CHESAPEAKE BAY WATER QUALITY MONITORING PROGRAM

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

JULY 1984—DECEMBER 2009 (VOLUME 1)

Prepared for

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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 2009), was prepared by Versar, Inc., at the request of Mr. Bruce Michael of the Maryland Department of Natural Resources under Contract # RAT7/06-201 between Versar, Inc., and Maryland DNR. The report assesses the status of Chesapeake Bay benthic communities in 2009 and evaluates their responses to changes in water quality.

ACKNOWLEDGEMENTS

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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 2009 and compared to results from previous years.

Sampling Design and Methods

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

Twenty-seven fixed sites are sampled once a year in late August or September. Three replicate sediment samples for benthos are collected at each fixed site with sampling gear used since 1984. These sites are part of a more extensive suite of sites that were sampled previously at various times and locations. The current suite of fixed sites was also sampled each May through 2008, when spring sampling was discontinued. The probability-based sampling design is stratified simple random. It was established in 1994. Twenty-five random sites are allocated annually to each of six strata in the Maryland portion of the Chesapeake Bay. A similar stratification scheme has been used by the Commonwealth of Virginia since 1996, permitting annual estimates of benthic condition for the entire Chesapeake Bay. The largest portion of the Chesapeake Bay, the mainstem, is divided into three strata, and five strata consist of the major tributaries (Patuxent, Potomac, Rappahannock, York, and James rivers). Two additional strata include the remaining smaller tributaries of 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 covering a surface area of sediment of 440 cm2 to a depth of 10 cm.

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

Trends in Fixed Site Benthic Condition

Statistically significant B-IBI trends ($p<0.1$) were detected at 10 of the 27 sites currently monitored for trends. Trends in benthic community condition declined at 4 sites (significantly decreasing B-IBI trend) and improved at 6 sites. Two of the improving trends were new this year. Additionally, 3 trends that were significant through 2008 disappeared with the addition of the 2009 data.

Sites with improving condition were located in the main stem of the Bay (Stations 15 and 26), Elk River (Station 29), lower Choptank River (Station 64), Bear Creek (Station 201) in the Patapsco River estuary, and Back River (Station 203). Sites with declining condition (Table 3-1) were located in the Patuxent River at Holland Cliff (Station 77), Patuxent River at Broomes Island (Station 71), Baltimore Harbor Middle Branch (Station 22), and Nanticoke River (Station 62). Trend direction and magnitude at fixed sites changed for the first time since 2006, with changes reflecting improvements in benthic community condition in the Maryland portion of the Bay. Nevertheless, major effects of hypoxia in the last few years were suggested by a decline in species richness at most stations, which was consistent and significant bay wide.

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

Baywide Benthic Community Condition

In 2009 the benthos throughout the main stem of the Chesapeake Bay improved from the Susquehanna Flats to the mouth of the Bay. Fifty-six percent of the Bay's tidal waters in 2009 met the benthic community restoration goals, compared to 41-42% in the last four years. The greatest improvement in benthic condition was in the Lower Bay, which consistently has the healthiest benthos for all tidal waters. When water quality conditions are sufficiently improved, it is expected that the Lower Bay benthos will respond first. However, these results should be interpreted with caution because they are based on a single year's change.

In the Maryland portion of the Bay, 58% of the tidal waters failed the Chesapeake Bay restoration goals in 2009. This was one of the lowest estimates of degradation for the 1995-2009 period of record. The severely degraded condition in both the Chesapeake Bay and the Maryland waters also decreased during the last four years of record. These results contrast with the high levels of degradation observed in the last few years. Improvements in benthic condition were associated with low Susquehanna River flow into Chesapeake Bay in 2009. Years of low runoff usually result in lower nutrient levels, fewer algal blooms, and improved water clarity, which contributes to improved benthic community condition.

Benthic condition reflects water quality problems in Chesapeake Bay. High percentages of severely degraded sites are symptomatic of prolonged oxygen stress whereas excess abundance and biomass of organisms are symptomatic of eutrophic conditions in the absence of low dissolved oxygen stress. Low dissolved oxygen events are common and severe in the Potomac River and the Maryland mainstem. The Patuxent River experiences annual events of variable intensity. Maryland eastern tributaries have high agricultural land use, high nutrient input, and high chlorophyll values but low frequencies of low dissolved oxygen events. Baywide restoration goal failure due to severely degraded benthic fauna was more common than failure due to excess abundance or biomass of benthic organisms, suggesting broad-scale effects of hypoxia on benthic organisms in Chesapeake Bay.

TABLE OF CONTENTS

Page

VOLUME 1

TABLE OF CONTENTS

Page

VOLUME 1

APPENDICES

VOLUME 2

DATA SUMMARIES

LIST OF TABLES

LIST OF FIGURES

Figure **Page**

LIST OF FIGURES (Continued)

1.0 INTRODUCTION

1.1 BACKGROUND

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

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

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

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

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

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

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

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

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

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

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

1.2 OBJECTIVES OF THIS REPORT

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

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

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

In addition to the improvements in technical content, we have enhanced electronic production and transmittal of data. Data and program information are available to the research community and the general public through the Chesapeake Bay Benthic Monitoring Program Home Page on the World-Wide-Web at http://www.baybenthos.versar.com. Expansion of the website continues, with new program information, data, and documents being added every year. The 2009 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 2009, 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 1985-2009 fixed site trend analysis. Appendices B and C present the B-IBI values for the 2009 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 2009 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.

