64.0
	1998	60	45	0	105	56.0
	1999	75	22	22	120	64.0
	2000	45	22	15	82	44.0
	2001	67	52	30	150	80.0
	2002	22	30	22	75	40.0
	2003	60	75	22	157	84.0
	2004	37	15	37	90	48.0
	2005	75	37	15	127	68.0
	2006	75	37	15	127	68.0
	2007	82	52	15	150	80.0
	2008	60	30	37	127	68.0
	2009	67	22	7	97	52.0
	2010	60	30	15	105	56.0

Table 3-5. Sites severely degraded (B-IBI≤2) and failing the restoration goals (scored at 1.0) for insufficient abundance, insufficient biomass, or both as a percentage of sites failing the goals (B-IBI<3), 1996 to 2010. Strata are listed in decreasing percent order of sites with insufficient abundance/biomass.

Stratum	**Sites Severely Degraded**		**Sites Failing the Goals Due to Insufficient Abundance, Biomass, or Both**	
	Number of Sites	**As Percentage of Sites Failing the Goals**	**Number of Sites**	**As Percentage of Sites Failing the Goals**
Potomac River	194	70.8	227	82.8
Patuxent River	123	51.5	192	80.3
Mid Bay Mainstem	127	54.5	175	75.1
Western Tributaries	138	63.3	153	70.2
Upper Bay Mainstem	66	55.0	80	66.7
Virginia Mainstem	46	33.8	87	64.0
Rappahannock River	140	56.7	151	61.1
Eastern Tributaries	63	35.2	92	51.4
York River	119	50.9	80	34.2
James River	80	38.8	55	26.7

Table 3-6. Sites failing the restoration goals (scored at 1.0) for excess abundance, excess biomass, or both as a percentage of sites failing the goals (B-IBI<3), 1996 to 2010. Strata are listed in decreasing percent order of sites with excess abundance/biomass.

Stratum	Number of Sites	As Percentage of Sites Failing the Goals
James River	66	32.0
Eastern Tributaries	41	22.9
York River	52	22.2
Upper Bay Mainstem	22	18.3
Western Tributaries	38	17.4
Rappahannock River	39	15.8
Mid Bay Mainstem	35	15.0
Patuxent River	25	10.5
Potomac River	28	10.2
Virginia Mainstem	10	7.4

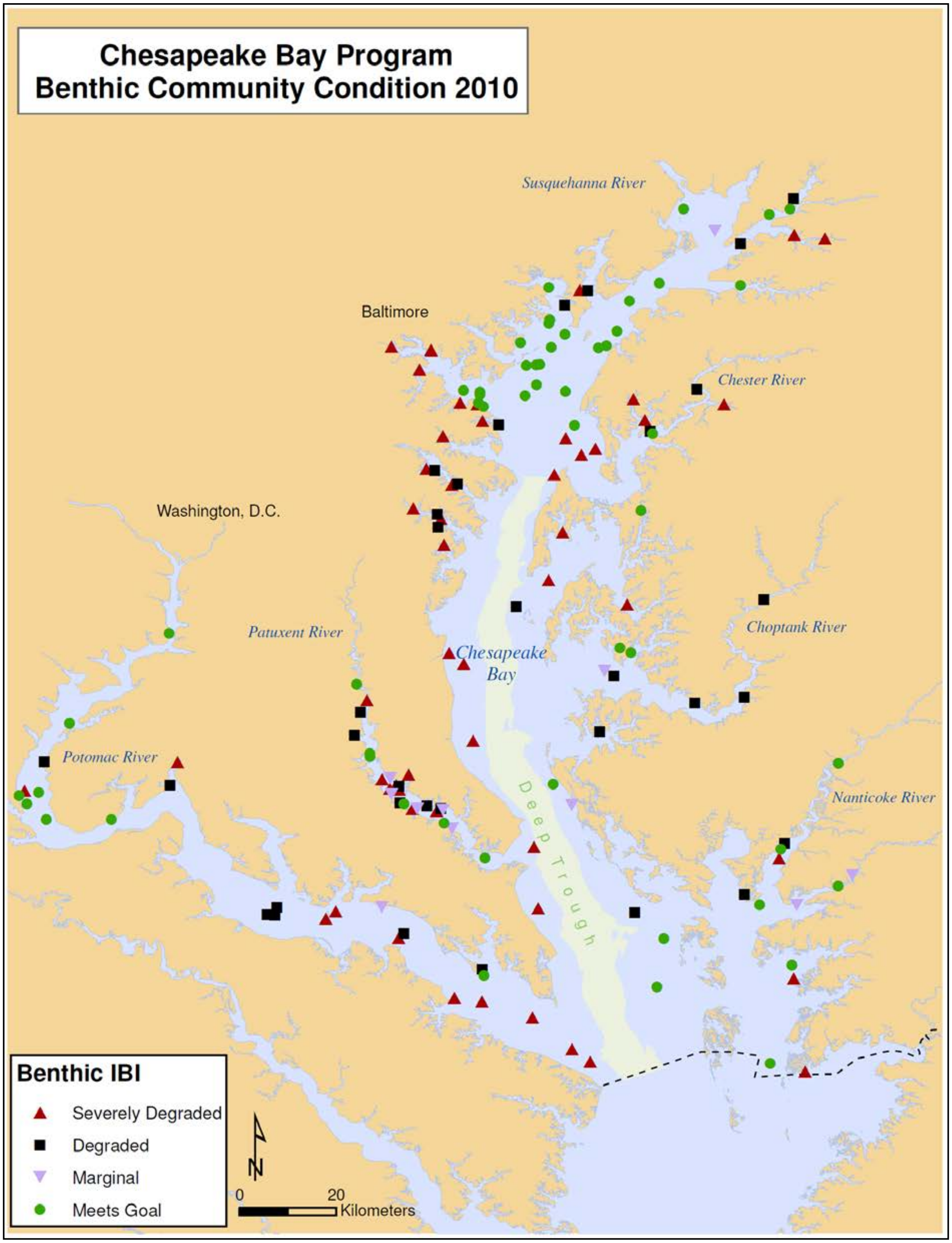

Figure 3-28. Results of probability-based benthic sampling of the Maryland Chesapeake Bay and its tidal tributaries in 2010. Each sample was evaluated in context of the Chesapeake Bay benthic community restoration goals.

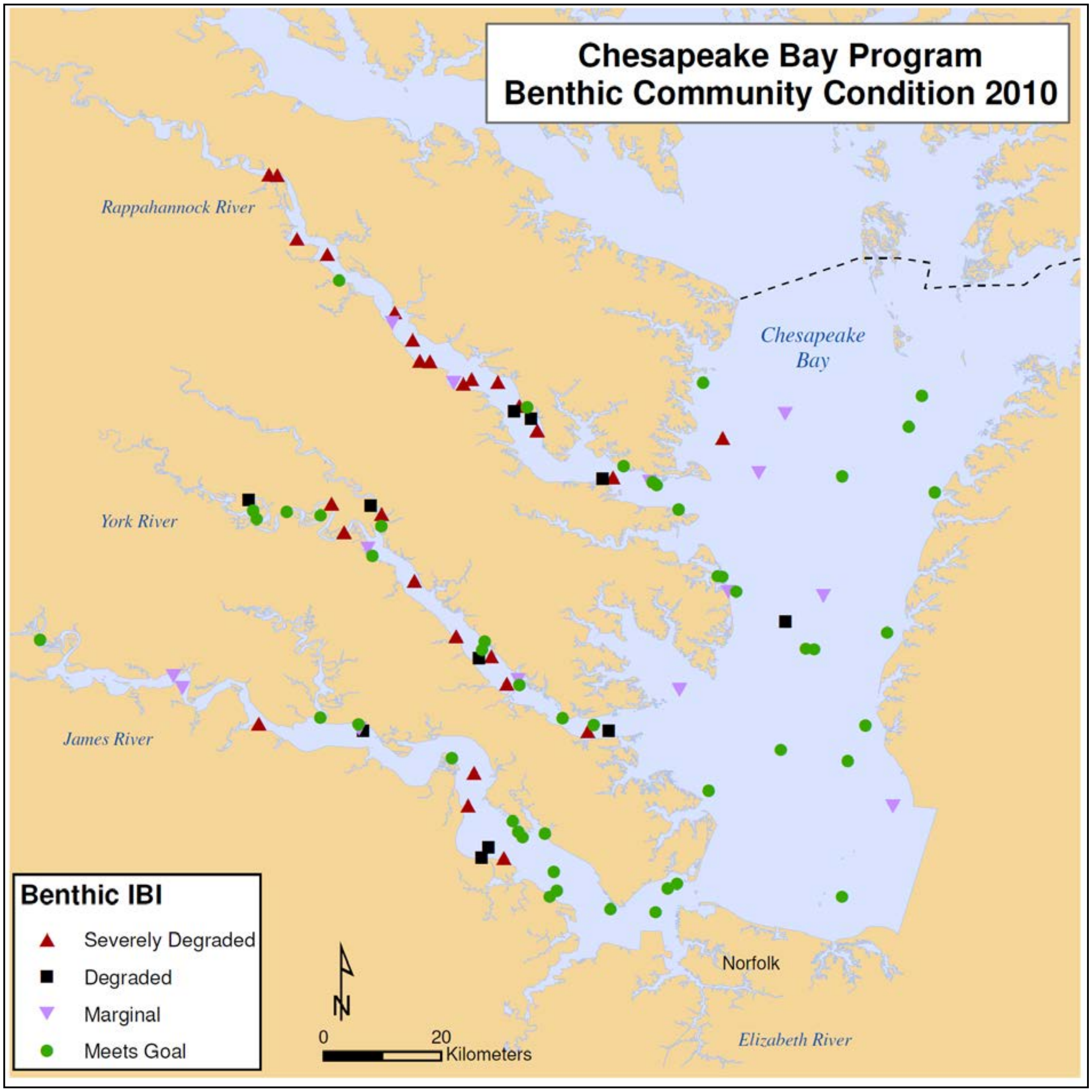

Figure 3-29. Results of probability-based benthic sampling of the Virginia Chesapeake Bay and its tidal tributaries in 2010. Each sample was evaluated in context of the Chesapeake Bay benthic community restoration goals.

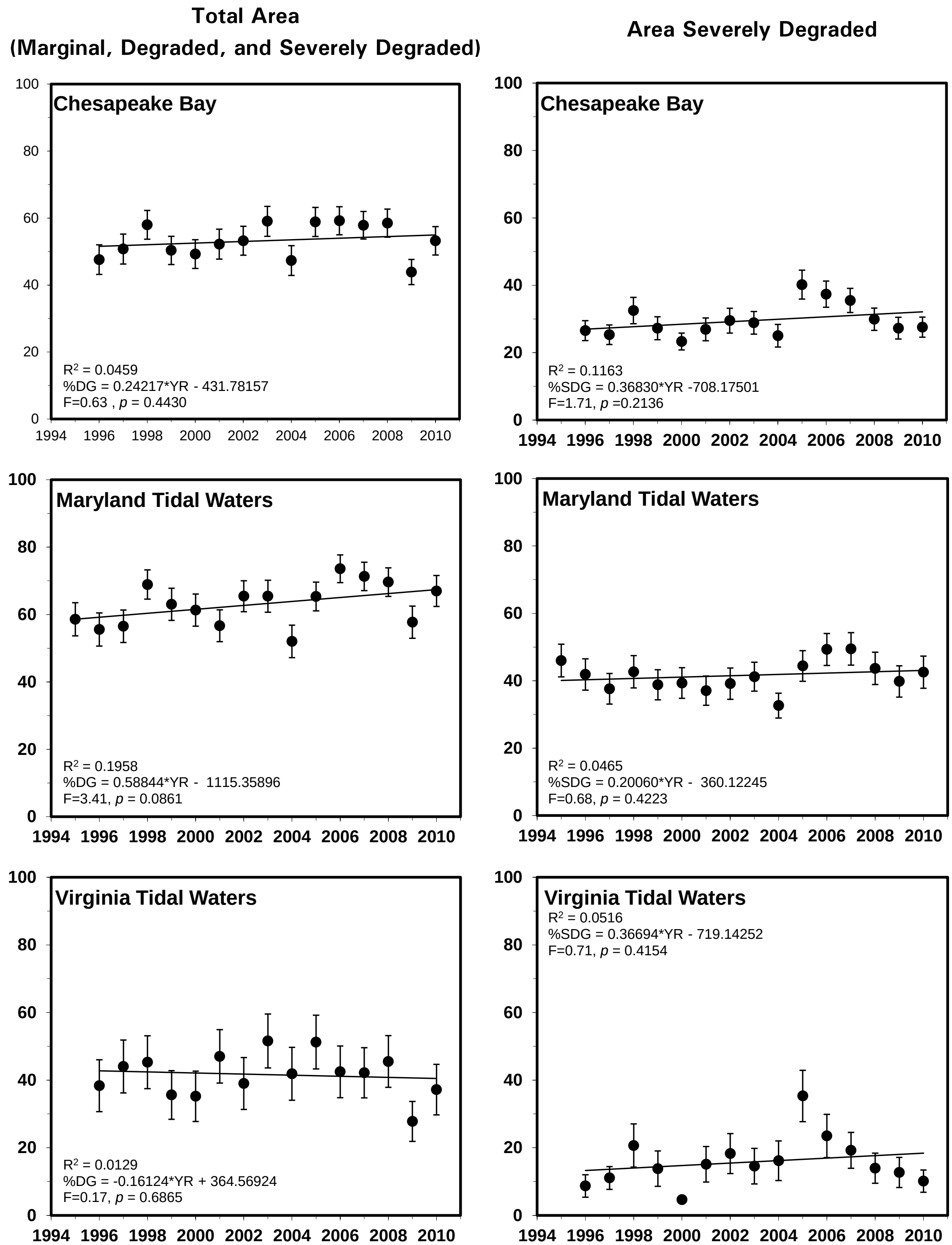

Figure 3-30. Proportion of the Chesapeake Bay, Maryland tidal waters, and Virginia tidal waters failing the Chesapeake Bay benthic community restoration goals, 1996 to 2010 (1995-2010 for Maryland). Panels on left show percent total area degraded (B-IBI <3.0); panels on right show percent area severely degraded (B-IBI ≤2.0). Error bars indicate ± 1 SE. The mainstem deep trough is included in the severely degraded condition estimates.

