CHESAPEAKE BAY WATER QUALITY MONITORING PROGRAM

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

JULY 1984 - DECEMBER 2011 (VOLUME 1)

Prepared for

Maryland Department of Natural Resources
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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 2011), 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 2011 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 Charles Tonkin; the laboratory technicians for processing samples, Dawn Hendrickson and Charles Tonkin; Suzanne Arcuri, Lisa Scott, 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 2011 and compared to results from previous years.

Sampling Design and Methods

Maryland's long-term benthic monitoring program currently contains two elements: (1) a fixed-site monitoring effort directed at identifying temporal trends, and (2) 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 sampling 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. Trend analysis was carried out with the nonparametric Mann-Kendall test.

Trends in Fixed Site Benthic Condition

Statistically significant B-IBI trends ($p<0.1$) were detected at 12 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. Two trends were new in 2011, both improving.

Sites with improving benthic condition were located in the Bay main stem (Station 26), Potomac River at Maryland Point (Station 40), lower Choptank River (Station 64), and Back River (Station 203). Sites with declining benthic 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 2011 were the appearance of an improving B-IBI trend in the Potomac River at Maryland Point (Station 40) and the re-appearance of the improving trend in the lower Choptank River (Station 64) that disappeared last year. Using the last three years of data, the average B-IBI score (status) remained about the same for most sites, increased at 3 sites, and declined at 5 sites. However, B-IBI scores in 2011 increased at 13 sites, indicating better overall benthic community condition in 2011 than in the previous year. There was an increase in abundance and species numbers at many of the fixed sites in 2011. This increase may have been related to very low salinities during the summer of 2011 which were preceded by unusually high river flows in the spring and early summer. Species that showed increased abundance were low salinity estuarine species that typically respond quickly to favorable conditions through high reproductive output. Fixed sites in the deep Potomac River, from Maryland Point to St. Clements Island, were affected by severe hypoxia in 2011 and did not show this pattern of increased abundance.

Baywide Benthic Community Condition

The area with degraded benthos (failing the B-IBI goals) decreased in the Maryland portion of the Bay from 67% in 2010 to 65% in 2011, and encompassed 4,083 ± 284 Km^2 of tidal bottom remaining to be restored. Bay-wide, the area with degraded benthos increased from 53% to 55%, and encompassed an estimated 6,386 ± 489 km^2 of bay bottom remaining to be restored. The increase in degradation in Chesapeake Bay was due to increases in degradation in the Virginia portion of the Bay, particularly declining benthic community condition in the York and James rivers.

In Maryland, all the sampling strata except for the Potomac River exhibited declines in percent area degraded, or no change. While there was a general improvement in benthic condition in Maryland tidal waters in 2011, the Potomac River remained in very poor condition. All of the probability-based sites in the lower Potomac River in 2011 failed the B-IBI, and the severely degraded condition increased. Very low dissolved oxygen conditions were recorded in the Potomac River in 2011, and these affected both the mesohaline and oligohaline portions of the river.

Benthic community condition in Maryland tidal waters in 2011 was generally good both before and after Hurricane Irene on 27 August 2011 and Tropical Strom Lee on 7 September 2011. The high river flow associated with Tropical Storm Lee caused a decrease in salinity and an increase in sediment loads entering the Chesapeake Bay. Increases in the organic carbon content of sediments in the Upper Bay, Maryland Western Tributaries, and Patuxent River, were observed after the storm. However, these changes did not show effects on benthic condition. Results for 2011 suggest no immediate effects of Tropical Storm Lee at sites sampled 1-14 days after the storm. Species composition in areas with the greatest salinity change remained unaltered when compared to the species composition of the same areas in the previous year.

Although river flow was high in spring and early summer, the absence of short, intense pulses in river flow during the spring may have been a factor contributing to better overall benthic community condition in 2011. Another contributing factor may have been the disruption of the pycnocline after the passing of Hurricane Irene. Strong winds associated with Hurricane Irene mixed the water column and caused low dissolved oxygen conditions to completely disappear from main stem waters in late summer. In any case, the improvements observed in Chesapeake Bay in 2011 were not substantial. More than half of the Chesapeake Bay tidal waters exhibited degraded benthic condition, and statistically significant degrading trends were observed over the 1995-2011 time series in the Patuxent River and Maryland Eastern Tributaries strata. The Patuxent River also exhibited very low benthic production in a study conducted by Dauer et al. (2011) that compared benthic secondary productivity among strata and urban regions. The 2011 results, however, suggest that benthic communities in the Chesapeake Bay are very dynamic over short periods of time, and are likely to recover quickly with pollution abatement as conditions improve.

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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 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 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 2011 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 2011, 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 1985-2011 fixed site trend analysis. Appendices B and C present the B-IBI values for the 2011 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 2011 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.

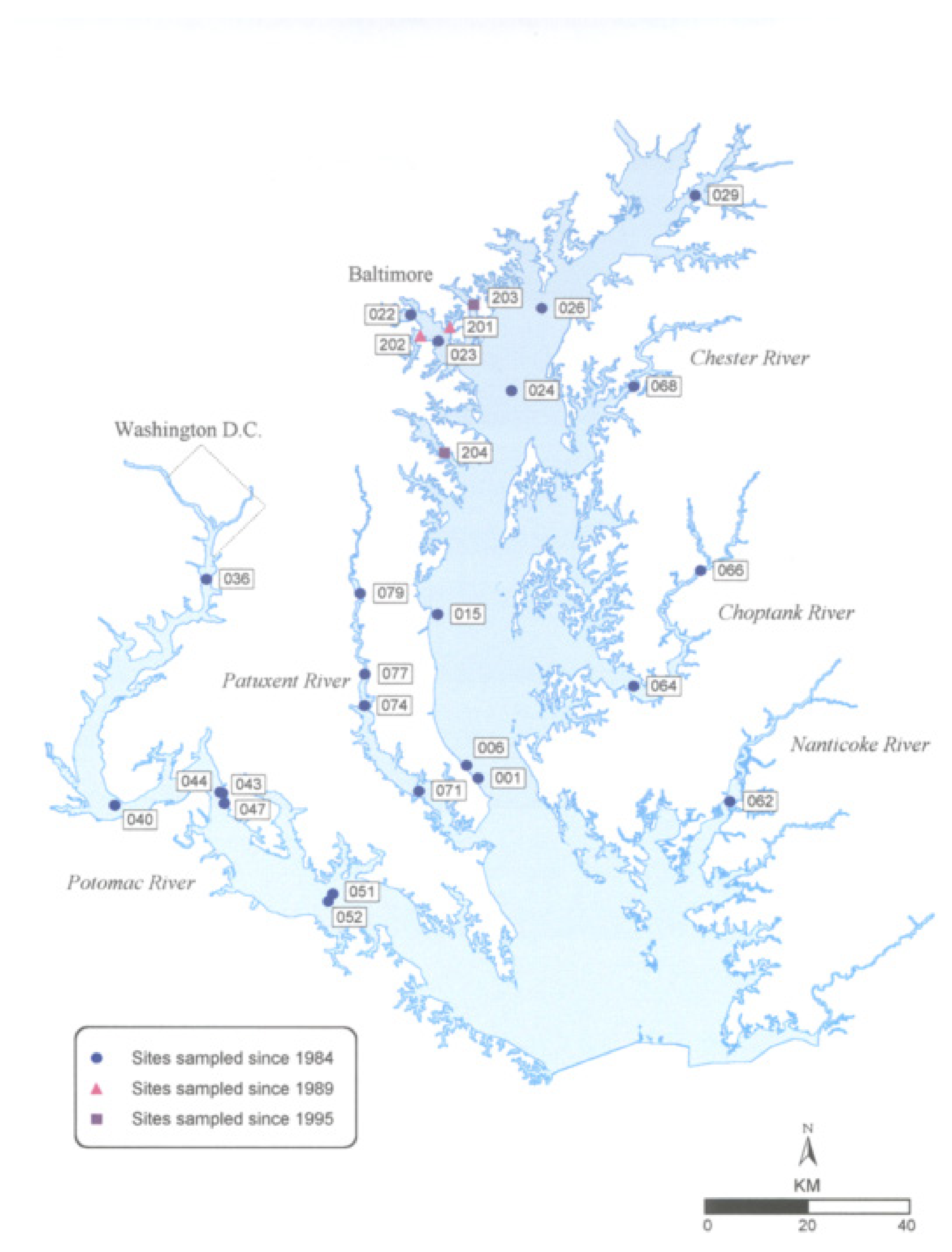


Figure 2-1. Fixed sites sampled in 2011.

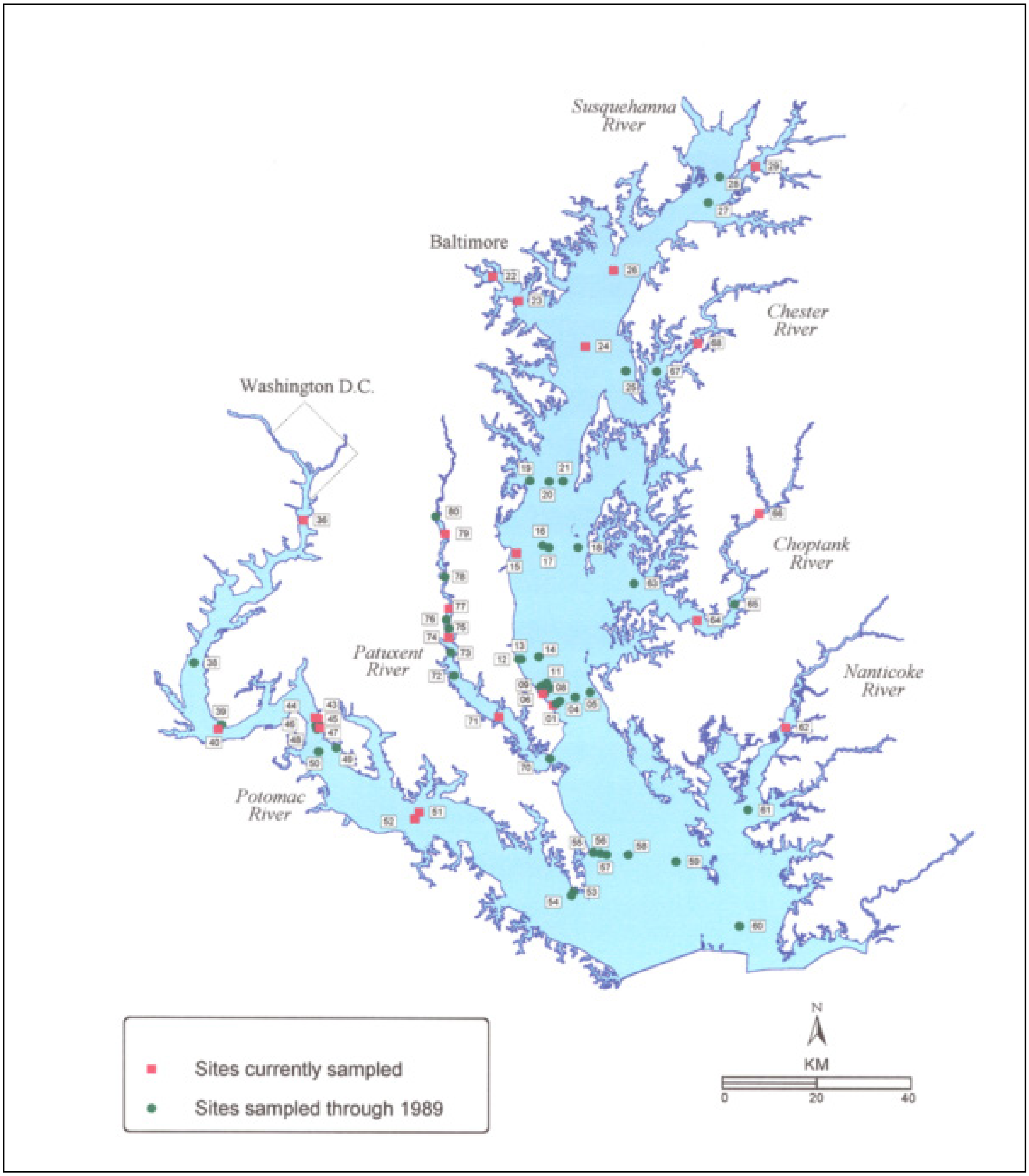


Figure 2-2. Fixed sites sampled from 1984 to 1989; some of these sites are part of the current design.

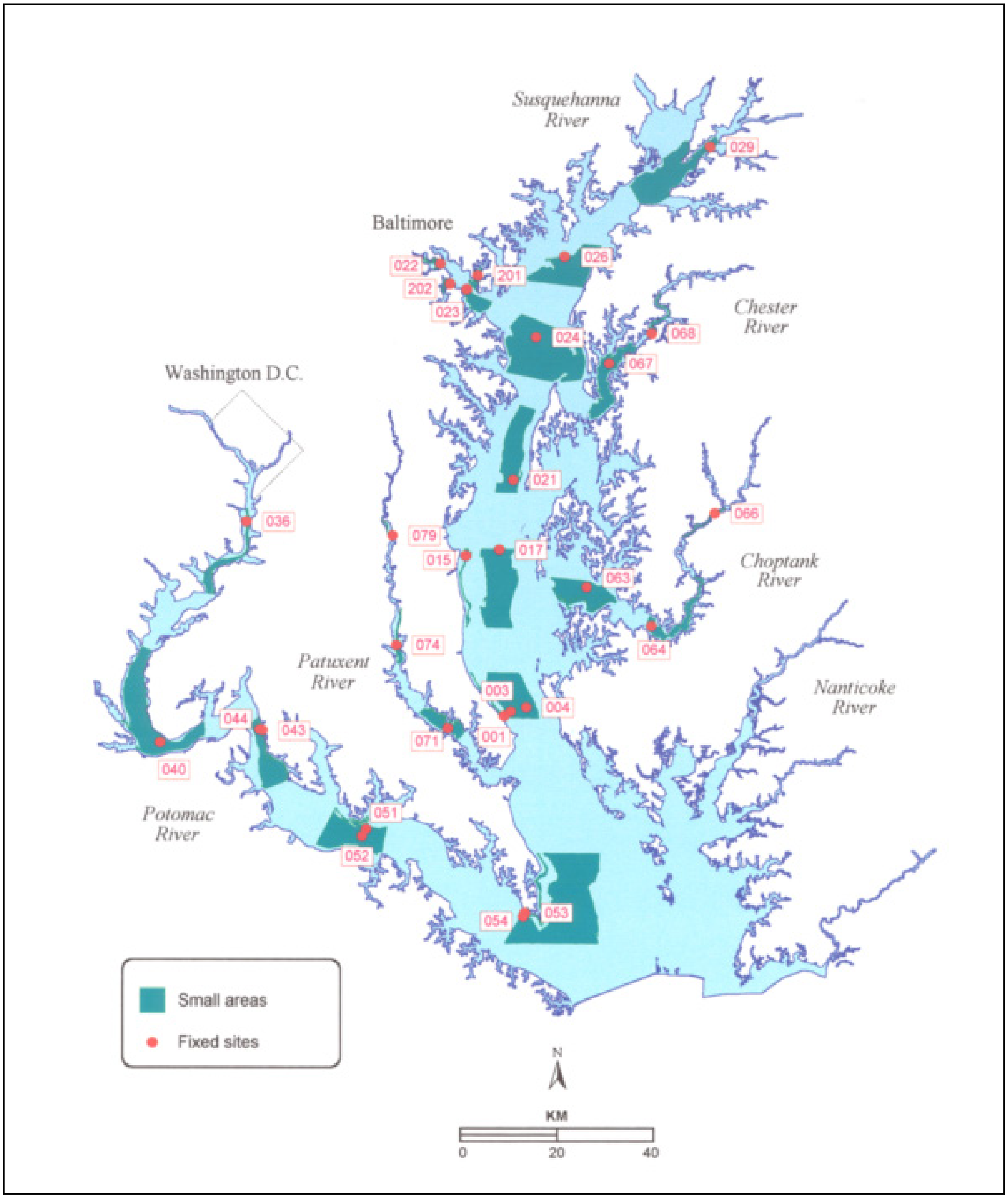


Figure 2-3. Small areas and fixed sites sampled from 1989 to 1994.

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 2011. 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.

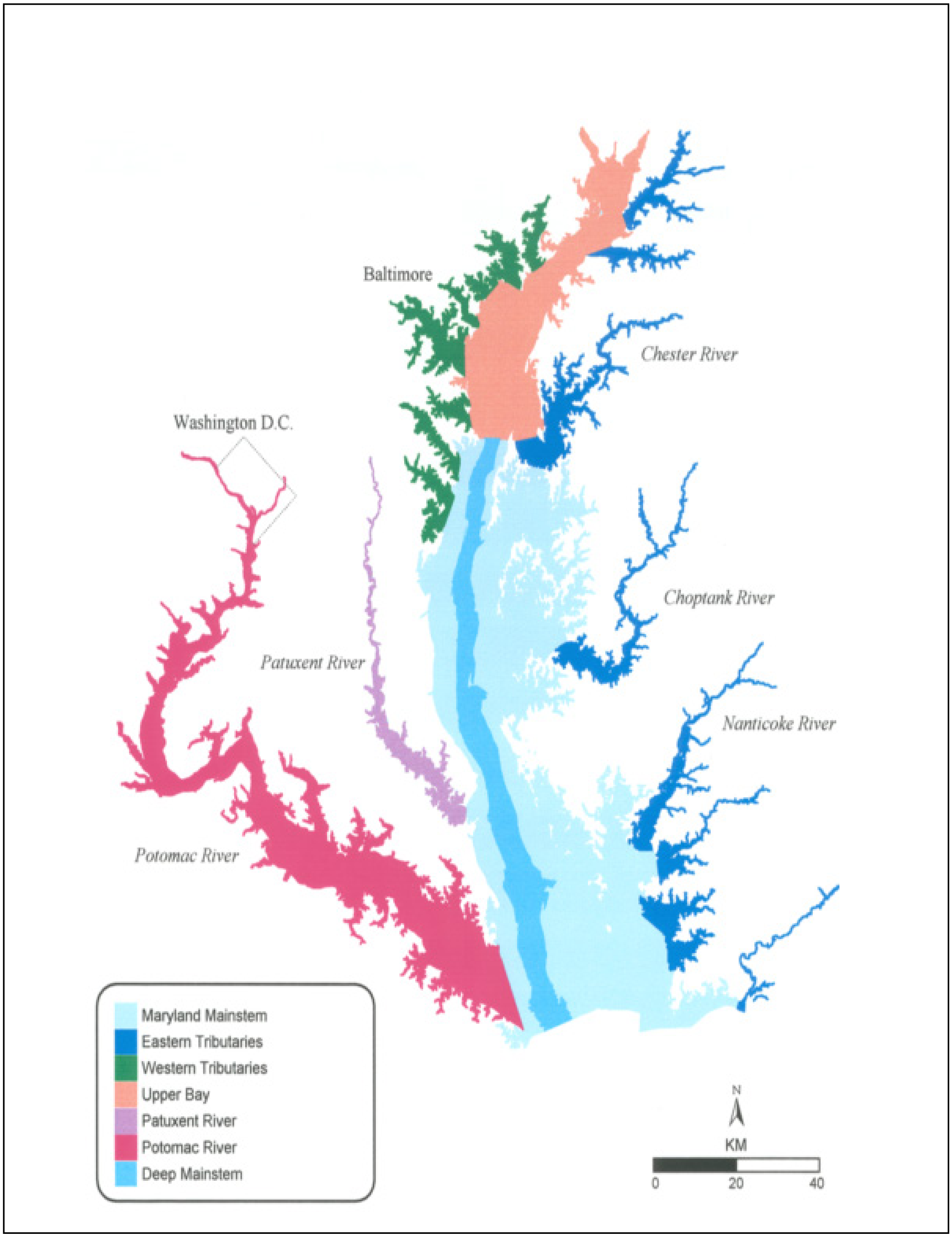


Figure 2-4. Maryland baywide sampling strata in and after 1995

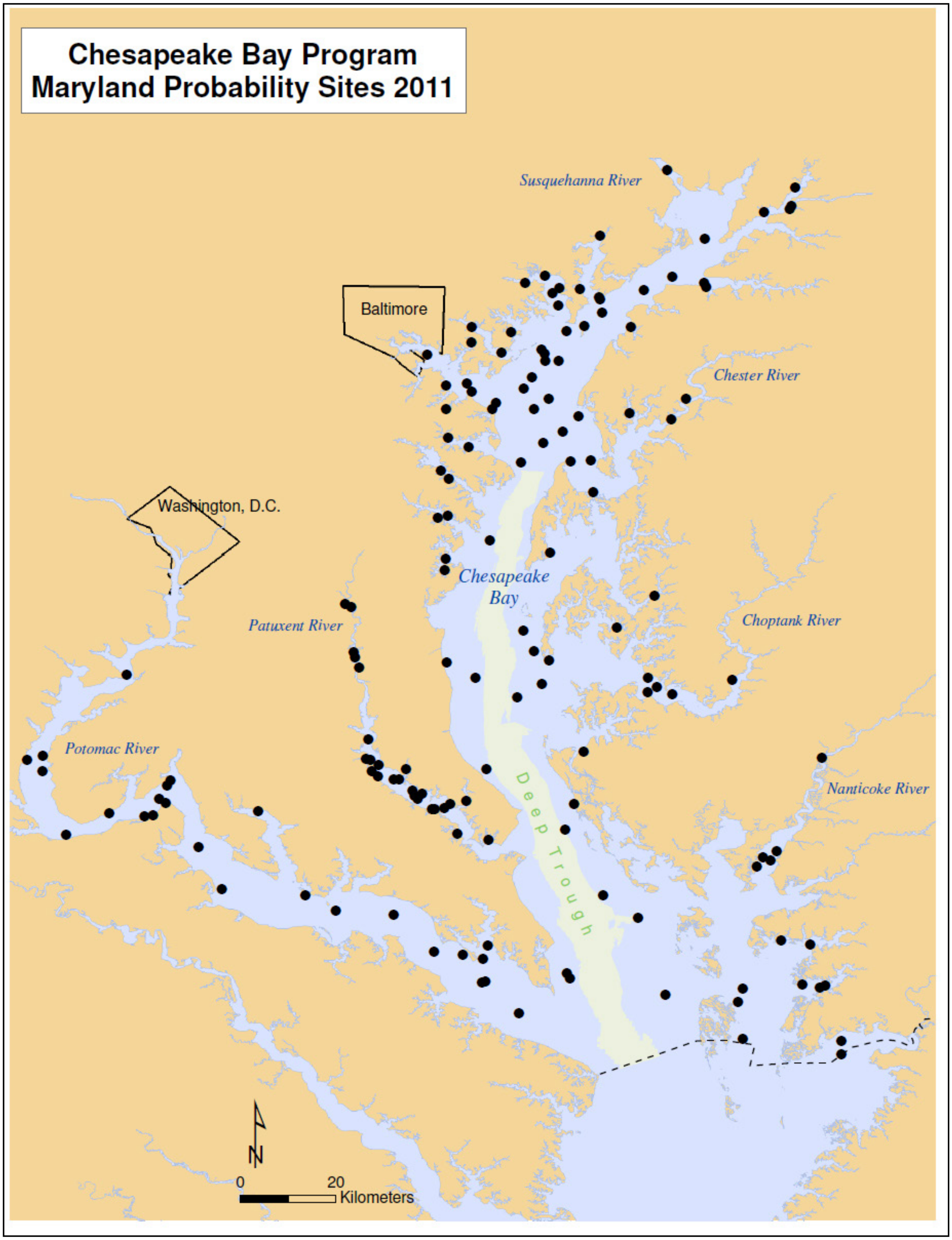


Figure 2-5. Maryland probability-based sampling sites for 2011

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 ('Deep Trough'). 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 Trough	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	Lower Bay 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.

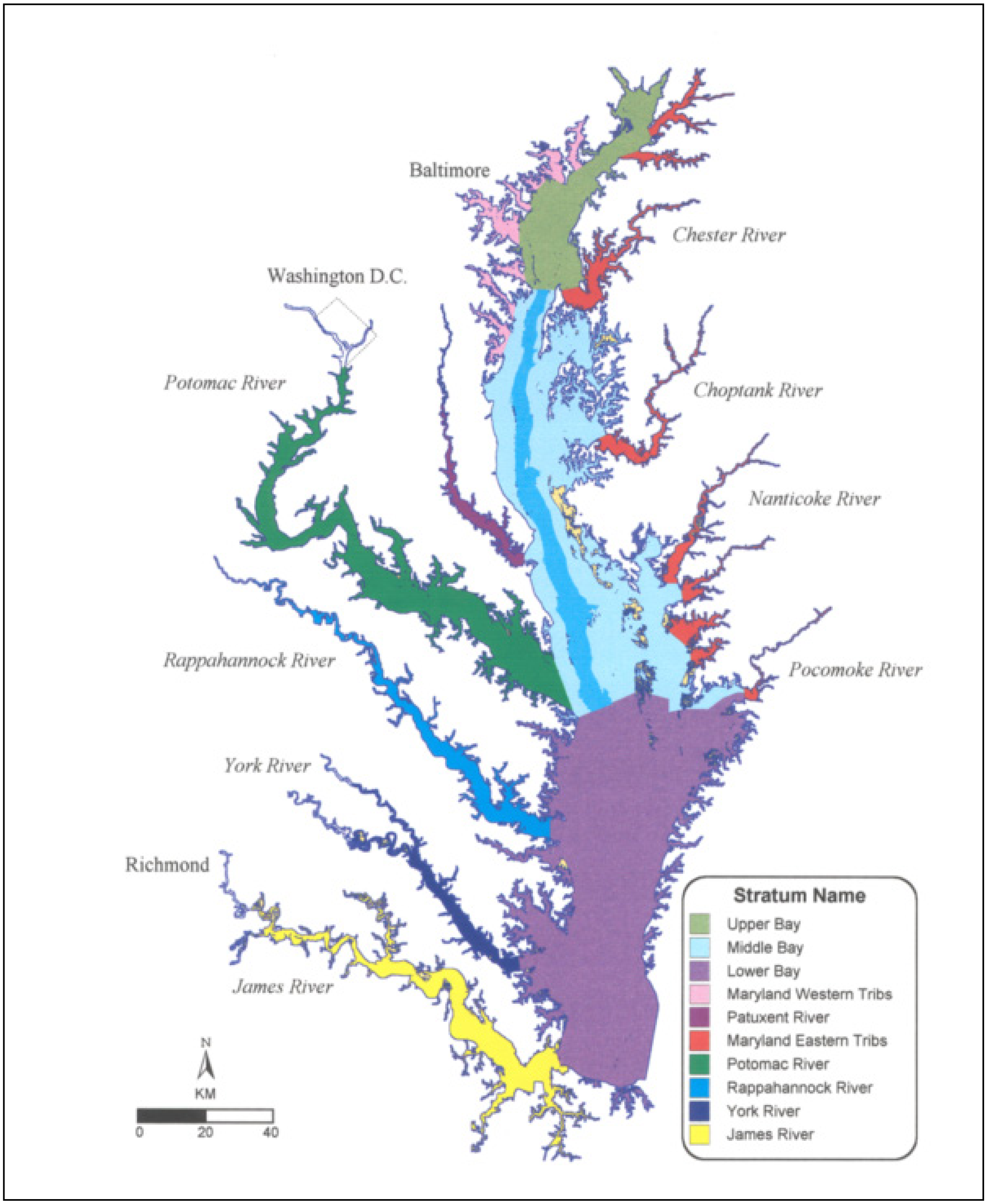


Figure 2-6. Chesapeake Bay stratification scheme

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.