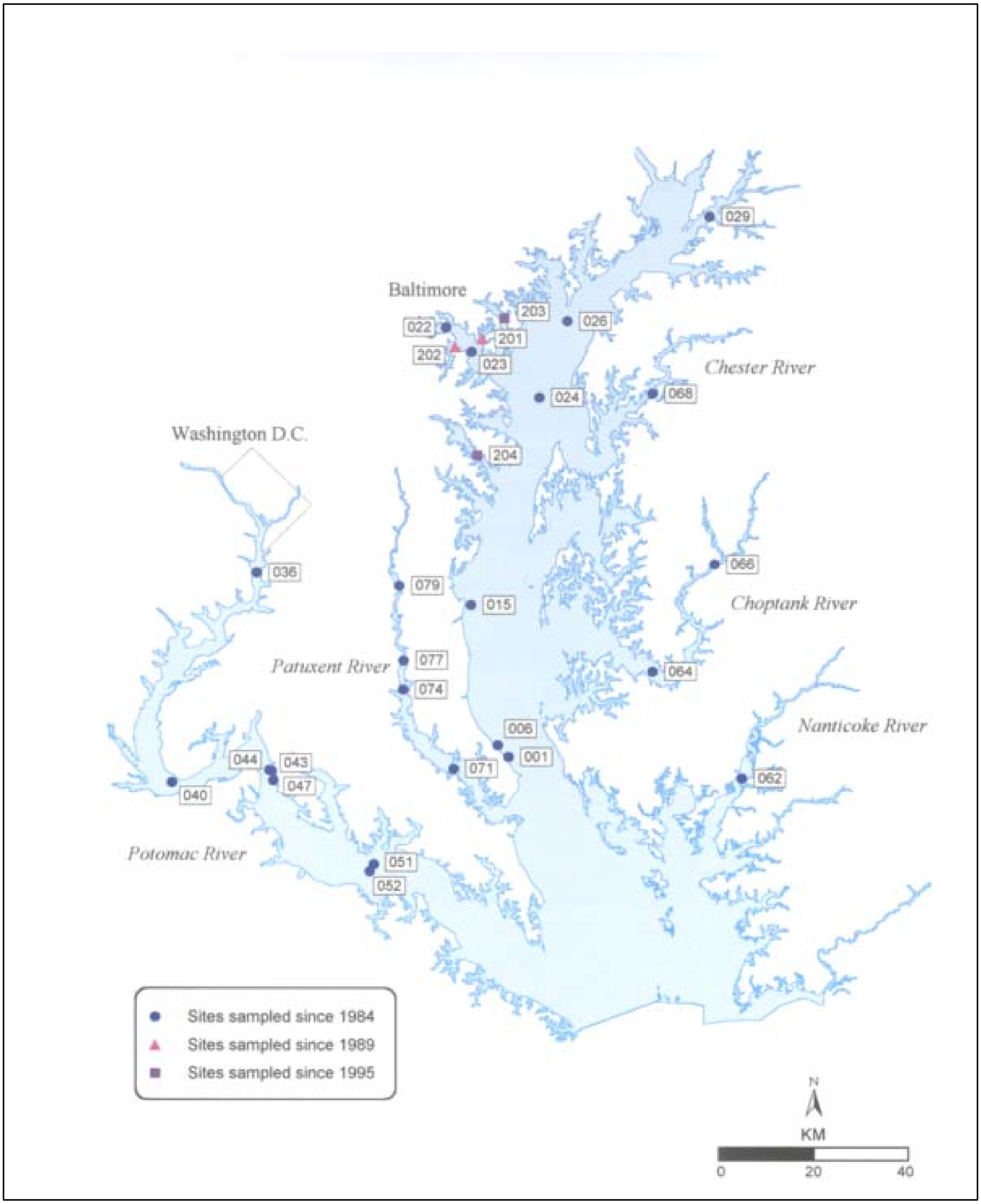

Figure 2-1. Fixed sites sampled in 2009.