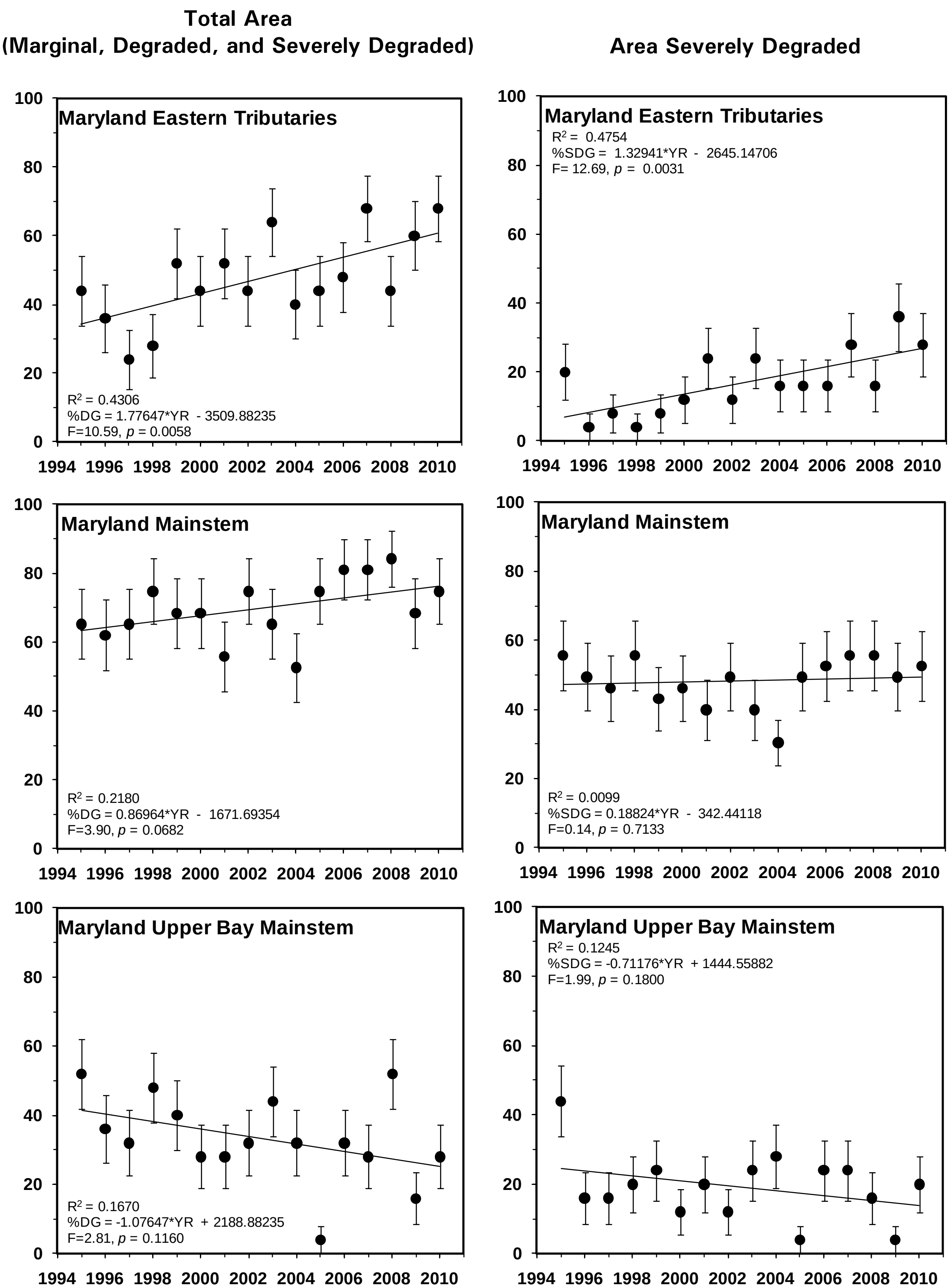

Figure 3-31. Proportion of the Maryland sampling strata failing the Chesapeake Bay benthic community restoration goals, 1995 to 2010. Panels on left show percent total area degraded (B-IBI < 3.0); panels on right show percent area severely degraded (B-IBI ≤2.0). Error bars indicate ± 1 SE. The deep trough is included in the Maryland mainstem stratum estimates.

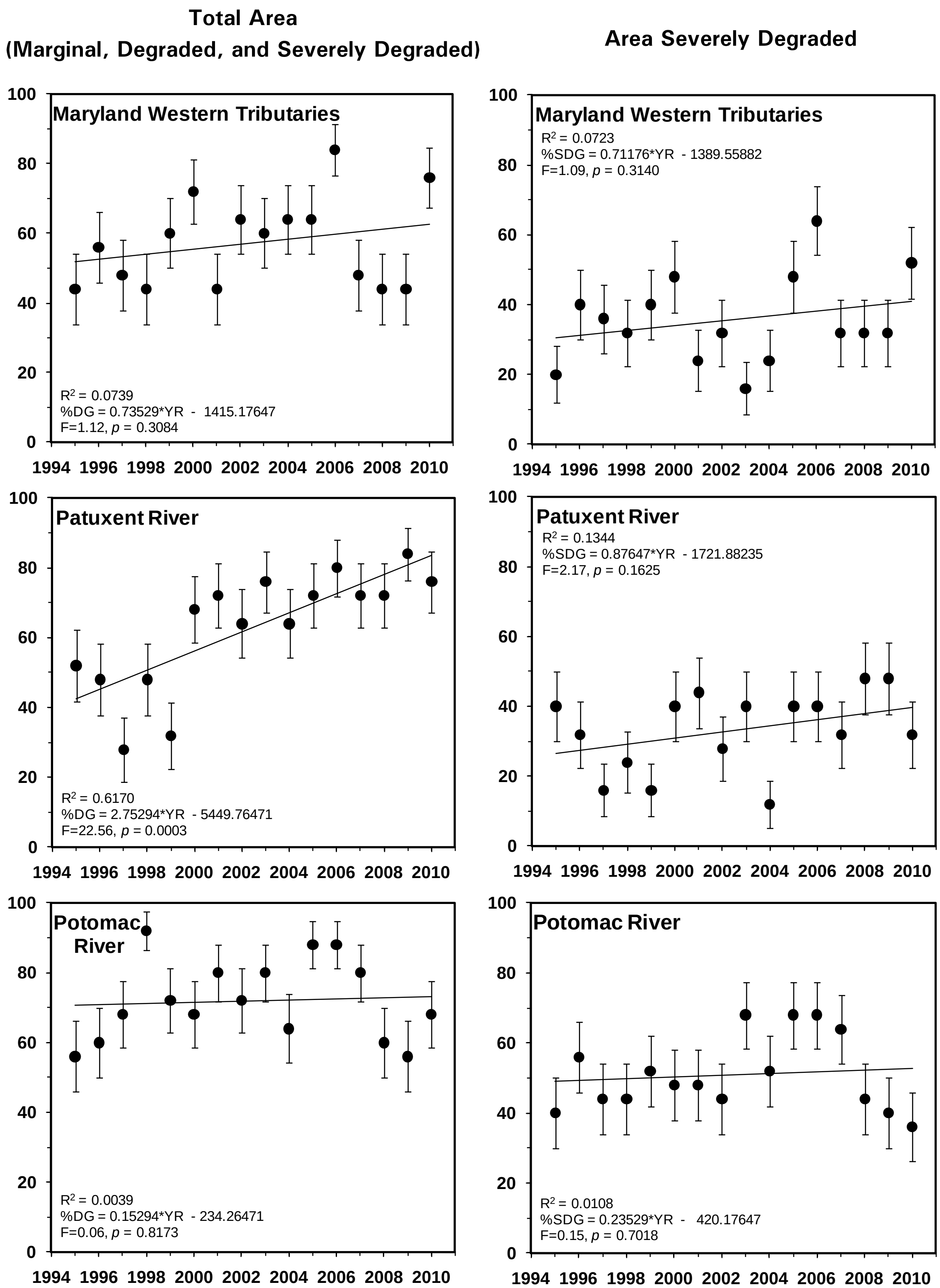

Figure 3-31. (Continued)

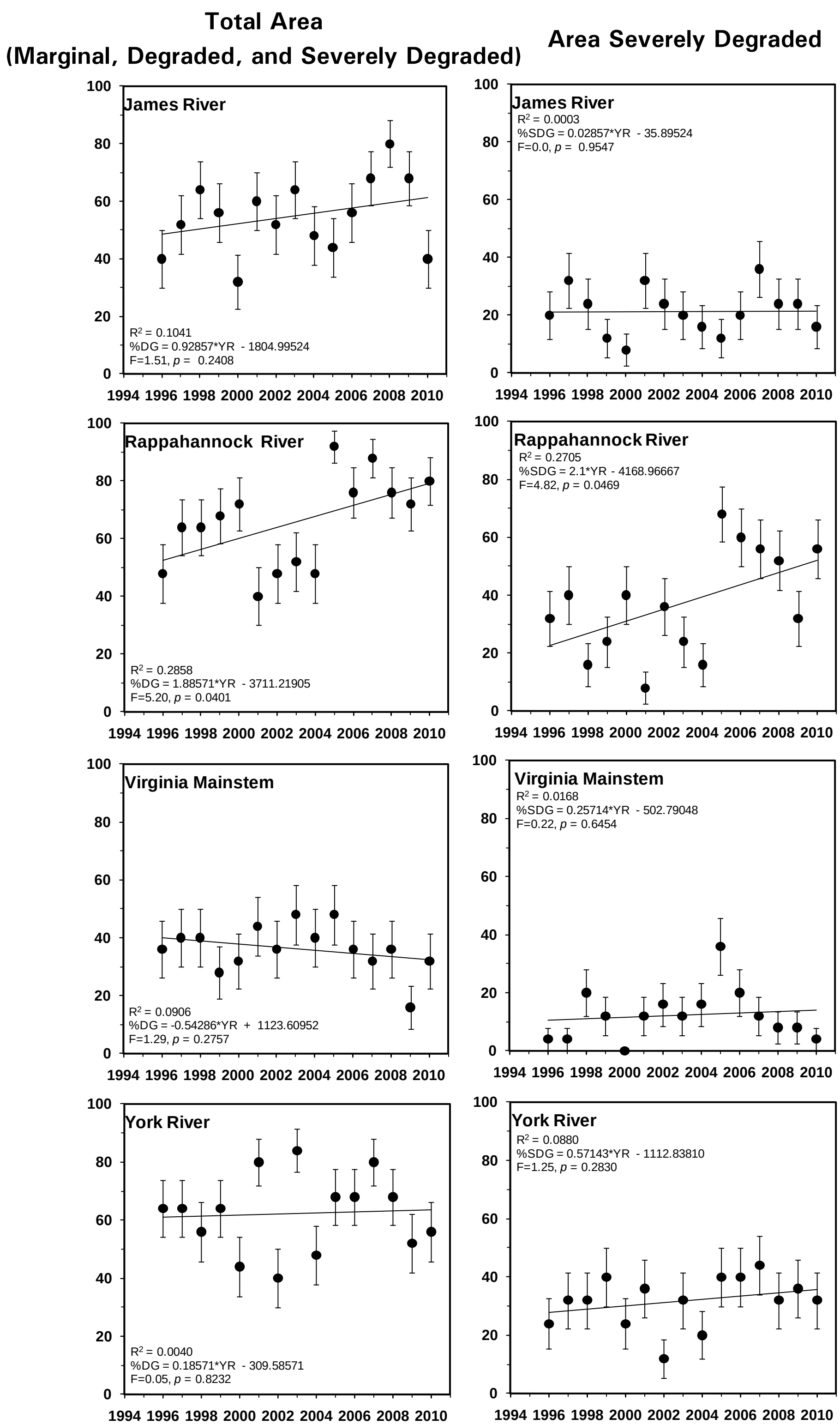

Figure 3-32. Proportion of the Virginia sampling strata failing the Chesapeake Bay benthic community restoration goals, 1996 to 2010. Panels on left show percent total area degraded (B-IBI <3.0); panels on right show percent area severely degraded (B-IBI ≤2.0). Error bars indicate ± 1 SE.

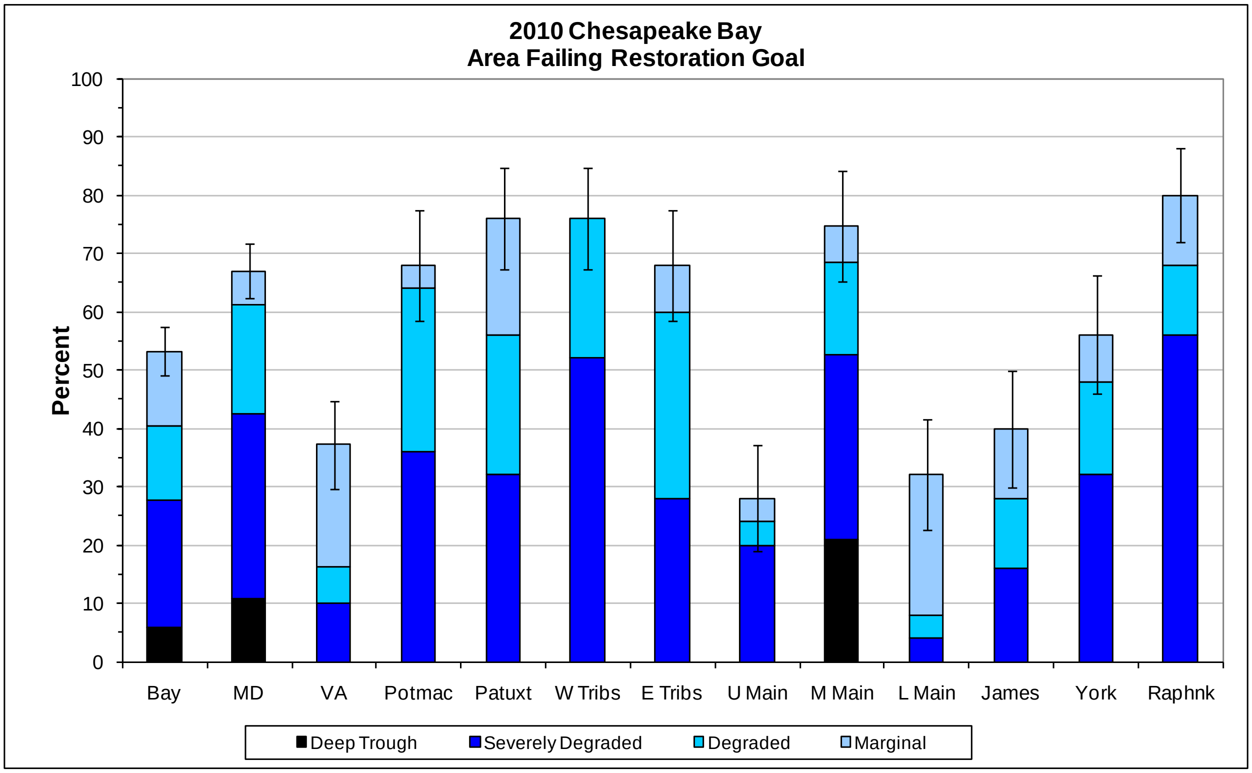

Figure 3-33. Proportion of the Chesapeake Bay, Maryland, Virginia, and the 10 sampling strata failing the Chesapeake Bay benthic community restorations goals in 2010. Error bars indicate ± 1 SE.