At probability-based sites with unsuitable bottom, three sampling attempts were made within a 37 m circle from the original point in different directions. If an acceptable sample could not be collected within this circle, three further attempts were made within a 37-100 m zone from the original point before the site was deemed unsampleable and discarded. An alternative site was then 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. Bivalve shells were crushed to 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:

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

and

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

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

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

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:

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

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).

2.4.4 B-IBI Salinity Habitat Class Correction in 2011

Because of two storms in 2011 (Hurricane Irene on 27 August 2011 and Tropical Storm Lee on 7 September 2011), salinities were very low after these two storms. Many of the probability-based sites were sampled after 27 August and during and after 7 September. Areas in the upper Chesapeake Bay that typically are low mesohaline, had tidal freshwater bottom salinities after Lee. The species composition of some of the 2011 sites was compared with the species composition of nearby sites sampled in 2010. The species composition was similar in both years. However, because of salinity habitat class differences, the B-IBI was quite different when calculated on the lower salinity classes of 2011. Therefore, a salinity habitat class correction was necessary for making the B-IBI more comparable to previous years. Box plots of bottom salinity were constructed for all sites, 1995-2010. Five years for which the salinity was clearly too high or too low (1995, 1996, 1999, 2002, and 2004) were removed. Using GIS, the bottom salinity values of the remaining years were mapped and the 2011 sites were superimposed on the map. The salinity class of the 2011 sites was then re-assigned to reflect the predominant salinity class of the average year. Some of the 2011 sites did not need re-assignment because their salinity, although low (e.g., 6) was still within the salinity class of the average year (e.g., 5-12). Affected sites included many of the sites in the Upper Bay and the Maryland Western Tributaries strata; some of the sites in the Maryland Eastern Tributaries and Maryland Mainstem strata; and some of the sites in the Patuxent River. The salinity class of probability-based sites sampled prior to the storms was not evaluated nor re-assigned. The 2011 sites in Virginia were all sampled prior to the storms so they did not need re-assignment nor did they exhibit lower salinity than expected.

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 seven-year (1985-2011) trends are presented for 23 of the 27 trend sites, 23-year trends are presented for two sites in Baltimore Harbor (Stations 201 and 202) first sampled in 1989, and 17-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 12 of the 27 sites (Table 3-1). Two trends were new, and the rest were the same trends reported for 2010. Trends in benthic community condition declined at 8 sites (significantly decreasing B-IBI trend) and improved at 4 sites. Except for the two new trends (improving), the number of trends and trend direction did not change over those reported for 2010, although some of the declining trends became stronger.

Sites with improving condition (Table 3-1) were located in the Bay main stem (Station 26), Potomac River at Maryland Point (Station 40), lower Choptank River (Station 64), and 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 2011 were the appearance of an improving B-IBI trend in the Potomac River at Maryland Point (Station 40) and the re-appearance of the improving trend in the lower Choptank River (Station 64) that disappeared last year. Using the last three years of data, the average B-IBI score (status) remained about the same for most sites, increased at 3 sites, and declined at 5 sites. However, B-IBI scores in 2011 increased at 13 sites, indicating better overall benthic community condition in 2011 than in the previous year.

The current condition at the fixed sites (Table 3-1 shaded areas) declined from meeting the goals to marginal in the Potomac River (Station 43), and from marginal to degraded in the mainstem (Station 01). The current condition improved from severely degraded to degraded in the lower Potomac River (Station 51) and North Beach (Station 15), from degraded to marginal in the Patuxent River at Holland Cliff (Station 77), and from marginal to meeting the goal in the lower Patapsco River (Station 23). 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 at least 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, biomass, and number of species, indicating a general tendency in the Chesapeake Bay toward low index scores.

Figures 3-1 through 3-27 show patterns in abundance, biomass, number of species, and B-IBI at the fixed sites. For 2010 we reported decreasing trends in abundance at most of the mesohaline sites, with overall lower abundance during the 1998-2010 period than during the 1984-1997 period. Number of species also showed decreasing trends at many of the mesohaline sites. While this pattern remained unchanged (11 sites had statistically significant declining trends in abundance and 12 sites had statistically significant declining trends in number of species), generally there was an increase in abundance and/or number of species in 2011. This increase was most pronounced in the Maryland main stem (Stations 15 and 24), Potomac River at Morgantown (Station 43), Potomac River at St. Clements Island (Station 51), and the lower Choptank River (Station 64), but the increase in abundance and species numbers was evident at most stations in both the lower and upper reaches of tributaries. Stations with sharp declining trends in abundance due to hypoxic conditions also showed increases in abundance and species numbers in 2011, for example at Station 22 in the Patapsco River estuary (Figure 3-4) and Station 71 in the lower Patuxent River (Figure 3-20).

The increase in abundance and species numbers in 2011 was probably related to wet conditions (and lower salinities) during the summer, even before Hurricane Irene (on 27 August 2011) and Tropical Storm Lee (7 September 2011) passed through the Bay. Species that showed increased abundance were low salinity estuarine species that typically respond quickly to favorable conditions through high reproductive output. For example, at

Station 15 (main stem), a decrease in salinity from 17 (2010) to 13 (2011) was associated with increases in abundance of the spionid polychaete *Marenzelleria viridis* and the haustorid amphipod *Lepidactilus dytiscus*. At Station 24 (main stem), a decrease in salinity from 15 (2010) to 6 (2011) was associated with increases in abundance of the amphipod *Leptocheirus plumulosus*, the nemertean *Carinoma tremaphoros*, and the deep burrowing polychaete *Heteromastus filiformis*. At Station 36 (Tidal freshwater Potomac River), the numbers of the oligochaete *Limnodrilus hoffmeisteri* were up in 2011 while the numbers of the brackish water clam *Corbicula fluminea* were down. At Station 51 (Shallow Potomac River at St. Clements Island), a decrease in salinity from 14 (2010) to 9 (2011) was associated with increases in abundance of the clams *Macoma mitchelli* and *Macoma balthica*, and increases in *L. plumulosus*, *M. viridis*, and *H. filiformis.* And at Station 203 (Back River), salinity decreased from 9 (2010) to 0.2 (2011) and the numbers of biomass-dominant *Chironomus* and *Coelonatypus* insect larvae increased.

Sites affected by hypoxia in 2011 did not show the patterns of increased abundance described above. The Potomac River experienced very low dissolved oxygen levels in the deeper oligohaline and mesohaline portions of the river in late August 2011. Dissolved oxygen concentrations were 0.39 ppm at Station 40 (Maryland Point), 0.38 ppm at Station 44 (Morgantown), and 0.68 ppm at Station 52 (St. Clements Island). A few *Rangia cuneata* clams were collected in one of the replicate samples at Station 40, resulting in a biomass spike and a high B-IBI score at this station (Figure 3-10). However, the effect of hypoxia on community metrics and the B-IBI at Stations 44 and 52 was more clear (Figures 3-12 and 3-15). Sites which are typically eutrophic and unaffected by low dissolved oxygen showed upward spikes in abundance above restorative thresholds and/or continuing eutrophic benthic condition in 2011, such as in the Elk River (Station 29, Figure 3-8), tidal freshwater Potomac River (Station 36, Figure 3-9), and Nanticoke River (Station 62, Figure 3-16), but not in the tidal freshwater Patuxent River (Station 79, Figure 3-23).

Table 3-1. Summer trends in benthic community condition, 1985-2011. Trends were identified using the van Belle and Hughes (1984) procedure. Current mean B-IBI and condition are based on 2009-2011 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 2010.

Station	Trend Significance	Median Slope (B-IBI units/yr)	Current Condition (2009-2011)	Initial Condition (1985-1987 unless otherwise noted)
Potomac River				
36	$p < 0.05$	−0.02	2.28 (Degraded)	3.14 (Meets Goal)
40	$p < 0.1$	0.01	3.41 (Meets Goal)	2.80 (Marginal)
43	$p < 0.01$	−0.00	2.91 (Marginal)	3.76 (Meets Goal)
44	$p < 0.05$	−0.04	2.16 (Degraded)	2.80 (Marginal)
47	NS	0.00	3.67 (Meets Goal)	3.89 (Meets Goal)
51	NS	0.00	2.04 (Degraded)	2.43 (Degraded)
52	NS	0.00	1.11 (Severely Degraded)	1.37 (Severely Degraded)
Patuxent River				
71	$p < 0.001$	−0.03	1.37 (Severely Degraded)	2.52 (Degraded)
74	NS	0.00	3.58 (Meets Goal)	3.78 (Meets Goal)
77	$p < 0.01$	−0.04	2.69 (Marginal)	3.76 (Meets Goal)
79	NS	0.00	3.33 (Meets Goal)	2.75 (Marginal)
Choptank River				
64	$p < 0.1$	0.02	3.30 (Meets Goal)	2.78 (Marginal)
66	NS	0.00	2.96 (Marginal)	2.60 (Degraded)
Maryland Mainstem				
01	NS	0.00	2.33 (Degraded)	2.93 (Marginal)
06	NS	0.00	2.85 (Marginal)	2.56 (Degraded)
15	NS	0.00	2.11 (Degraded)	2.22 (Degraded)
24	NS	0.00	3.11 (Meets Goal)	3.04 (Meets Goal)
26	$p < 0.001$	0.02	4.07 (Meets Goal)	3.16 (Meets Goal)
Maryland Western Shore Tributaries				
22	$p < 0.001$	−0.04	1.00 (Severely Degraded)	2.08 (Degraded)
23	NS	0.00	3.36 (Meets Goal)	2.49 (Degraded)
201	NS	0.00	1.76 (Severely Degraded)	1.10 (Severely Degraded) (a)
202	$p < 0.05$	−0.00	1.09 (Severely Degraded)	1.40 (Severely Degraded) (a)
203	$p < 0.01$	0.06	2.52 (Degraded)	2.08 (Degraded) (b)
204	NS	−0.02	3.52 (Meets Goal)	3.67 (Meets Goal) (b)
Maryland Eastern Shore Tributaries				
29	NS	0.00	2.26 (Degraded)	2.38 (Degraded)
62	$p < 0.001$	−0.04	2.38 (Degraded)	3.42 (Meets Goal)
68	NS	0.00	3.58 (Meets Goal)	3.51 (Meets Goal)

Table 3-2. Summer trends in benthic community attributes at mesohaline stations 1985-2011. 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 1989-2011 data; (b): trends based on 1995-2011 data; (c): attribute trend based on 1990-2011 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 1985-2011. 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 1995-2011 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	⇑ ***

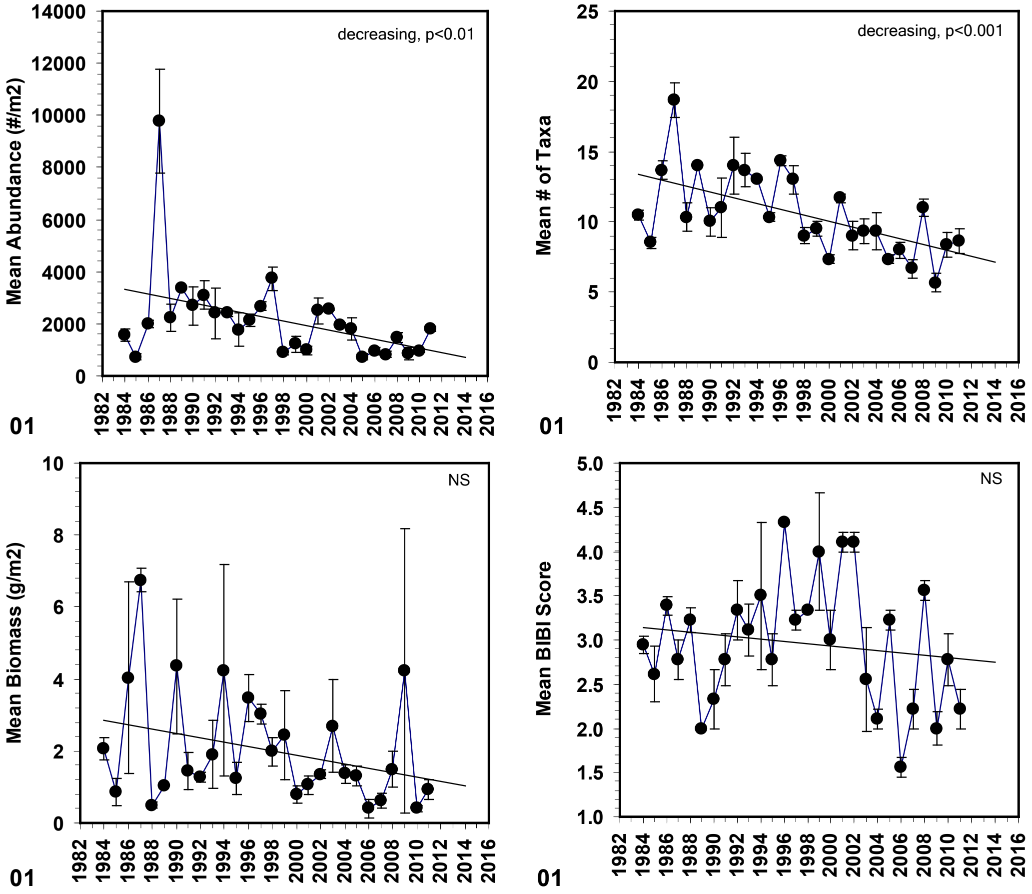


Figure 3-1. Trends in abundance, biomass, number of species, and B-IBI (mean ± 1 SE) at fixed sites. See text for details. Station 01 = Chesapeake Bay main stem (≤ 5 m), Calvert Cliffs.

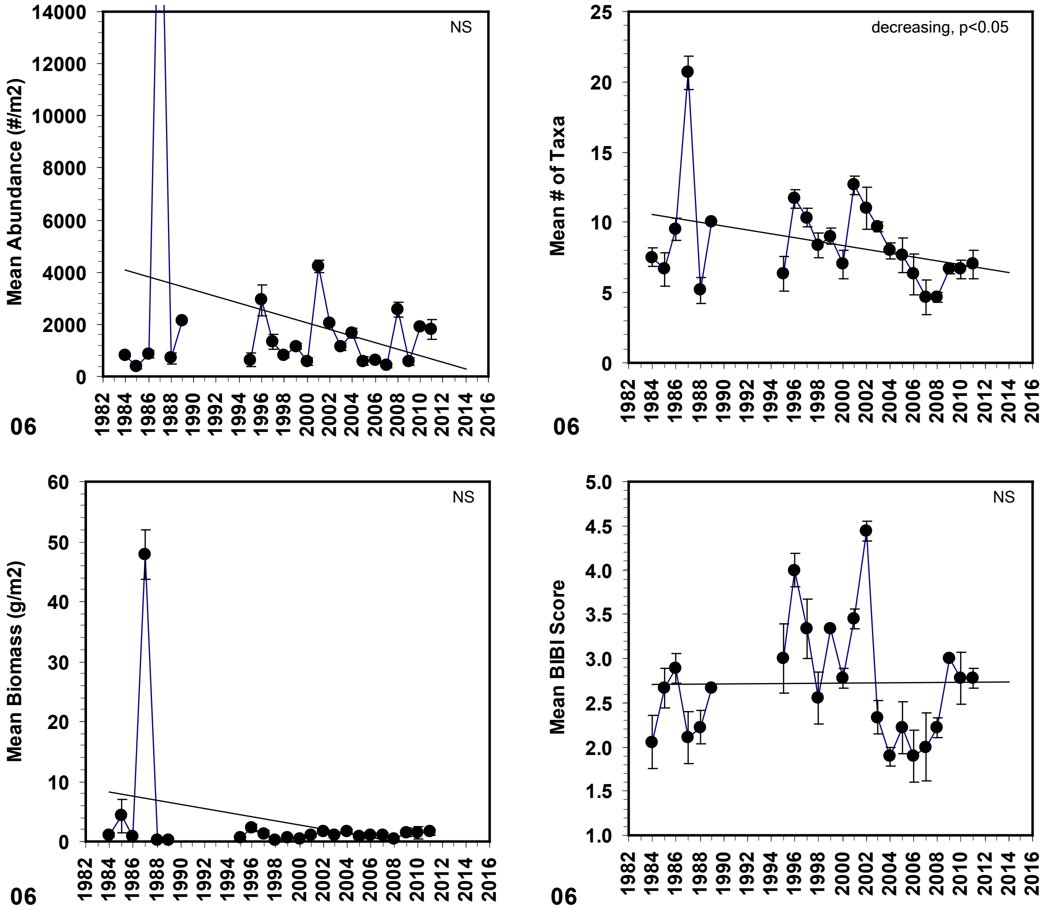


Figure 3-2. Trends in abundance, biomass, number of species, and B-IBI (mean ± 1 SE) at fixed sites. See text for details. Station 06 = Chesapeake main stem (≤ 5 m), Calvert Cliffs.

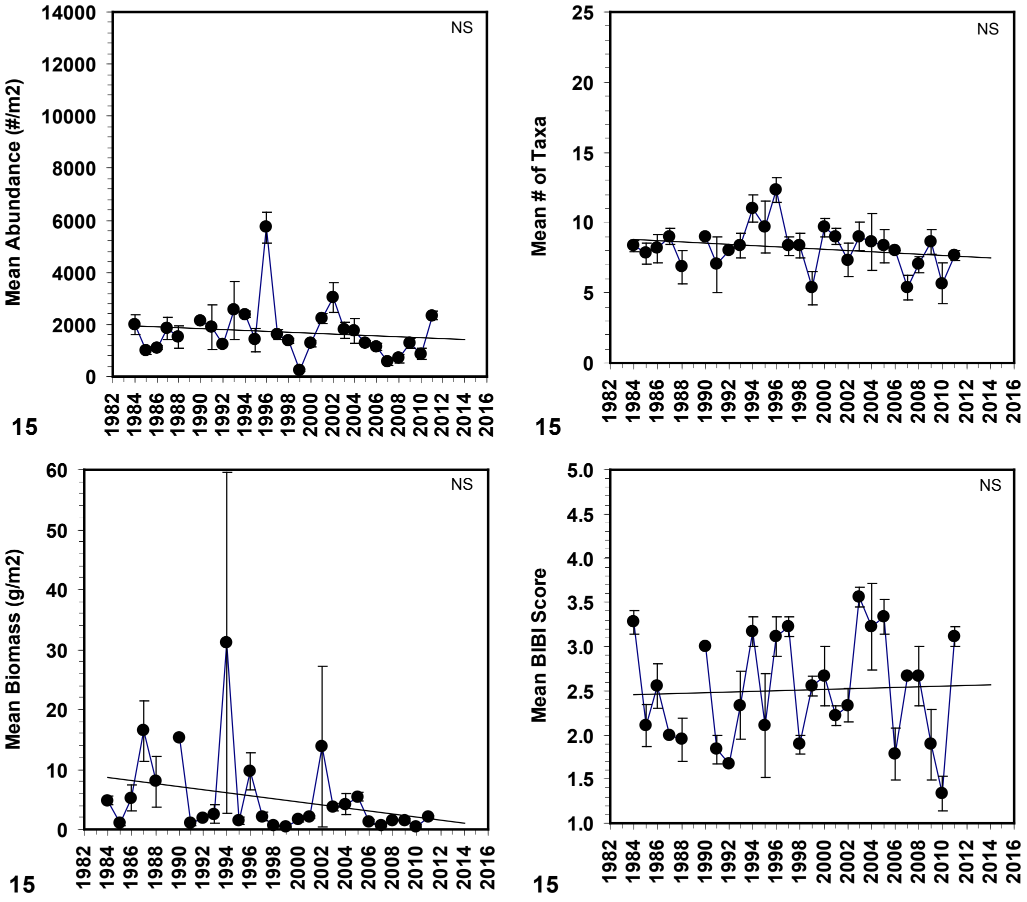


Figure 3-3. Trends in abundance, biomass, number of species, and B-IBI (mean ± 1 SE) at fixed sites. See text for details. Station 15 = Chesapeake main stem (≤ 5 m), North Beach.

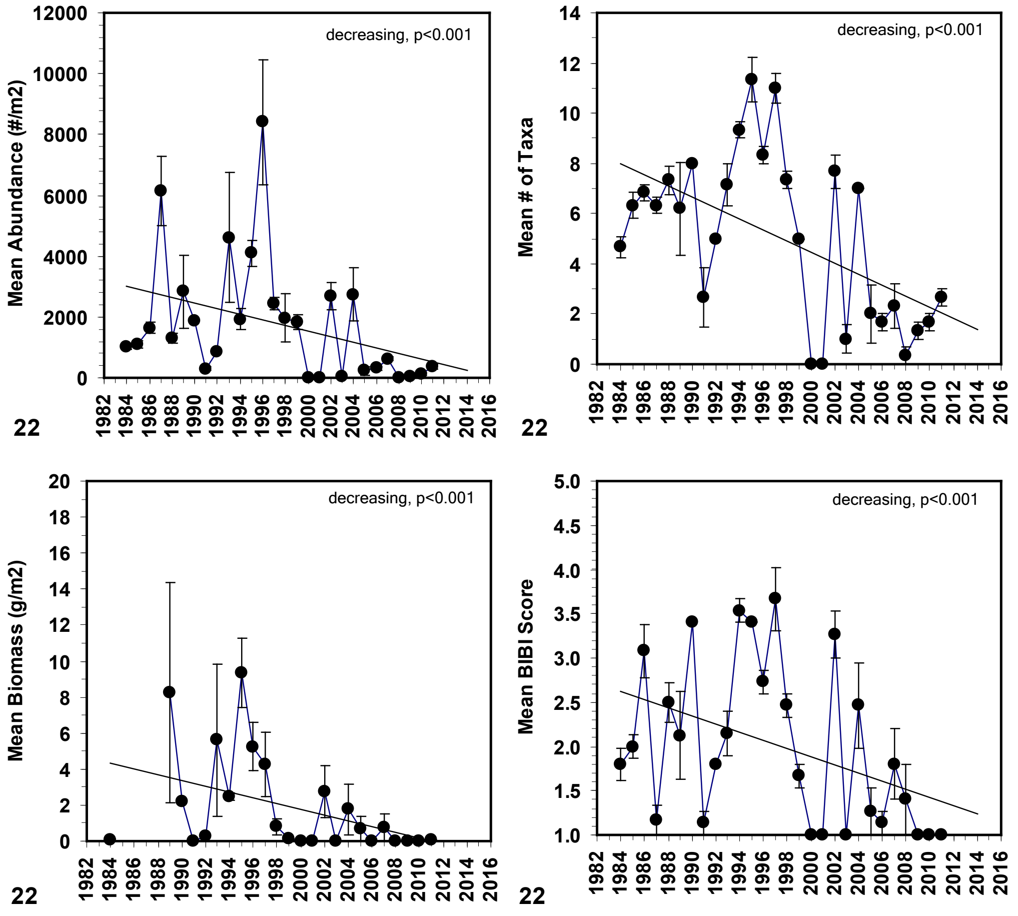


Figure 3-4. Trends in abundance, biomass, number of species, and B-IBI (mean ± 1 SE) at fixed sites. See text for details. Station 22 = Patapsco River estuary (2-6 m), Middle Branch.

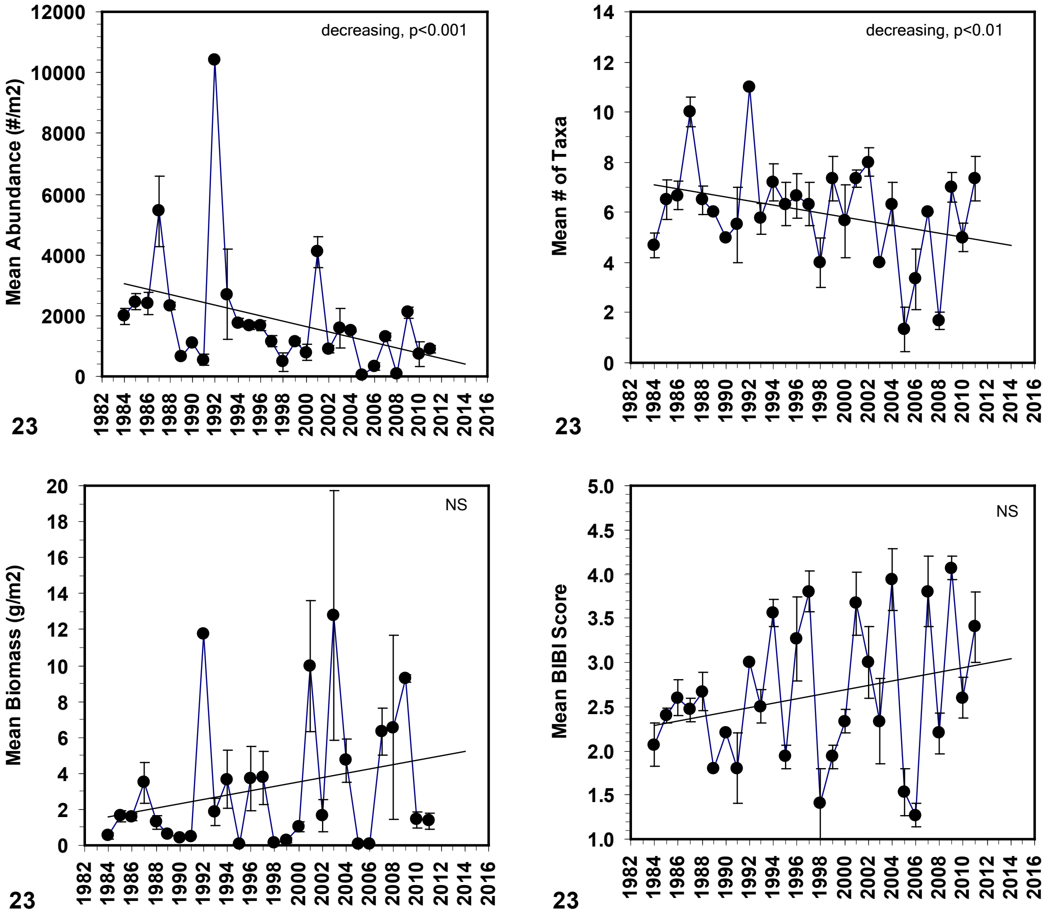


Figure 3-5. Trends in abundance, biomass, number of species, and B-IBI (mean ± 1 SE) at fixed sites. See text for details. Station 23 = Patapsco River estuary (4-7 m), main stem.