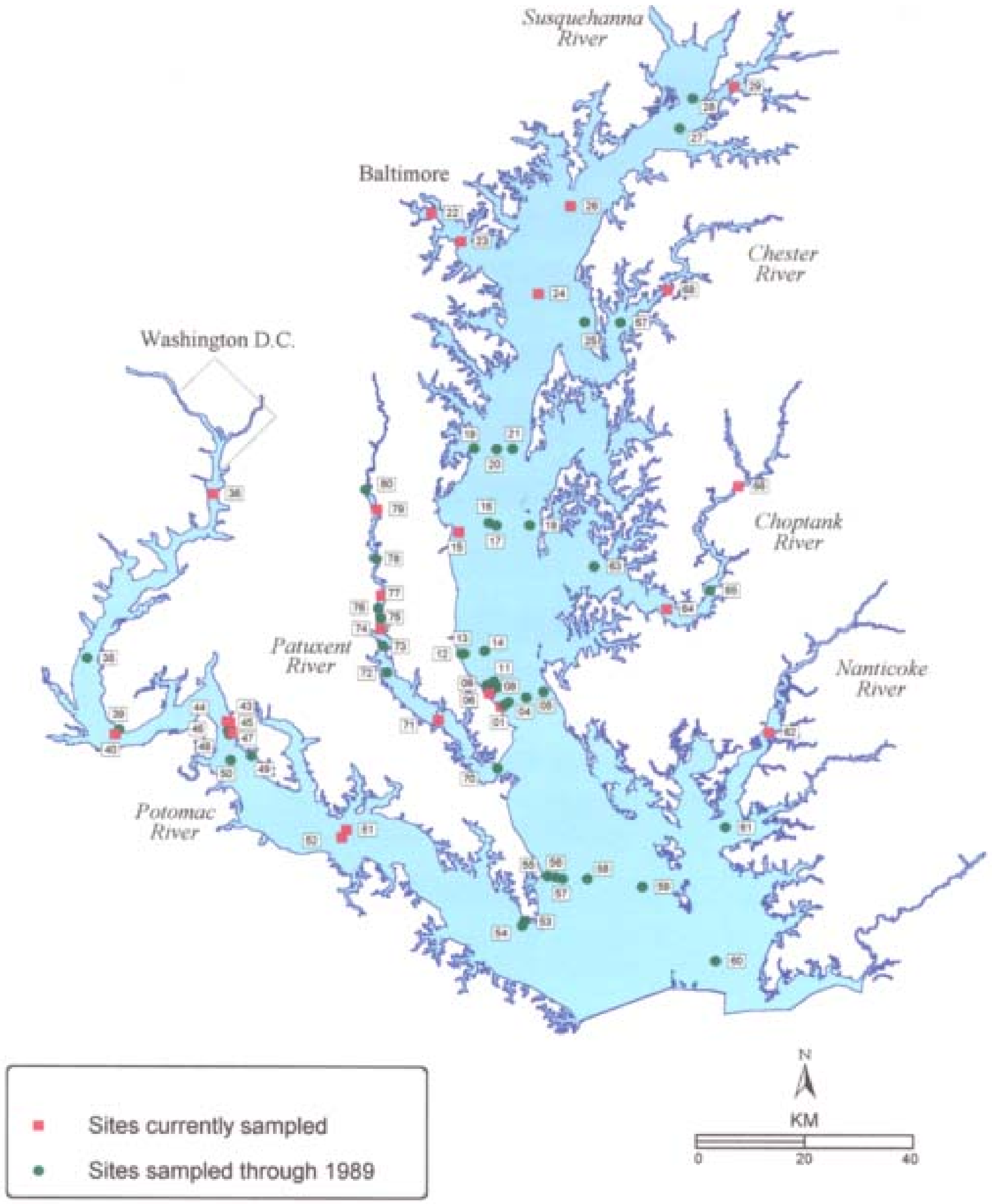

Figure 2-2. Fixed sites sampled from 1984 to 1989; some of these sites are part of the current design.

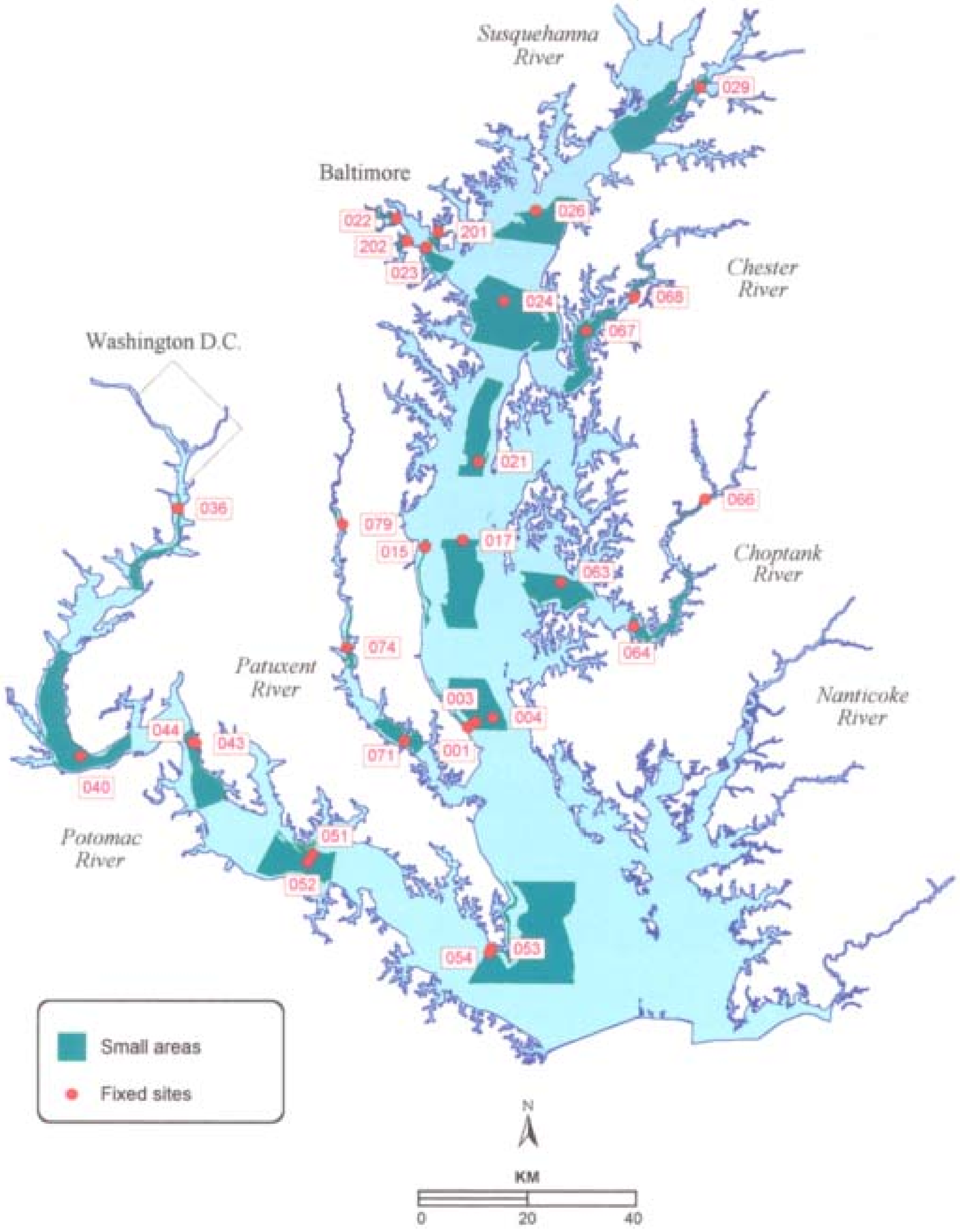

Figure 2-3. Small areas and fixed sites sampled from 1989 to 1994.

Table 2-1. Location, habitat type (Table 5, Weisberg et al. 1997), sampling gear, and habitat criteria for fixed sites

Stratum	**Sub-Estuary**	**Habitat**	**Station**	**Latitude (NAD 83)**	**Longitude (NAD 83)**	**Sampling Gear**	**Habitat Criteria**		
							Depth (m)	**Siltclay (%)**	**Distance (km)**
Potomac River	Potomac River	Tidal Freshwater	036	38.769781	77.037531	WildCo Box Corer	< =5	> =40	1.0
		Oligohaline	040	38.357458	77.230534	WildCo Box Corer	6.5-10	> =80	1.0
		Low Mesohaline	043	38.384125	76.989028	Modified Box Corer	< =5	< =30	1.0
		Low Mesohaline	047	38.365125	76.984695	Modified Box Corer	< =5	< =30	0.5
		Low Mesohaline	044	38.385625	76.995695	WildCo Box Corer	11-17	> =75	1.0
		High Mesohaline Sand	051	38.205462	76.738020	Modified Box Corer	< =5	< =20	1.0
		High Mesohaline Mud	052	38.192297	76.747687	WildCo Box Corer	9-13	> =60	1.0
Patuxent River	Patuxent River	Tidal Freshwater	079	38.750448	76.689020	WildCo Box Corer	< =6	> =50	1.0
		Low Mesohaline	077	38.604452	76.675017	WildCo Box Corer	< =5	> =50	1.0
		Low Mesohaline	074	38.547288	76.674851	WildCo Box Corer	< =5	> =50	0.5
		High Mesohaline Mud	071	38.395124	76.548844	WildCo Box Corer	12-18	> =70	1.0