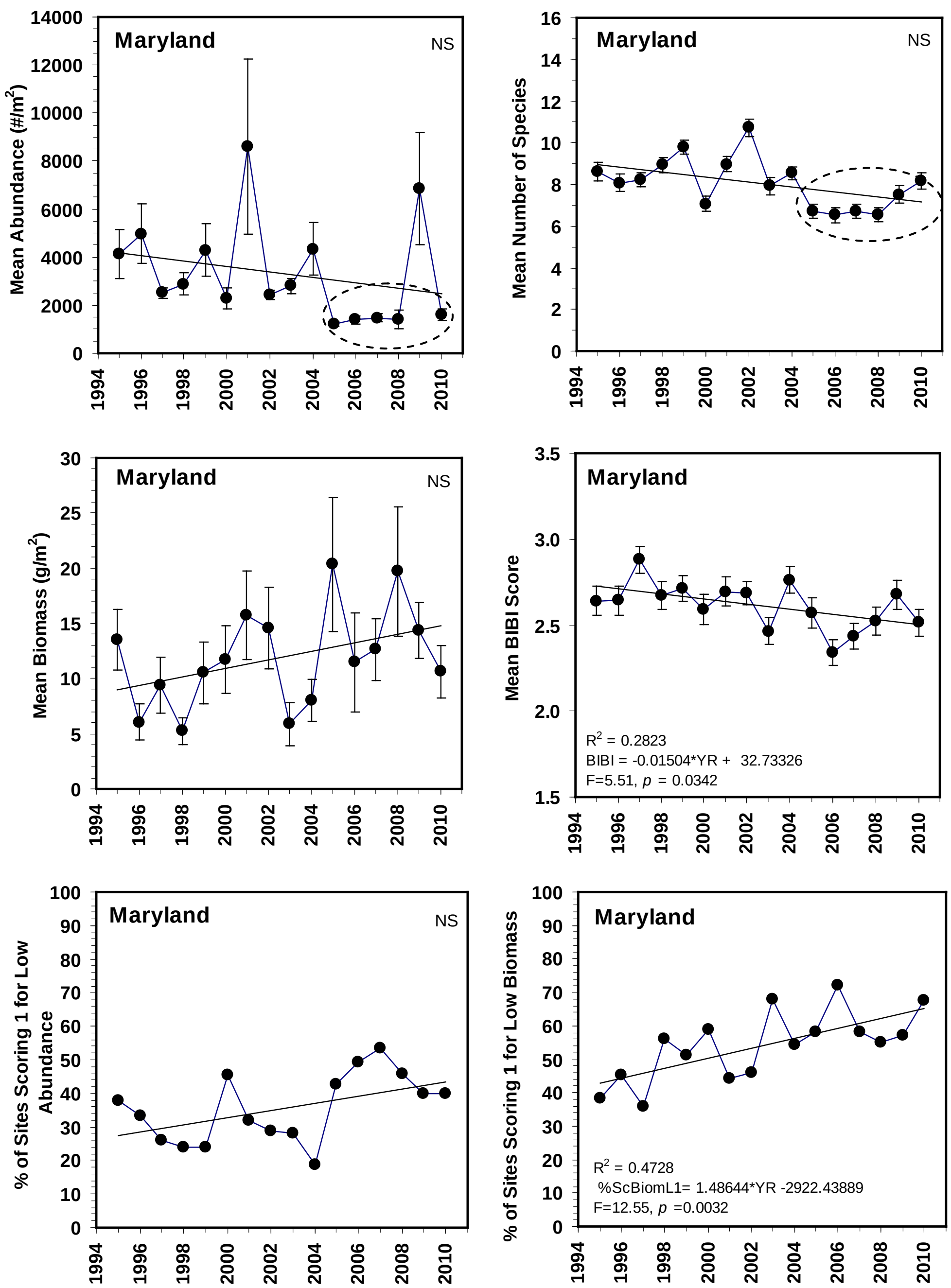

Figure 3-34. Trends in abundance, biomass, number of species, B-IBI (mean ± 1 SE), and percent sites scoring "1" for low abundance or low biomass in Maryland tidal waters (N=150 sites per year).

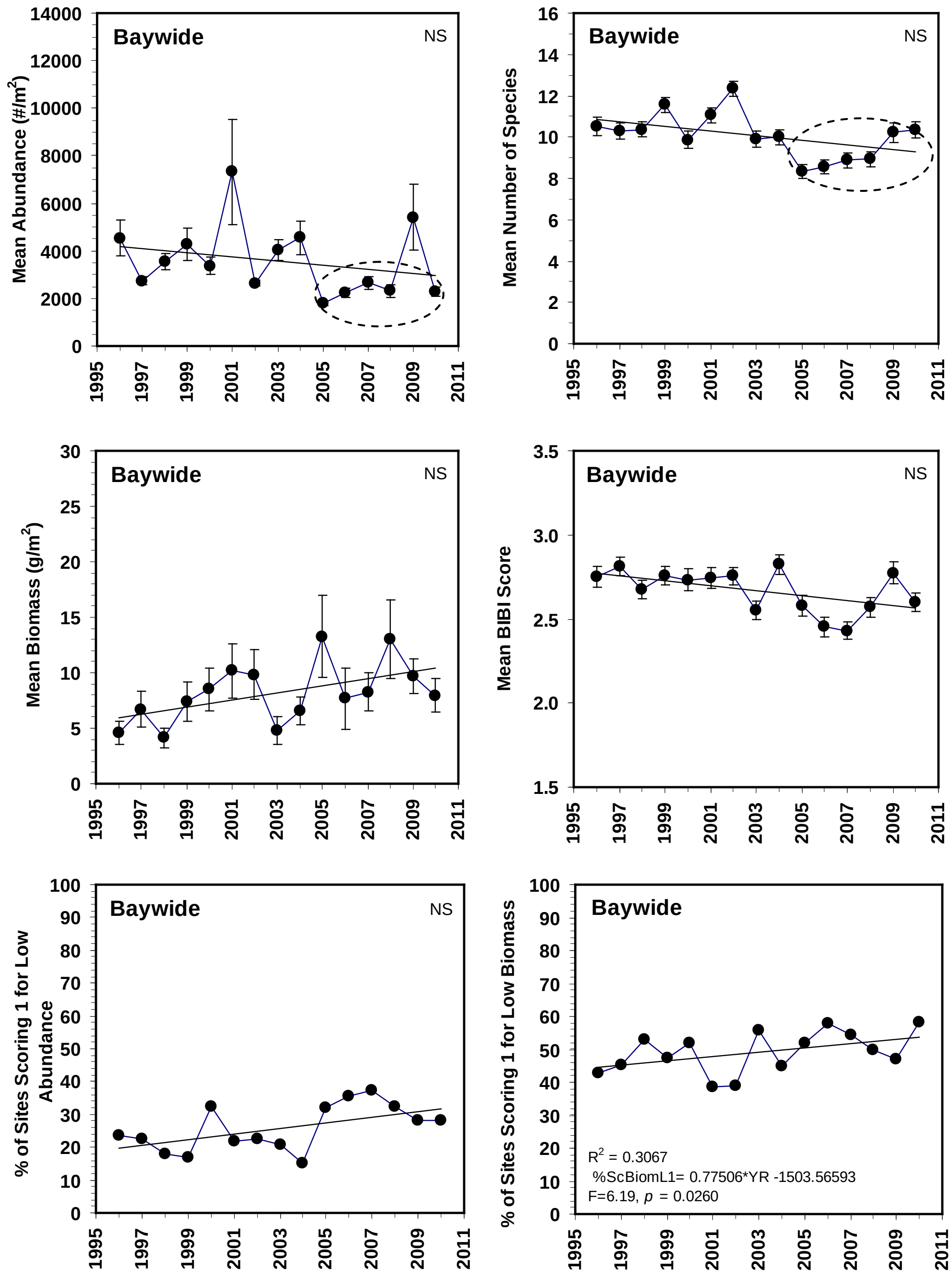

Figure 3-35. Trends in abundance, biomass, number of species, B-IBI (mean ± 1 SE), and percent sites scoring "1" for low abundance or low biomass in Chesapeake Bay (N=250 sites per year).

3.3 BASIN-LEVEL BOTTOM COMMUNITY CONDITION

Probability-based sampling can be used to produce areal estimates of degradation for regions of interest. The 2010 random sites were post-stratified into 15 reporting regions used by the Chesapeake Bay Program to assess the health of the Bay's ecosystem (Figure 3-36). The Bay Program conducts an annual integrated assessment for the Bay and its tidal tributaries using indicators of water quality conditions (chlorophyll *a*, dissolved oxygen, and water clarity), living resources (plankton and benthos), and habitat (Bay grasses) combined into a Bay Health Index (Williams et al. 2009). Reporting regions align with Tributary Strategy basins, for which benthic community condition is also summarized on a regular basis. Tributary Teams consider basin summaries that synthesize monitoring information from several sources, including watershed, ambient water quality, habitat, and living resources components. This information is linked to nutrient and sediment pollution sources and is intended to provide the Tributary Teams with resources to consult in setting Tributary Strategy goals.

Probability-based estimates for each region followed the methods described in Section 2.4.3 for single Benthic Monitoring Program strata (formulae 1 and 2), except for regions that overlapped strata (Maryland Upper Eastern Shore, Choptank River, Maryland Lower Eastern Shore, and Mid Bay regions). Regions that overlapped benthic program strata were partitioned into the portions corresponding to each stratum, and the estimates for each portion or sub-region were weighted by area and combined into region-wide estimates, as described in Section 2.4.3 (formulae 3 and 4). For example, the Choptank River reporting region consisted of two sub-regions: the Choptank River proper (Bay Program segments CHOTF, CHOOH, and CHOMH2) and the open waters of the Choptank and Little Choptank Rivers (Bay Program segments CHOMH1 and LCHMH). While the former sub-region is part of the Maryland eastern tributaries stratum, the latter is part of the Maryland mid-Bay mainstem stratum. Thus, degradation estimates were produced for each of the Choptank River sub-regions, weighted by the proportion of area represented by each sub-region, and combined.

By basin, the Upper Bay and Lower Bay were in best condition, with less than 30% of the bottom area estimated to fail the restoration goals in 2010 (Table 3-7). The Maryland Lower Western Shore, Rappahannock River, and Mid Bay regions were in worst condition, with 80% or greater of the bottom area estimated to fail the restoration goals. The Elizabeth River basin did not have data in 2010. The remaining of the regions exhibited 40-76% degradation. Note that the uncertainty associated with the estimates is generally large because of small sample size or poor data coverage in sub-regions. Thus, at the basin level, large changes in benthic condition are likely to occur from year to year, and this should be taken into account when comparing basins and years. The most salient change this year was an increase in percent degradation in the Maryland Western Shore tributaries, from 68% to 100% in the Lower tributaries (West, Rhode, South, Severn, and Magothy rivers), and from 25% to 75% in the Upper tributaries (Gunpowder and Bush rivers).

Table 3-7. Estimated tidal area failing to meet the Chesapeake Bay benthic community restoration goals in 2010 by Bay Health Index Reporting Region and Tributary Strategy Basin. The Elizabeth River Biological Monitoring Program was not conducted in 2010. See Figure 3-36 for reporting regions.

Region/Basin	Percent Failing	Km^2 Failing	SE	N
Maryland Lower Western Shore	100	100	0.0	10
Rappahannock River	80.0	298	8.2	25
Mid Bay	79.7	1,899	8.9	15
Patuxent River	76.0	97	8.7	25
Maryland Upper Western Shore	75.0	67	25.0	4
Maryland Upper Eastern Shore*	72.2	331	14.3	17
Choptank River	69.1	297	18.9	8
Potomac River	68.0	867	9.5	25
York River	56.0	105	10.1	25
Patapsco/Back Rivers	54.5	60	15.7	11
Maryland Lower Eastern Shore**	43.2	445	19.8	14
James River	40.0	256	10.0	25
Lower Bay	28.6	888	10.1	21
Upper Bay	28.0	221	9.2	25
Elizabeth River	-	-	-	0

*Northeast River and **Pocomoke Sound, not included in regional estimates because of insufficient data.

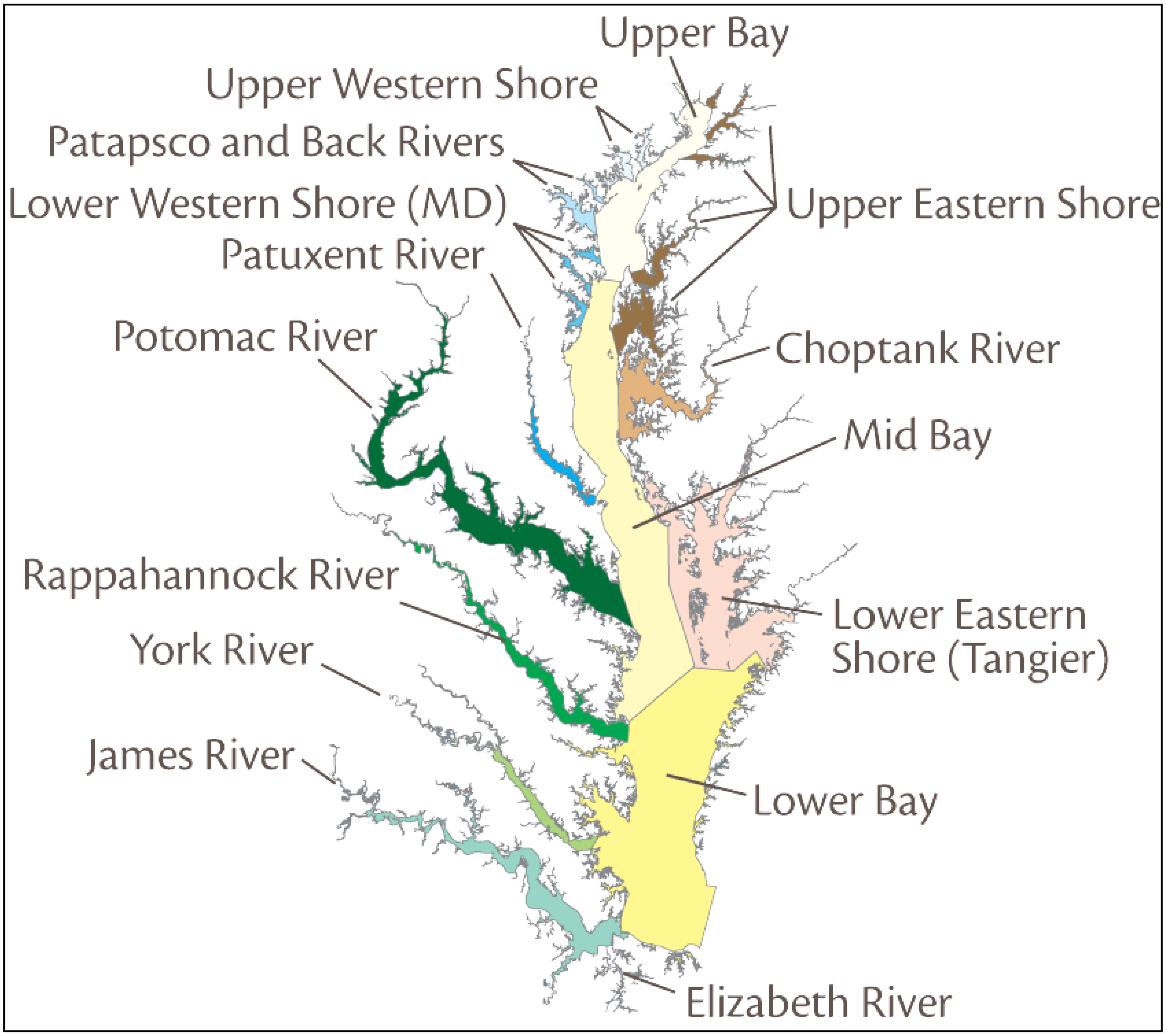

Figure 3-36. Bay Health Index Reporting Regions and Tributary Strategy basins. Figure courtesy of EcoCheck, NOAA-UMCES Partnership.