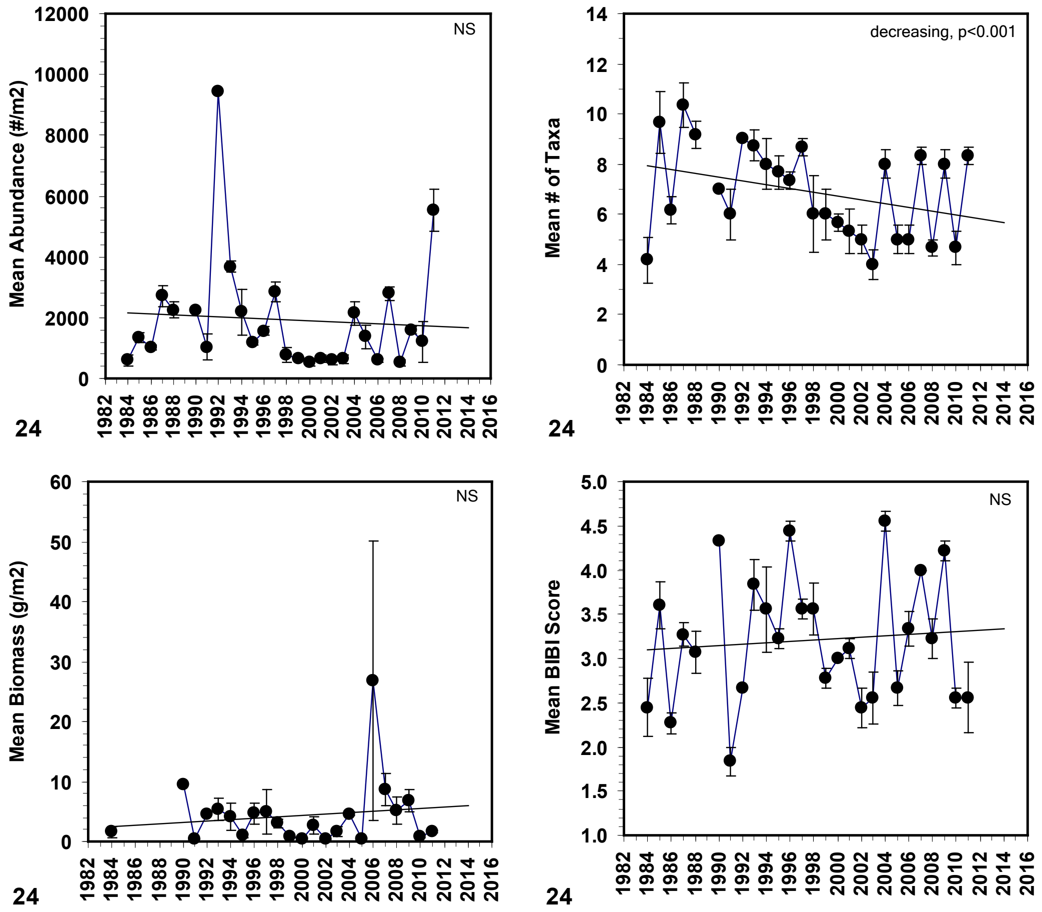


Figure 3-6. Trends in abundance, biomass, number of species, and B-IBI (mean ± 1 SE) at fixed sites. See text for details. Station 24 = Chesapeake Bay main stem (5-8 m), near the mouth of the Patapsco River.

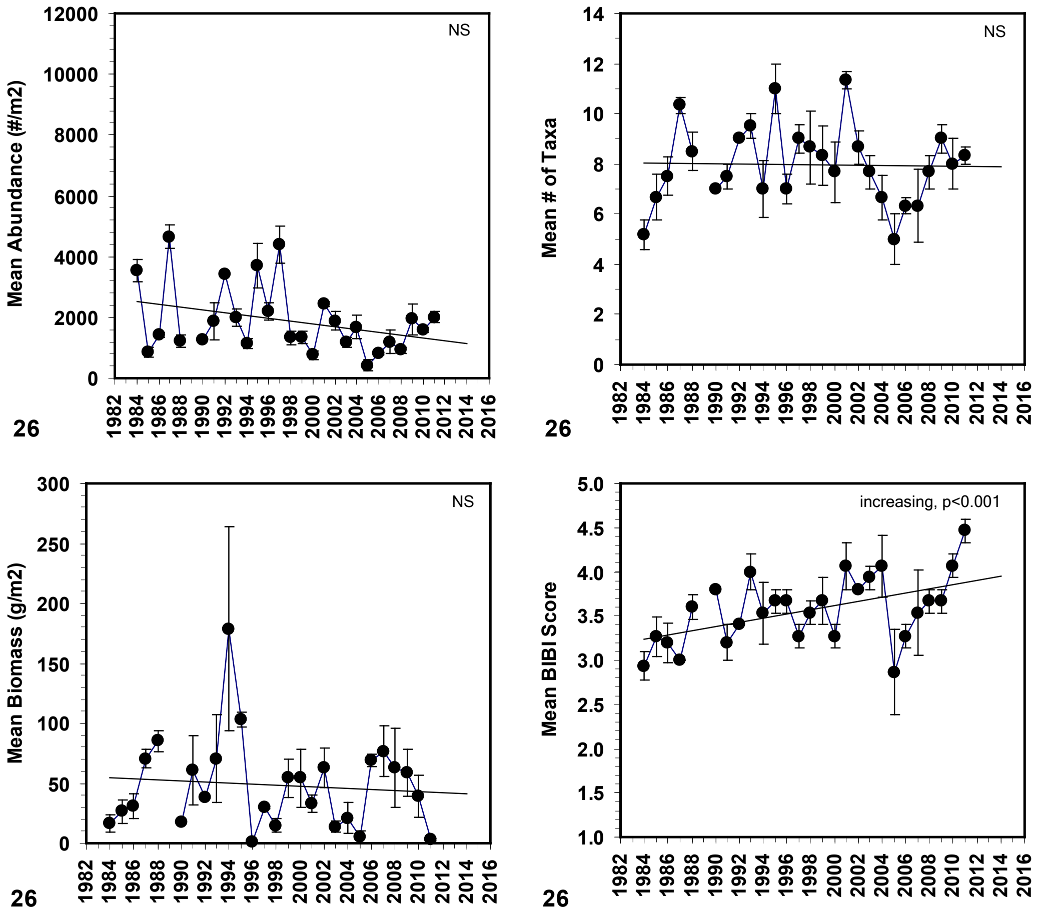


Figure 3-7. Trends in abundance, biomass, number of species, and B-IBI (mean ± 1 SE) at fixed sites. See text for details. Station 26 = Chesapeake Bay main stem (2-5 m), near Pooles Island.

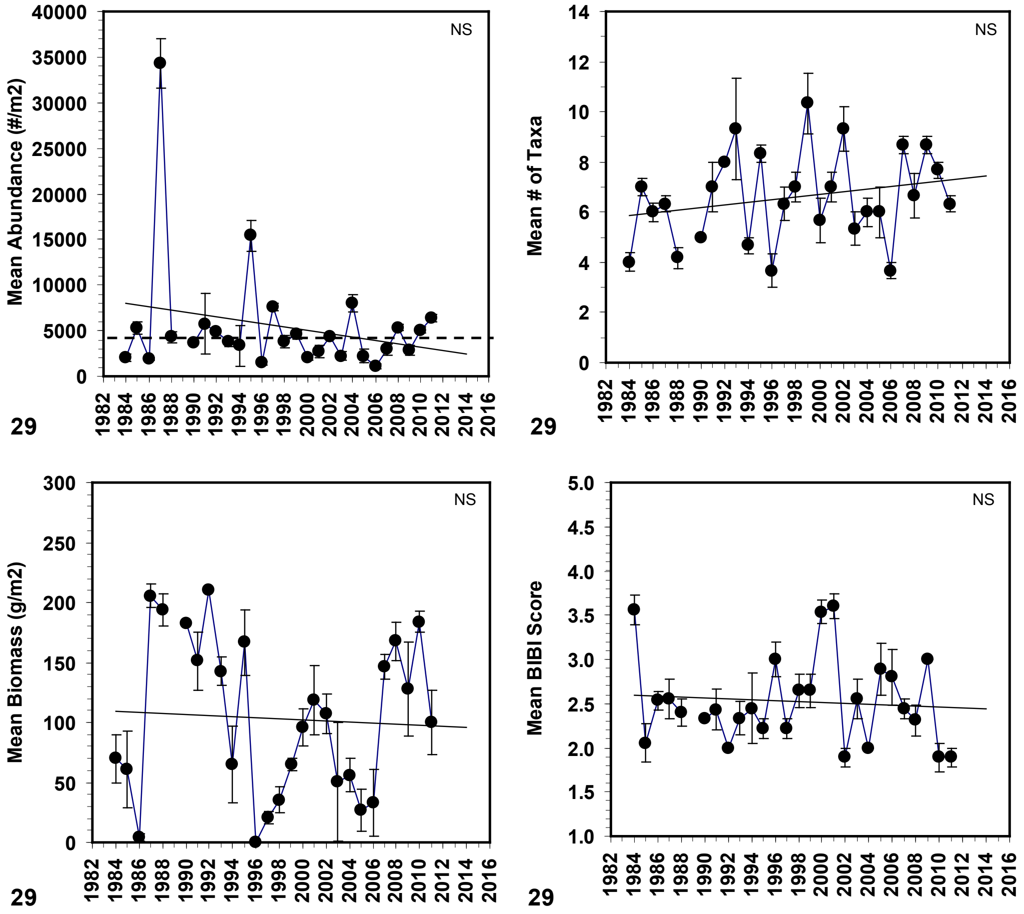


Figure 3-8. Trends in abundance, biomass, number of species, and B-IBI (mean ± 1 SE) at fixed sites. See text for details. Station 29 = Elk River. Dashed line: upper B-IBI threshold for abundance.

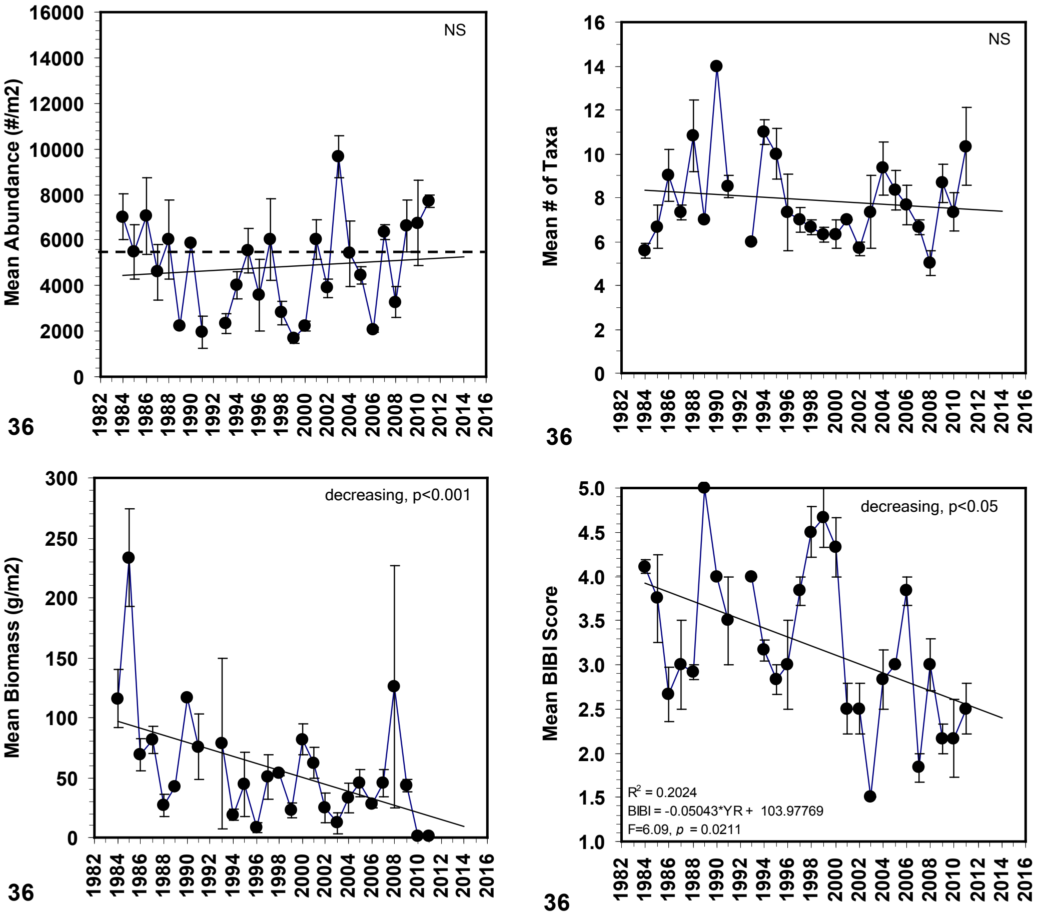


Figure 3-9. Trends in abundance, biomass, number of species, and B-IBI (mean ± 1 SE) at fixed sites. See text for details. Station 36 = Tidal freshwater Potomac River (≤ 5 m), Rosier Bluff. Dashed line: upper B-IBI threshold for abundance.

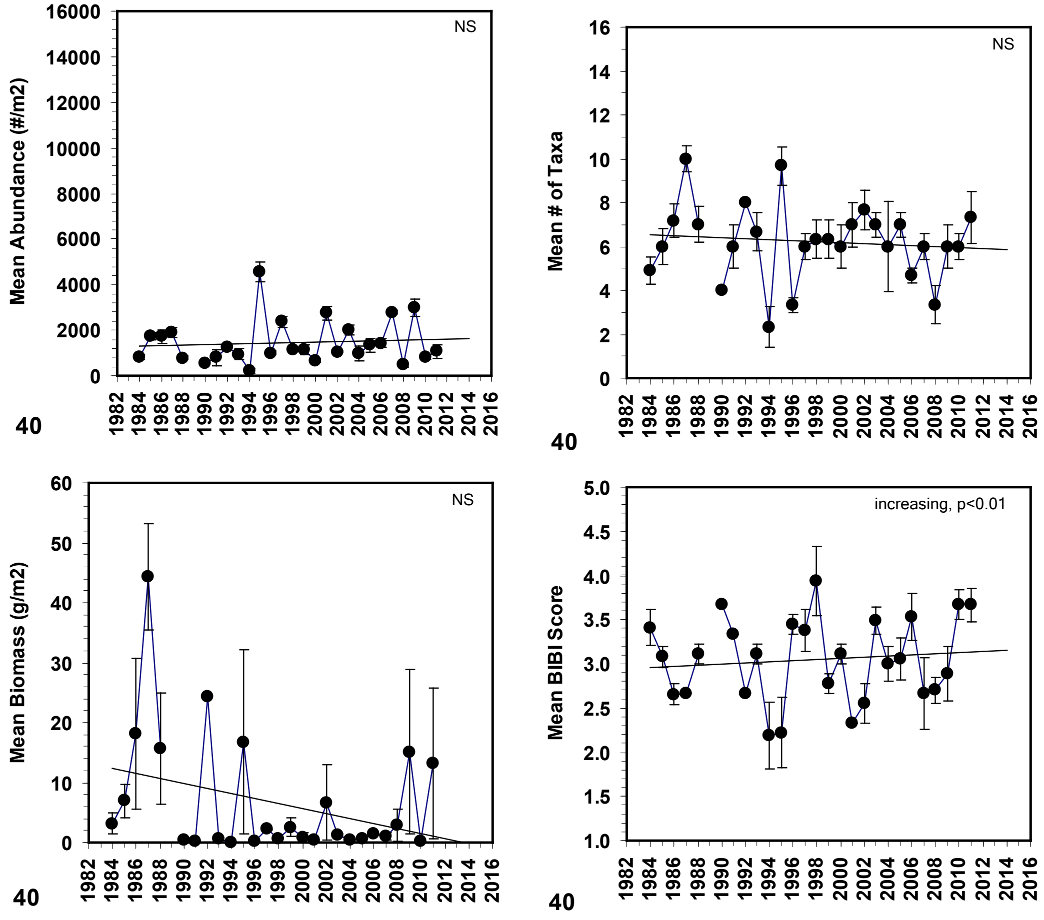


Figure 3-10. Trends in abundance, biomass, number of species, and B-IBI (mean ± 1 SE) at fixed sites. See text for details. Station 40 = Oligohaline Potomac River (6-10 m), Maryland Point.

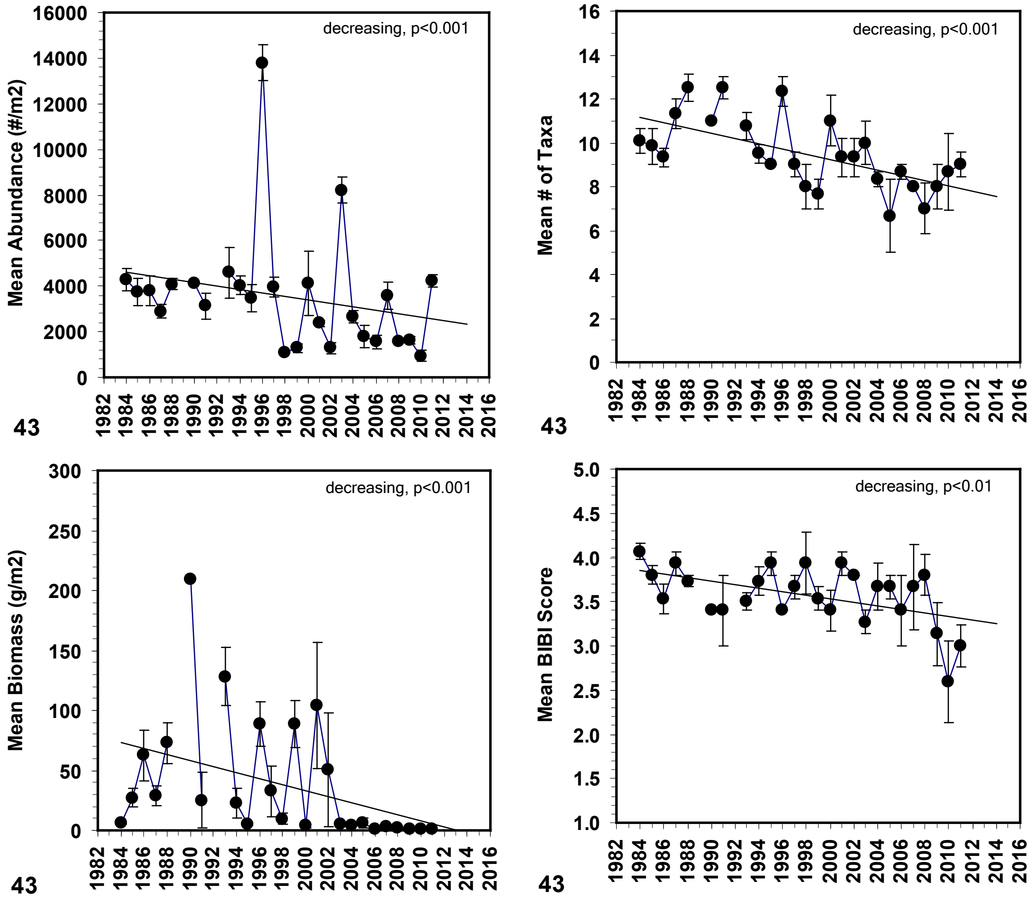


Figure 3-11. Trends in abundance, biomass, number of species, and B-IBI (mean ± 1 SE) at fixed sites. See text for details. Station 43 = Mesohaline Potomac River (≤ 5 m), Morgantown.

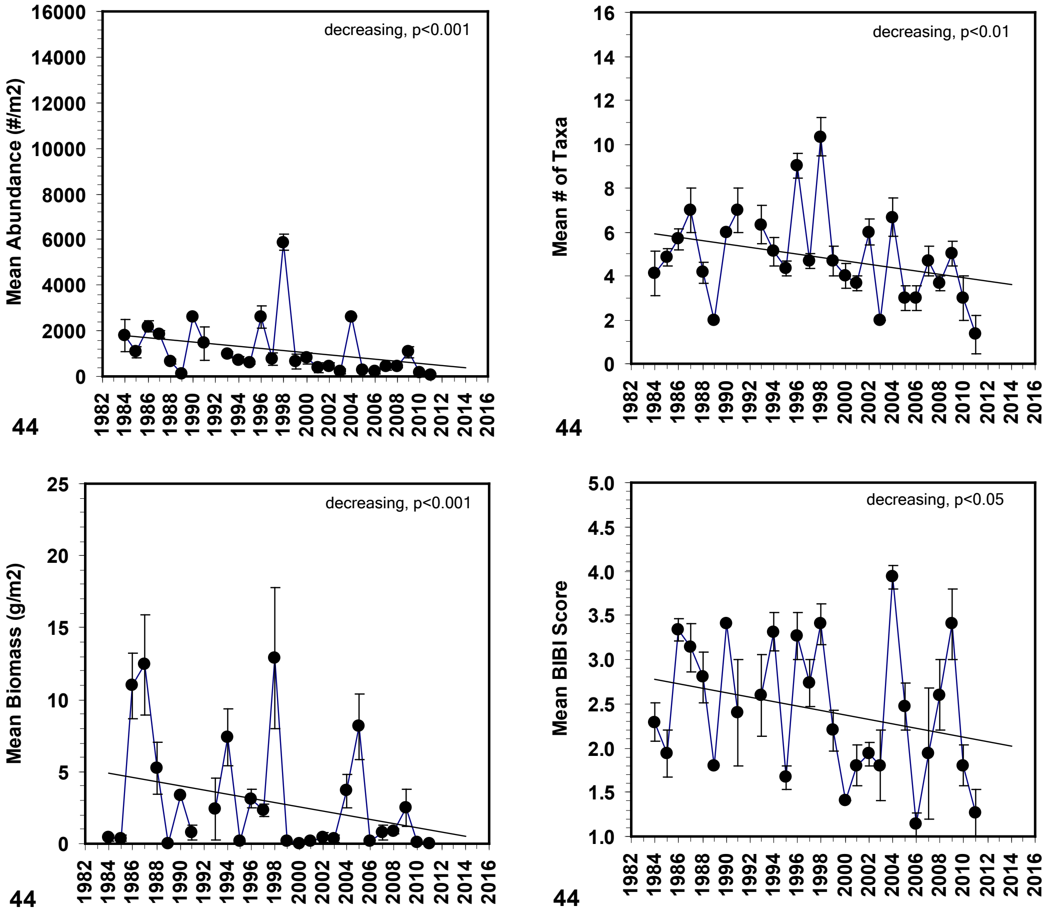


Figure 3-12. Trends in abundance, biomass, number of species, and B-IBI (mean ±1 SE) at fixed sites. See text for details. Station 44 = Mesohaline Potomac River (11-17 m), Morgantown.

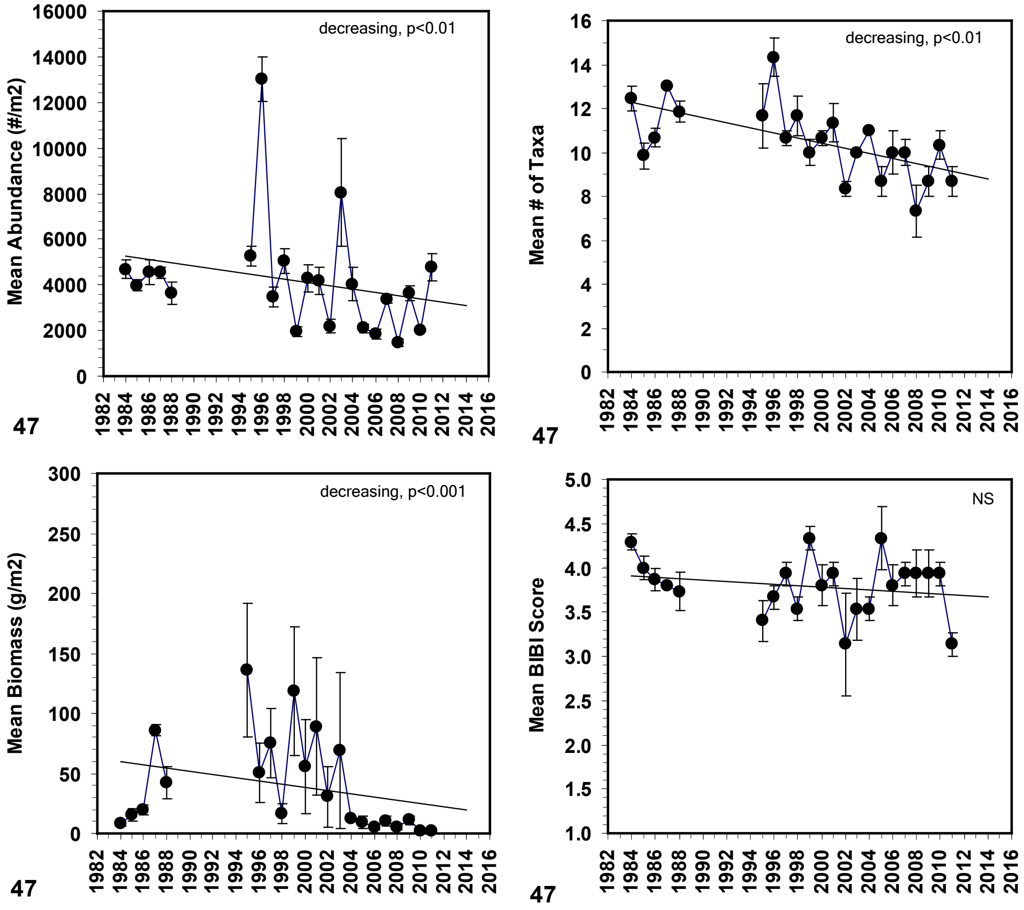


Figure 3-13. Trends in abundance, biomass, number of species, and B-IBI (mean ± 1 SE) at fixed sites. See text for details. Station 47 = Mesohaline Potomac River (≤ 5 m), Morgantown.