Table 2-1. (Continued)

Stratum	Sub-Estuary	Habitat	Station	Latitude (NAD 83)	Longitude (NAD 83)	Sampling Gear	Habitat Criteria		
							Depth (m)	**Siltclay (%)**	**Distance (km)**
Upper Western Tributaries	Patapsco River	Low Mesohaline	023	39.208275	76.523352	WildCo Box Corer	4-7	> =50	1.0
	Middle Branch	Low Mesohaline	022	39.254940	76.587354	WildCo Box Corer	2-6	> =40	1.0
	Bear Creek	Low Mesohaline	201	39.234275	76.497184	WildCo Box Corer	2-4.5	> =70	1.0
	Curtis Bay	Low Mesohaline	202	39.217940	76.563853	WildCo Box Corer	5-8	> =60	1.0
	Back River	Oligohaline	203	39.275107	76.446015	Young-Grab	1.5-2.5	> =80	1.0
	Severn River	High Mesohaline Mud	204	39.006778	76.504683	Young-Grab	5-7.5	> =50	1.0
Eastern Tributaries	Chester River	Low Mesohaline	068	39.132941	76.078679	WildCo Box Corer	4-8	> =70	1.0
	Choptank River	Oligohaline	066	38.801447	75.921825	WildCo Box Corer	< =5	> =60	1.0
		High Mesohaline Mud	064	38.590464	76069340	WildCo Box Corer	7-11	> =70	1.0
	Nanticoke River	Low Mesohaline	062	38.383952	75.849988	Petite Ponar Grab	5-8	> =75	1.0

Table 2-1. (Continued)

Stratum	Sub-Estuary	Habitat	Station	Latitude (NAD 83)	Longitude (NAD 83)	Sampling Gear	Habitat Criteria		
							Depth (m)	**Siltclay (%)**	**Distance (km)**
Upper Bay	Elk River	Oligohaline	029	39.479615	75.944499	WildCo Box Corer	3-7	> =40	1.0
	Mainstem	Low Mesohaline	026	39.271441	76.290011	WildCo Box Corer	2-5	> =70	1.0
		High Mesohaline Mud	024	39.122110	76.355346	WildCo Box Corer	5-8	> =80	1.0
Mid Bay	Mainstem	High Mesohaline Sand	015	38.715118	76.513677	Modified Box Corer	< =5	< =10	1.0
		High Mesohaline Sand	001	38.419956	76.416672	Modified Box Corer	< =5	< =20	1.0
		High Mesohaline Sand	006	38.442456	76.443006	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 2009. 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.