3.4 RELATIONSHIP OF BENTHIC CONDITION MEASURES WITH FLOW AND HYPOXIC VOLUME

Chesapeake Bay is a spatially complex ecosystem subject to various sources of variability. For example, water quality in Chesapeake Bay is usually influenced by years of high and low precipitation and hence river flow. Because dry and wet years can mask most pollution trends, changes in water quality resulting from management actions independent of freshwater flow are of greatest interest to environmental managers. It has been hypothesized that high spring flows in the Bay's tributaries, which are responsible for high nutrient and sediment runoff, usually lead to earlier and spatially more extensive water-column stratification within the Bay, more extensive hypoxia, and greater benthic community degradation.

Last year, a series of analyses were conducted to address the question of whether river flow influences patterns of benthic degradation in Chesapeake Bay. These analyses consisted of second-order polynomial regressions of B-IBI versus time and river flow at fixed monitoring sites, and analysis of covariance (ANCOVA) of percent degraded and severely degraded benthic condition versus time and river flow at the random strata (Llansó et al. 2010). Results suggested that freshwater flow was not significant when used as a continuous variable, but that years of high and low river flow in the spring were closely associated with benthic condition in the mainstem. The period of analysis was 1985-2007. However, when 2008 and 2009 were added to the time series, these relationships were no longer statistically significant. Using data through 2009, additional analyses were conducted this year to determine which river flow measures best correlated with benthic community condition. Because river flow is a proxy for changes in water quality that affect benthic communities in a more direct way, hypoxic volume, a more direct measure of stress on benthic communities, was also investigated.

General linear models (GLM) were used to evaluate the correspondence between measures of benthic community condition and river flow, and between measures of benthic community condition and hypoxic volume. The random and the fixed sites were evaluated separately. Rather than using ANCOVA designs with both categorical and continuous predictor variables, Analysis of Variance (ANOVA) was used in the GLM with river flow and hypoxic volume as categorical predictor variables. Percent silt-clay was initially used as a covariate, but it was subsequently removed from the analysis because it was generally not statistically significant. Flow was represented by spring (March-June), summer (July-September), and annual (January-December) averages of daily fall-line gage measurements from the Susquehanna River at Conowingo, and alternatively from the Patuxent, Potomac, Rappahannock, York, and James rivers. Spring, summer, and annual mean flows above the 75^{th} percentile of the normal range of mean flows for the baseline period were categorized as high; otherwise, flows were categorized as normal or low. The baseline period was the longest period of record available in the USGS National Water Information System (http://waterdata.usgs.gov/nwis). For the Susquehanna River the baseline period was 1968-2009, and for the Potomac River, 1934-2009 (Figures 3-37 and 3-38). It was observed that river flow in years of heavy precipitation lasting only a few days but contributing to near-record precipitation levels exhibited high standard deviations (S.D.), particularly 2005 through 2008. High S.D. reflected high variability in river flow, particularly spring pulse events. Thus to capture this variability, spring flow was categorized in this study as of high or low S.D. and used as an independent variable in the GLM analysis. Hypoxic volume was computed by the Chesapeake Bay Program by spatial interpolation of dissolved oxygen depth profiles taken fortnightly at mid channel stations. Monthly estimates by Chesapeake Bay Program segment were first aggregated to the stratum level and then averaged to obtain a summer mean (June-September). Segment-level hypoxic volumes were used when analyzing fixed site trends.

Measures of benthic community condition included the B-IBI attributes (abundance, biomass, Shannon diversity, percent abundance and percent biomass of pollution-indicative taxa, percent abundance and percent biomass of pollution-sensitive taxa, and percent abundance of carnivore and omnivores), B-IBI scores, number of species, percent area degraded (failing the B-IBI), percent area severely degraded (percent sites with B-IBI values $\leq$ 2.0), and percent sites scoring "1" (degraded) for either insufficient abundance, insufficient biomass, excess abundance, or excess biomass. B-IBI attributes, B-IBI scores, and number of species, were averaged for each stratum (n = 25 samples per stratum, 150 samples for Maryland waters, 250 samples for Chesapeake Bay) and for each fixed site (n = 3 samples per site). Abundance, biomass, and number of species were calculated using either all of the species present in a sample or only the infaunal species (the B-IBI metric). Abundance and biomass-based attributes were log-transformed (log of $x + 1$ on base 10) to reduce the dependence between the variance and the mean and to normalize the data. Percentages were transformed by first expressing them as proportions and then taking the arc sine square-root of the proportion. The period of record for the B-IBI at the time of the analysis was 1995-2009 (1996-2009 baywide) for the random sites and 1985-2009 for the fixed sites.

A variety of benthic condition measures (thereafter metrics) differed significantly between years of high and low S.D. of spring flow (Table 3-8). Most of these metrics performed in a direction that was consistent with the expectation (e.g., reduced abundance, biomass, number of species, and mean B-IBI, and increased percent area degraded in years with high S.D. of spring flow). Significance was assessed at the 0.005 alpha level to protect against false positives that may occur when many tests are run simultaneously, and to identify the stronger relationships. Large F values indicated strong relationships for percent area degraded, mean B-IBI, percent carnivore-omnivore abundance, and mean number of species in Chesapeake Bay. In Maryland waters, mean abundance, mean B-IBI, and percent area degraded were significant. In Virginia waters, mean B-IBI, mean number of species, and percent carnivore-omnivore abundance were significant. Some of these metrics were also significant for the mainstem strata (Upper Bay mainstem, Maryland mid-Bay mainstem, and Virginia mainstem). In the tributaries, only the Potomac River and the James River exhibited significant metrics. Two of the Potomac River metrics (percent abundance and percent biomass of pollution indicative taxa) could not be interpreted unambiguously, as the values of these metrics are expected to increase in degraded habitats. The results indicated lower numbers and biomass of pollution indicative taxa in years of high S.D. of spring flow.

Fewer metrics differed significantly between years of high and low or normal annual flow, and very few between years of high and low or normal spring flow and summer flow (Table 3-8). Biomass was significantly higher in years of low or normal annual flow than in years of high annual flow at the Chesapeake Bay level and in Maryland waters, but not in Virginia waters (Table 3-8). One metric, the percent number of sites scoring "1" for excess biomass, performed contrary to expectation, with higher values (presumably indicating degraded conditions) in years of low or normal river flow.

At the fixed sites few metrics were significant at the 0.005 alpha level for any of the flow variables. The results were often contrary to expectation suggesting that in general the patterns observed at the fixed sites were not consistent with years of high and low S.D. of spring flow, or years of high and low or normal river flow. The exception was Station 71 in the lower Patuxent River (Table 3-9). At this site mean B-IBI, abundance, Shannon diversity, and number of species were consistently higher in years of low S.D. of spring flow. This relationship was primarily driven by several consecutive years (2005-2009) of high variability in spring flow resulting from brief (1-3 days) severe rain events (Figure 3-39).

Surprisingly, there were very few significant relationships between the metrics and hypoxic volume, for both the random and the fixed sites using the same GLM models than for river flow (results not shown). Those metrics that were significant showed responses that were inconsistent with the expectations. The average summer hypoxic volume was plotted for Chesapeake Bay and the Maryland mainstem (Figure 3-40). There were no significant trends in summer hypoxic volume for these two strata or any of the other sampling strata. However, an increase in hypoxic volume was noted for the period 1998-2010 for the month of June (Figure 3-41), but not for the summer average or any of the other summer months (Figure 3-42). Thus while summer hypoxia has not increased in Chesapeake Bay in the last 25 years, there has been a shift in hypoxia from mid summer to early summer. This shift coincided with an overall decrease in abundance and species numbers over the 1998-2010 period at fixed sites in the Maryland mainstem, Patapsco River, Elk River, lower Potomac River, and lower Patuxent River (Figures 3-1 through 3-27).

Table 3-8. General linear model results of B-IBI metrics for four river flow scenarios, with river flow as categorical predictor variable. River flow was the average of spring (March-June), summer (July-September), or annual (January-December) daily fall-line gage measurements from the Susquehanna River at Conowingo (UPB), York River (YRK), combined Maryland tributaries (MDW), or combined Chesapeake Bay tributaries (CBY). S.D. Spring Flow was the standard deviation of spring (March-June) daily fall-line gage measurements from the Susquehanna River at Conowingo (CBY, MMS, UPB, VAW, and VBY), Potomac River (PMR), or James River (JAM). Only statistically significant results at α = 0.005 are included in this table. High = High flow/ S.D., Low = Low or normal flow/ S.D. Sampling Stratum: CBY = Chesapeake Bay, JAM = James River, MDW = Maryland tidal waters, MMS = Maryland mainstem, PMR = Potomac River, UPB = Upper Bay mainstem, VAW = Virginia tidal waters, VBY = Virginia mainstem, YRK = York River. Metric: Mean_Abun = mean abundance (# individuals per m^2), Mean_Biom = mean biomass (g afdw per m^2), Mean_BIBI = mean benthic index of biotic integrity, Mean_Num_Spp = Mean number of species, Pct_Abun_CarOmn = Percent abundance of carnivore and omnivores, Pct_Abun_Pol_Ind = Percent abundance of pollution indicative taxa, Pct_Abun_Pol_Sen = Percent abundance of pollution sensitive taxa, Pct_Area_Fail = Percent area degraded (B-IBI < 3.0), Pct_Biom_Pol_Ind = Percent biomass of pollution indicative taxa, Pct_Biom_SC_1 = Percent sites scoring as “1” (degraded) for insufficient and/or excess biomass. Pct_HighAbun_SC_1 = Percent sites scoring as “1” for excess abundance, Pct_HighBiom_SC_1 = Percent sites scoring as “1” for excess biomass, Pct_LowBiom_SC_1 = Percent sites scoring as “1” for insufficient biomass. Suffix “All” denotes metrics calculated on all the organisms in a sample (infauna plus epifauna). Means are transformed values for abundance and biomass-based metrics and percentages. * = Result contrary to expectation.

Factor	Stratum	Metric	Overall ANOVA										Fit Statistics	Mean Metric for Levels of Factor			
			Model					Error			Corrected Total			High		Low	
			DF	SS	MS	F Value	Prob. F	DF	SS	MS	DF	SS	R^2	N	Mean	N	Mean
Spring Flow	UPB	Pct_HighBiom_SC_1	1	0.2429	0.2429	11.800	0.0044	13	0.2676	0.0206	14	0.5106	0.476	3	0.14	12	0.45*
	YRK	Mean_Biom	1	0.2243	0.2243	12.003	0.0047	12	0.2243	0.0187	13	0.4486	0.500	2	0.78	12	0.42*
Summer Flow	CBY	Pct_HighBiom_SC_1	1	0.0513	0.0513	13.128	0.0035	12	0.0469	0.0039	13	0.0982	0.522	4	0.07	10	0.20*
	MDW	Pct_HighBiom_SC_1	1	0.0944	0.0944	15.656	0.0016	13	0.0784	0.0060	14	0.1728	0.546	4	0.09	11	0.27*
	UPB	Pct_HighBiom_SC_1	1	0.2849	0.2849	16.414	0.0014	13	0.2257	0.0174	14	0.5106	0.558	4	0.16	11	0.47*
Annual Flow	CBY	Pct_Abun_Pol_Sen	1	0.0144	0.0144	14.885	0.0023	12	0.0116	0.0010	13	0.0261	0.554	4	0.48	10	0.55
	CBY	Mean_Biom	1	0.1589	0.1589	21.585	0.0006	12	0.0884	0.0074	13	0.2473	0.643	4	0.77	10	1.01
	CBY	Mean_Biom_All	1	0.1535	0.1535	19.133	0.0009	12	0.0963	0.0080	13	0.2497	0.615	4	0.79	10	1.02
	CBY	Pct_HighBiom_SC_1	1	0.0639	0.0639	22.377	0.0005	12	0.0343	0.0029	13	0.0982	0.651	4	0.06	10	0.21*
	MDW	Mean_Biom	1	0.2756	0.2756	32.589	0.0001	13	0.1100	0.0085	14	0.3856	0.715	4	0.86	11	1.17
	MDW	Mean_Biom_All	1	0.2784	0.2784	30.739	0.0001	13	0.1177	0.0091	14	0.3961	0.703	4	0.87	11	1.17
	MDW	Pct_HighBiom_SC_1	1	0.1111	0.1111	23.391	0.0003	13	0.0617	0.0047	14	0.1728	0.643	4	0.08	11	0.27*
	UPB	Mean_Biom	1	0.4272	0.4272	13.640	0.0027	13	0.4072	0.0313	14	0.8345	0.512	3	0.99	12	1.42
	UPB	Mean_Biom_All	1	0.4315	0.4315	13.476	0.0028	13	0.4162	0.0320	14	0.8477	0.509	3	1.00	12	1.42
	UPB	Pct_HighBiom_SC_1	1	0.3458	0.3458	27.293	0.0002	13	0.1647	0.0127	14	0.5106	0.677	3	0.09	12	0.47*
S.D. Spring Flow	CBY	Pct_Abun_CarOmn	1	0.0060	0.0060	23.850	0.0004	12	0.0030	0.0003	13	0.0091	0.665	6	0.47	8	0.51
	CBY	Mean_BIBI	1	0.1743	0.1743	43.770	0.0000	12	0.0478	0.0040	13	0.2221	0.785	6	2.54	8	2.77
	CBY	Mean_Num_Spp	1	8.4242	8.4242	12.110	0.0045	12	8.3473	0.6956	13	16.7715	0.502	6	9.16	8	10.73