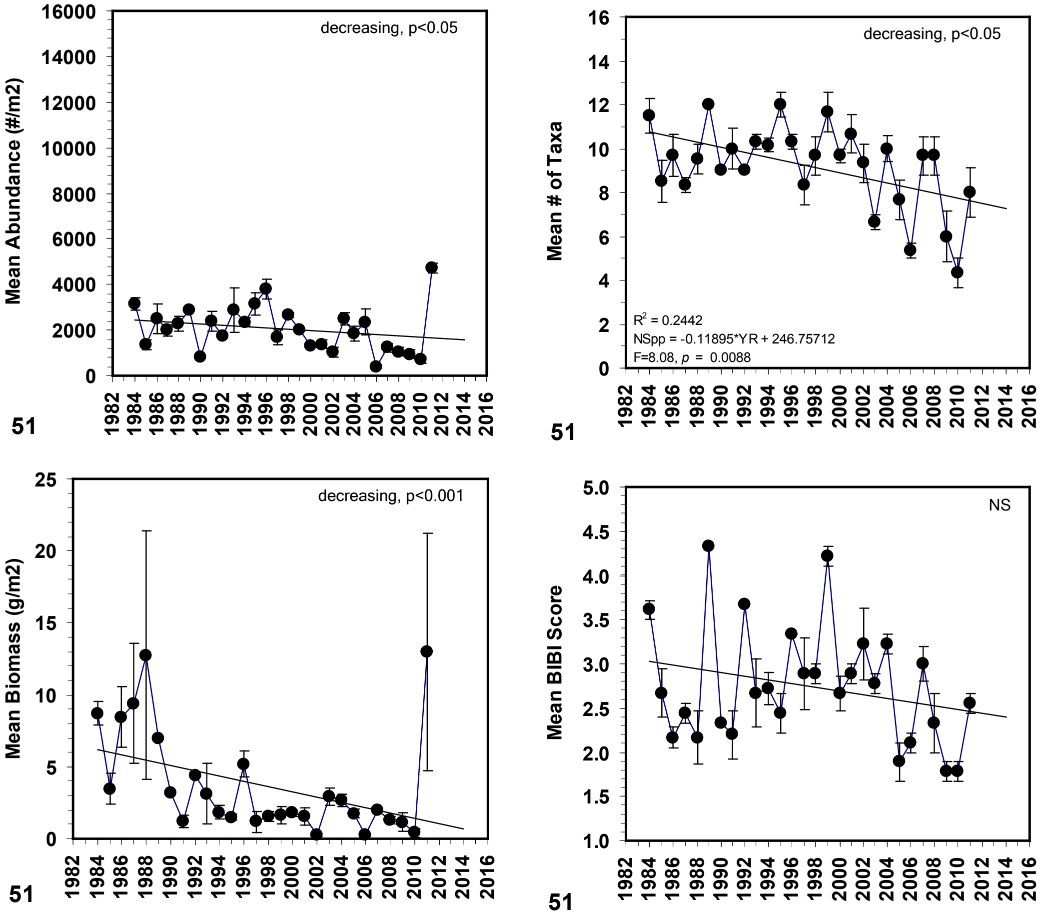


Figure 3-14. Trends in abundance, biomass, number of species, and B-IBI (mean ± 1 SE) at fixed sites. See text for details. Station 51 = Mesohaline Potomac River (≤ 5 m), St. Clements Island.

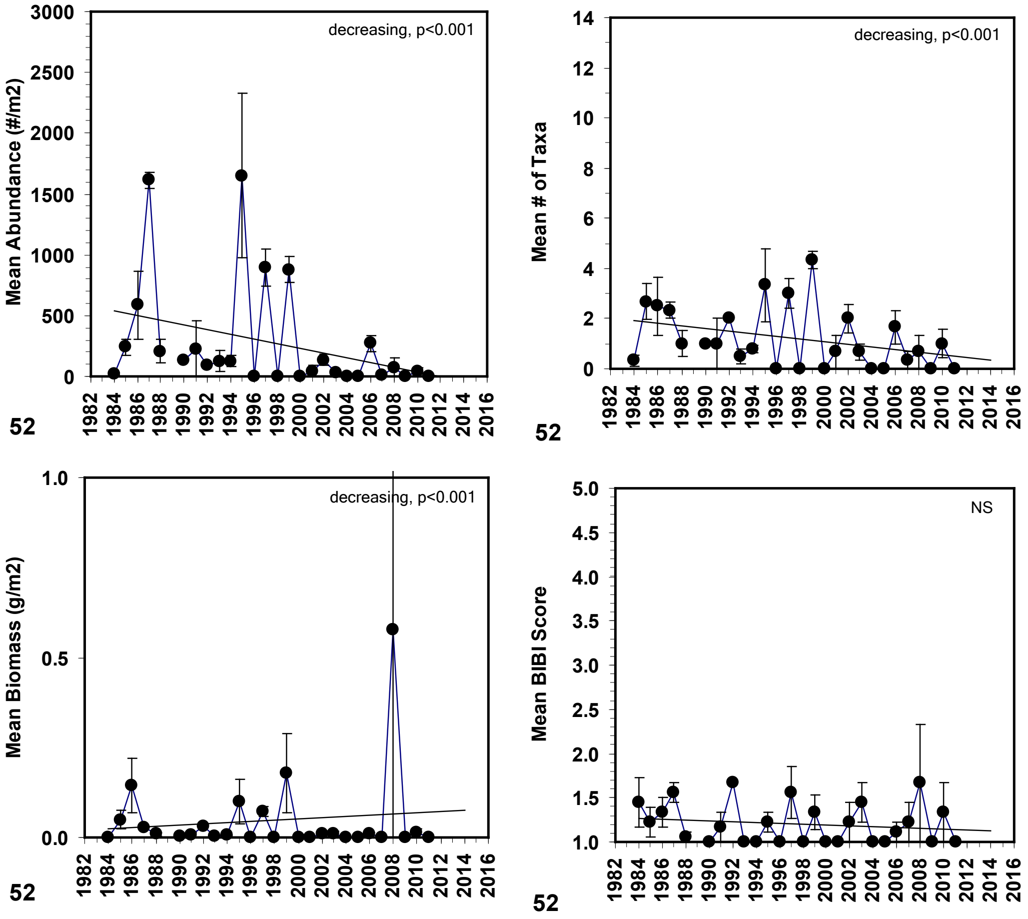


Figure 3-15. Trends in abundance, biomass, number of species, and B-IBI (mean ± 1 SE) at fixed sites. See text for details. Station 52 = Mesohaline Potomac River (9-13 m), St. Clements Island.

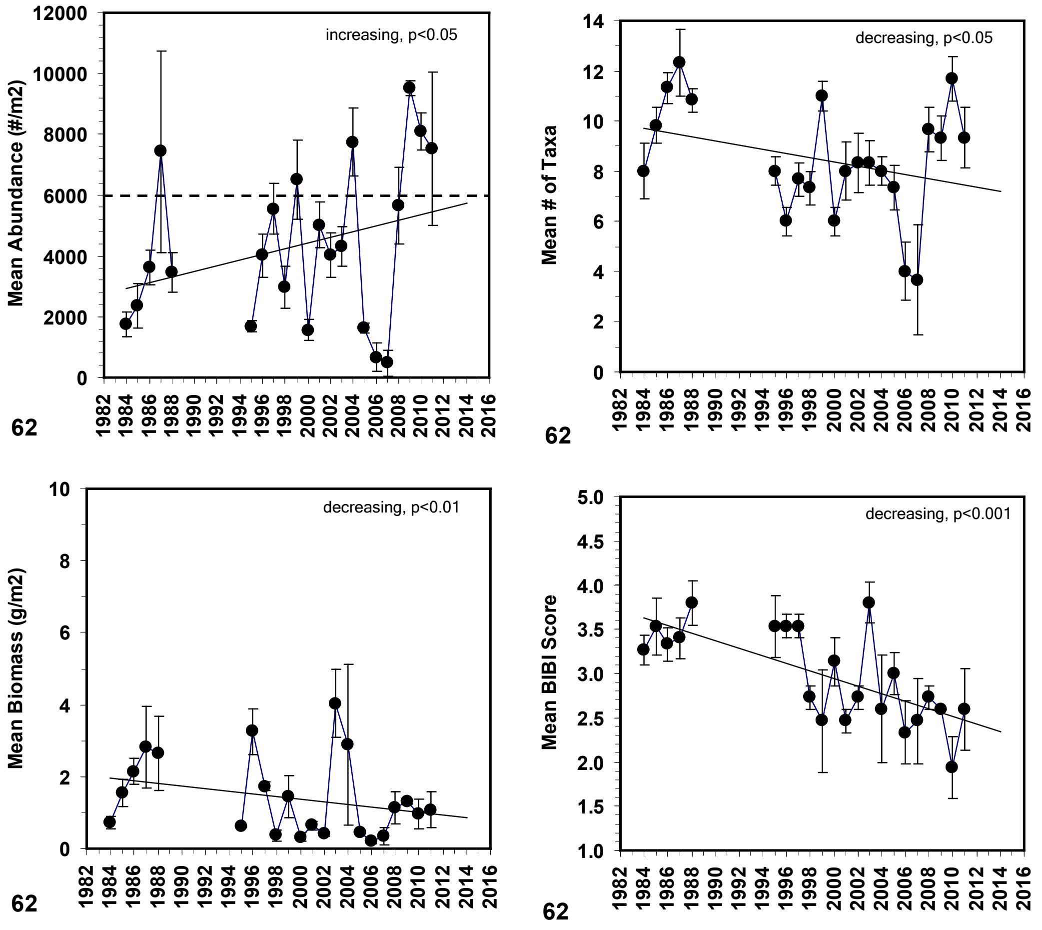


Figure 3-16. Trends in abundance, biomass, number of species, and B-IBI (mean ± 1 SE) at fixed sites. See text for details. Station 62 = Nanticoke River. Dashed line: upper B-IBI threshold for abundance.

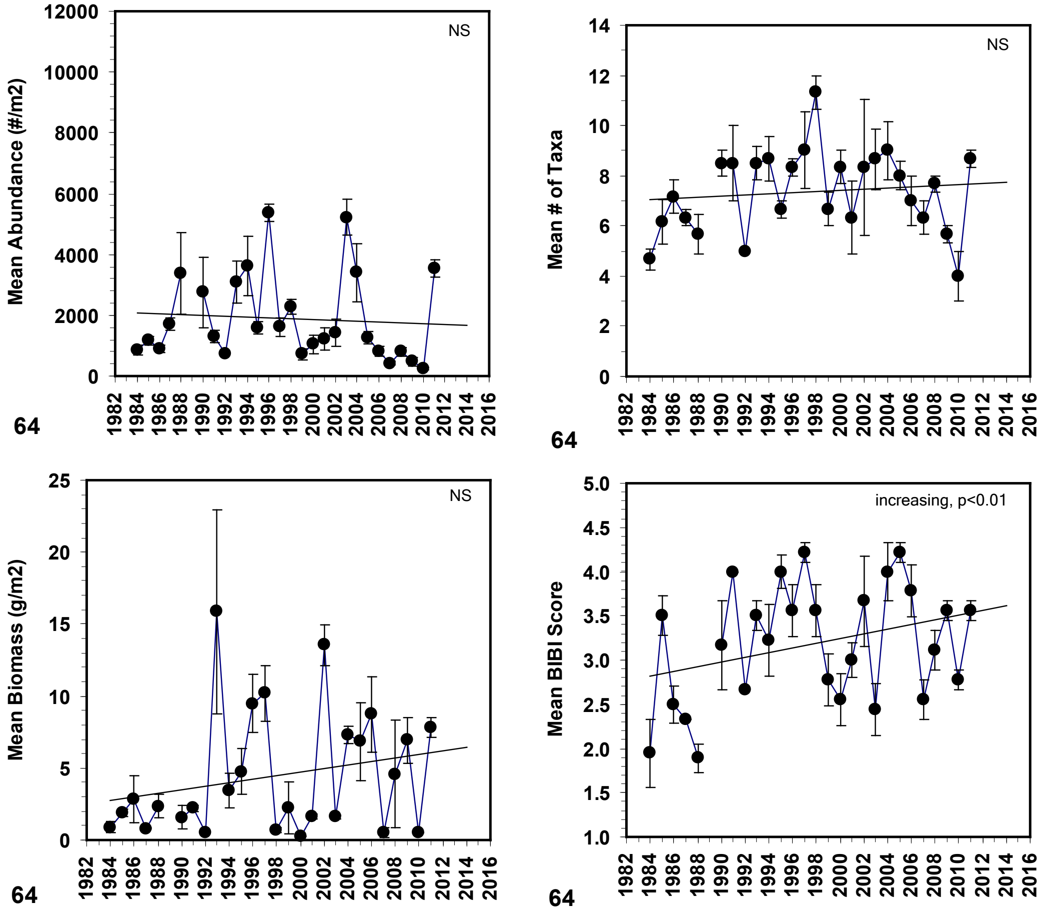


Figure 3-17. Trends in abundance, biomass, number of species, and B-IBI (mean ± 1 SE) at fixed sites. See text for details. Station 64 = Mesohaline Choptank River.

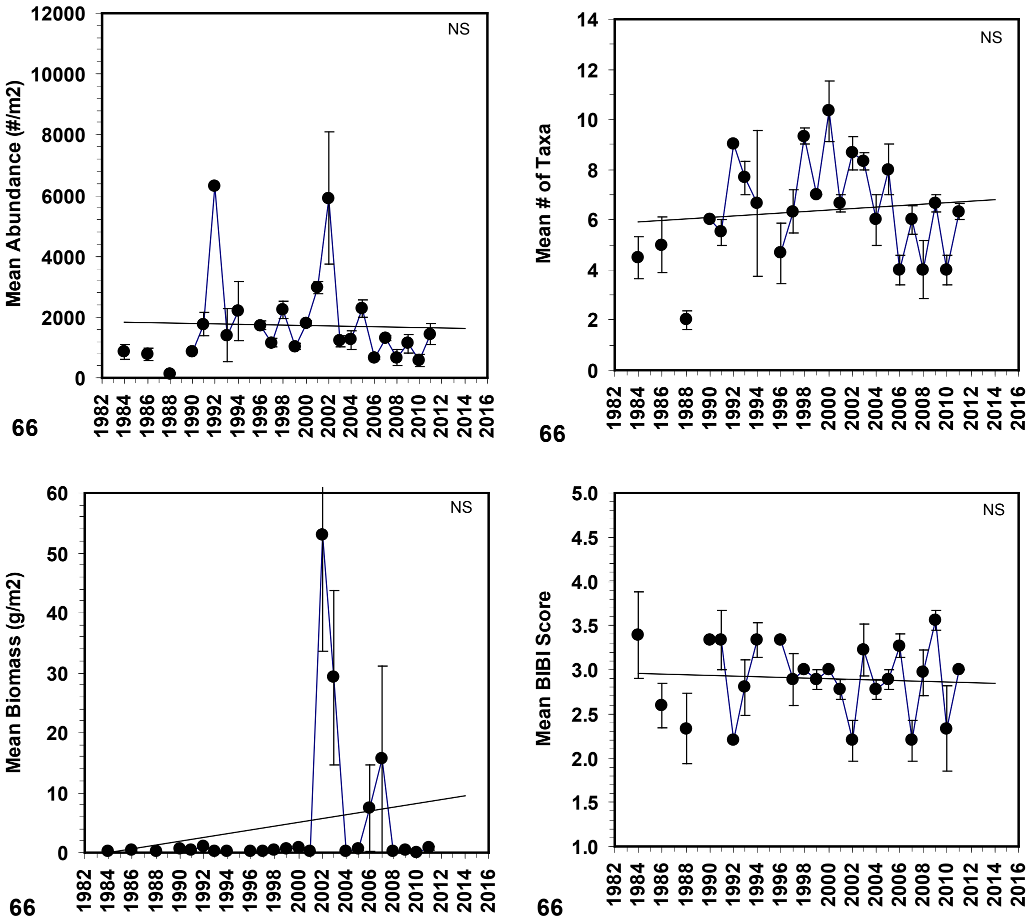


Figure 3-18. Trends in abundance, biomass, number of species, and B-IBI (mean ± 1 SE) at fixed sites. See text for details. Station 66 = Oligohaline Choptank River.

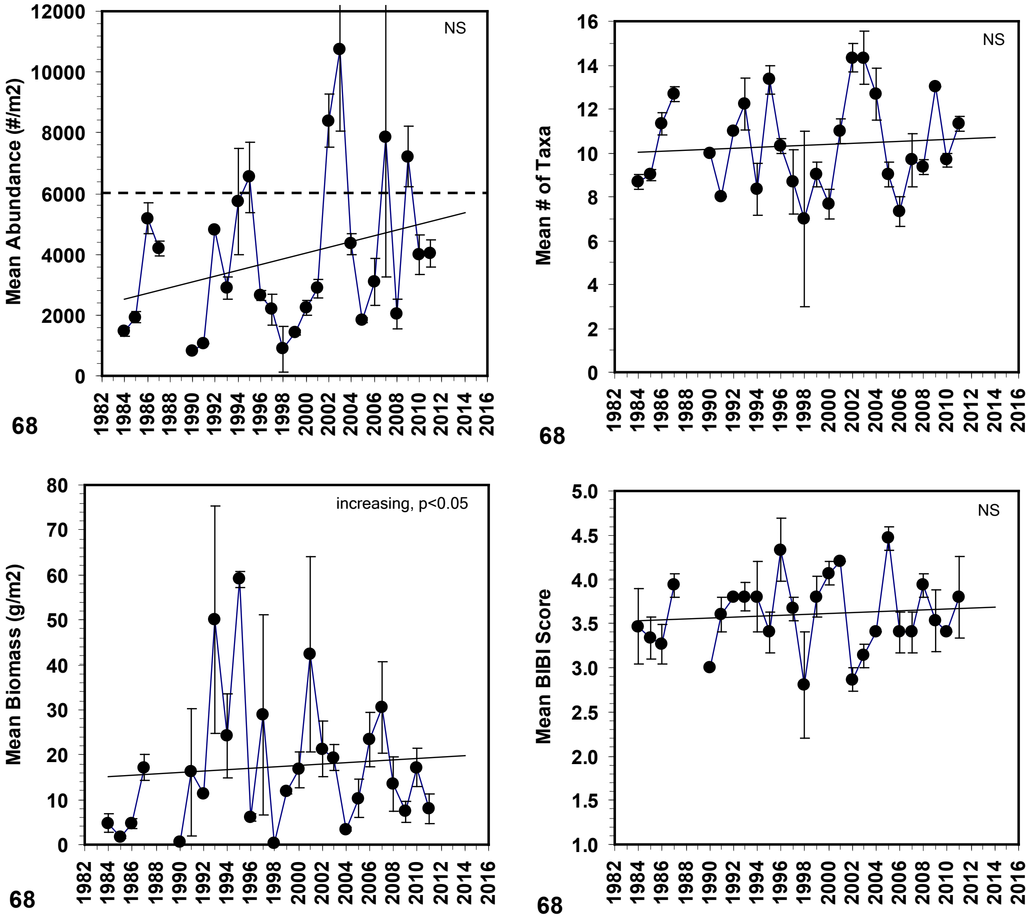


Figure 3-19. Trends in abundance, biomass, number of species, and B-IBI (mean ± 1 SE) at fixed sites. See text for details. Station 68 = Chester River. Dashed line: upper B-IBI threshold for abundance.

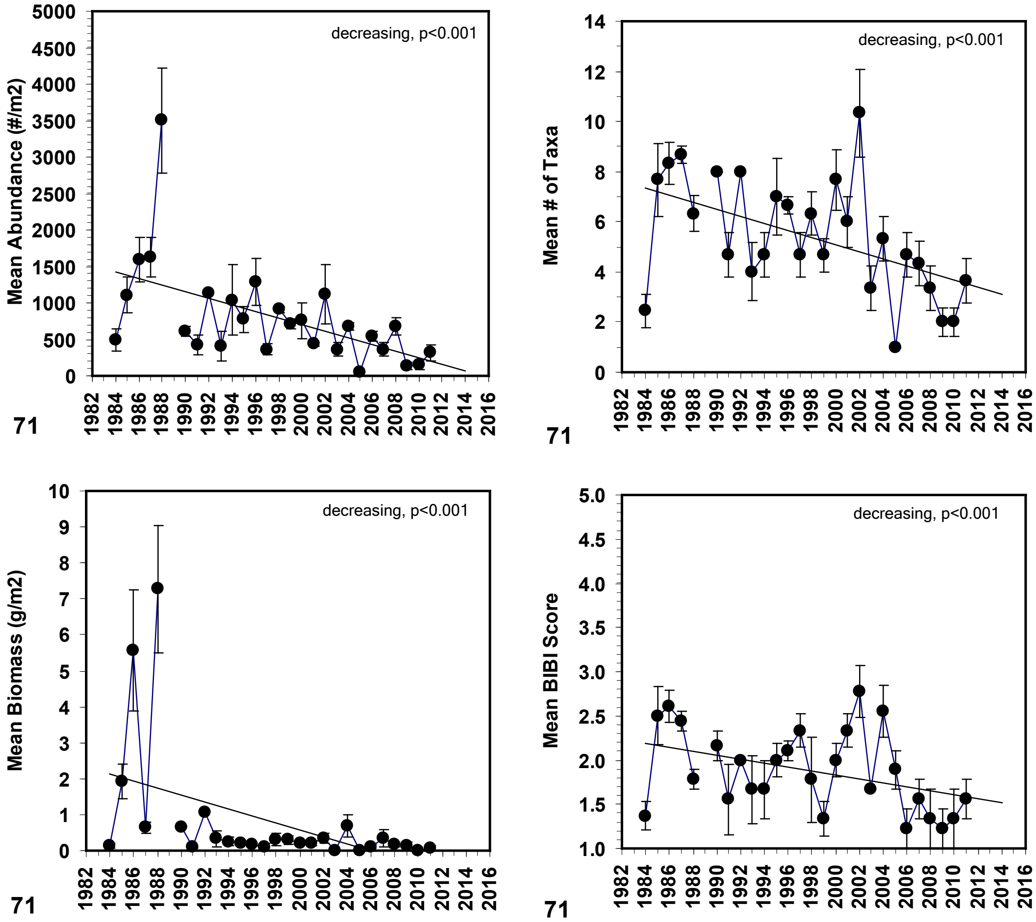


Figure 3-20. Trends in abundance, biomass, number of species, and B-IBI (mean ± 1 SE) at fixed sites. See text for details. Station 71 = Mesohaline Patuxent River (12-18 m), Broomes Island.

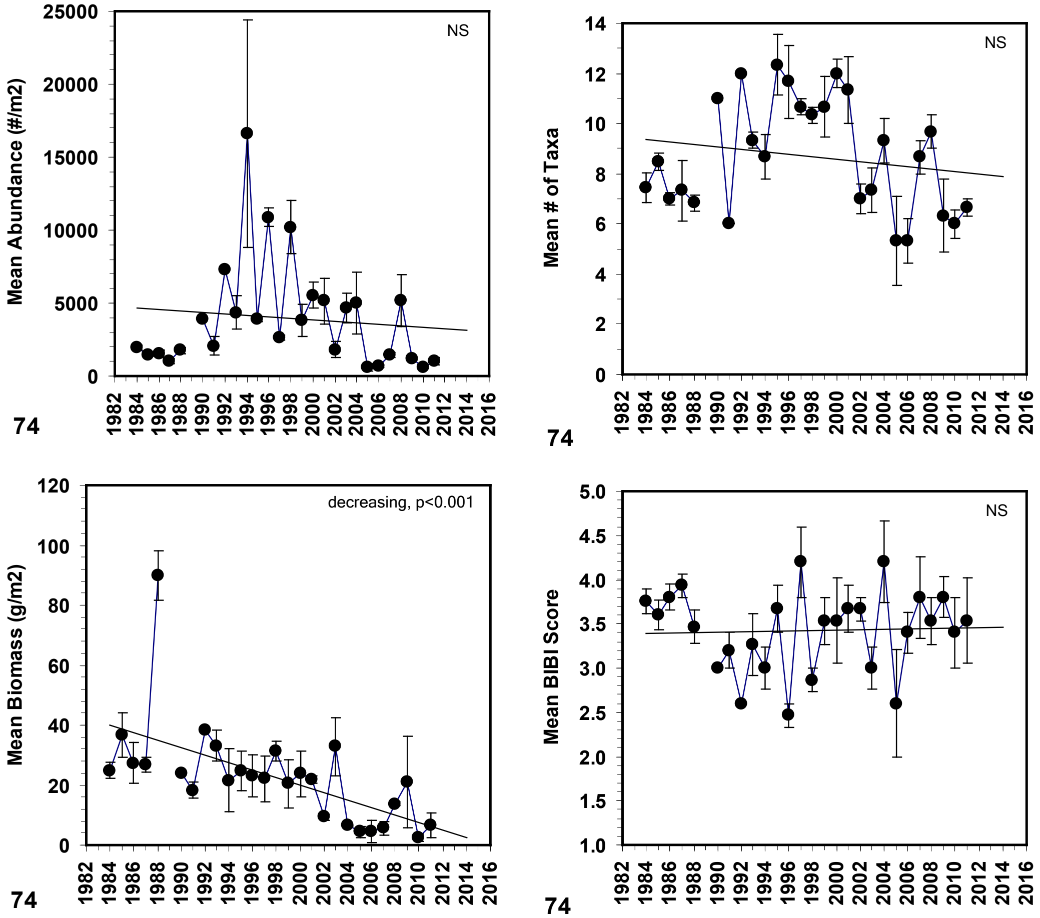


Figure 3-21. Trends in abundance, biomass, number of species, and B-IBI (mean ± 1 SE) at fixed sites. See text for details. Station 74 = Mesohaline Patuxent River (≤ 5 m), Chalk Point.