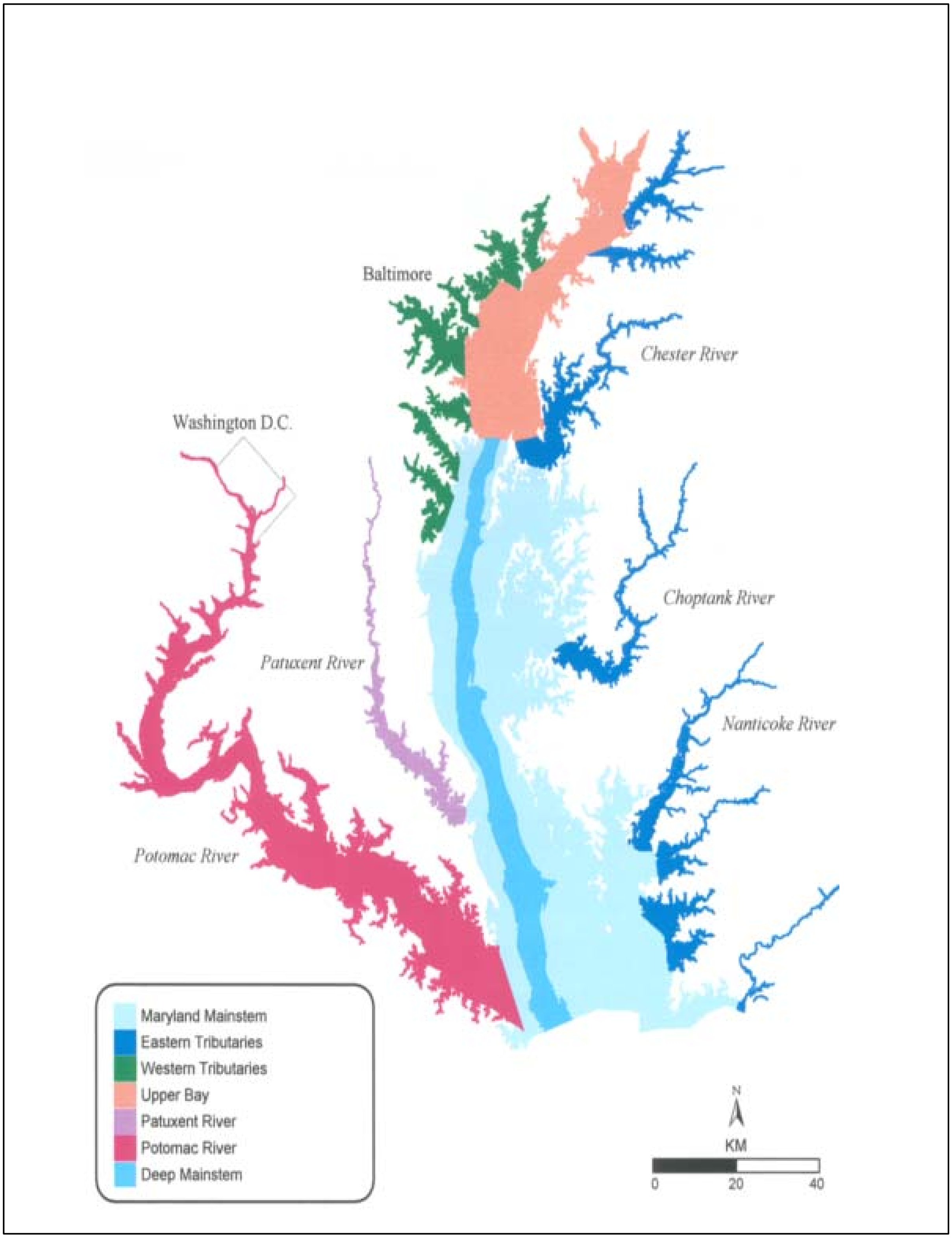

Figure 2-4. Maryland baywide sampling strata in and after 1995

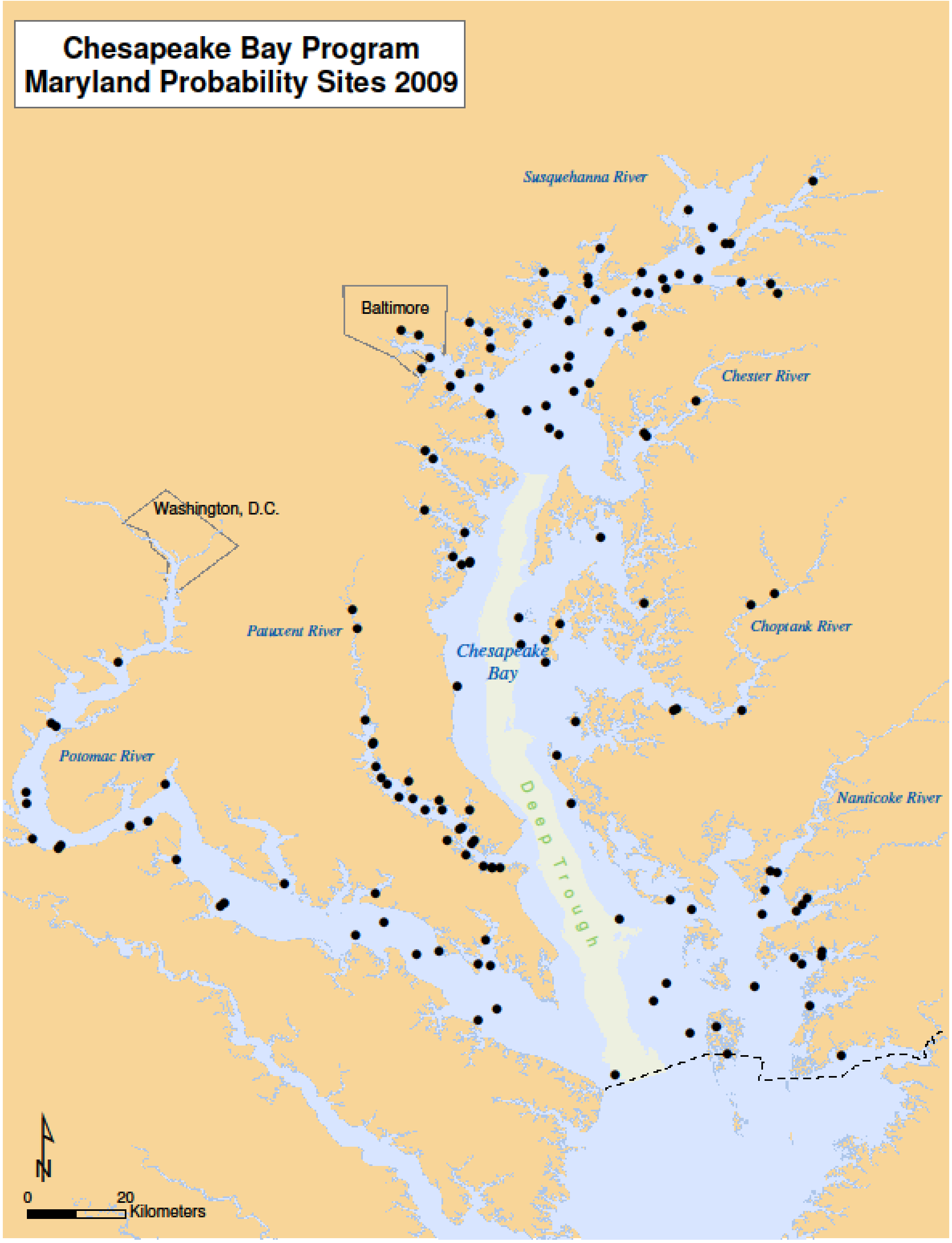

Figure 2-5. Maryland probability-based sampling sites for 2009

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

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

*Excludes Virginia tidal creeks and district of Columbia waters

2.2 SAMPLE COLLECTION

2.2.1 Station Location

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

2.2.2 Water Column Measurements

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

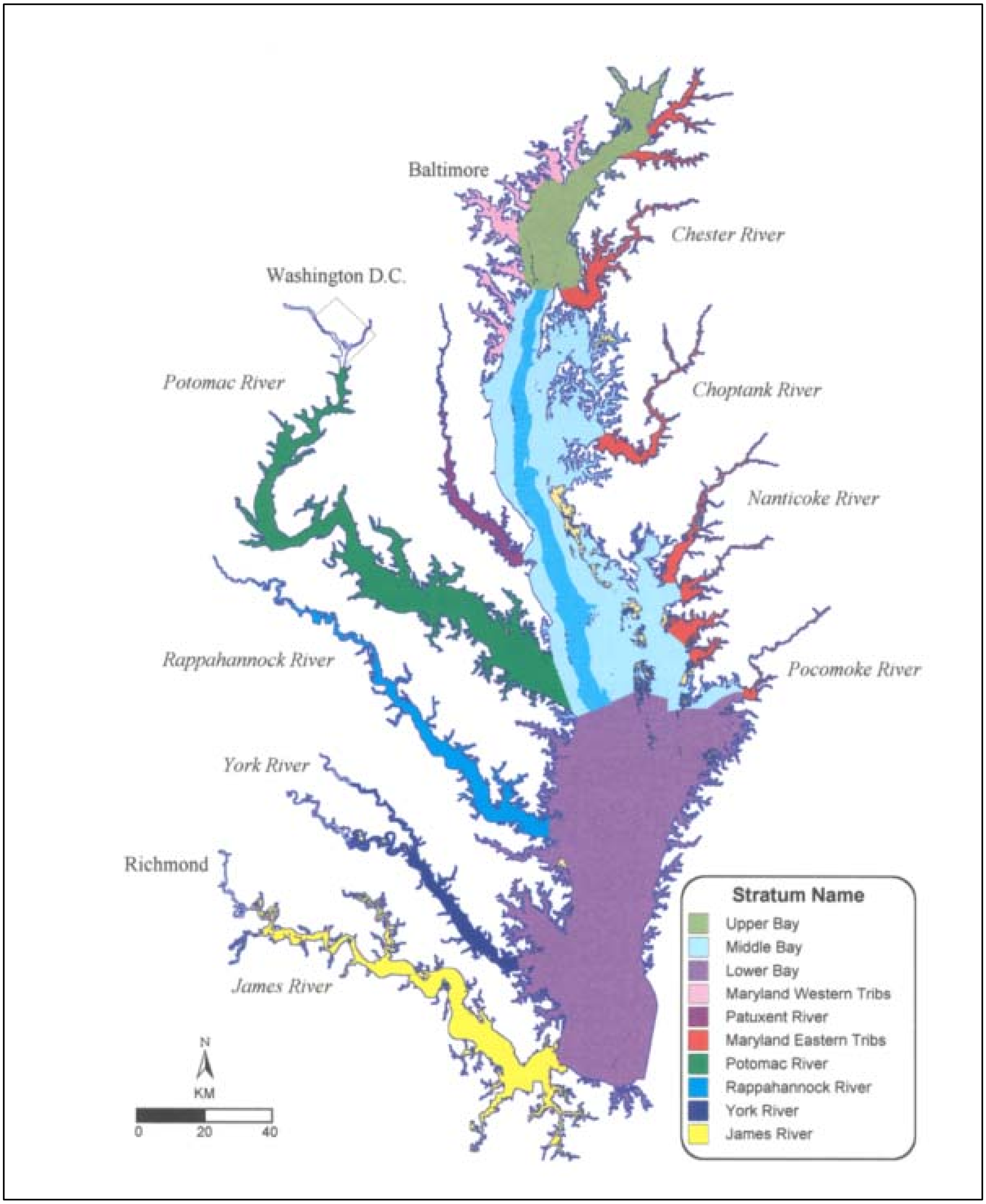

Figure 2-6. Chesapeake Bay stratification scheme

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

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

2.2.3 Benthic Samples

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

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

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

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

2.3 LABORATORY PROCESSING

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

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

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

Polychaeta	**Mollusca**
Eteone heteropoda	*Acteocina canaliculata*
Glycinde solitaria	*Corbicula fluminea*
Heteromastus filiformis	*Gemma gemma*
Marenzelleria viridis	*Haminoe solitaria*
Neanthes succinea	*Macoma balthica*
Paraprionospio pinnata	*Macoma mitchelli*
Streblospio benedicti	*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:

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

and

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

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

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

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:

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

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).

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 five-year (1985-2009) trends are presented for 23 of the 27 trend sites, 21-year trends are presented for two sites in Baltimore Harbor (Stations 201 and 202) first sampled in 1989, and 15-year trends are presented for two western shore tributaries (Back River Station 203, and Severn River Station 204) first sampled in 1995. Trend site locations are shown in Figure 2-1.