Table 3-8. (Continued)

Factor	Stratum	Metric	Overall ANOVA										Fit Statistics	Mean Metric for Levels of Factor			
			Model					Error			Corrected Total			High		Low	
			DF	SS	MS	F Value	Prob. F	DF	SS	MS	DF	SS	R^2	N	Mean	N	Mean
S.D. Spring Flow (continued)	CBY	Mean_Num_Spp_All	1	11.7470	11.7470	12.761	0.0038	12	11.0468	0.9206	13	22.7938	0.515	6	10.02	8	11.87
	CBY	Pct_Area_Fail	1	0.0296	0.0296	54.550	0.0000	12	0.0065	0.0005	13	0.0361	0.820	6	0.87	8	0.78
	CBY	Pct_Bmas_SC_1	1	0.0305	0.0305	15.244	0.0021	12	0.0240	0.0020	13	0.0545	0.560	6	0.86	8	0.76
	CBY	Pct_LowBiom_SC_1	1	0.0292	0.0292	19.364	0.0009	12	0.0181	0.0015	13	0.0472	0.617	6	0.82	8	0.73
	MDW	Mean_Abun	1	0.4899	0.4899	13.782	0.0026	13	0.4621	0.0355	14	0.9520	0.515	6	3.24	9	3.61
	MDW	Mean_Abun_All	1	0.4294	0.4294	12.675	0.0035	13	0.4404	0.0339	14	0.8697	0.494	6	3.28	9	3.63
	MDW	Mean_BIBI	1	0.1407	0.1407	15.067	0.0019	13	0.1214	0.0093	14	0.2622	0.537	6	2.50	9	2.70
	MDW	Pct_Area_Fail	1	0.0682	0.0682	12.200	0.0040	13	0.0727	0.0056	14	0.1409	0.484	6	1.07	9	0.93
	MDW	Pct_HighAbun_SC_1	1	0.0719	0.0719	11.458	0.0049	13	0.0816	0.0063	14	0.1535	0.468	6	0.24	9	0.39*
	VAW	Pct_Abun_CarOmn	1	0.0067	0.0067	12.682	0.0039	12	0.0063	0.0005	13	0.0130	0.514	6	0.45	8	0.49
	VAW	Mean_BIBI	1	0.2249	0.2249	31.164	0.0001	12	0.0866	0.0072	13	0.3115	0.722	6	2.61	8	2.86
	VAW	Mean_Num_Spp	1	11.5920	11.5920	18.934	0.0009	12	7.3469	0.6122	13	18.9389	0.612	6	12.07	8	13.90
	VAW	Mean_Num_Spp_All	1	17.3636	17.3636	22.330	0.0005	12	9.3310	0.7776	13	26.6945	0.650	6	13.05	8	15.30
	MMS	Mean_Abun	1	1.5468	1.5468	12.582	0.0036	13	1.5982	0.1229	14	3.1450	0.492	6	3.29	9	3.95
	MMS	Mean_Abun_All	1	1.5137	1.5137	12.399	0.0038	13	1.5870	0.1221	14	3.1007	0.488	6	3.31	9	3.96
	MMS	Pct_Area_Fail	1	0.0682	0.0682	12.200	0.0040	13	0.0727	0.0056	14	0.1409	0.484	6	1.07	9	0.93
	MMS	Pct_LowBiom_SC_1	1	0.1514	0.1514	12.373	0.0038	13	0.1590	0.0122	14	0.3104	0.488	6	1.07	9	0.87
	UPB	Mean_Abun	1	0.2464	0.2464	11.537	0.0048	13	0.2777	0.0214	14	0.5241	0.470	6	3.20	9	3.46
	UPB	Mean_Abun_All	1	0.2402	0.2402	11.881	0.0043	13	0.2628	0.0202	14	0.5030	0.478	6	3.23	9	3.49
	PMR	Pct_Abun_Pol_Ind	1	0.2267	0.2267	12.476	0.0037	13	0.2363	0.0182	14	0.4630	0.490	6	0.43	9	0.68*
	PMR	Pct_Abun_CarOmn	1	0.0874	0.0874	16.346	0.0014	13	0.0695	0.0053	14	0.1569	0.557	6	0.34	9	0.50
	PMR	Pct_Biom_Pol_Ind	1	0.2382	0.2382	11.788	0.0044	13	0.2627	0.0202	14	0.5010	0.476	6	0.23	9	0.49*
	VBY	Mean_Num_Spp	1	49.1185	49.1185	17.153	0.0014	12	34.3622	2.8635	13	83.4807	0.588	6	17.26	8	21.05
	VBY	Mean_Num_Spp_All	1	75.6834	75.6834	19.664	0.0008	12	46.1867	3.8489	13	121.8702	0.621	6	18.41	8	23.11
	JAM	Pct_Abun_CarOmn	1	0.0131	0.0131	13.668	0.0031	12	0.0115	0.0010	13	0.0247	0.532	4	0.38	10	0.45

Table 3-9. General linear model results of B-IBI metrics at the fixed Station 71 in the lower Patuxent River. The categorical predictor variable, S.D. Spring Flow, was the standard deviation of spring (March-June) daily fall-line gage measurements from the Patuxent River. High = High S.D., Low = Low S.D. See Table 3-8 for metric definition, Mean_Shann = mean Shannon diversity. Abundance-based metric means are transformed values.

			Overall ANOVA										Fit Statistics	Mean Metric for Levels of Factor			
			Model					Error			Corrected Total			High		Low	
Factor	Site	Metric	DF	SS	MS	F Value	Prob. F	DF	SS	MS	DF	SS	R^2	N	Mean	N	Mean
S.D. Spring Flow	071	Mean_Num_Spp_All	1	71.1111	71.1111	22.957	0.0001	22	68.1481	3.0976	23	139.2593	0.511	10	4.00	15	7.56
	071	Mean_Num_Spp	1	57.3336	57.3336	21.421	0.0001	22	58.8840	2.6765	23	116.2176	0.493	10	3.74	15	6.93
	071	Mean_BIBI	1	2.1007	2.1007	16.862	0.0005	22	2.7407	0.1246	23	4.8414	0.434	10	1.56	15	2.17
	071	Mean_Shann	1	4.3378	4.3378	13.361	0.0014	22	7.1424	0.3247	23	11.4801	0.378	10	1.36	15	2.24
	071	Mean_Abun_All	1	0.8112	0.8112	8.502	0.0080	22	2.0990	0.0954	23	2.9102	0.279	10	2.59	15	2.97
	071	Mean_Abun	1	0.8553	0.8553	7.802	0.0106	22	2.4117	0.1096	23	3.2670	0.262	10	2.56	15	2.95
	071	Pct_Abun_Pol_Sen	1	0.1711	0.1711	7.666	0.0112	22	0.4910	0.0223	23	0.6621	0.258	10	0.15	15	0.32

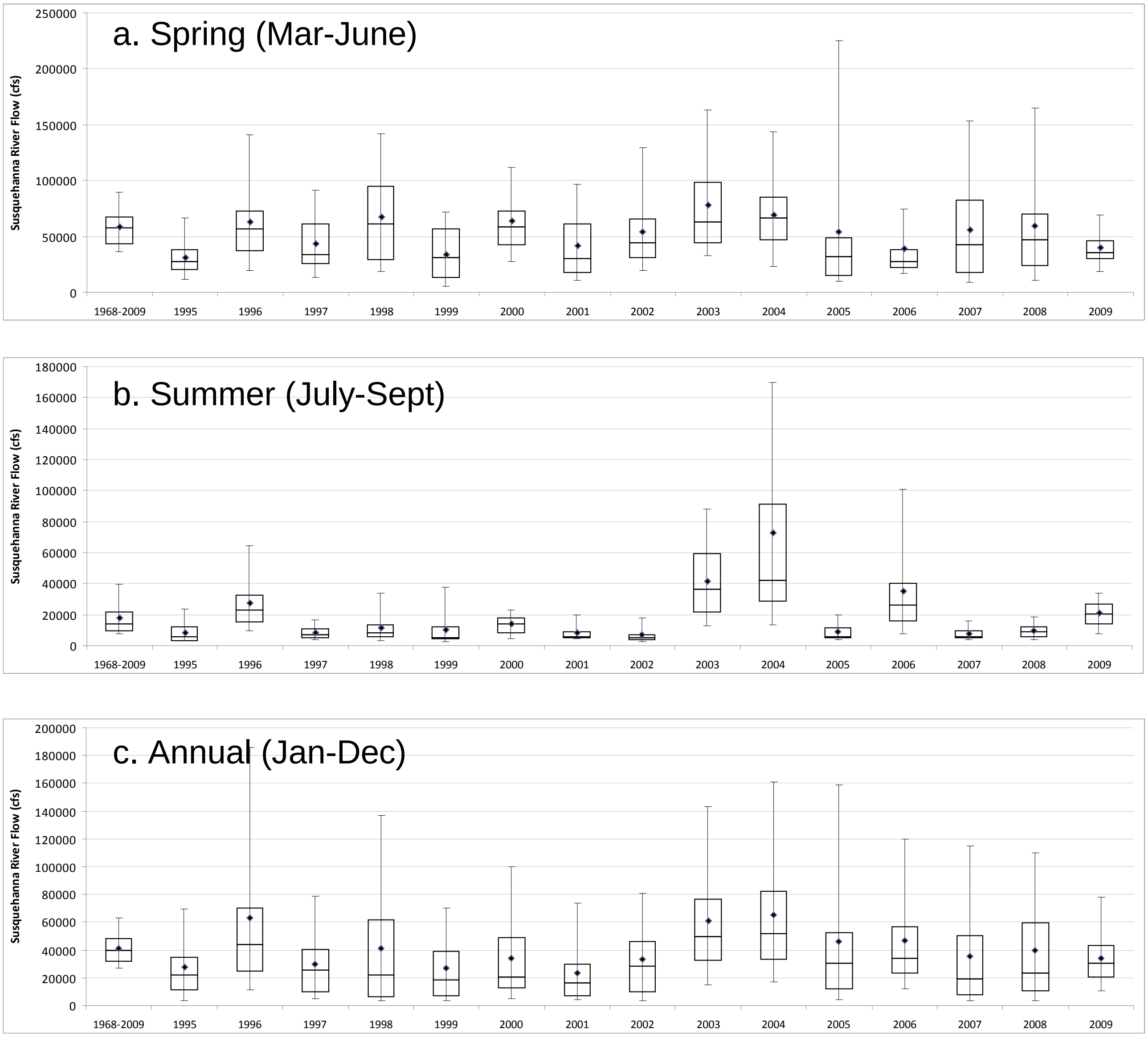

Figure 3-37. Spring, summer, and annual mean flow (dots within boxes) into Chesapeake Bay from the Susquehanna River by year, 1995-2009. The average range of spring, summer, and annual flows for 1968-2009 (first box of each plot) was used as baseline to categorize years of high and low river flow.

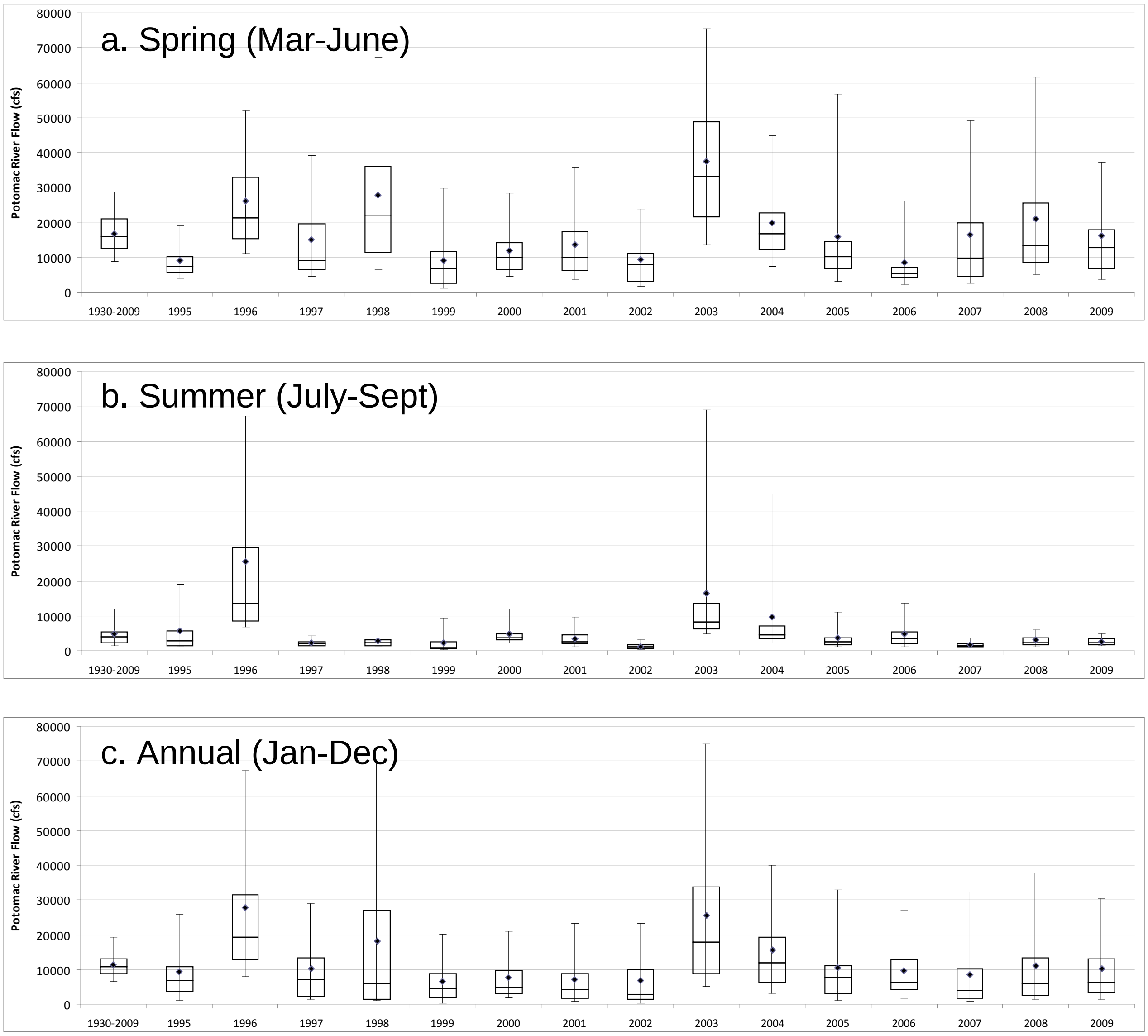

Figure 3-38. Spring, summer, and annual mean flow (dots within boxes) into Chesapeake Bay from the Potomac River by year, 1995-2009. The average range of spring, summer, and annual flows for 1930-2009 (first box of each plot) was used as baseline to categorize years of high and low river flow.