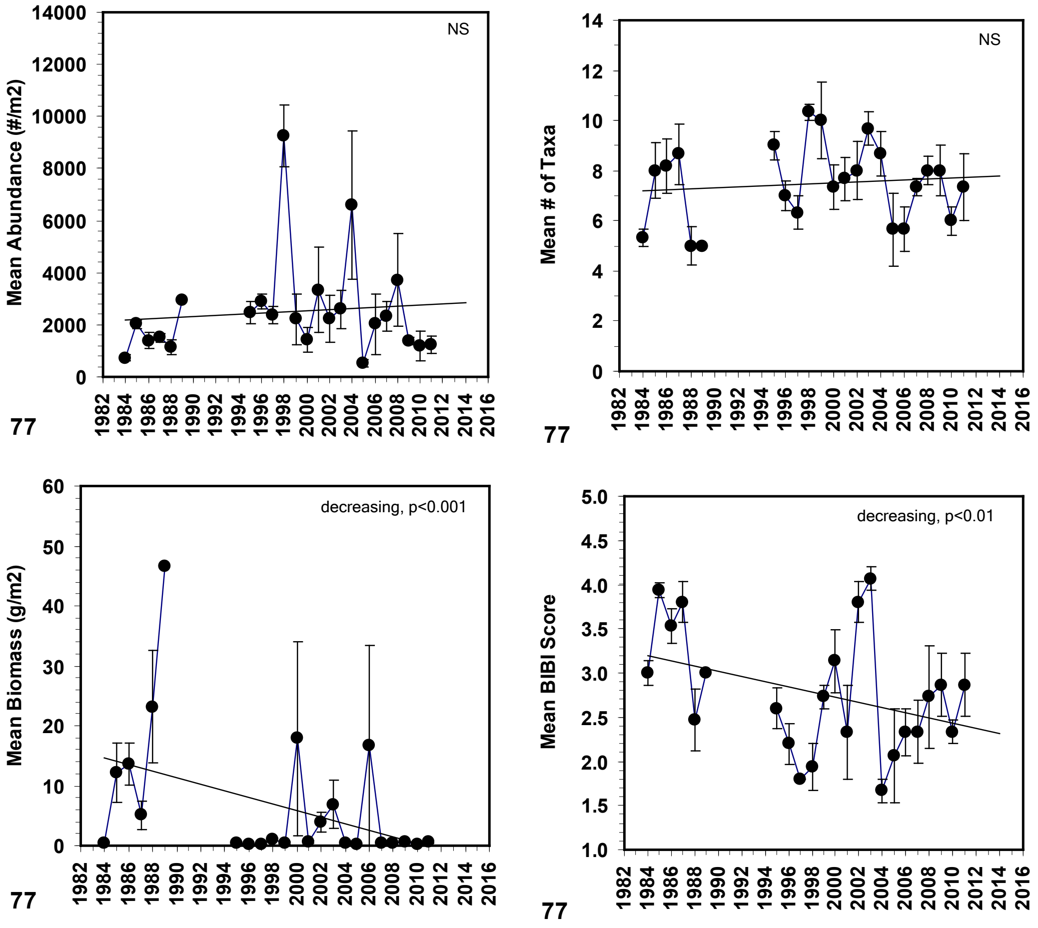


Figure 3-22. Trends in abundance, biomass, number of species, and B-IBI (mean ± 1 SE) at fixed sites. See text for details. Station 77 = Mesohaline Patuxent River (≤ 5 m), Holland Cliff.

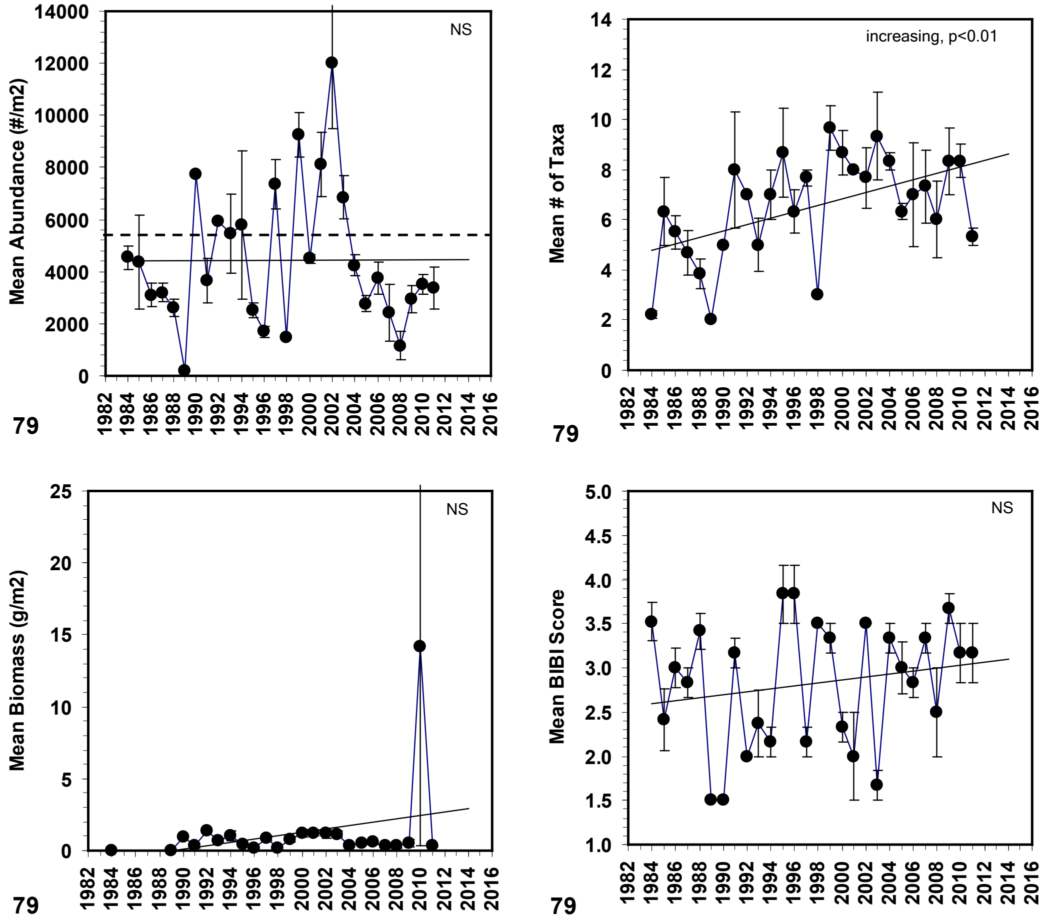


Figure 3-23. Trends in abundance, biomass, number of species, and B-IBI (mean ± 1 SE) at fixed sites. See text for details. Station 79 = Tidal freshwater Patuxent River (≤ 6 m), Lyons Creek. Dashed line: upper B-IBI threshold for abundance.

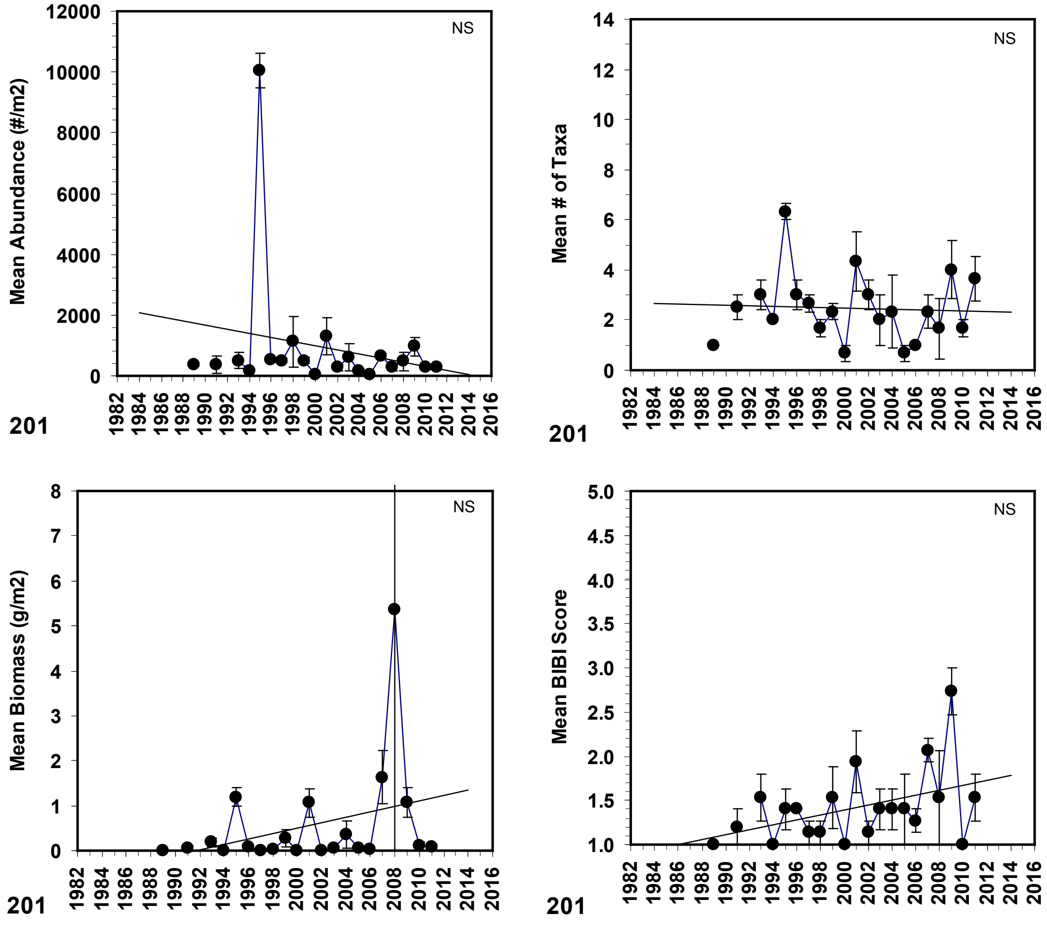


Figure 3-24. Trends in abundance, biomass, number of species, and B-IBI (mean ± 1 SE) at fixed sites. See text for details. Station 201 = Patapsco River estuary, Bear Creek.

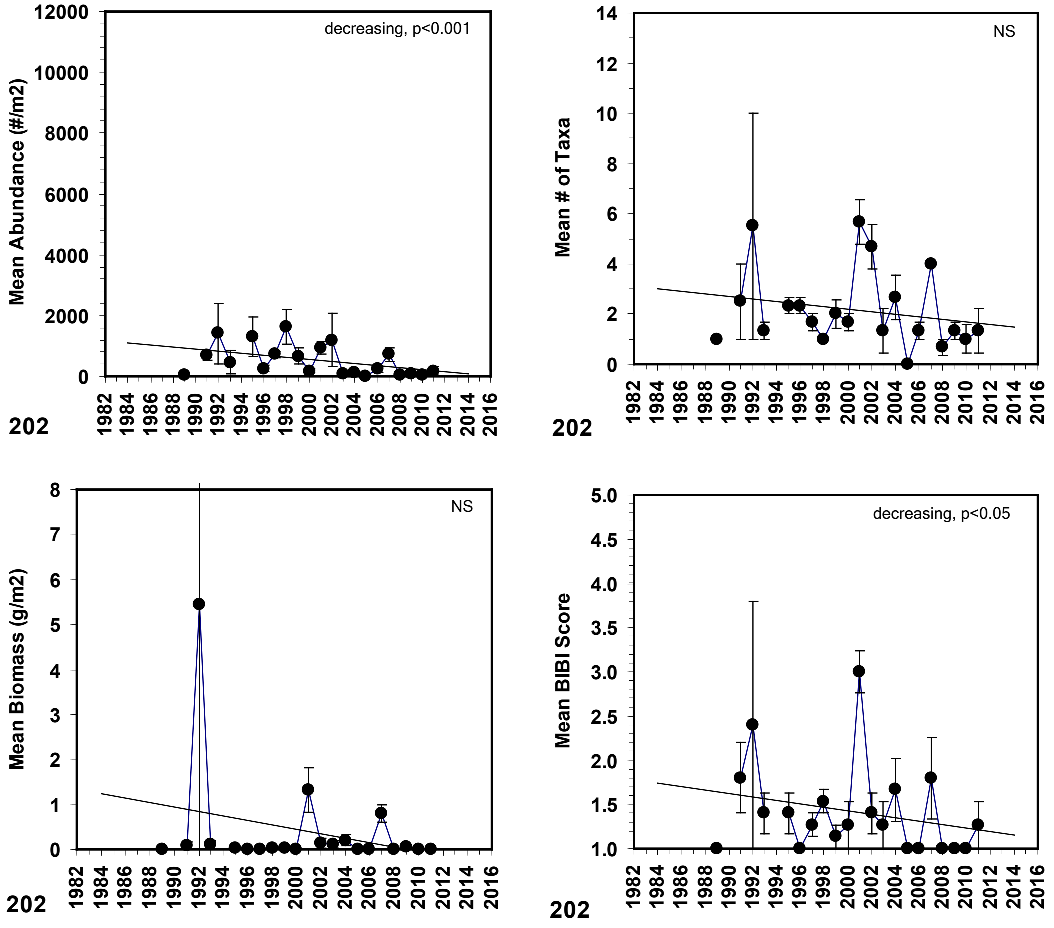


Figure 3-25. Trends in abundance, biomass, number of species, and B-IBI (mean ± 1 SE) at fixed sites. See text for details. Station 202 = Patapsco River estuary, Curtis Creek.

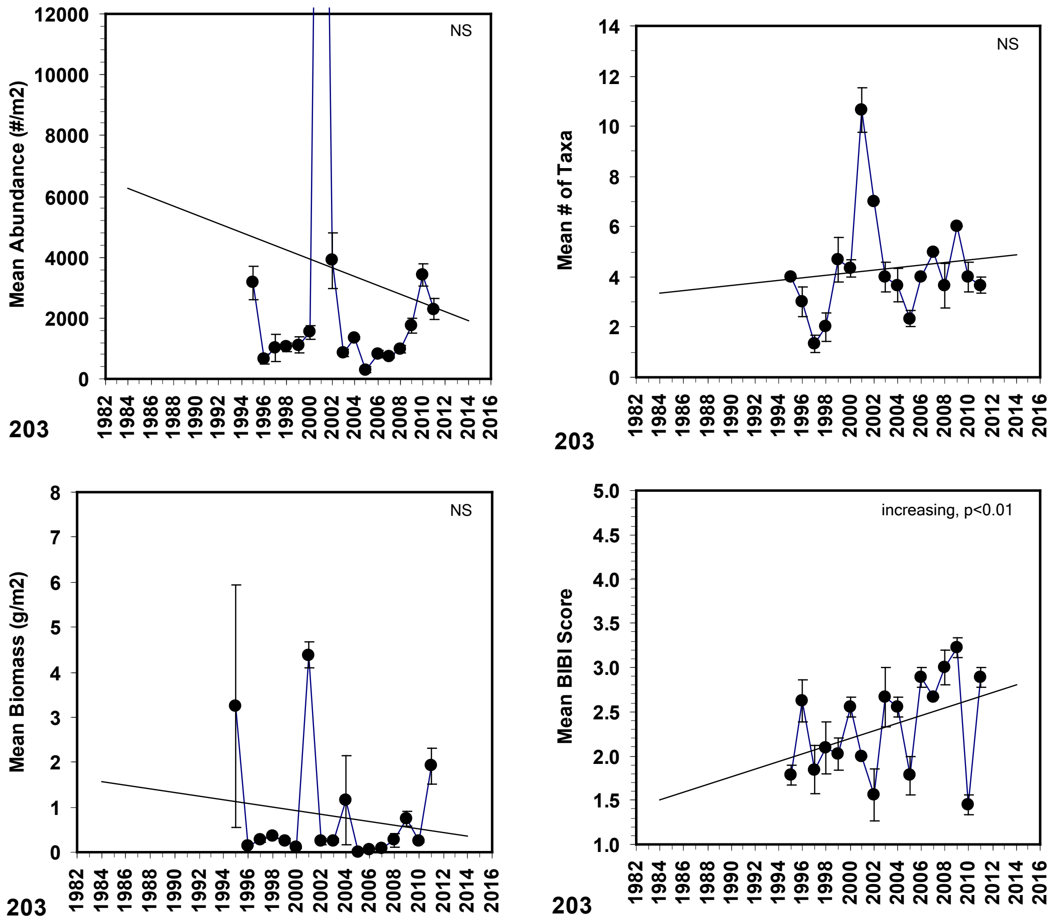


Figure 3-26. Trends in abundance, biomass, number of species, and B-IBI (mean ± 1 SE) at fixed sites. See text for details. Station 203 = Back River.

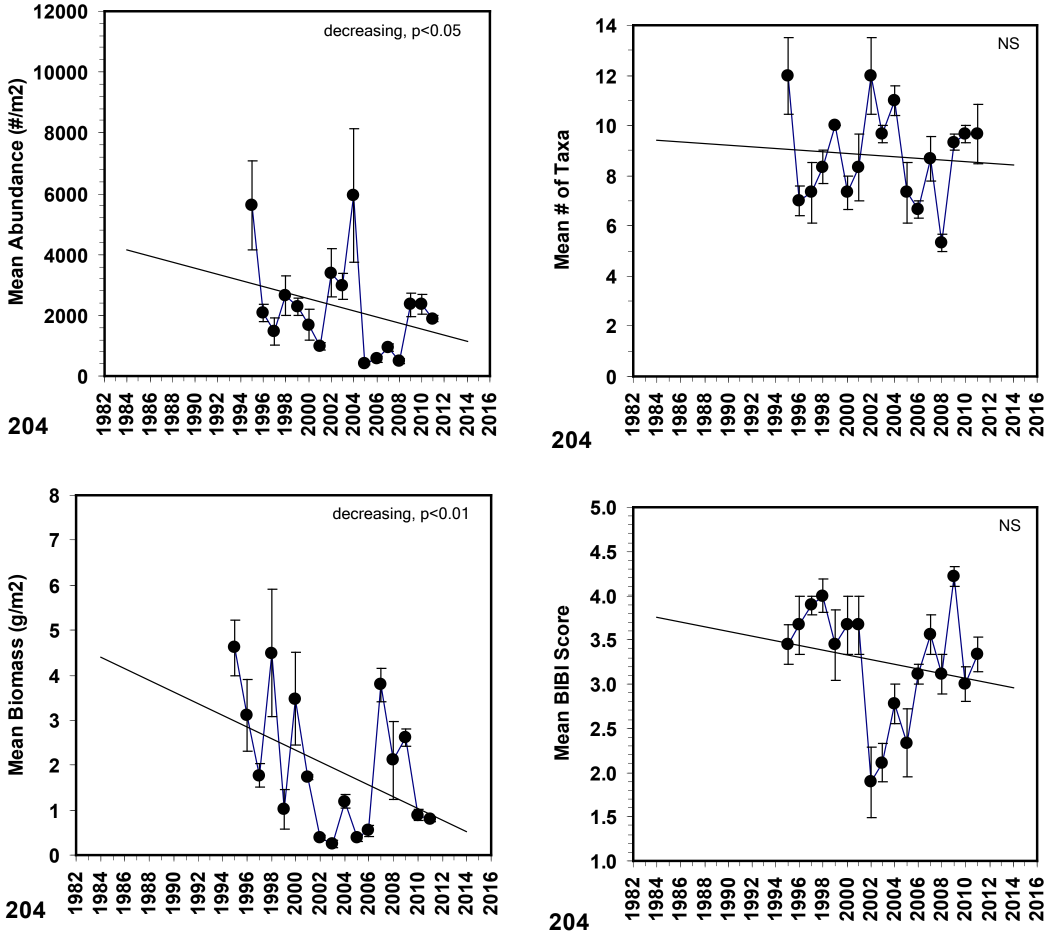


Figure 3-27. Trends in abundance, biomass, number of species, and B-IBI (mean ± 1 SE) at fixed sites. See text for details. Station 204 = Severn River.

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 the 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) or natural disasters (e.g., tropical weather systems). Probability-based sampling information is used annually in the Bay Report Card and for Chesapeake Bay aquatic life use support decisions under the Clean Water Act (Llansó et al. 2005b, 2009a).

Probability-based sampling was employed prior to 1994 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 2011 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 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 2011 Maryland and Virginia probability-based sampling and provides eighteen years (1994-2011) 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 2011, 66 met and 84 failed the Chesapeake Bay benthic community restoration goals (Figure 3-28), an increase in the number of samples meeting the goals relative to 2010. Of the 250 probability samples collected in the entire Chesapeake Bay in 2011, 101 met and 149 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, about the same number of sites met the goals in 2011 (40%) than in 2010 (41%), but not as many as in 2009 (47%).

The area with degraded benthos in the Maryland Bay decreased in 2011 (Maryland Tidal Waters, Figure 3-30 left panel), and a decrease was also observed in the magnitude of the severely degraded condition (Maryland Tidal Waters, 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 2011, 65% (±5% SE) of the Maryland Bay was estimated to fail the restoration goals (Figure 3-30). In 2010 and 2009 the estimates were 67% and 58% (±5% SE), respectively. Expressed as area, 4,083±284 km^2 of the Maryland tidal waters in Chesapeake Bay remained to be restored in 2011 (Table 3-4).

In 2011, 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 Potomac River exhibited a large increase in both percent degraded and percent severely degraded condition in 2011, and this stratum was among the most degraded (Figures 3-31 and 3-33). The Potomac River was the only stratum showing an increase in percent degraded area in 2011. All other Maryland strata showed a decrease or, in the Upper Bay mainstem, no change. Benthic community condition, therefore, showed signs of improvement in 2011 relative to 2010.

In the Potomac River, the increase in degradation was both in the upper (above Morgantown) and the lower tidal portions of the river. The upper Potomac showed a 19% increase in degradation in 2011 relative to 2010, whereas the lower Potomac exhibited degraded condition in 100% of its area, mostly severe. This is in contrast with previous years that showed declines in the severely degraded condition of the lower Potomac River. Over the 1995-2011 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. Over the same time series, statistically significant increasing trends in percent area degraded were detected in the Patuxent River (ANOVA, F = 18.78, p = 0.0006) and the Maryland Eastern Tributaries (ANOVA, F = 9.99, p = 0.0065).

In Virginia, the percentage of area degraded increased in the York and James rivers (Table 3-4, Figure 3-32). A statistically significant increasing trend in percent area degraded was detected in the Rappahannock River over the 1996-2011 time series (ANOVA, F=5.99, *p* = 0.0282). Degradation in the James River in 2011 affected a majority of the sampling sites throughout the river (Figure 3-32).

For the Chesapeake Bay, the estimate of degradation increased from 53% in 2010 to 55% in 2011, due to increases in degradation in the Virginia portion of the Bay (Figure 3-30). The extent of degradation, however, was not as severe as for the 2005-2008 period. Weighting results from the 250 probability sites in Maryland and Virginia, 55% (±4%) or 6,386±489 km^2 of the tidal Chesapeake Bay was estimated to fail the restoration goals in 2011, and 58% of that area (3,698 km^2) was severely degraded (Table 3-4). There was no statistically significant change in percent area degraded over the time series (ANOVA, F = 0.79, *p* = 0.389).

Flow into Chesapeake Bay in 2011 was higher than normal in spring (March-June) and within the long-term (1937-2011) average in the summer. There was no one single pulse in river flow such as those observed in the last few years (except 2009), but the high river flow was sustained by multiple rain events. Perhaps overall lower than normal salinities during the summer combined with the disruption of the pycnocline during Hurricane Irene contributed to better than average benthic conditions in Chesapeake Bay in 2011. Abundance, number of species, and the mean B-IBI score were up in 2011 (Figures 3-34 and 3-35), whereas the number of sites scoring “1” for low abundance and low biomass (below restorative thresholds) were down.