Statistically significant B-IBI trends ($p<0.1$) were detected at 10 of the 27 sites (Table 3-1). Trends in benthic community condition declined at 4 sites (significantly decreasing B-IBI trend) and improved at 6 sites. Two of the improving trends were new this year. Additionally, 3 trends that were significant through 2008 disappeared with the addition of the 2009 data. Trend direction and magnitude at fixed sites changed for the first time since 2006, with the changes reflecting improvements in benthic community condition in the Maryland portion of the Chesapeake Bay.

Sites with improving condition (Table 3-1) were located in the main stem of the Bay (Stations 15 and 26), Elk River (Station 29), lower Choptank River (Station 64), Bear Creek (Station 201) in the Patapsco River estuary, and Back River (Station 203). Sites with declining condition (Table 3-1) were located in the Patuxent River at Holland Cliff (Station 77), Patuxent River at Broomes Island (Station 71), Baltimore Harbor Middle Branch (Station 22), and Nanticoke River (Station 62).

The most important changes occurred in the Potomac River at Morgantown (Station 44) and the Severn River (Station 204), which had declining trends that disappeared in 2009. Also, Bear Creek (Station 201) showed a new improving trend this year, with condition improving from severely degraded to degraded. This B-IBI trend coincided with a decreasing trend in organic carbon content in the sediments, from a high of 7% TOC in 1998 to a low of 3% TOC in 2009. The Elk River (Station 29) also showed a new improving trend this year, but this station is highly variable and flips between high and low B-IBI values from year to year.

In terms of status, 10 sites met the goals and 17 failed the goals using the last three years of data. Initially, 10 sites met the goals and 17 failed the goals (Table 3-1), although these are not the same sites that currently meet or fail the goals. Five sites changed status in 2009 relative to the previous reporting year (Table 3-1 shaded areas). The most significant changes in status are for sites that met the goals and now fail, or vice versa. Two sites improved from failing to meeting the goals, the Patuxent River at Lyons Creek (Station 79) and the mainstem of the Patapsco River (Station 23). None declined in status.