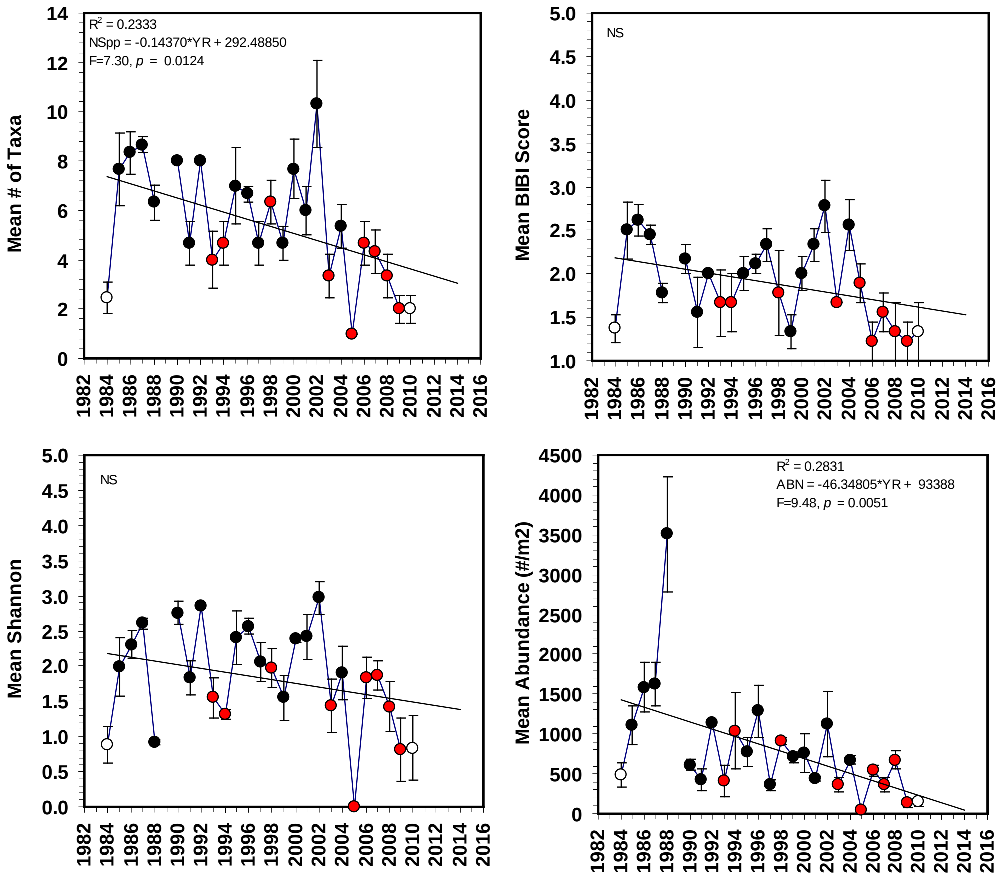

Figure 3-39. Number of species, B-IBI score, Shannon diversity, and abundance (mean ± 1 SE) at Station 71 in the lower Patuxent River, Broomes Island. Data points are colored according to years of high or low standard deviation of mean daily spring flow (Mar-June) into Chesapeake Bay from the Patuxent River. Red filled circles = high S.D. of spring flow; black filled circles = low S.D. of spring flow; unfilled circles = data points outside the time series used in the GLM analysis (see text). Trends evaluated by ANOVA; NS = not significant.

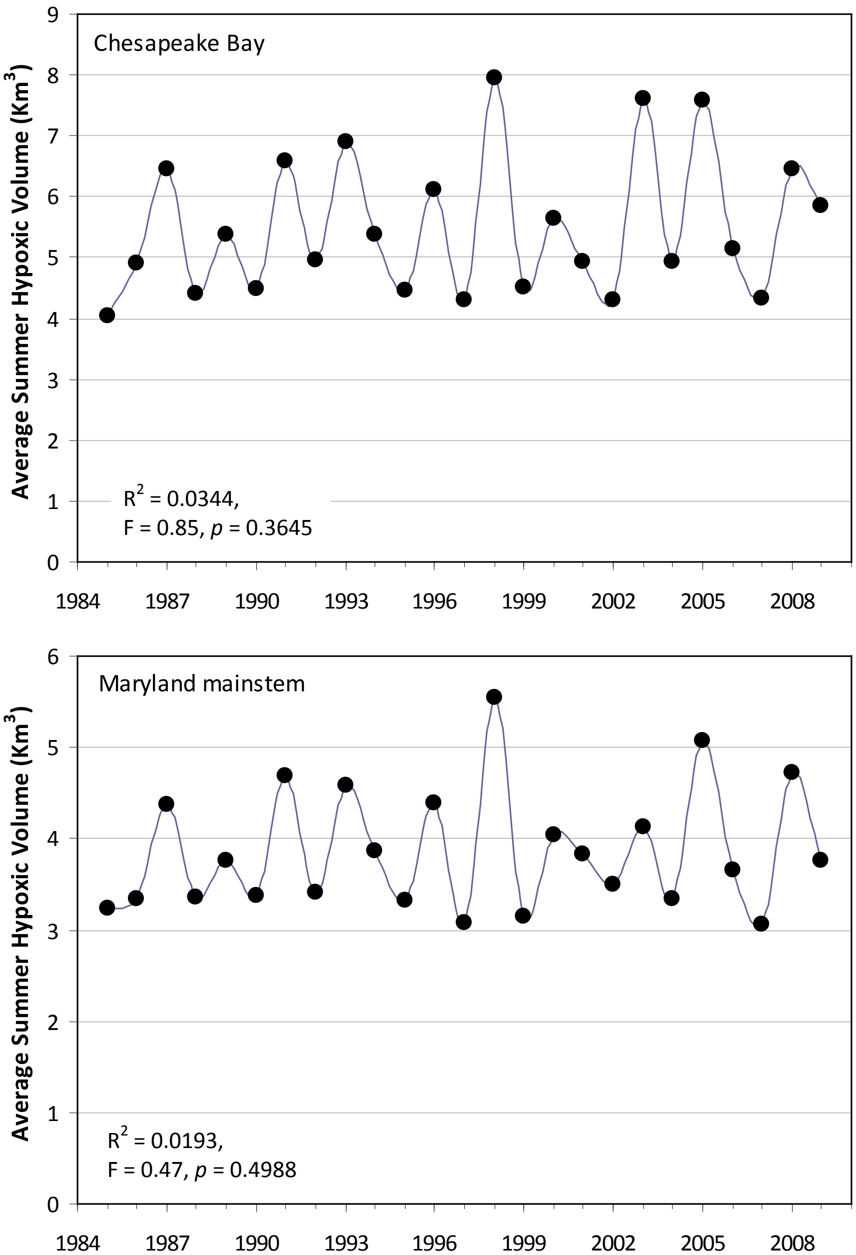

Figure 3-40. Average summer (June-September) hypoxic volume in Chesapeake Bay and the Maryland mainstem. Hypoxic volume was calculated by the Chesapeake Bay Program by spatial interpolation of dissolved oxygen depth profiles taken fortnightly at mid channel stations in the mainstem of the Chesapeake Bay and tributaries. Trends evaluated by ANOVA.

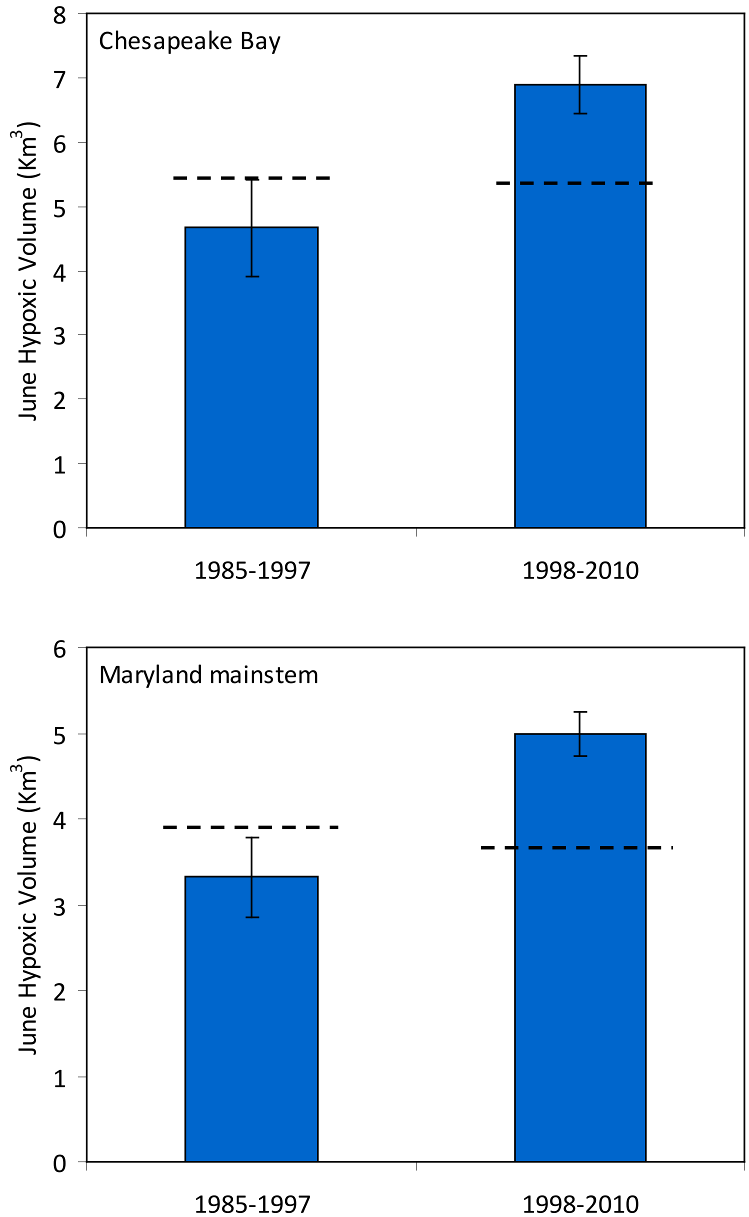

Figure 3-41. Hypoxic volume (mean ± 1 SE) during the month of June in Chesapeake Bay and the Maryland mainstem for two time periods, 1985-1997 and 1998-2010. Also indicated are the summer averages for the same two periods (dashed lines, June-September). Hypoxic volume was calculated by the Chesapeake Bay Program by spatial interpolation of dissolved oxygen depth profiles taken fortnightly at mid channel stations in the mainstem of the Chesapeake Bay and tributaries.

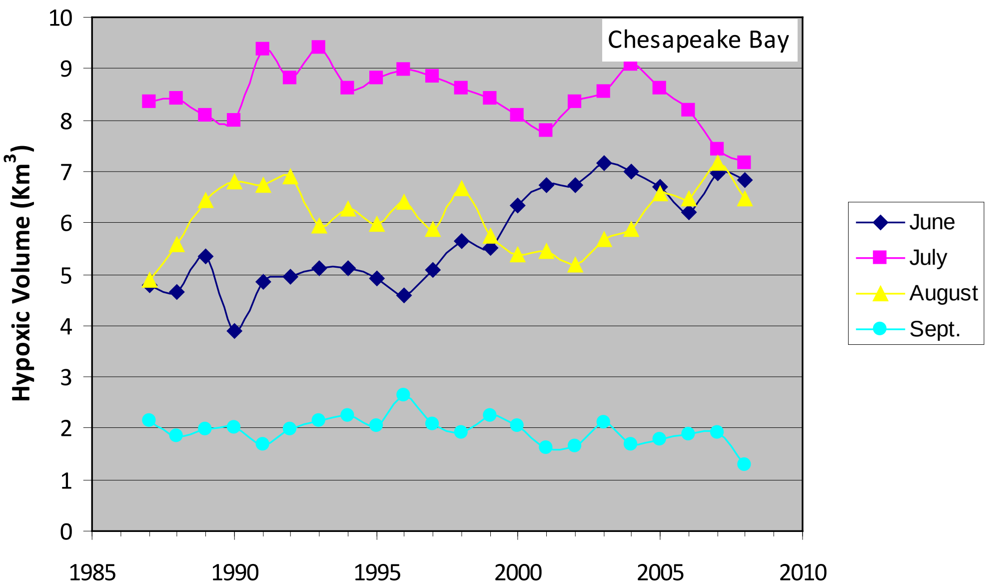

Figure 3-42. 5-year running average of hypoxic volume for the months of June, July, August, and September, 1985-2010, in Chesapeake Bay. The plot shows an increase in hypoxia since 1998 in June, but not in July, August, or September. Hypoxic volume was calculated by the Chesapeake Bay Program by spatial interpolation of dissolved oxygen depth profiles taken fortnightly at mid channel stations in the mainstem of the Chesapeake Bay and tributaries.

4.0 DISCUSSION

The highlights for 2010 are: (1) Changes in trend direction and magnitude at the fixed sites indicated generally degrading benthic conditions in Chesapeake Bay. (2) In Maryland and baywide, the area degraded increased by about 10 percent relative to 2009, but the extent of the severely degraded condition remained unchanged. (3) The Patuxent River, Maryland mid-Bay mainstem, and Maryland Western Tributaries had the poorest condition among the Maryland strata. (4) Significant increasing trends in percent area degraded were detected in the Patuxent River and the Maryland Eastern Tributaries. (5) Changes in benthic condition in the last 6 years were associated with high variability in river flow, particularly a greater incidence of pulses in spring river flow.

In 2010 there were increases in benthic degradation in all of the Maryland and Virginia strata, except in the Patuxent River and James River strata. The Patuxent River, however, had a significant degrading trend over the 1995-2010 time series, which continued from previous years. Fifty-three percent of the Bay's tidal waters in 2010 failed the benthic community restoration goals, compared to 44% in 2009. On the other hand, the extent of degradation was not as high as during the 2005-2008 period. In the Maryland portion of the Bay, 67% of the tidal waters failed the restoration goals, compared to 58% in 2009. The severely degraded condition in both the Chesapeake Bay and the Maryland Bay, which had steadily decreased for the previous four years, remained the same.