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 1996-2011, four strata (Potomac River, Patuxent River, Mid Bay mainstem, and Maryland Western Tributaries) had a large percentage (> 69%) 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 the 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
	2011	3,698	1,556	1,132	6,386	55.0
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
	2011	2,332	1,048	703	4,083	65.4

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
	2011	1,366	508	429	2,303	42.9
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
	2011	86	107	86	278	52.0

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
	2011	1,391	408	510	2,310	71.5
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
	2011	94	126	0	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
	2011	47	70	0	117	40.0
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
	2011	51	31	5	87	68.0

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
	2011	663	306	102	1,071	84.0
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
	2011	355	164	55	574	84.0

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
	2011	134	119	30	283	76.0
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
	2011	824	165	330	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
	2011	52	60	15	127	68.0

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 2011. 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	207	70.2	242	82.0
Patuxent River	133	52.0	207	80.9
Mid Bay Mainstem	134	53.8	185	74.3
Western Tributaries	142	62.3	159	69.7
Upper Bay Mainstem	69	54.3	84	66.1
Rappahannock River	148	55.6	167	62.8
Virginia Mainstem	51	35.4	90	62.5
Eastern Tributaries	67	34.9	96	50.0
York River	126	50.2	84	33.5
James River	93	41.0	57	25.1

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 2011. 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	83	36.6
Eastern Tributaries	45	23.4
York River	55	21.9
Upper Bay Mainstem	25	19.7
Western Tributaries	40	17.5
Rappahannock River	40	15.0
Mid Bay Mainstem	37	14.9
Patuxent River	27	10.5
Potomac River	30	10.2
Virginia Mainstem	12	8.3

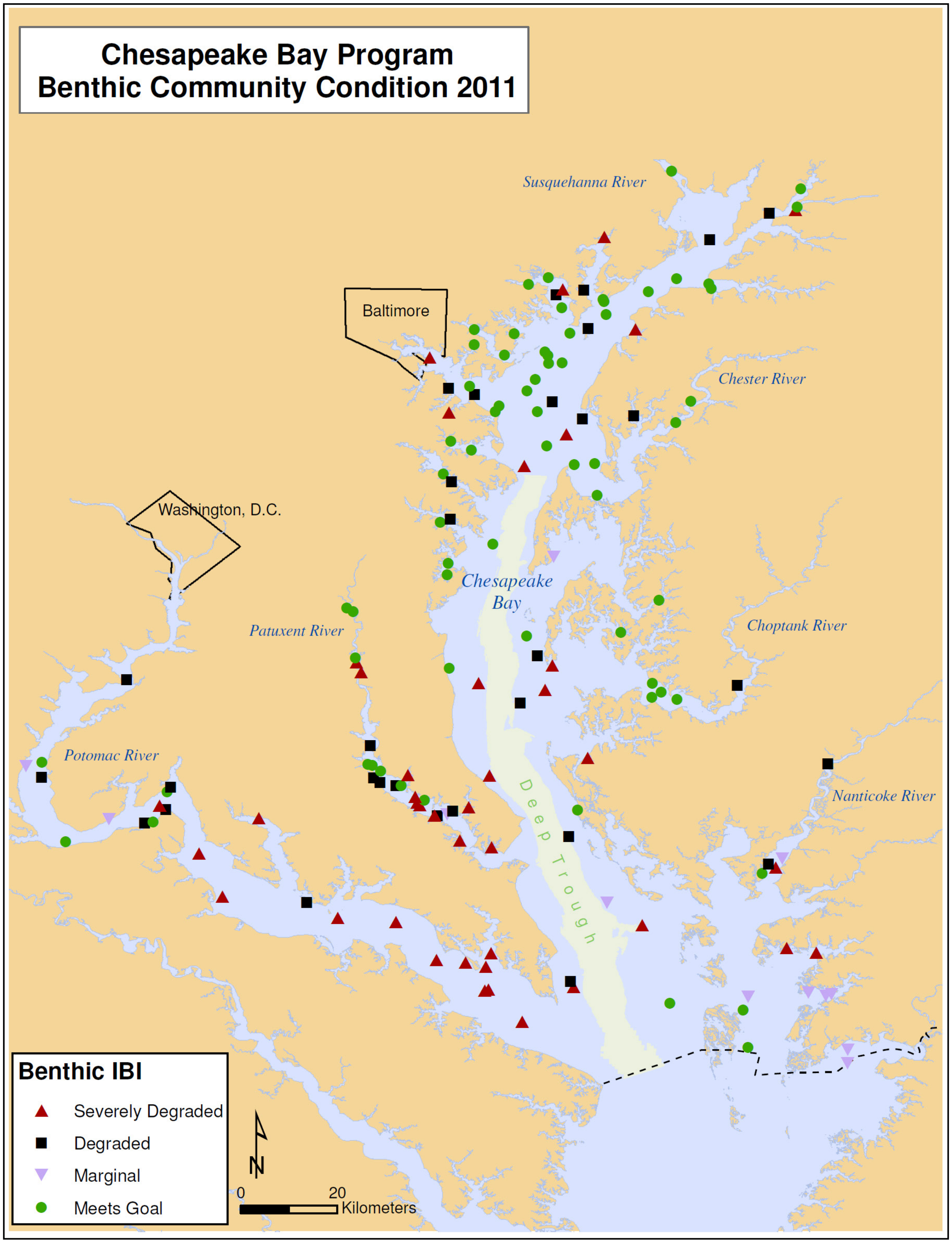


Figure 3-28. Results of probability-based benthic sampling of the Maryland Chesapeake Bay and its tidal tributaries in 2011. Each sample was evaluated in context of the Chesapeake Bay benthic community restoration goals.

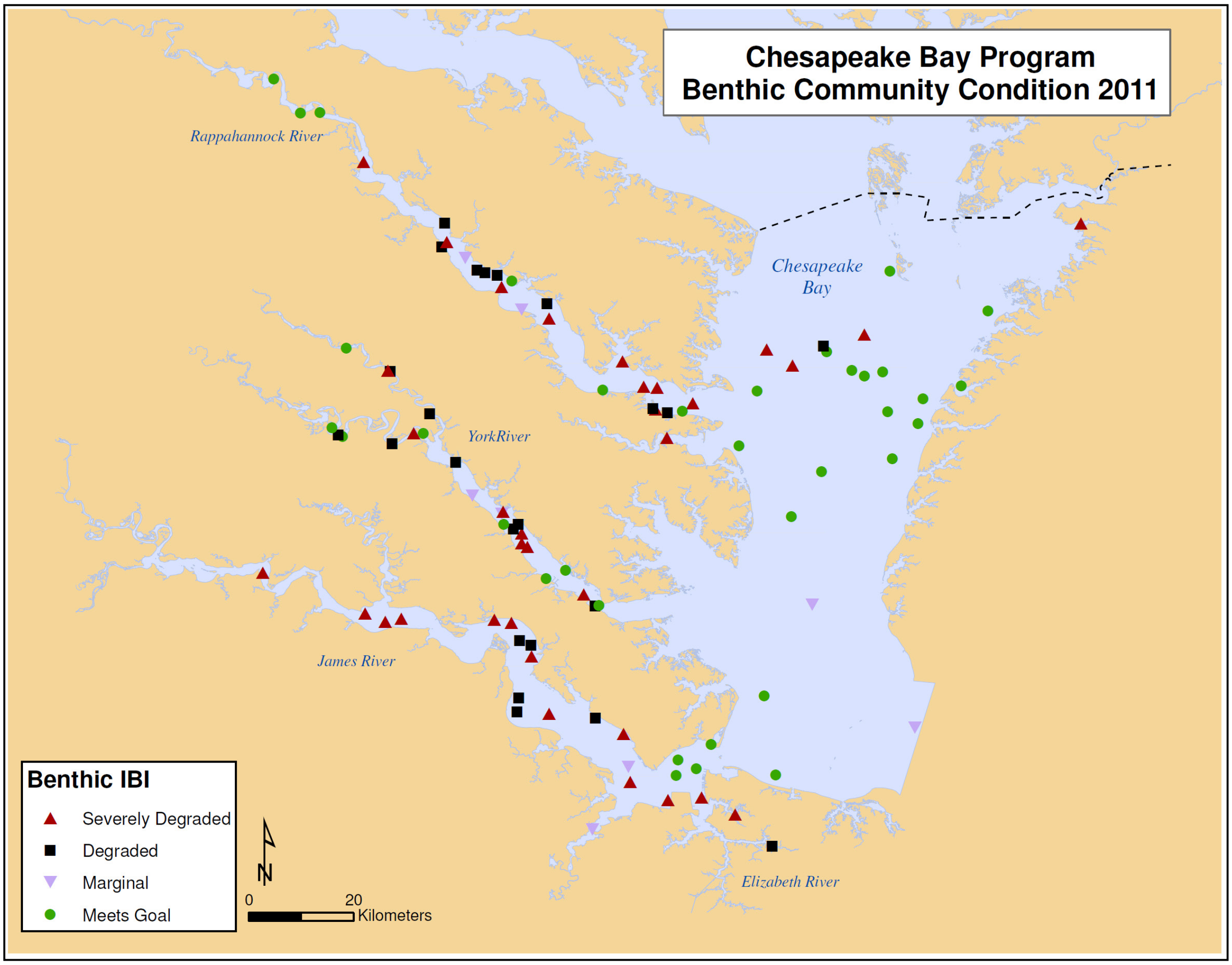


Figure 3-29. Results of probability-based benthic sampling of the Virginia Chesapeake Bay and its tidal tributaries in 2011. Each sample was evaluated in context of the Chesapeake Bay benthic community restoration goals.

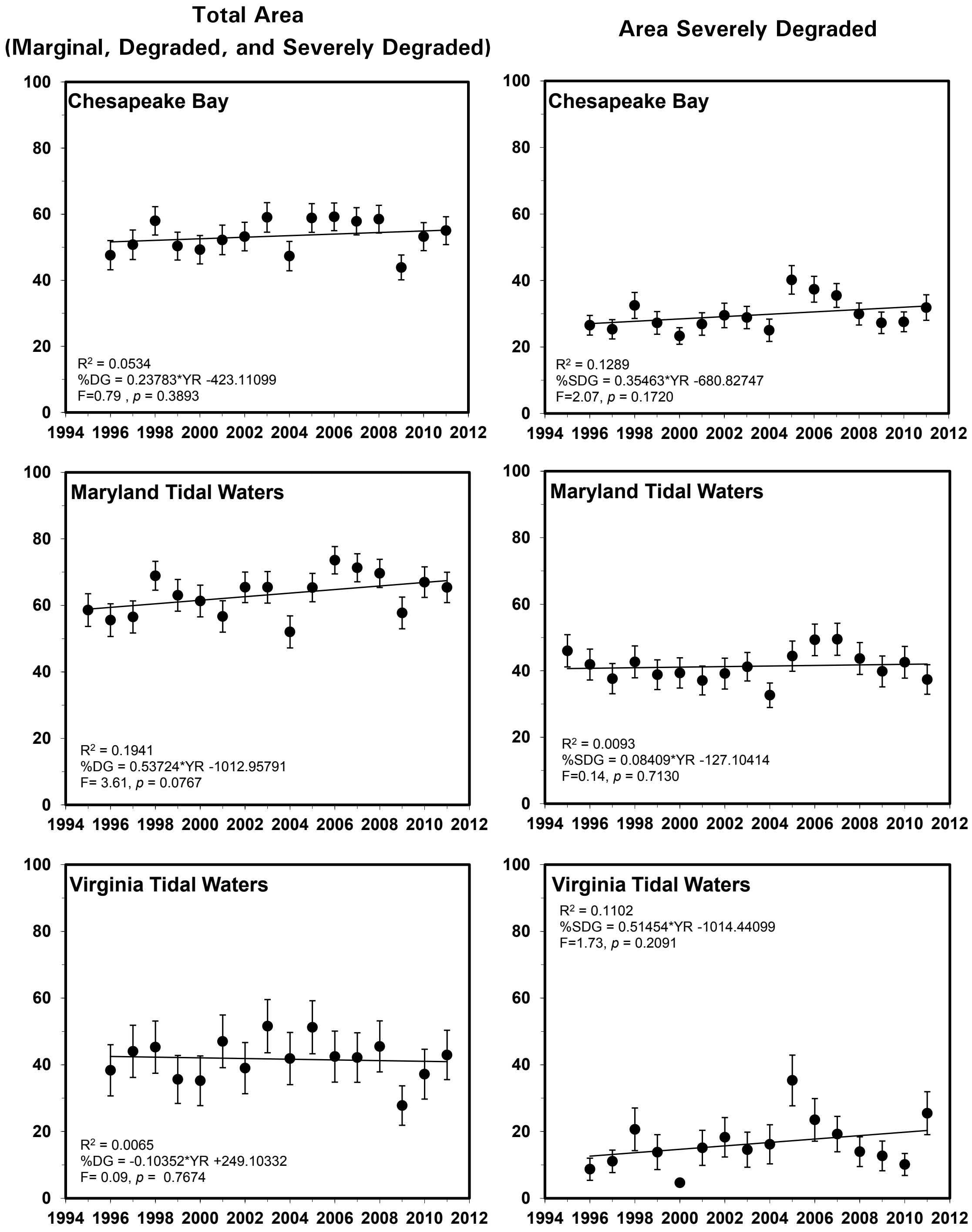


Figure 3-30. Proportion of the Chesapeake Bay, Maryland tidal waters, and Virginia tidal waters failing the Chesapeake Bay benthic community restoration goals, 1996 to 2011 (1995-2011 for Maryland). Panels on left show percent total area degraded (B-IBI < 3.0); panels on right show percent area severely degraded (B-IBI ≤ 2.0). Error bars indicate ± 1 SE. The mainstem deep trough is included in the severely degraded condition estimates.

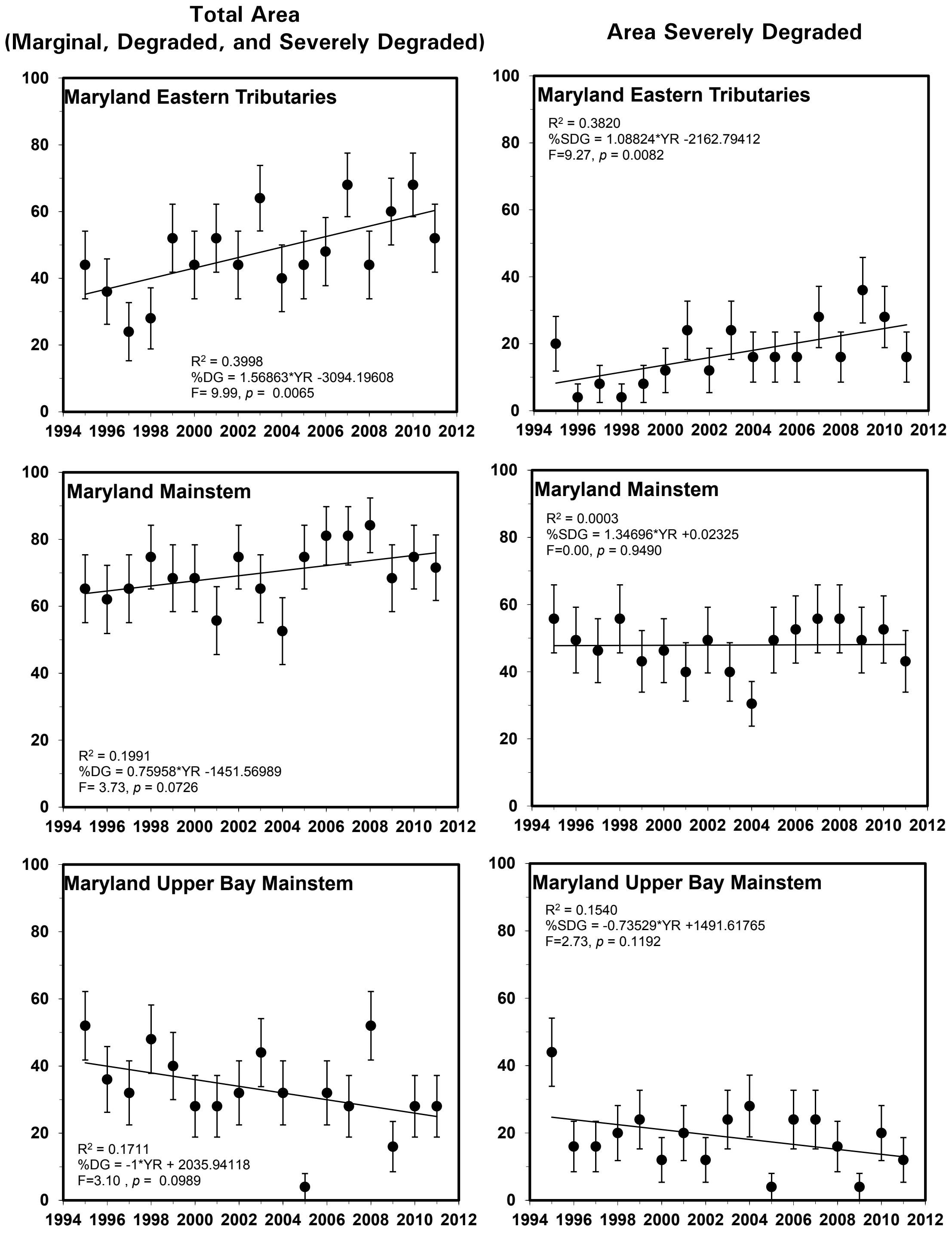


Figure 3-31. Proportion of the Maryland sampling strata failing the Chesapeake Bay benthic community restoration goals, 1995 to 2011. Panels on left show percent total area degraded (B-IBI < 3.0); panels on right show percent area severely degraded (B-IBI ≤ 2.0). Error bars indicate ± 1 SE. The deep trough is included in the Maryland mainstem stratum estimates.

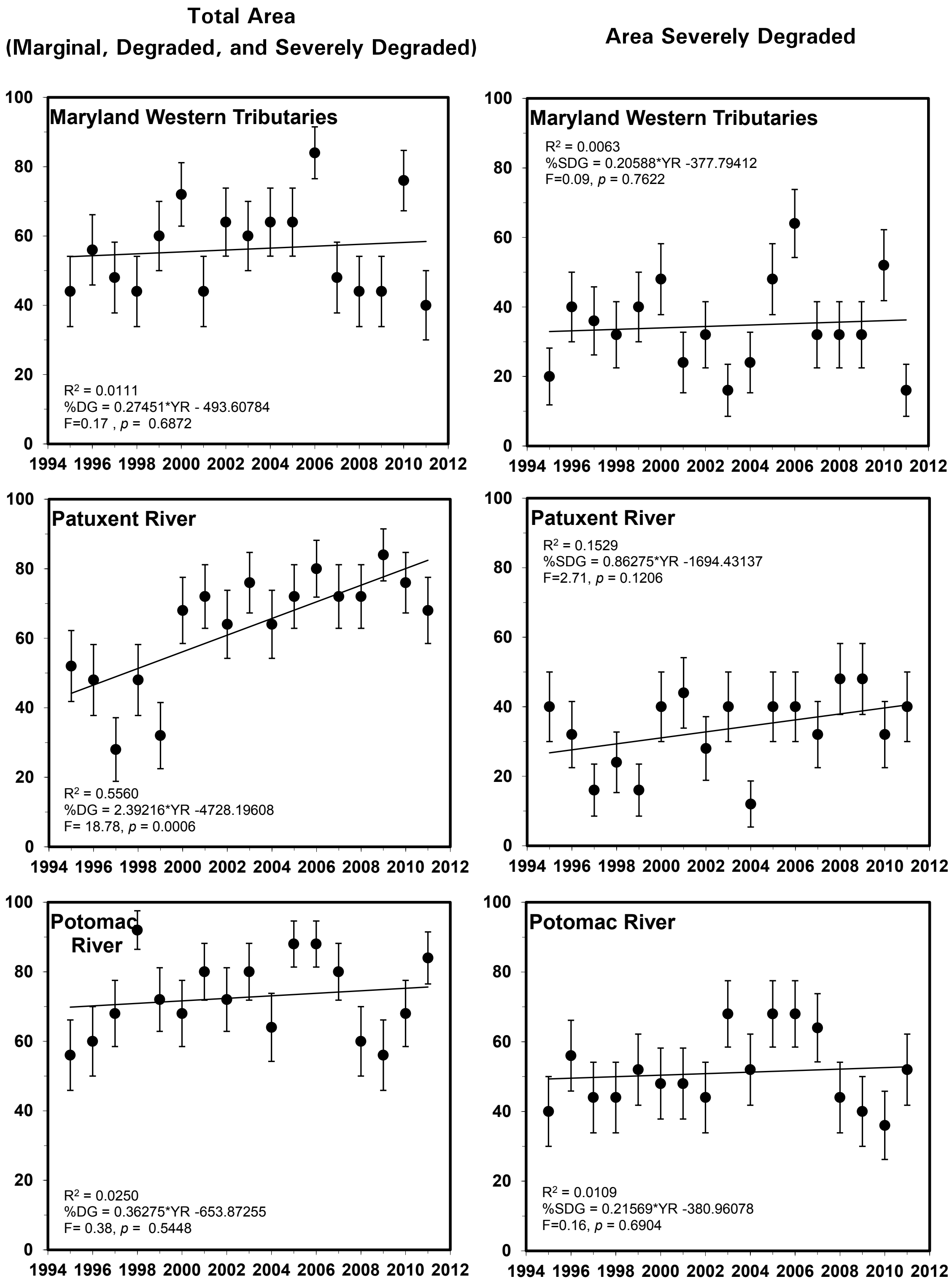
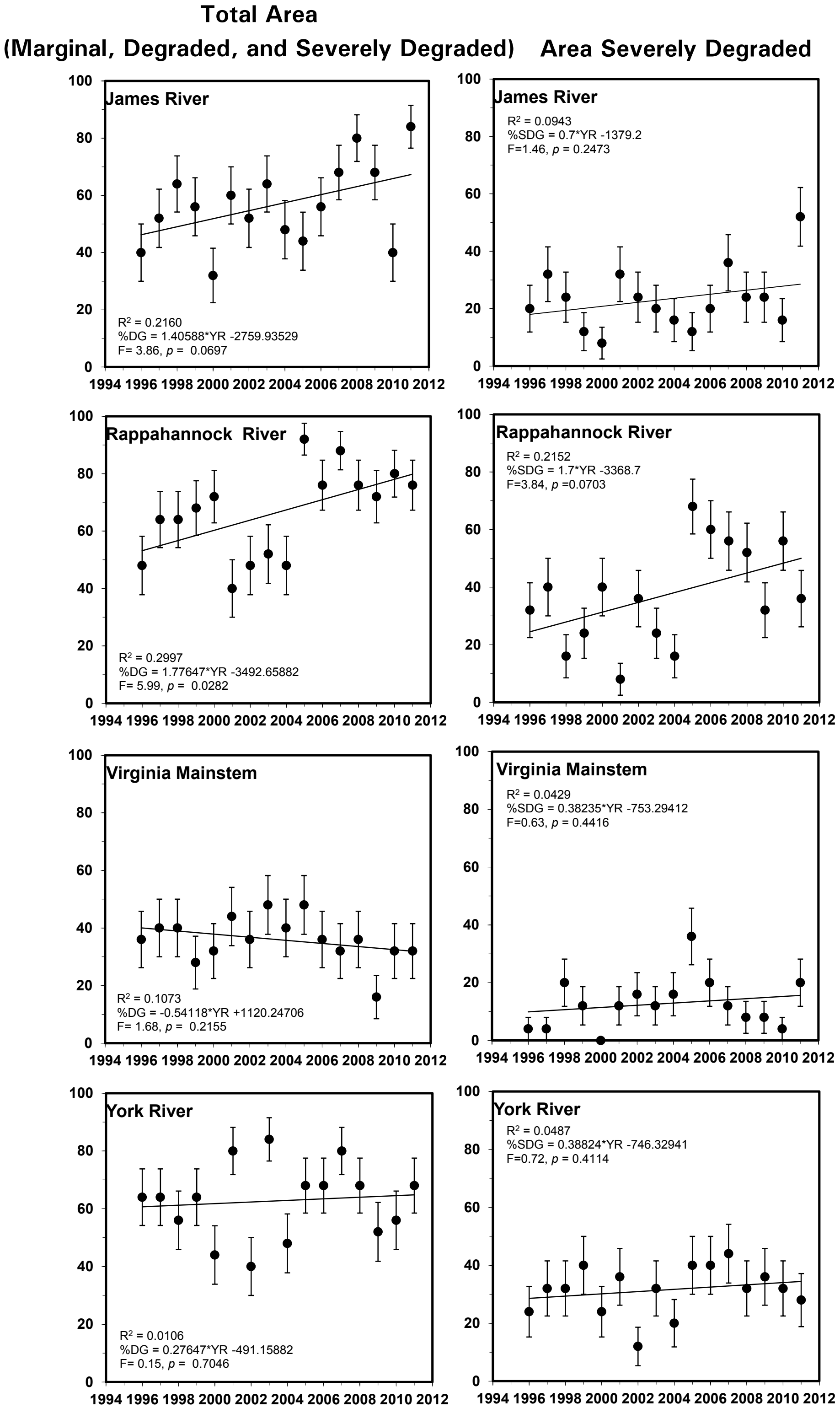


Figure 3-31. (Continued)



Total Area

(Marginal, Degraded, and Severely Degraded)

Area Severely Degraded

Figure 3-32. Proportion of the Virginia sampling strata failing the Chesapeake Bay benthic community restoration goals, 1996 to 2011. 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.

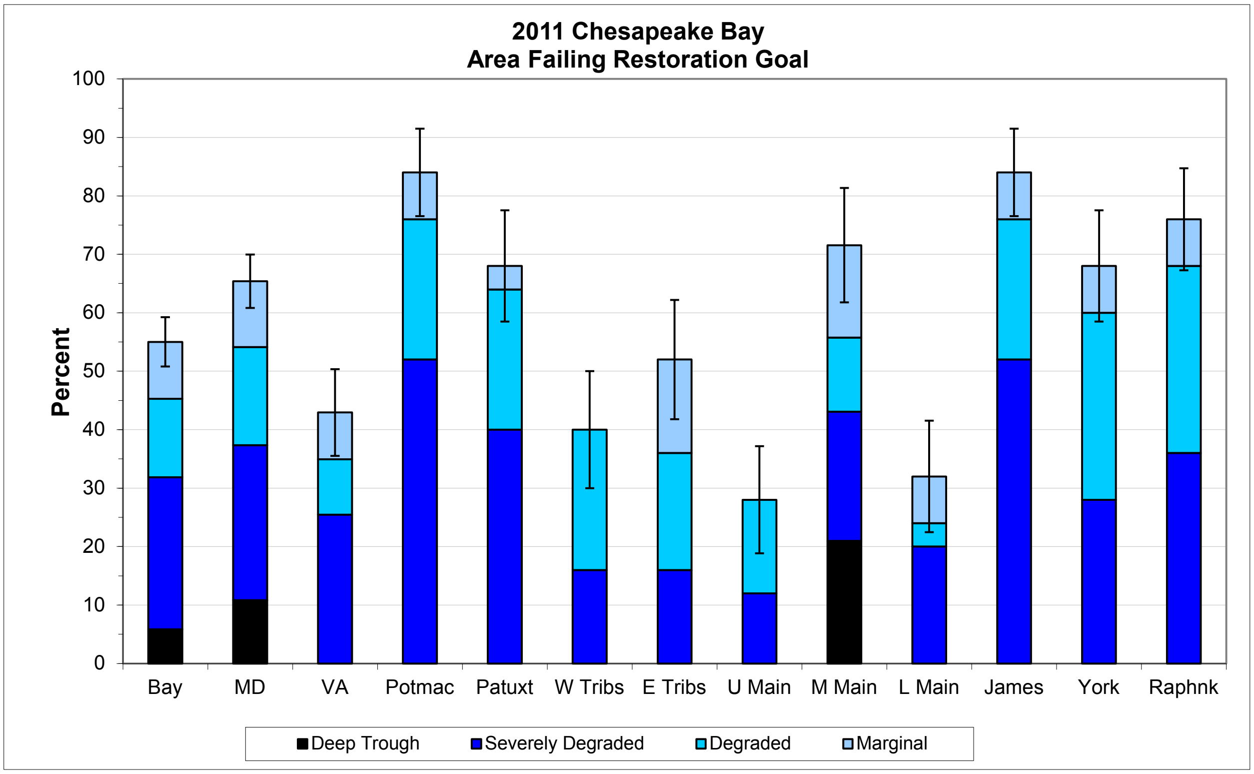


Figure 3-33. Proportion of the Chesapeake Bay, Maryland, Virginia, and the 10 sampling strata failing the Chesapeake Bay benthic community restoration goals in 2011. Error bars indicate ± 1 SE.