Trends in community attributes that are components of the B-IBI are presented in Table 3-2 (mesohaline stations), Table 3-3 (oligohaline and tidal freshwater stations), and Appendix A. Sites with decreasing B-IBI trends had negative (declining trends below restorative thresholds) in abundance, biomass, or both, and usually in one other component of the B-IBI (Table 3-2). Several sites with no B-IBI trends also exhibited statistically significant declining trends in abundance and number of species, indicating a general tendency in the Chesapeake Bay toward low index scores despite the bay-wide improvements observed in 2009. Figures 3-1 through 3-9 provide examples of patterns in abundance, biomass, and number of species at fixed sites. The B-IBI is also provided in these figures. The mainstem of the Maryland Chesapeake Bay, represented by stations near Calvert Cliffs (Stations 01 and 06) and off the Patapsco River estuary (Station 24) showed declines in abundance and number of taxa. These declines were not observed in mainstem Station 26, near Pooles Island (Figure 3-4), probably because this site is located outside the area of the main stem that experiences low dissolved oxygen events. Station 23 in the lower Patapsco River estuary showed trends that were typical of other areas in the Patapsco River, such as Middle Branch (Station 22) and Curtis Bay (Station 202). However, Bear Creek (Station 201) exhibited a significantly improving B-IBI trend that was associated with a dramatic decline in the organic content of sediment (Figure 3-5). This station is located near historical sources of toxic contamination.

The Potomac River tidal freshwater (Station 36) showed declines in biomass and number of taxa; however, the fixed station in the oligohaline portion of the river (Station 40) did not show trends in the B-IBI components (Figures 3-6 and 3-7). The upper Potomac River contrasts with the lower Potomac River, which showed significant declines in abundance, biomass, and number of taxa at all sites in Morgantown (Stations 43, 44, and 47) and the deep (9-13 m) mainstem (Station 52). Station 51 in the lower shallow Potomac River also exhibited significant declines in abundance and biomass, but not in species numbers. These figures are not shown. Other tributary sites worth mentioning in the context of patterns of abundance, biomass, and species numbers are the Patuxent River at Chalk Point (Station 74) and the Nanticoke River (Station 62). The Chalk Point station (unlike other stations in the Patuxent River) is characterized by good overall benthic community condition, and the B-IBI meets the restoration goals. However, abundance and biomass showed declines (statistically significant for biomass) over the time series, and these were most pronounced in the last few years (Figure 3-8). The Nanticoke River station showed declines in biomass, species numbers, and the B-IBI, with a pattern in the last two years suggesting recovery in all the metrics (Figure 3-9).

Table 3-1. Summer trends in benthic community condition, 1985-2009. Trends were identified using the van Belle and Hughes (1984) procedure. Current mean B-IBI and condition are based on 2007-2009 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 2008.

Station	Trend Significance	Median Slope (B-IBI units/yr)	Current Condition (2007-2009)	Initial Condition (1985-1987 unless otherwise noted)
Potomac River				
36	NS	0.00	2.33 (Degraded)	3.14 (Meets Goal)
40	NS	0.00	2.75 (Marginal)	2.80 (Marginal)
43	NS	0.00	3.53 (Meets Goal)	3.76 (Meets Goal)
44	NS	0.00	2.64 (Degraded)	2.80 (Marginal)
47	NS	0.00	3.93 (Meets Goal)	3.89 (Meets Goal)
51	NS	0.00	2.37 (Degraded)	2.43 (Degraded)
52	NS	0.00	1.30 (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	3.71 (Meets Goal)	3.78 (Meets Goal)
77	$p < 0.01$	–0.04	2.64 (Degraded)	3.76 (Meets Goal)
79	NS	0.00	3.17 (Meets Goal)	2.75 (Marginal)
Choptank River				
64	$p < 0.05$	0.02	3.07 (Meets Goal)	2.78 (Marginal)
66	NS	0.00	2.91 (Marginal)	2.60 (Degraded)
Maryland Mainstem				
01	NS	0.00	2.59 (Degraded)	2.93 (Marginal)
06	NS	0.00	2.41 (Degraded)	2.56 (Degraded)
15	$p < 0.1$	0.02	2.41 (Degraded)	2.22 (Degraded)
24	NS	0.01	3.81 (Meets Goal)	3.04 (Meets Goal)
26	$p < 0.05$	0.00	3.62 (Meets Goal)	3.16 (Meets Goal)
Maryland Western Shore Tributaries				
22	$p < 0.01$	–0.03	1.40 (Severely Degraded)	2.08 (Degraded)
23	NS	0.00	3.36 (Meets Goal)	2.49 (Degraded)
201	$p < 0.05$	0.00	2.11(Degraded)	1.10 (Severely Degraded) (a)
202	NS	0.00	1.27 (Severely Degraded)	1.40 (Severely Degraded)(a)
203	$p < 0.001$	0.07	2.96 (Marginal)	2.08 (Degraded) (b)
204	NS	–0.03	3.63 (Meets Goal)	3.67 (Meets Goal) (b)
Maryland Eastern Shore Tributaries				
29	$p < 0.05$	0.01	2.59 (Degraded)	2.38 (Degraded)
62	$p < 0.001$	–0.04	2.60 (Degraded)	3.42 (Meets Goal)
68	NS	0.00	3.62 (Meets Goal)	3.51 (Meets Goal)

Table 3-2. Summer trends in benthic community attributes at mesohaline stations 1985-2009. 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 1989-2009 data; (b): trends based on 1995-2009 data; (c): attribute trend based on 1990-2009 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. Summary trends in benthic community attributes at oligohaline and tidal freshwater stations 1985-2009. 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 1995-2009 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	⇑ ***