When averaged over the Chesapeake Bay and the Maryland Bay, benthic condition measures at the probability-based sites showed considerable variability over the 1995-2010 time series. However, there was a marked decline in abundance and species numbers in 2005 that continued through 2008 and into 2010. Essentially, the last six years of monitoring showed very low abundance and low species numbers compared to previous years, except for 2009. The mean B-IBI was also, on average, lower during the 2005-2010 time period. Low abundance and species numbers in the last six years, with or without an upward spike in 2009, also occurred at fixed sites in the Maryland mainstem, Patapsco River, Elk River, lower Potomac River and lower Patuxent River. The mainstem, Patapsco River, and lower (mesohaline) portions of the Potomac and Patuxent rivers are influenced by hypoxia. In addition, changes in trend direction and/or magnitude at eight fixed sites in 2010 indicated generally degrading benthic conditions in Chesapeake Bay.

One factor associated with the observed changes in benthic condition was river flow. The Bay has experienced higher than normal spring flows in most recent years except 2004 and 2009. High spring flows are responsible for high nutrient runoff and earlier and spatially more extensive water-column stratification within the Bay, factors that usually lead to more extensive hypoxia (Tuttle et al. 1987). The Susquehanna river provides 50% of the freshwater flow to the Chesapeake Bay, and so the influence of river flow on benthic community condition would be expected to be more pronounced on the mainstem of the Bay. However, river flow alone does not seem to capture much of the year to year variability in benthic condition. Analyses conducted last year suggested a relationship between spring flow and percent area degraded in the mainstem. This relationship did not hold with the addition of the 2008 and 2009 data. But when short term variability in river flow was considered, a much stronger association between spring flow and benthic condition was found.

Pulses in river flow following severe rain events bring sudden high sediment loads, nutrient loads, detritus, and organic matter into Chesapeake Bay (Kemp et al. 2005). When mean daily flow is examined, high standard deviations (S.D.) reflect pulse events. Four such pulse events occurred in the springs of 2005 through 2008, and again in March 2010 as a result of heavy rains and rapid snow melt. Each of these years exhibited low abundance, reduced species numbers, and poor benthic condition as measured by the B-IBI. General linear models (GLM) revealed strong relationships between mean abundance, mean number of species, mean B-IBI, percent area degraded, and other benthic condition measures, and years of high or low S.D. of spring flow for mainstem strata and for Maryland, Virginia, and Chesapeake Bay tidal waters. The time series in these analyses was 1995-2009 (1996-2009 baywide). However, similar analyses using the fixed sites over the 1985-2009 time series found significant relationships only for Station 71 in the lower Patuxent River. Mainstem sites that should have been affected by large pulse events from the Susquehanna River in the 1980s, showed no correspondence between the S.D. of spring flow and the benthic condition measures.

Several explanations can be invoked to explain the strong relationships observed at the strata level but not at the fixed site level. One possible explanation is that trends at fixed sites reflect local water quality problems, whereas strata reflect basin-wide conditions averaged over large areas. This explanation, however, is not supported by the very low abundance and species numbers that were observed at many of the fixed sites since 2005. Both fixed sites and strata showed similar patterns in the last six years of monitoring. However, it is in the early years of the time series that relationships at the fixed sites break down. There were significant pulse events in the 1980s and 1990s but these spanned no more than two consecutive years. Thus a second explanation is more likely. Several consecutive years of heavy rains and large pulse events in river flow are likely to have a compounded effect on benthos, and communities may be unable to recover fully from one year to the next. Indeed, in the Neuse River estuary Powers et al. (2005) found limited recovery of the benthic communities after unusually intense spring rainfall, and in the York River Long and Seitz (2009) found that recovery in hypoxic areas was complete after a mild hypoxic year but only partial after a severe hypoxic year.

A link between spring flow and benthic community condition is summer hypoxia (Tuttle et al. 1987). Summer hypoxia is probably the greatest stressor affecting benthic communities in Chesapeake Bay (Dauer et al. 2000, Kemp et al. 2005). Therefore, it may be surprising that the GLM analysis revealed no significant differences among years of high and low hypoxic volume. Hypoxic volume provides a measure of the volume of the water column below the pycnocline containing low dissolved oxygen concentrations, but it does not provide information about the duration, frequency, or severity of the low dissolved oxygen events. These are critical factors in the fate and recovery of benthic populations subjected to summer hypoxia (Llansó 1992, Diaz and Rosenberg 1995, Long and Seitz 2009). Thus a failure to relate hypoxic volume to benthic condition measures in the GLM analysis should not be surprising. However, a general relationship between hypoxic volume and benthic condition should at least be discerned. We found no changes in summer hypoxic volume over the 1985-2010 time series, but a shift in summer hypoxia from mid summer to early summer occurred in 1998. This shift coincided with, on average, lower abundance and species numbers at some of the fixed sites, sites that because of their location in the mainstem and the lower reaches of tributaries would be expected to undergo hypoxia. Earlier hypoxia may interact with the establishment and recovery of populations from previous year events, especially at a time when recruitment and growth is ongoing for many species. Cascading effects up the food chain as a result of a shift in hypoxia from mid summer to early summer are also likely (Powers et al. 2005).

The connection between spring flow and earlier summer hypoxia cannot be established with our data alone. Factors that influence the development, spatial variation, and magnitude of seasonal hypoxia are complex (Tuttle et al. 1987, Boynton and Kemp 2000), but the results of the benthic monitoring program in the last few years suggest worsening conditions in Chesapeake Bay that coincide with an increasing incidence of pulses in river flow and earlier hypoxic events. These factors, which may be related to decadal cycles or climate change, may override attempts to restore the Chesapeake Bay through reductions of point and non-point nutrient and sediment loads, so that longer and more intense restoration efforts may be needed before widespread improvements in abundance, diversity, and biomass of organisms can be observed.

The results presented in this report were enabled by the combination of probability-based sampling and fixed point monitoring. Probability-based sampling allow determination of levels of benthic community degradation at multiple spatial scales, from strata and Tributary Strategy basins (this report) to tidal creeks (Dauer and Llansó 2003) and Bay Program segments (Llansó et al. 2003). Probability-based data are also useful for reporting overall condition and identification of impaired waters (305b report) under the Clean Water Act (Llansó et al. 2005b, 2009a). These assessments are dependent on fully validated thresholds for assessing benthic community condition at sampling sites. The thresholds were established and validated by Ranasinghe et al. (1994) and updated by Weisberg et al. (1997). The thresholds and the B-IBI and its components allow for a validated, unambiguous approach to characterizing conditions in the Chesapeake Bay. The B-IBI has been shown by Alden et al. (2002) to be sensitive, stable, robust, and statistically sound. Its performance was verified by Llansó et al (2009b) using data independent of those used in the initial index development effort. This last study revealed good classification performance of the B-IBI, balanced Type I and Type II errors, and the influence of a variety of metrics in the final B-IBI score, characteristics that made assessments in Chesapeake Bay more reliable with the B-IBI than with any of the alternative benthic indicators.

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APPENDIX A

FIXED SITE COMMUNITY ATTRIBUTE
1985-2010 TREND ANALYSIS RESULTS

Appendix Table A-1. Summer trends in benthic community attributes at mesohaline stations 1985-2010. Shown is the median slope of the trend. Monotonic trends were identified using the van Belle and Hughes (1984) procedure. (a): trends based on 1989-2010 data; (b): trends based on 1995-2010 data; (c): attribute trend based on 1990-2010 data; (d): attributes are used in B-IBI calculations when species specific biomass is unavailable; (e): attribute and trend are not part of the reported B-IBI. Probability values shown in Table 3-2.

Station	B-IBI	Abundance	Biomass	Shannon Diversity	Indicative Abundance	Sensitive Abundance	Indicative Biomass (c)	Sensitive Biomass (c)	Abundance Carnivore/ Omnivores
Potomac River									
43	0.0000	-90.4348	-0.9390	-0.0053	0.2482	-0.9117 (d)	0.0146 (e)	-1.6097	-0.1799 (e)
44	-0.0222	-32.7921	-0.0704	0.0013	-0.3622	-0.2315 (d)	0.0000 (e)	-0.2363	0.6536 (e)
47	0.0000	-80.0000	-0.9004	0.0043	0.1073	-1.2446 (d)	0.0085 (e)	-1.4567	-0.1328 (e)
51	0.0000	-42.1053	-0.1293	0.0024	-0.7273	0.1649	0.0952 (e)	-1.2609 (e)	0.1714
52	0.0000	-3.5294	-0.0001	0.0000	0.0000 (d)	0.0000 (d)	0.0000	0.0000	0.0000
Patuxent River									
71	-0.0333	-45.4545	-0.0389	-0.0293	-0.6584 (d)	-0.0717 (d)	0.6122	0.0000	0.0000
74	0.0000	-1.3141	-1.2516	-0.0093	0.1277	-0.6693 (d)	-0.0015 (e)	-0.2161	-0.2281 (e)
77	-0.0400	2.5000	-0.0893	0.0054	0.3839	-0.3577 (d)	-1.1873 (e)	0.4001	-0.563 (e)
Choptank River									
64	0.0159	-27.5454	0.0240	0.0158	-0.1736 (d)	0.6944 (d)	0.0059	-0.8409	0.8207
Maryland Mainstem									
01	0.0000	-40.0000	-0.0182	-0.0084	-0.2770	-0.0909	-0.0329(e)	-0.1755 (e)	-0.3291
06	0.0000	13.3333	0.0061	-0.0193	0.0000	-0.3925	0.0218(e)	-0.1755 (e)	-0.7407
15	0.0000	-6.9565	-0.0363	0.0021	-0.3282	0.0000	0.1455(e)	-1.5456 (e)	0.2252
24	0.0000	-30.0000	0.0087	-0.0277	-0.5393 (d)	0.3631 (d)	-0.0050	0.4042	0.7522
26	0.0167	-8.4319	0.0033	0.0086	0.0000	-0.2165 (d)	-0.0001 (e)	-0.0095	0.1042 (e)
Maryland Western Shore Tributaries									
22	-0.0400	-53.3333	-0.0243	-0.0631	2.0202	0.0000 (d)	1.0551 (e)	0.0000	-0.4237 (e)
23	0.0000	-81.5640	0.0160	-0.0139	-0.2179	0.8587 (d)	-0.0318 (e)	0.9032	0.1942 (e)
201(a)	0.0000	-9.5909	0.0006	0.0000	0.0000	0.0000 (d)	0.0000 (e)	0.0000	0.0000 (e)
202(a)	0.0000	-29.4385	-0.0001	0.0000	0.0000	0.0000 (d)	0.0000 (e)	0.0000	0.0000 (e)
204(b)	-0.0278	-83.1302	-0.1118	0.0103	0.5021 (d)	0.2103 (d)	0.0122	-0.6126	-0.1221
Maryland Eastern Shore Tributaries									
62	-0.0444	75.0000	-0.0425	-0.0399	0.0000	-0.4377 (d)	0.0268 (e)	-2.4630	-0.2625 (e)
68	0.0000	43.2956	0.4298	-0.0170	-0.0173	0.1799 (d)	0.0001 (e)	0.0013	-0.0769 (e)

Appendix Table A-2. Summer trends in benthic community attributes at oligohaline and tidal freshwater stations 1985-2010. Shown is the median slope of the trend. Monotonic trends were identified using the van Belle and Hughes (1984) procedure. (a): trends based on 1989-2010 data; NA: attribute not calculated. Probability values shown in Table 3-3.

Station	B-IBI	Abundance	Tolerance Score	Freshwater Indicative Abundance	Oligohaline Indicative Abundance	Oligohaline Sensitive Abundance	Tanypodinae to Chironomidae Ratio	Abundance Deep Deposit Feeders	Abundance Carnivore/ Omnivores
Potomac River									
36	-0.0227	7.1727	0.022	0.9101	NA	NA	NA	0.6503	NA
40	0.0000	4.7711	-0.0167	NA	0.1295	0.0000	0.0000	NA	0.0000
Patuxent River									
79	0.0000	15.2689	-0.0103	-0.4188	NA	NA	NA	-0.017	NA
Choptank River									
66	0.0000	9.7203	0.067	NA	0.5291	0.0000	0.0000	NA	0.0165
Maryland Western Shore Tributaries									
203(a)	0.0519	2.6453	-0.03	NA	0.0000	0.0000	3.0501	NA	1.8441
Maryland Eastern Shore Tributaries									
29	0.0000	-41.7083	-0.0278	NA	-1.0172	-0.0258	0.0000	NA	0.1682

APPENDIX B

FIXED SITE B-IBI VALUES, SUMMER 2010

Appendix Table B-1. Fixed site B-IBI values, Summer 2010

Station	Sampling Date	Latitude (WGS84 Decimal Degrees)	Longitude (WGS84 Decimal Degrees)	B-IBI	Status
001	9/13/2010	38.41905	-76.4184	2.78	Marginal
006	9/13/2010	38.44199	-76.4442	2.78	Marginal
015	9/13/2010	38.71515	-76.5138	1.33	Severely Degraded
022	9/29/2010	39.25808	-76.5951	1.00	Severely Degraded
023	8/30/2010	39.20816	-76.5235	2.60	Degraded
024	9/16/2010	39.12215	-76.3554	2.56	Degraded
026	9/15/2010	39.27147	-76.2899	4.07	Meets Goal
029	9/23/2010	39.47952	-75.9449	1.89	Severely Degraded
036	9/14/2010	38.76984	-77.0375	2.17	Degraded
040	10/6/2010	38.35743	-77.2305	3.67	Meets Goal
043	10/3/2010	38.38446	-76.9884	2.60	Degraded
044	10/3/2010	38.38566	-76.9958	1.80	Severely Degraded
047	10/3/2010	38.3638	-76.9837	3.93	Meets Goal
051	10/3/2010	38.20528	-76.7394	1.78	Severely Degraded
052	9/1/2010	38.19233	-76.7477	1.33	Severely Degraded
062	9/20/2010	38.38398	-75.8499	1.93	Severely Degraded
064	9/8/2010	38.59048	-76.0693	2.78	Marginal
066	9/8/2010	38.80151	-75.922	2.33	Degraded
068	9/9/2010	39.13246	-76.0785	3.40	Meets Goal
071	9/3/2010	38.39503	-76.5489	1.33	Severely Degraded
074	8/26/2010	38.54888	-76.6761	3.40	Meets Goal
077	8/26/2010	38.60444	-76.675	2.33	Degraded
079	8/26/2010	38.75024	-76.689	3.17	Meets Goal
201	8/30/2010	39.23413	-76.4975	1.00	Severely Degraded
202	8/30/2010	39.21778	-76.5642	1.00	Severely Degraded
203	9/15/2010	39.27496	-76.4444	1.44	Severely Degraded
204	8/25/2010	39.0069	-76.5047	3.00	Meets Goal