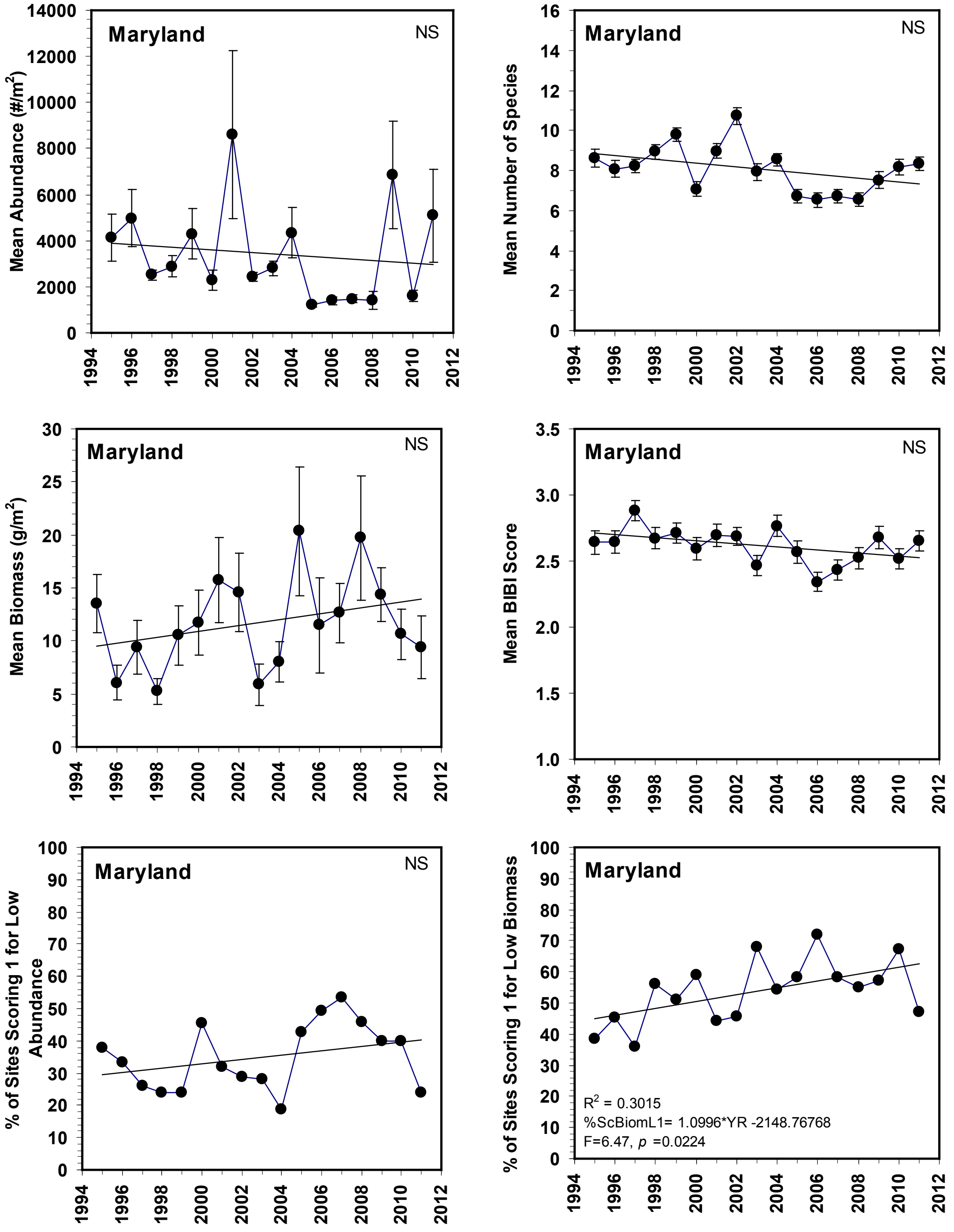


Figure 3-34. Trends in abundance, biomass, number of species, B-IBI (mean ± 1 SE), and percent sites scoring “1” for low abundance/ low biomass in Maryland tidal waters (N = 150 sites per year).

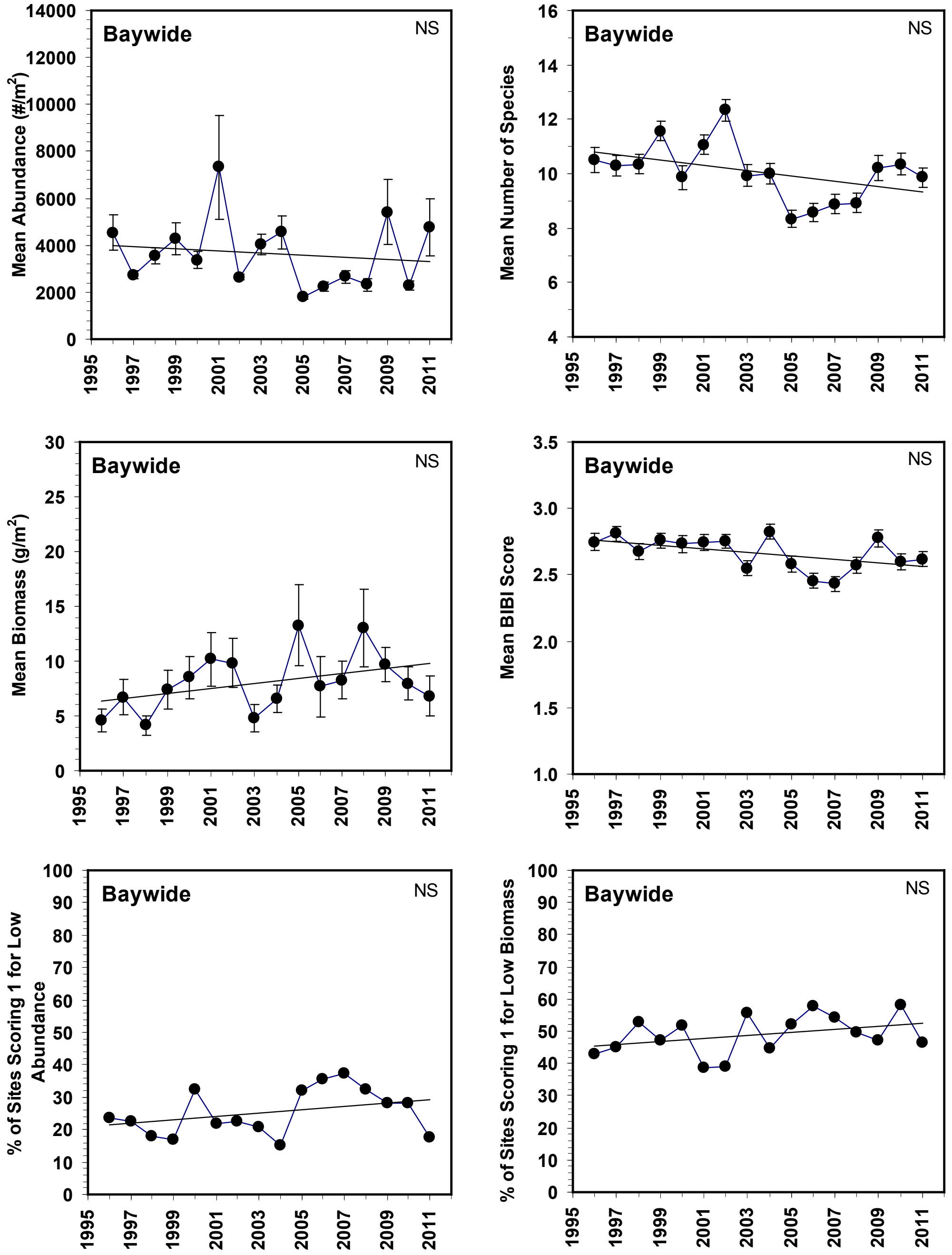


Figure 3-35. Trends in abundance, biomass, number of species, B-IBI (mean ± 1 SE), and percent sites scoring "1" for low abundance/ low biomass in Chesapeake Bay (N=250 sites per year).

3.3 BASIN-LEVEL BOTTOM COMMUNITY CONDITION

Probability-based sampling can be used to produce areal estimates of degradation for regions of interest. The 2011 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 (BHI, Williams et al. 2009). BHI 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.

At the BHI reporting region level, percent area degraded improved substantially (decreased) in 2011 in the Patuxent River, Maryland Upper Eastern Shore tributaries, Choptank River, Maryland Upper and Lower Western Shore tributaries, Patapsco/Back rivers, and Rappahannock River relative to 2010; remained about the same in the Upper Bay and Lower Bay; and increased in the Mid Bay, Maryland Lower Eastern Shore tributaries, and Potomac, York, and James rivers (Table 3-7). Note that the uncertainty associated with the estimates is generally large because of small sample size or poor data coverage in some of the sub-regions. Thus, at the BHI reporting region level, large changes in benthic condition are likely to occur from year to year, and this should be considered when comparing regions and years. The Potomac River change was substantial. All of the lower Potomac River probability-based sites in 2011 failed the B-IBI, and the severely degraded condition increased. If the lower and the upper tidal Potomac River sites are post-stratified, the percent degraded area further increases from 84% to

88%, with both the lower and the upper tidal Potomac River contributing to the increased benthic condition failure in 2011.

Table 3-7. Estimated tidal area failing to meet the Chesapeake Bay benthic community restoration goals in 2011 by Bay Health Index (BHI) Reporting Region and Tributary Strategy Basin. The Elizabeth River Biological Monitoring Program was not conducted in 2011. See Figure 3-36 for reporting regions.

Region/Basin	Percent Failing	Km^2 Failing	SE	N
Elizabeth River	100.0	47	0.0	3
Potomac River	84.0	1,071	7.5	25
James River	81.8	524	8.4	22
Rappahannock River	76.0	283	8.7	25
Mid Bay	82.0	1,504	7.9	15
Maryland Lower Eastern Shore	55.7	828	19.7	18
Patuxent River	68.0	87	9.5	25
York River	68.0	127	9.5	25
Maryland Upper Western Shore	50.0	44	18.9	8
Patapsco/Back Rivers	44.4	49	17.6	9
Choptank River	56.0	241	26.1	8
Maryland Upper Eastern Shore*	40.2	184	26.6	12
Upper Bay	28.0	221	9.2	25
Lower Bay	27.3	848	9.7	22
Maryland Lower Western Shore	25.0	25	16.4	8

*Northeast River not included in regional estimates because of insufficient data.

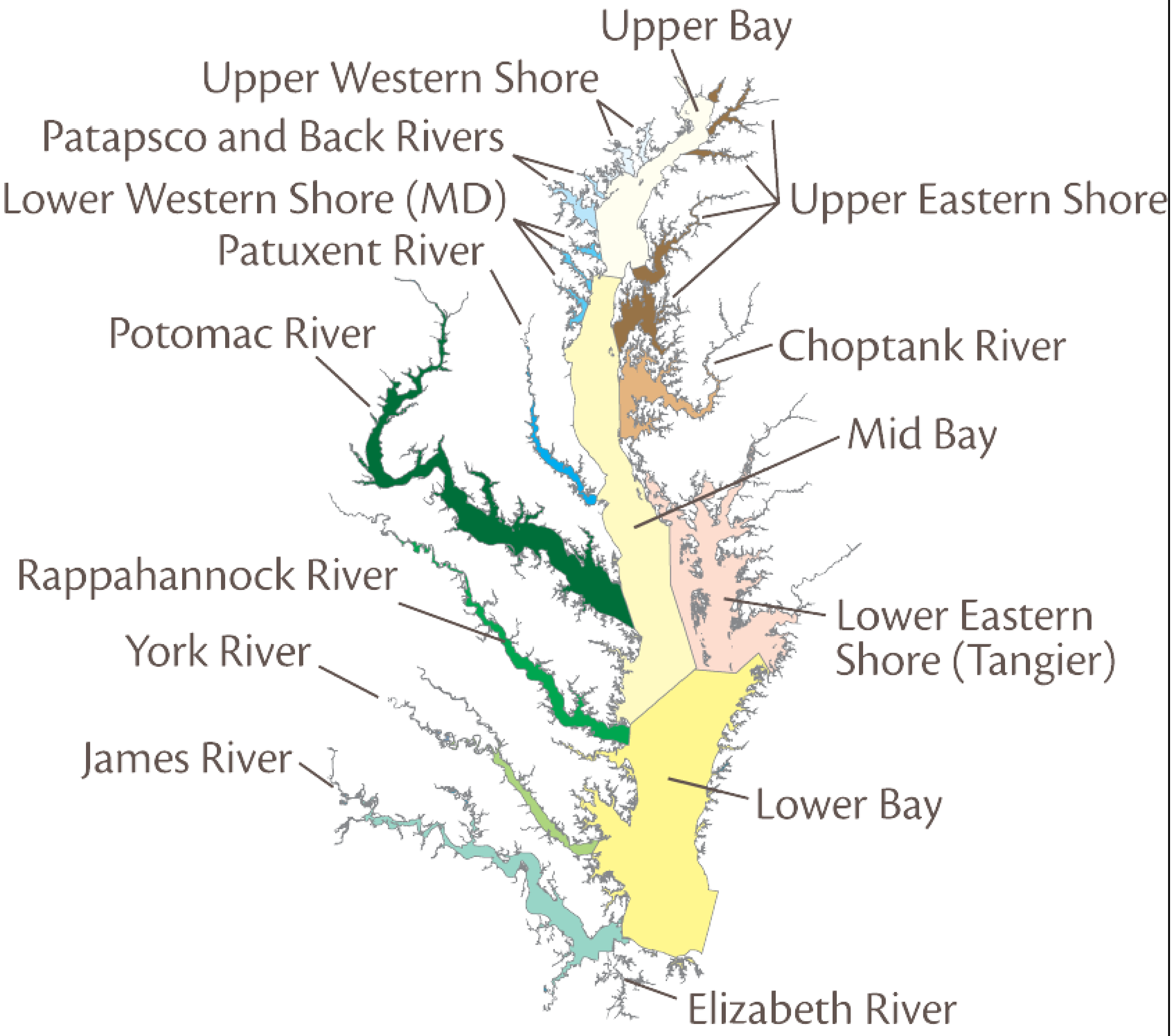


Figure 3-36. Bay Health Index Reporting Regions and Tributary Strategy Basins. Figure courtesy of *EcoCheck*, NOAA-UMCES Partnership.

4.0 DISCUSSION

The highlights for 2011 are: (1) The direction and magnitude of the B-IBI trends at the fixed sites were similar to those reported previously; however, B-IBI scores in 2011 were higher at 13 sites, indicating better overall condition in 2011 than in 2010. (2) The area with degraded benthos in Maryland decreased by 2 percentage points. Although this decrease was within the error margin of the estimate, all of the Maryland strata except for the Potomac River showed either no change or a decrease in percent area degraded, indicating a general improvement in benthic condition in 2011. (3) The Potomac River, Patuxent River, and the Maryland mid-Bay mainstem were the Maryland strata in poorest condition.

In 2011 there were decreases in benthic community degradation in the Maryland Western Tributaries, Maryland Eastern Tributaries, Patuxent River, and Maryland Mainstem, and no change in the Upper Bay Mainstem. Increases in degradation were observed in the York and James rivers, but the Virginia Mainstem exhibited no change. Also, there were no storm effects on benthic condition. Two storms passed over the Chesapeake Bay in 2011, Hurricane Irene on 27 August and Tropical Storm Lee on 7 September. Tropical Storm Lee lowered the salinity of Chesapeake Bay to historical values and increased sediment loads. Salinity was already low in Chesapeake Bay during the summer due to high river flow in spring and early summer. Benthic communities exhibited an increase in the abundance of low-salinity estuarine species. This increase was observed at the fixed sites and resulted in better B-IBI scores in 2011 than in 2010. After the storms, salinity decreased further. However, species composition in areas with the largest changes in salinity remained unaltered relative to the composition of the benthic communities in the same areas in 2010. An increase in the percentage of the organic carbon content of the sediments in 2011 was also observed (Figure 4-1), but this change did not have an effect on benthic condition.

The general improvement in benthic condition observed in the Maryland portion of the Chesapeake Bay and tributaries (except in the Potomac River) in 2011 suggests no immediate effects of Tropical Storm Lee at sites sampled 1-14 days after the storm. High river flow into the Bay in the spring and early summer may have been a factor contributing to better overall benthic community condition, observed through an increase in the abundance and species numbers of the macrofauna. Another contributing factor may have been the disruption of the pycnocline after the passing of Hurricane Irene and increase in the oxygen content of bottom waters. The winds associated with Hurricane Irene mixed the water column and caused low dissolved oxygen conditions to completely disappear from mainstem waters in late summer, except in the mainstem deep trough. Hypoxic conditions in Chesapeake Bay often develop in June and the Bay remains hypoxic throughout the summer, impeding normal recovery of the benthic communities from one year to the next. Although storms accompanied by heavy rain contribute to increased runoff and nutrient inputs that often fuel phytoplankton blooms and end up reducing the oxygen content of the water, these effects are typically more pronounced in early summer.

Mid to late summer storms usually have the beneficial effect of mixing up the water column permitting the replenishment of oxygen in bottom waters.

Comparing conditions in the Maryland southwestern tributaries can be illustrative of differences in benthic condition between 2010 and 2011. There were 10 probability-based sites in the southwestern tributaries in 2010, and 8 sites in 2011. The 8 sites in 2011 had good B-IBI scores, with 6 sites meeting the B-IBI restoration goals and 2 sites in the marginal range. The 10 sites in 2010, however, failed the restoration goals and had very low scores. The number of species was higher in 2011 (mean: 9.6; range: 8-14) than in 2010 (mean: 5.4; range: 0-11), with 6 sites in 2010 with < 5 species, and 1 site azoic. Abundance was higher in 2011 (mean: 3,408; range: 1,590-7,565) than in 2010 (mean: 904; range: 0-3,839), with 6 sites in 2010 with <591 individuals per m^2, which is below restorative thresholds. All systems were well represented in both years: In 2011, the West, South, Severn, and Magothy rivers had 2 sites each; in 2010 the Rhode River had 1 site, the South and Severn rivers had 4 sites each, and the Magothy had 1 site. Water depth at the sampling sites was similar in 2011 (range: 0.4-4.3 m) and 2010 (range: 0.7-5.8 m), except for 1 site in 2010 (10 m). Sites were sampled at about the same time of the year (23 August 2011 and 25 August 2010) and site distribution was comparable in both years. Bottom dissolved oxygen, however, was higher in 2011 (range: 5.7-8.8 ppm) than in 2010 (range: 0.9-6.4 ppm). The location, water depth, and bottom type of the sites were similar in both years, yet macrofaunal abundance, species numbers, and dissolved oxygen concentrations were lower in 2010. Good dissolved oxygen conditions prevailed in the southwestern tributaries in 2011 even before the arrival of Hurricane Irene on 27 August.

Llansó et al. (2011) suggested that pulses in river flow following severe spring rain events contribute to poor benthic community condition in late summer in the tributaries and main stem of the Bay, based on GLM analysis results. Although river flow was high in the spring and early summer of 2011, dry conditions followed by one storm event were not observed; rather, multiple events contributed to sustained high river flow, and these conditions may have been more favorable to benthic community recruitment processes in the Bay.

All of the Potomac River sites were sampled after Hurricane Irene, yet 100% of the lower Potomac tidal bottom area failed the restoration goals in 2011. The lower Potomac River is typically anoxic during the summer, and it is unlikely that such degraded system would have recovered in one season. The prevalence of severely degraded benthic conditions in the lower Potomac River coincided with unusually degraded conditions in the upper oligohaline and tidal freshwater portions of the river. It is uncertain which factors contribute to benthic condition in the upper Potomac River; however, at Station 36 (Rosier Bluff), there is a decreasing trend in the abundance of *Corbicula fluminea*, a bivalve which is scored positively by the B-IBI, and an increasing trend in the abundance of oligochaeta, which are considered indicative of pollution in tidal freshwater systems.

The improvements in Chesapeake Bay in 2011 were not substantial. Over half of the Chesapeake Bay tidal waters (55%) exhibited degraded benthic condition. Over the 1995-2011 time series there were statistically significant degrading trends in the Patuxent River and the Maryland Eastern Tributaries, which continued from previous years. The 2011 results, however, suggest that benthic communities in the Chesapeake Bay are very dynamic over short periods of time, and are likely to recover quickly with pollution abatement as conditions improve.

Recently, we conducted a study in collaboration with Old Dominion University and the Virginia Institute of Marine Science (Dauer et al. 2011) that evaluated secondary productivity as indicator of the ecological value of the benthos to higher trophic levels in Chesapeake Bay. Benthic production estimates were calculated using the methods of Brey (2001) for estimating P/B ratios based on mean body mass per individual, sample depth, and sample temperature. Secondary production estimates were generated at three spatial scales: (1) the seven B-IBI Weisberg et al. (1997) habitat types, (2) the ten benthic sampling strata of the monitoring program, and (3) the 73 Chesapeake Bay Program segments that are used as management tool to report overall condition in specific regions of the Bay (303d reporting). Standing crop values per sample were assumed to be representative of one year of benthic community biomass so that the resultant productivity estimates could be expressed in units of gC/m^2/yr for each species. Results indicated that high secondary productivity can be associated with low B-IBI levels characterized as severely degraded (BIBI $\leq$ 2.0) as well as with high B-IBI values considered undegraded (BIBI $\geq$ 3.0). The former occurred in stressed systems dominated by large numbers of small polychaetes with high turnover ratios, such as the Elizabeth River. The latter occurred in systems dominated by bivalve species of high biomass, such as the upper reaches of tributaries. At the strata level, benthic secondary productivity varied widely, but the highest estimates were for the Upper Bay Mainstem, while the lowest estimates were for the Patuxent River (Figure 4-2). Again, the Patuxent River emerged as an impacted system with very low secondary production values.

Low rates of benthic production were associated with low levels of dissolved oxygen, more clearly in the lower Potomac River. In the Potomac River mesohaline segment (POTMH), very low bottom dissolved oxygen levels occur each summer, especially at depths > 5 m. Benthic secondary productivity was by far highest at depths shallower than 5 m, and below this depth production declined from 243 gC/m^2/yr to 5 gC/m^2/yr in water depths > 20 m. The percentage of azoic samples (no benthos found) increased with depth with over 70% of the benthic samples in > 20 m being azoic.

The study by Dauer et al. (2011) clearly illustrates a relationship between low dissolved oxygen and low secondary production, but the relationship between benthic community condition as measured by the B-IBI and rates of benthic secondary productivity is not simple. High levels of benthic secondary productivity can be driven by very high abundances of small polychaetes which can dominate benthic communities under eutrophic conditions. The next steps in using benthic secondary production estimates will be to develop a protocol to reflect the actual availability of the benthic production to higher trophic levels. Important ecological factors that will be considered are: (1) protective coverings such as molluscan shells and crustacean exoskeletons that reduce predation, (2) depth of dwelling within the sediment that might provide a refuge from predation, (3) body size factors that affect strength of protective coverings and/or age-related sediment depth dwelling location, and (4) general behaviors that can modify susceptibility to predation, e.g. rapid motility.

The results presented in the present 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 classifiation 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.