APPENDIX C

RANDOM SITE B-IBI VALUES, SUMMER 2010

Appendix Table C-1. Random site B-IBI values, Summer 2010

Station	Sampling Date	Latitude (WGS84 Decimal Degrees)	Longitude (WGS84 Decimal Degrees)	B-IBI	Status
MET-17401	21-Sep-10	38.09038	-75.8802	2.00	Sev. Degraded
MET-17402	21-Sep-10	38.11539	-75.8835	3.00	Meets Goal
MET-17403	21-Sep-10	38.22553	-75.875	2.67	Marginal
MET-17404	21-Sep-10	38.26188	-75.7972	3.00	Meets Goal
MET-17405	21-Sep-10	38.2814	-75.7717	2.67	Marginal
MET-17407	20-Sep-10	38.33027	-75.904	3.33	Meets Goal
MET-17408	20-Sep-10	38.34116	-75.8969	2.33	Degraded
MET-17409	20-Sep-10	38.49016	-75.797	3.67	Meets Goal
MET-17410	8-Sep-10	38.60079	-76.0643	2.33	Degraded
MET-17411	8-Sep-10	38.61182	-75.9723	2.60	Degraded
MET-17412	8-Sep-10	38.79308	-75.9355	2.33	Degraded
MET-17413	9-Sep-10	39.1014	-76.1426	3.40	Meets Goal
MET-17414	9-Sep-10	39.10475	-76.1471	2.60	Degraded
MET-17415	9-Sep-10	39.12708	-76.1569	1.80	Sev. Degraded
MET-17417	9-Sep-10	39.15619	-76.0096	1.40	Sev. Degraded
MET-17418	9-Sep-10	39.1652	-76.1779	1.80	Sev. Degraded
MET-17419	9-Sep-10	39.18353	-76.0605	2.60	Degraded
MET-17420	23-Sep-10	39.37633	-75.9789	3.00	Meets Goal
MET-17421	23-Sep-10	39.45396	-75.9788	2.60	Degraded
MET-17422	23-Sep-10	39.46347	-75.8224	2.00	Sev. Degraded
MET-17423	23-Sep-10	39.47093	-75.8795	1.67	Sev. Degraded
MET-17424	23-Sep-10	39.50811	-75.9252	3.00	Meets Goal
MET-17425	23-Sep-10	39.51831	-75.8869	3.33	Meets Goal
MET-17426	23-Sep-10	39.53774	-75.8806	2.33	Degraded
MET-17427	20-Sep-10	38.31295	-75.9073	2.00	Sev. Degraded
MMS-17501	20-Sep-10	37.918	-75.8586	2.00	Sev. Degraded
MMS-17502	21-Sep-10	37.93236	-75.924	3.33	Meets Goal
MMS-17503	1-Sep-10	37.93585	-76.2586	1.33	Sev. Degraded
MMS-17504	1-Sep-10	38.07408	-76.1343	3.00	Meets Goal
MMS-17505	1-Sep-10	38.16487	-76.1215	4.33	Meets Goal
MMS-17506	1-Sep-10	38.21215	-76.1759	2.33	Degraded
MMS-17507	1-Sep-10	38.22073	-76.3555	1.00	Sev. Degraded
MMS-17508	21-Sep-10	38.22698	-75.9432	3.33	Meets Goal
MMS-17509	2-Sep-10	38.3342	-76.3634	1.00	Sev. Degraded
MMS-17510	2-Sep-10	38.41197	-76.2928	2.67	Marginal
MMS-17511	2-Sep-10	38.45062	-76.3273	3.67	Meets Goal
MMS-17512	2-Sep-10	38.53157	-76.476	1.00	Sev. Degraded
MMS-17513	2-Sep-10	38.65113	-76.2145	2.33	Degraded

Appendix Table C-1. (Continued)					
Station	Sampling Date	Latitude (WGS84 Decimal Degrees)	Longitude (WGS84 Decimal Degrees)	B-IBI	Status
MMS-17514	2-Sep-10	38.66092	-76.232	2.67	Marginal
MMS-17515	2-Sep-10	38.67447	-76.4933	1.00	Sev. Degraded
MMS-17516	2-Sep-10	38.6947	-76.5199	1.00	Sev. Degraded
MMS-17517	2-Sep-10	38.69483	-76.1828	3.00	Meets Goal
MMS-17518	2-Sep-10	38.70362	-76.203	3.00	Meets Goal
MMS-17520	2-Sep-10	38.77947	-76.3961	2.33	Degraded
MMS-17521	8-Sep-10	38.78442	-76.19	1.33	Sev. Degraded
MMS-17522	2-Sep-10	38.82978	-76.3357	1.00	Sev. Degraded
MMS-17524	2-Sep-10	38.91843	-76.3096	1.67	Sev. Degraded
MMS-17525	22-Sep-10	38.95857	-76.1643	3.00	Meets Goal
MMS-17526	21-Sep-10	38.24583	-75.9716	2.33	Degraded
MMS-17527	8-Sep-10	38.54817	-76.2407	2.33	Degraded
MWT-17301	25-Aug-10	38.89508	-76.53	1.67	Sev. Degraded
MWT-17302	25-Aug-10	38.9281	-76.5412	2.60	Degraded
MWT-17303	25-Aug-10	38.9434	-76.5358	1.00	Sev. Degraded
MWT-17304	25-Aug-10	38.95131	-76.5421	2.20	Degraded
MWT-17305	25-Aug-10	38.96277	-76.5873	1.00	Sev. Degraded
MWT-17306	25-Aug-10	39.00588	-76.5153	1.80	Sev. Degraded
MWT-17307	25-Aug-10	39.00794	-76.5051	2.33	Degraded
MWT-17308	25-Aug-10	39.03256	-76.5471	2.60	Degraded
MWT-17309	25-Aug-10	39.03639	-76.5632	1.80	Sev. Degraded
MWT-17310	27-Aug-10	39.09695	-76.532	1.40	Sev. Degraded
MWT-17311	30-Aug-10	39.15171	-76.4567	3.00	Meets Goal
MWT-17312	30-Aug-10	39.15572	-76.4679	1.80	Sev. Degraded
MWT-17313	30-Aug-10	39.15852	-76.4659	3.80	Meets Goal
MWT-17314	30-Aug-10	39.15881	-76.5001	1.40	Sev. Degraded
MWT-17315	30-Aug-10	39.17359	-76.4634	3.33	Meets Goal
MWT-17316	30-Aug-10	39.17836	-76.4631	4.00	Meets Goal
MWT-17317	30-Aug-10	39.18174	-76.4936	3.00	Meets Goal
MWT-17318	30-Aug-10	39.22109	-76.576	1.00	Sev. Degraded
MWT-17319	30-Aug-10	39.25595	-76.5529	1.00	Sev. Degraded
MWT-17320	30-Aug-10	39.25732	-76.5546	1.00	Sev. Degraded
MWT-17321	30-Aug-10	39.26306	-76.6281	1.00	Sev. Degraded
MWT-17322	12-Sep-10	39.34014	-76.3058	2.60	Degraded
MWT-17323	12-Sep-10	39.36689	-76.2631	2.60	Degraded
MWT-17324	12-Sep-10	39.36806	-76.2783	1.80	Sev. Degraded
MWT-17325	12-Sep-10	39.37285	-76.3353	3.00	Meets Goal
PMR-17101	1-Sep-10	37.95933	-76.2924	1.00	Sev. Degraded

Appendix Table C-1. (Continued)

Station	Sampling Date	Latitude (WGS84 Decimal Degrees)	Longitude (WGS84 Decimal Degrees)	B-IBI	Status
PMR-17102	1-Sep-10	38.01803	-76.3663	1.67	Sev. Degraded
PMR-17103	1-Sep-10	38.04772	-76.4598	1.00	Sev. Degraded
PMR-17104	1-Sep-10	38.0546	-76.5111	2.00	Sev. Degraded
PMR-17105	1-Sep-10	38.09532	-76.4557	3.33	Meets Goal
PMR-17106	1-Sep-10	38.1078	-76.4589	2.33	Degraded
PMR-17107	1-Sep-10	38.16588	-76.6146	1.00	Sev. Degraded
PMR-17108	1-Sep-10	38.1735	-76.6046	2.33	Degraded
PMR-17109	1-Sep-10	38.20108	-76.7497	1.67	Sev. Degraded
PMR-17110	1-Sep-10	38.20788	-76.8438	2.33	Degraded
PMR-17111	1-Sep-10	38.20863	-76.8583	2.33	Degraded
PMR-17112	1-Sep-10	38.21473	-76.7313	1.67	Sev. Degraded
PMR-17113	3-Oct-10	38.22242	-76.6457	2.67	Marginal
PMR-17114	1-Sep-10	38.22245	-76.8402	2.33	Degraded
PMR-17115	6-Oct-10	38.38518	-77.1479	3.80	Meets Goal
PMR-17116	6-Oct-10	38.38527	-77.2687	4.20	Meets Goal
PMR-17117	6-Oct-10	38.41375	-77.3047	3.33	Meets Goal
PMR-17118	6-Oct-10	38.42987	-77.3192	3.00	Meets Goal
PMR-17119	6-Oct-10	38.4355	-77.2829	3.40	Meets Goal
PMR-17120	6-Oct-10	38.4386	-77.309	1.80	Sev. Degraded
PMR-17121	6-Oct-10	38.44924	-77.039	2.20	Degraded
PMR-17122	6-Oct-10	38.49224	-77.0252	1.80	Sev. Degraded
PMR-17123	6-Oct-10	38.49263	-77.2725	2.33	Degraded
PMR-17124	6-Oct-10	38.56365	-77.2256	4.00	Meets Goal
PMR-17125	14-Sep-10	38.73105	-77.041	3.50	Meets Goal
PXR-17202	3-Sep-10	38.36817	-76.5153	2.67	Marginal
PXR-17203	3-Sep-10	38.37795	-76.53	3.33	Meets Goal
PXR-17204	26-Aug-10	38.40145	-76.5432	1.67	Sev. Degraded
PXR-17205	26-Aug-10	38.40283	-76.532	2.67	Marginal
PXR-17206	26-Aug-10	38.40513	-76.5886	1.67	Sev. Degraded
PXR-17207	26-Aug-10	38.40505	-76.5801	2.67	Marginal
PXR-17208	26-Aug-10	38.40594	-76.5357	2.33	Degraded
PXR-17209	26-Aug-10	38.41029	-76.5617	2.33	Degraded
PXR-17210	26-Aug-10	38.41377	-76.6041	3.00	Meets Goal
PXR-17211	26-Aug-10	38.41617	-76.6118	2.33	Degraded
PXR-17212	26-Aug-10	38.43153	-76.6278	2.67	Marginal
PXR-17213	26-Aug-10	38.44098	-76.6129	2.00	Sev. Degraded
PXR-17214	26-Aug-10	38.44277	-76.6303	1.33	Sev. Degraded
PXR-17215	26-Aug-10	38.44683	-76.6136	2.33	Degraded

Appendix Table C-1. (Continued)

Station	Sampling Date	Latitude (WGS84 Decimal Degrees)	Longitude (WGS84 Decimal Degrees)	B-IBI	Status
PXR-17216	26-Aug-10	38.44957	-76.6192	2.00	Sev. Degraded
PXR-17217	26-Aug-10	38.46054	-76.6448	1.67	Sev. Degraded
PXR-17218	26-Aug-10	38.46193	-76.6301	2.67	Marginal
PXR-17219	26-Aug-10	38.46867	-76.5963	2.00	Sev. Degraded
PXR-17220	26-Aug-10	38.50187	-76.6675	3.33	Meets Goal
PXR-17221	26-Aug-10	38.50818	-76.6676	3.33	Meets Goal
PXR-17222	26-Aug-10	38.54132	-76.6964	2.60	Degraded
PXR-17223	25-Aug-10	38.58377	-76.6852	2.20	Degraded
PXR-17224	26-Aug-10	38.60613	-76.6735	2.00	Sev. Degraded
PXR-17225	26-Aug-10	38.63612	-76.6922	3.33	Meets Goal
PXR-17226	3-Sep-10	38.31368	-76.4536	3.00	Meets Goal
UPB-17602	16-Sep-10	39.06245	-76.2746	1.00	Sev. Degraded
UPB-17603	16-Sep-10	39.074	-76.2489	1.67	Sev. Degraded
UPB-17604	16-Sep-10	39.09318	-76.3036	1.00	Sev. Degraded
UPB-17605	16-Sep-10	39.11731	-76.2874	3.00	Meets Goal
UPB-17606	29-Sep-10	39.11802	-76.4282	2.33	Degraded
UPB-17607	29-Sep-10	39.12553	-76.459	1.00	Sev. Degraded
UPB-17608	29-Sep-10	39.17213	-76.3794	4.67	Meets Goal
UPB-17609	29-Sep-10	39.17908	-76.3041	4.67	Meets Goal
UPB-17610	29-Sep-10	39.19253	-76.3581	4.60	Meets Goal
UPB-17611	15-Sep-10	39.22794	-76.3771	4.20	Meets Goal
UPB-17612	15-Sep-10	39.22914	-76.3588	4.20	Meets Goal
UPB-17613	15-Sep-10	39.22964	-76.3518	3.80	Meets Goal
UPB-17614	15-Sep-10	39.26049	-76.2433	4.20	Meets Goal
UPB-17615	15-Sep-10	39.26141	-76.3308	3.80	Meets Goal
UPB-17616	15-Sep-10	39.26428	-76.2282	3.80	Meets Goal
UPB-17617	15-Sep-10	39.27067	-76.3876	3.80	Meets Goal
UPB-17618	12-Sep-10	39.28512	-76.3053	3.40	Meets Goal
UPB-17619	15-Sep-10	39.29157	-76.2085	4.20	Meets Goal
UPB-17620	12-Sep-10	39.30612	-76.3352	3.00	Meets Goal
UPB-17621	12-Sep-10	39.31218	-76.3334	3.40	Meets Goal
UPB-17622	15-Sep-10	39.3471	-76.1856	5.00	Meets Goal
UPB-17623	15-Sep-10	39.38025	-76.1301	3.00	Meets Goal
UPB-17624	23-Sep-10	39.47686	-76.0271	2.67	Marginal
UPB-17625	23-Sep-10	39.51857	-76.0846	4.50	Meets Goal
UPB-17626	16-Sep-10	39.02539	-76.3247	2.00	Sev. Degraded