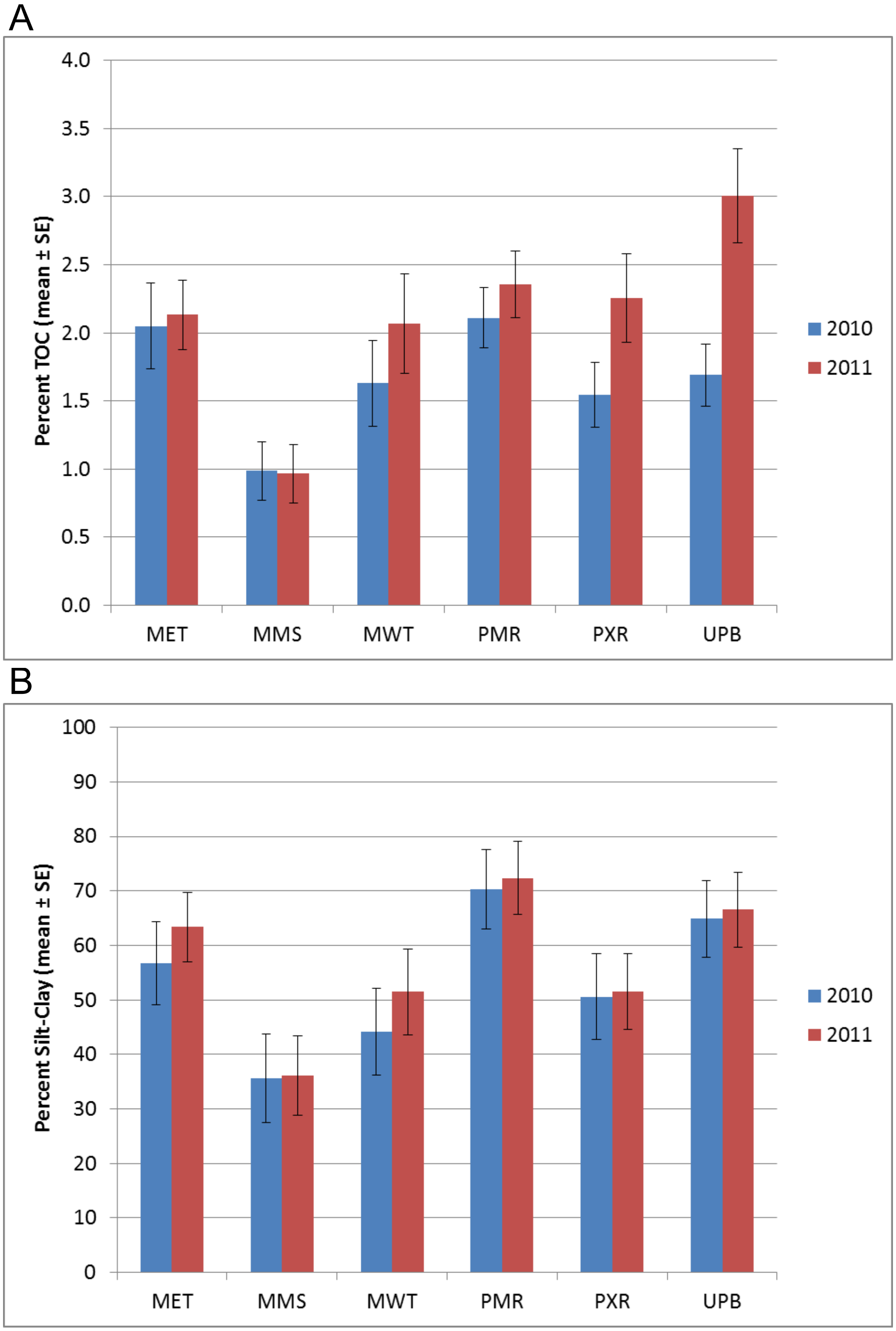


Figure 4-1. Sediment samples collected after Tropical Storm Lee indicated that the Upper Bay (UPB), Maryland Western Tributaries (MWT), and the Patuxent River (PXR) had higher concentrations of total organic carbon (TOC) in sediments in 2011 than in 2010 (A), while silt-clay content did not change significantly (B).

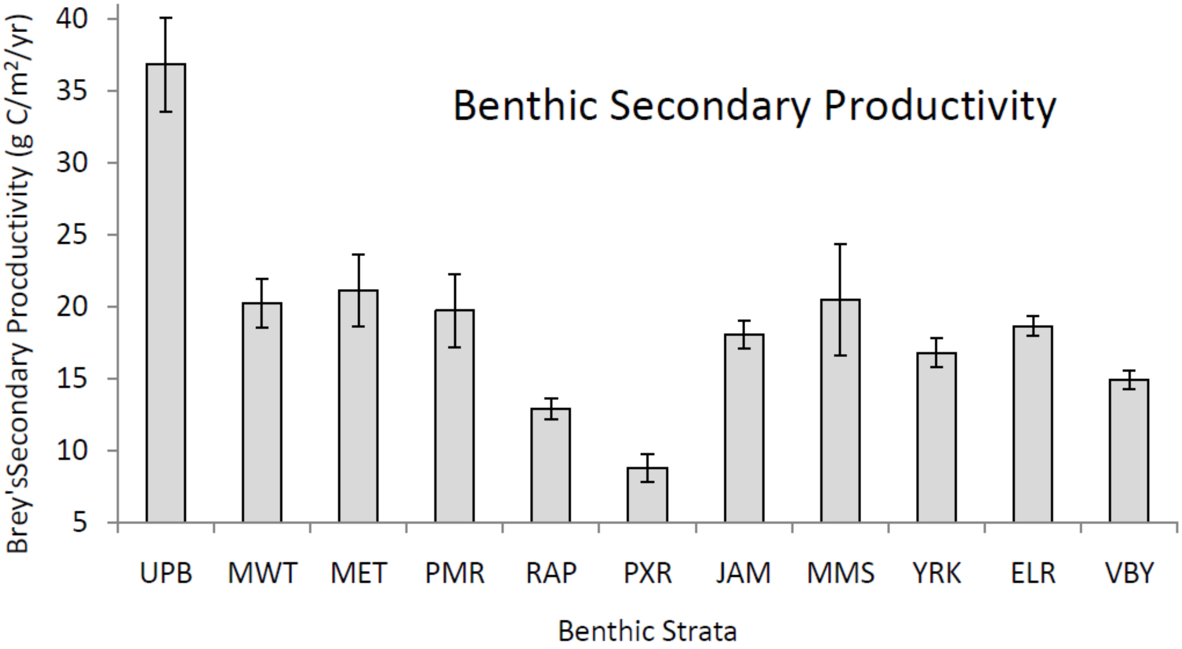


Figure 4-2. Mean secondary production by benthic program strata, 1996-2009. Error bar indicates +/- 1 Standard Error. ELR = Elizabeth River. The Patuxent River (PXR) emerged as a highly degraded system with very low secondary production values.

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APPENDIX A

FIXED SITE COMMUNITY ATTRIBUTE 1985-2011 TREND ANALYSIS RESULTS

Appendix Table A-1. Summer trends in benthic community attributes at mesohaline stations 1985-2011. Shown is the median slope of the trend. Monotonic trends were identified using the van Belle and Hughes (1984) procedure. (a): trends based on 1989-2011 data; (b): trends based on 1995-2011 data; (c): attribute trend based on 1990-2011 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	-76.9231	-0.9073	-0.0057	0.2451	-0.9870 (d)	0.0234 (e)	-1.8058	-0.1492 (e)
44	-0.0348	-35.0000	-0.0749	-0.0038	-0.2717	-0.3222 (d)	0.0000 (e)	-0.4729	0.5952 (e)
47	0.0000	-63.3333	-0.9850	0.0027	0.1634	-1.2872 (d)	0.0175 (e)	-1.5940	-0.1156 (e)
51	0.0000	-30.7692	-0.0996	-0.0031	-0.7744	0.1015	0.0492 (e)	-0.9345 (e)	0.0059
52	0.0000	-3.6888	-0.0001	-0.0000	0.0000 (d)	0.0000 (d)	0.0000	0.0000	0.0000
Patuxent River									
71	-0.0333	-43.9583	-0.0358	-0.0272	-0.5226 (d)	-0.1157 (d)	0.4441	0.0000	0.0000
74	0.0000	-13.8000	-1.2203	-0.0049	0.0227	-0.5769 (d)	-0.0017 (e)	-0.2445	-0.2582 (e)
77	-0.0364	-3.0556	-0.0793	0.0069	0.3327	-0.2465 (d)	-1.0907 (e)	0.4001	-0.5034 (e)
Choptank River									
64	0.0175	-20.0000	0.0512	0.0121	-0.4213 (d)	0.6779 (d)	-0.0002	-0.4500	0.5681
Maryland Mainstem									
01	0.0000	-36.3636	-0.0190	-0.0079	-0.2129	-0.2326	-0.0081 (e)	-0.2747 (e)	-0.5018
06	0.0000	17.1429	0.0092	-0.0209	-0.0281	-0.5515	0.0554 (e)	-1.3779 (e)	-0.7246
15	0.0000	0.0000	-0.0297	0.0011	-0.4964	0.0339	0.0306 (e)	-0.4645 (e)	0.1059
24	0.0000	-19.2857	0.0039	-0.0335	-0.5510 (d)	0.1941 (d)	-0.0042	0.1783	0.5079
26	0.0222	-1.8637	-0.3919	0.0095	0.0000	-0.0748 (d)	0.0000 (e)	-0.0220	0.1962 (e)
Maryland Western Shore Tributaries									
22	-0.0400	-51.9565	-0.0212	-0.0586	1.8688	0.0000 (d)	0.6802 (e)	-0.0000	-0.3671 (e)
23	0.0000	-74.3019	0.0102	-0.0086	-0.3030	0.9259 (d)	-0.0346 (e)	0.8255	0.3179 (e)
201(a)	0.0000	-9.9999	0.0009	0.0000	0.0000	0.0000 (d)	0.0000 (e)	0.0000	-0.0000 (e)
202(a)	-0.0000	-27.2727	-0.0003	0.0000	0.0000	0.0000 (d)	0.0000 (e)	0.0000	-0.0000 (e)
204(b)	-0.0208	-68.1600	-0.1069	0.0071	0.4698 (d)	0.0272 (d)	0.0156	-1.0805	-0.0841
Maryland Eastern Shore Tributaries									
62	-0.0444	96.0000	-0.0383	-0.0398	0.0000	-0.4269 (d)	0.0402 (e)	-2.0240	-0.2609 (e)
68	0.0000	44.2211	0.3158	-0.0106	0.0231	0.2415 (d)	0.0013 (e)	-0.0163	-0.0568 (e)

Appendix Table A-2. Summer trends in benthic community attributes at oligohaline and tidal freshwater stations 1985-2011. Shown is the median slope of the trend. Monotonic trends were identified using the van Belle and Hughes (1984) procedure. (a): trends based on 1989-2011 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	-0.0238	30.4549	0.0199	0.8029	NA	NA	NA	0.5821	NA
40	0.0050	2.3529	-0.0152	NA	-0.1176	0.0392	-0.0000	NA	0.0000
Patuxent River									
79	0.0000	8.3370	-0.0097	-0.4167	NA	NA	NA	-0.0068	NA
Choptank River									
66	0.0000	11.1027	0.0565	NA	0.5148	0.0000	0.0000	NA	0.0587
Maryland Western Shore Tributaries									
203(a)	0.0556	18.1447	-0.0418	NA	0.0000	0.0000	2.2539	NA	2.4408
Maryland Eastern Shore Tributaries									
29	0.0000	-21.2724	-0.0114	NA	-0.5978	-0.0161	0.0000	NA	0.1397

APPENDIX B

FIXED SITE B-IBI VALUES, SUMMER 2011

Appendix Table B-1. Fixed site B-IBI values, Summer 2011

Station	Sampling Date	Latitude (WGS84 Decimal Degrees)	Longitude (WGS84 Decimal Degrees)	B-IBI	Status
001	8/26/2011	38.41905	-76.4184	2.22	Degraded
006	8/26/2011	38.44199	-76.4442	2.78	Marginal
015	8/26/2011	38.71515	-76.5138	3.11	Meets Goal
022	8/22/2011	39.25808	-76.5951	1.00	Severely Degraded
023	8/22/2011	39.20816	-76.5235	3.40	Meets Goal
024	9/8/2011	39.12215	-76.3554	2.56	Degraded
026	9/8/2011	39.27147	-76.2899	4.47	Meets Goal
029	8/29/2011	39.47952	-75.9449	1.89	Severely Degraded
036	9/20/2011	38.76984	-77.0375	2.50	Degraded
040	9/1/2011	38.35743	-77.2305	3.67	Meets Goal
043	9/19/2011	38.38446	-76.9884	3.00	Meets Goal
044	9/1/2011	38.38566	-76.9958	1.27	Severely Degraded
047	9/19/2011	38.3638	-76.9837	3.13	Meets Goal
051	9/19/2011	38.20528	-76.7394	2.56	Degraded
052	9/1/2011	38.19233	-76.7477	1.00	Severely Degraded
062	9/13/2011	38.38398	-75.8499	2.60	Degraded
064	9/7/2011	38.59048	-76.0693	3.56	Meets Goal
066	9/12/2011	38.80151	-75.922	3.00	Meets Goal
068	8/24/2011	39.13246	-76.0785	3.80	Meets Goal
071	9/6/2011	38.39503	-76.5489	1.56	Severely Degraded
074	9/6/2011	38.54888	-76.6761	3.53	Meets Goal
077	9/16/2011	38.60444	-76.675	2.87	Marginal
079	9/16/2011	38.75024	-76.689	3.17	Meets Goal
201	8/22/2011	39.23413	-76.4975	1.53	Severely Degraded
202	8/22/2011	39.21778	-76.5642	1.27	Severely Degraded
203	8/22/2011	39.27496	-76.4444	2.89	Marginal
204	8/23/2011	39.0069	-76.5047	3.33	Meets Goal

APPENDIX C

RANDOM SITE B-IBI VALUES, SUMMER 2011

Appendix Table C-1. Random site B-IBI values, Summer 2011

Station	Sampling Date	Latitude (WGS84 Decimal Degrees)	Longitude (WGS84 Decimal Degrees)	B-IBI	Status
MET-18401	9/13/2011	38.054755	-75.82110501	2.67	Marginal
MET-18402	9/13/2011	38.05725334	-75.81090834	2.67	Marginal
MET-18403	9/13/2011	38.05984334	-75.85357001	2.67	Marginal
MET-18404	9/13/2011	38.13504834	-75.83883001	2.00	Severely Degraded
MET-18405	9/13/2011	38.14349834	-75.89379834	1.67	Severely Degraded
MET-18406	9/13/2011	38.281575	-75.93910667	3.67	Meets Goal
MET-18407	9/13/2011	38.29349	-75.91371667	2.00	Severely Degraded
MET-18408	9/13/2011	38.29904834	-75.92770167	2.33	Degraded
MET-18409	9/13/2011	38.30979334	-75.90222667	2.67	Marginal
MET-18410	9/14/2011	38.48550334	-75.81718334	2.33	Degraded
MET-18411	9/7/2011	38.60488333	-76.09826667	3.80	Meets Goal
MET-18412	9/7/2011	38.60886667	-76.14458333	3.40	Meets Goal
MET-18413	9/7/2011	38.61861667	-76.1274	3.80	Meets Goal
MET-18414	9/7/2011	38.63185	-75.98541667	2.20	Degraded
MET-18415	9/7/2011	38.6349	-76.14378333	4.20	Meets Goal
MET-18416	8/24/2011	38.98455834	-76.24674501	3.00	Meets Goal
MET-18418	8/24/2011	39.1197	-76.10030001	3.40	Meets Goal
MET-18419	8/24/2011	39.13213	-76.17876334	2.60	Degraded
MET-18420	8/24/2011	39.15912167	-76.07234167	3.80	Meets Goal
MET-18421	8/29/2011	39.37706834	-76.03862501	3.33	Meets Goal
MET-18422	8/29/2011	39.50904667	-75.92599334	2.60	Degraded
MET-18423	8/29/2011	39.515035	-75.87755001	1.67	Severely Degraded
MET-18424	8/29/2011	39.52002334	-75.87439334	3.33	Meets Goal
MET-18425	8/29/2011	39.55416334	-75.86744001	3.33	Meets Goal
MET-18426	8/29/2011	39.36849334	-76.03452834	4.00	Meets Goal
MMS-18501	9/14/2011	37.928515	-75.78088167	2.67	Marginal
MMS-18502	9/14/2011	37.95423667	-75.78052834	2.67	Marginal
MMS-18503	9/2/2011	37.95916667	-75.96575	3.67	Meets Goal
MMS-18504	9/2/2011	38.02775	-75.97445	4.00	Meets Goal
MMS-18505	9/2/2011	38.0406	-76.1113	3.33	Meets Goal
MMS-18506	9/2/2011	38.05241667	-75.9656	2.67	Marginal
MMS-18507	9/2/2011	38.07088333	-76.29025	2.00	Severely Degraded
MMS-18508	9/2/2011	38.08133333	-76.29641667	2.33	Degraded
MMS-18509	9/2/2011	38.1858	-76.16258333	1.00	Severely Degraded
MMS-18510	9/2/2011	38.22728333	-76.22828333	2.67	Marginal
MMS-18511	9/2/2011	38.35021667	-76.29961667	2.33	Degraded
MMS-18512	9/22/2011	38.39926667	-76.28303333	3.33	Meets Goal
MMS-18513	8/26/2011	38.46403167	-76.44722334	1.00	Severely Degraded

Appendix Table C-1. (Continued)

Station	Sampling Date	Latitude (WGS84 Decimal Degrees)	Longitude (WGS84 Decimal Degrees)	B-IBI	Status
MMS-18514	9/12/2011	38.49655834	-76.26440167	1.67	Severely Degraded
MMS-18515	9/7/2011	38.598	-76.38963333	2.33	Degraded
MMS-18516	9/7/2011	38.62313333	-76.34318333	1.00	Severely Degraded
MMS-18517	8/26/2011	38.63611834	-76.46734	1.00	Severely Degraded
MMS-18518	8/26/2011	38.66356834	-76.52154834	4.00	Meets Goal
MMS-18519	9/7/2011	38.66845	-76.32966667	2.00	Severely Degraded
MMS-18520	9/7/2011	38.68643333	-76.35751667	2.33	Degraded
MMS-18521	9/7/2011	38.7237	-76.37776667	3.33	Meets Goal
MMS-18522	9/12/2011	38.73025334	-76.20226834	3.67	Meets Goal
MMS-18523	9/12/2011	38.78913667	-76.13140834	3.33	Meets Goal
MMS-18524	9/7/2011	38.86961667	-76.32738333	2.67	Marginal
MMS-18525	8/23/2011	38.89356834	-76.44042501	3.80	Meets Goal
MWT-18301	8/23/2011	38.83679834	-76.52562501	3.40	Meets Goal
MWT-18302	8/23/2011	38.85796667	-76.52350334	3.40	Meets Goal
MWT-18303	8/23/2011	38.93460001	-76.53833667	3.00	Meets Goal
MWT-18304	8/23/2011	38.94056834	-76.52000334	2.60	Degraded
MWT-18305	8/23/2011	39.02359	-76.53263834	3.40	Meets Goal
MWT-18306	8/23/2011	39.06877834	-76.48064667	3.00	Meets Goal
MWT-18307	8/23/2011	39.08507667	-76.51890167	3.00	Meets Goal
MWT-18308	8/22/2011	39.13886501	-76.52288001	1.40	Severely Degraded
MWT-18309	8/22/2011	39.17158334	-76.47445501	2.60	Degraded
MWT-18310	8/22/2011	39.183655	-76.52313	2.60	Degraded
MWT-18311	8/22/2011	39.187385	-76.48371501	3.80	Meets Goal
MWT-18312	8/22/2011	39.24103667	-76.55794001	1.00	Severely Degraded
MWT-18313	8/22/2011	39.24531334	-76.41902001	3.00	Meets Goal
MWT-18314	8/22/2011	39.26507667	-76.47533167	3.67	Meets Goal
MWT-18315	8/22/2011	39.28459667	-76.40075834	3.00	Meets Goal
MWT-18316	8/22/2011	39.29276167	-76.47490334	3.50	Meets Goal
MWT-18318	9/17/2011	39.33291334	-76.312255	3.40	Meets Goal
MWT-18319	9/17/2011	39.34815834	-76.23575501	4.20	Meets Goal
MWT-18320	9/17/2011	39.35721667	-76.323	2.60	Degraded
MWT-18321	9/17/2011	39.365285	-76.27144834	2.20	Degraded
MWT-18322	9/17/2011	39.36690667	-76.31034667	1.80	Severely Degraded
MWT-18323	9/17/2011	39.37645667	-76.37424834	3.50	Meets Goal
MWT-18324	9/17/2011	39.38953834	-76.33736834	3.67	Meets Goal
MWT-18325	8/30/2011	39.464795	-76.23351	1.67	Severely Degraded
MWT-18326	8/23/2011	39.00946667	-76.51744334	2.60	Degraded
PMR-18101	9/2/2011	38.00603333	-76.38651667	1.00	Severely Degraded

Appendix Table C-1. (Continued)

Station	Sampling Date	Latitude (WGS84 Decimal Degrees)	Longitude (WGS84 Decimal Degrees)	B-IBI	Status
PMR-18103	9/2/2011	38.06423333	-76.45545	1.00	Severely Degraded
PMR-18104	9/2/2011	38.06598333	-76.44908333	1.00	Severely Degraded
PMR-18105	9/2/2011	38.10886667	-76.45338333	1.00	Severely Degraded
PMR-18106	9/2/2011	38.11646667	-76.49168333	2.00	Severely Degraded
PMR-18107	9/1/2011	38.12098333	-76.54533333	1.00	Severely Degraded
PMR-18108	9/1/2011	38.19205	-76.62105	1.00	Severely Degraded
PMR-18109	9/1/2011	38.19946667	-76.72926667	1.00	Severely Degraded
PMR-18110	9/19/2011	38.227945	-76.78677667	2.60	Degraded
PMR-18111	9/1/2011	38.23928333	-76.94378333	1.00	Severely Degraded
PMR-18112	9/1/2011	38.319	-76.9876	1.00	Severely Degraded
PMR-18114	9/1/2011	38.34031667	-77.23585	3.00	Meets Goal
PMR-18115	9/1/2011	38.37555	-77.08858333	2.60	Degraded
PMR-18116	9/1/2011	38.3773	-77.07293333	3.00	Meets Goal
PMR-18117	9/19/2011	38.382145	-77.15497001	2.67	Marginal
PMR-18118	9/19/2011	38.38498667	-76.87572001	1.40	Severely Degraded
PMR-18119	9/19/2011	38.401205	-77.04925334	2.60	Degraded
PMR-18120	9/1/2011	38.40783333	-77.06151667	1.80	Severely Degraded
PMR-18121	9/1/2011	38.4336	-77.04681667	3.40	Meets Goal
PMR-18122	9/1/2011	38.44228333	-77.04045	2.60	Degraded
PMR-18123	9/1/2011	38.48066667	-77.30953333	2.67	Marginal
PMR-18124	9/1/2011	38.4888	-77.27965	4.00	Meets Goal
PMR-18125	9/20/2011	38.64155167	-77.12233501	2.50	Degraded
PMR-18126	9/2/2011	38.1335	-76.44433333	1.00	Severely Degraded
PMR-18127	9/1/2011	38.46006667	-77.28036667	2.60	Degraded
PXR-18201	9/2/2011	38.3307	-76.44355	1.00	Severely Degraded
PXR-18202	9/2/2011	38.34296667	-76.50198333	2.00	Severely Degraded
PXR-18203	9/6/2011	38.3889	-76.54391667	2.60	Degraded
PXR-18204	9/20/2011	38.38946334	-76.54947167	1.67	Severely Degraded
PXR-18205	9/6/2011	38.3915	-76.5258	2.67	Marginal
PXR-18206	9/6/2011	38.39831667	-76.51541667	2.33	Degraded
PXR-18207	9/6/2011	38.40455	-76.48516667	1.00	Severely Degraded
PXR-18208	9/6/2011	38.40906667	-76.57645	1.00	Severely Degraded
PXR-18209	9/6/2011	38.41388333	-76.58176667	2.00	Severely Degraded
PXR-18210	9/6/2011	38.41843333	-76.56773333	3.00	Meets Goal
PXR-18211	9/6/2011	38.42403333	-76.58565	1.40	Severely Degraded
PXR-18212	9/6/2011	38.44505	-76.62078333	2.60	Degraded
PXR-18213	9/6/2011	38.4451	-76.61108333	3.40	Meets Goal
PXR-18214	9/20/2011	38.45097334	-76.65053334	2.20	Degraded

Appendix Table C-1. (Continued)

Station	Sampling Date	Latitude (WGS84 Decimal Degrees)	Longitude (WGS84 Decimal Degrees)	B-IBI	Status
PXR-18215	9/20/2011	38.45980167	-76.66256667	2.60	Degraded
PXR-18216	9/20/2011	38.46478667	-76.59836667	1.80	Severely Degraded
PXR-18217	9/6/2011	38.47271667	-76.64925	3.00	Meets Goal
PXR-18218	9/6/2011	38.48251667	-76.66493333	3.40	Meets Goal
PXR-18219	9/6/2011	38.48436667	-76.6732	3.80	Meets Goal
PXR-18220	9/6/2011	38.51925	-76.66893333	2.60	Degraded
PXR-18221	9/16/2011	38.65561667	-76.68582334	1.67	Severely Degraded
PXR-18222	9/16/2011	38.67386667	-76.69376001	1.00	Severely Degraded
PXR-18223	9/16/2011	38.68276501	-76.69627667	3.00	Meets Goal
PXR-18224	9/16/2011	38.76812167	-76.70056167	3.00	Meets Goal
PXR-18225	9/16/2011	38.77450334	-76.71252001	3.00	Meets Goal
UPB-18601	8/23/2011	39.03903667	-76.38202334	2.00	Severely Degraded
UPB-18602	9/8/2011	39.04131667	-76.28936667	3.80	Meets Goal
UPB-18603	9/8/2011	39.04368333	-76.25113333	3.40	Meets Goal
UPB-18604	9/8/2011	39.07653333	-76.34035	3.80	Meets Goal
UPB-18605	9/8/2011	39.09791667	-76.30376667	1.00	Severely Degraded
UPB-18606	9/9/2011	39.12685	-76.27418334	2.60	Degraded
UPB-18607	9/9/2011	39.13961667	-76.43586501	3.40	Meets Goal
UPB-18608	9/8/2011	39.13968333	-76.35755	3.40	Meets Goal
UPB-18609	9/8/2011	39.1505	-76.42895	3.80	Meets Goal
UPB-18610	9/8/2011	39.1588	-76.32988333	2.60	Degraded
UPB-18611	9/8/2011	39.17838333	-76.37703333	3.80	Meets Goal
UPB-18612	9/8/2011	39.19976667	-76.36158333	3.80	Meets Goal
UPB-18613	9/8/2011	39.23033333	-76.33675	4.60	Meets Goal
UPB-18614	9/8/2011	39.23066667	-76.31163333	4.20	Meets Goal
UPB-18615	9/8/2011	39.24435	-76.3381	3.40	Meets Goal
UPB-18616	9/8/2011	39.2516	-76.34335	3.00	Meets Goal
UPB-18617	9/17/2011	39.28540001	-76.29689667	4.20	Meets Goal
UPB-18618	9/8/2011	39.29296667	-76.17591667	2.00	Severely Degraded
UPB-18619	9/17/2011	39.29424834	-76.26321001	2.60	Degraded
UPB-18620	9/17/2011	39.32036667	-76.22959334	3.40	Meets Goal
UPB-18621	9/17/2011	39.344575	-76.23366501	3.00	Meets Goal
UPB-18622	9/8/2011	39.36333333	-76.15143333	3.00	Meets Goal
UPB-18623	8/29/2011	39.38729834	-76.09867834	3.00	Meets Goal
UPB-18624	8/29/2011	39.45974167	-76.03723	2.33	Degraded
UPB-18625	8/29/2011	39.58705167	-76.10803834	5.00	Meets Goal