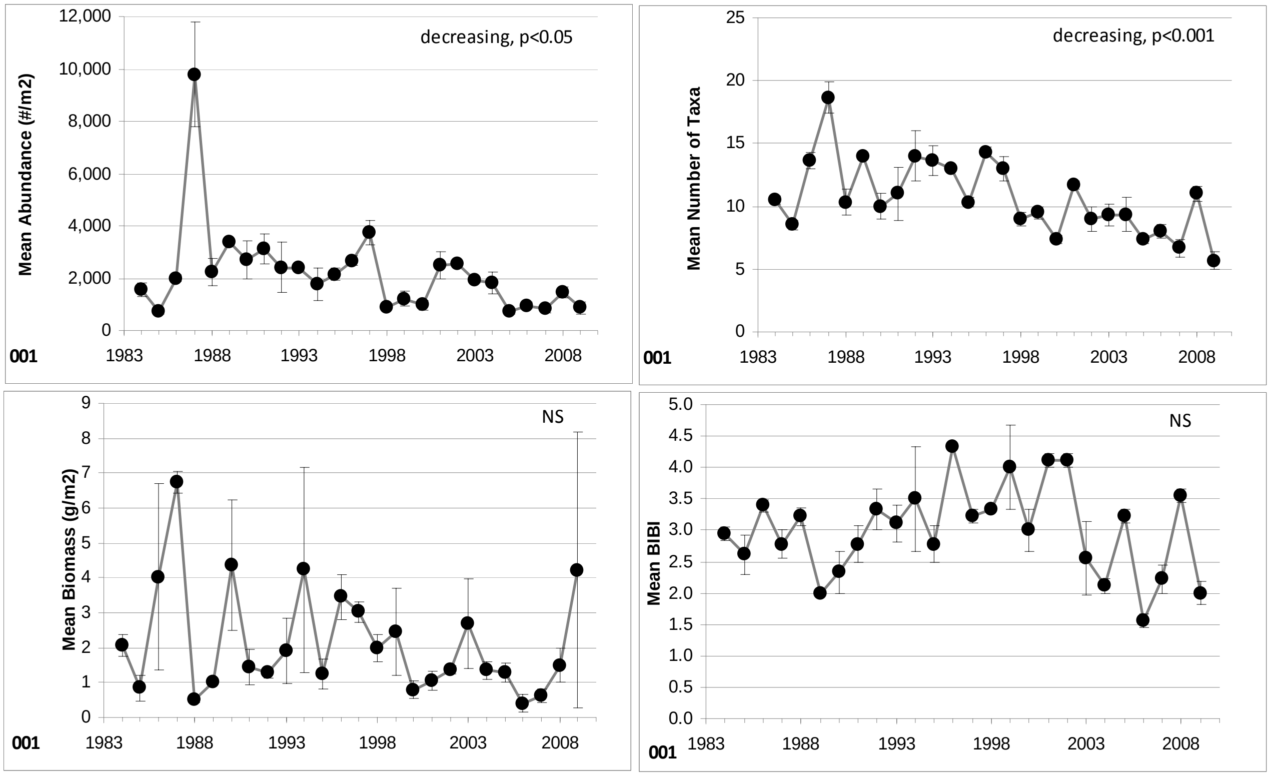

Figure 3-1. Trends in abundance, biomass, number of species, and B-IBI (±1 SE) at long-term fixed stations. See text for details. Station 01 = Chesapeake Bay mainstem (< 5 m) at Calvert Cliffs.

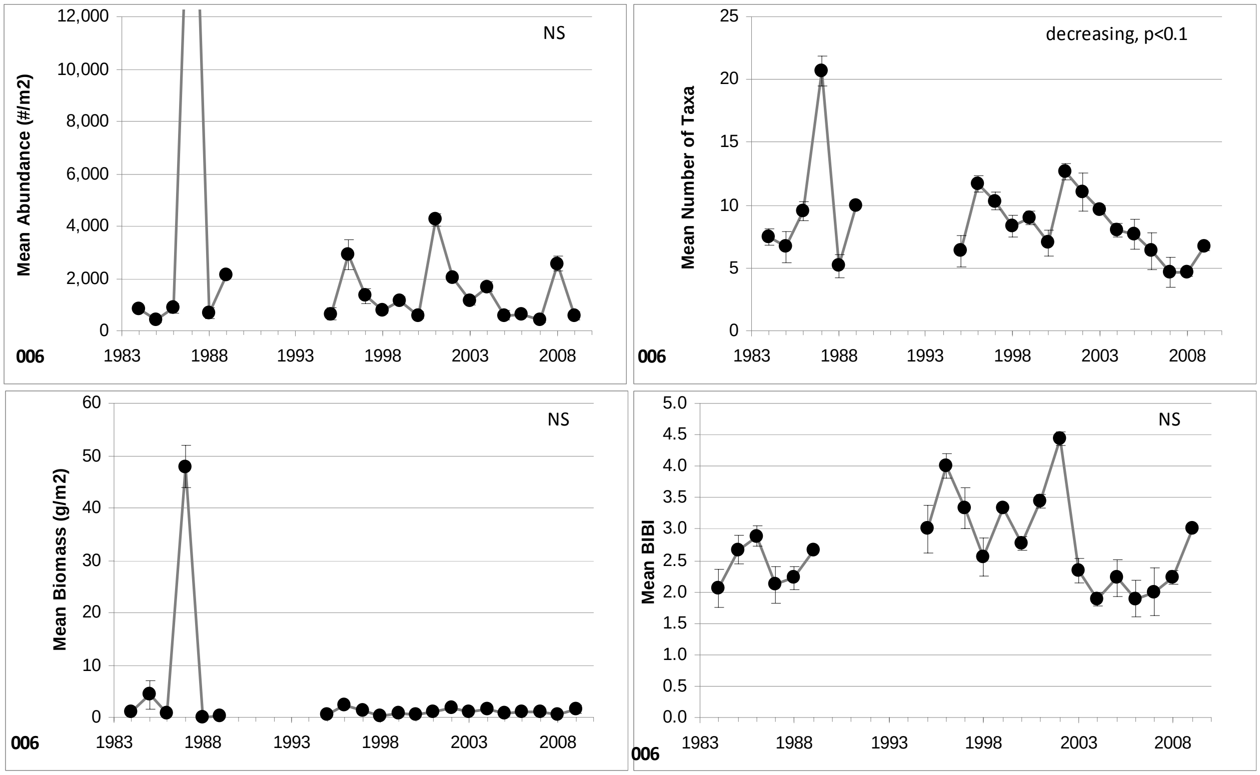

Figure 3-2. Trends in abundance, biomass, number of species, and B-IBI (± 1 SE) at long-term fixed stations. See text for details. Station 06 = Chesapeake mainstem (< 5 m) at Calvert Cliffs.

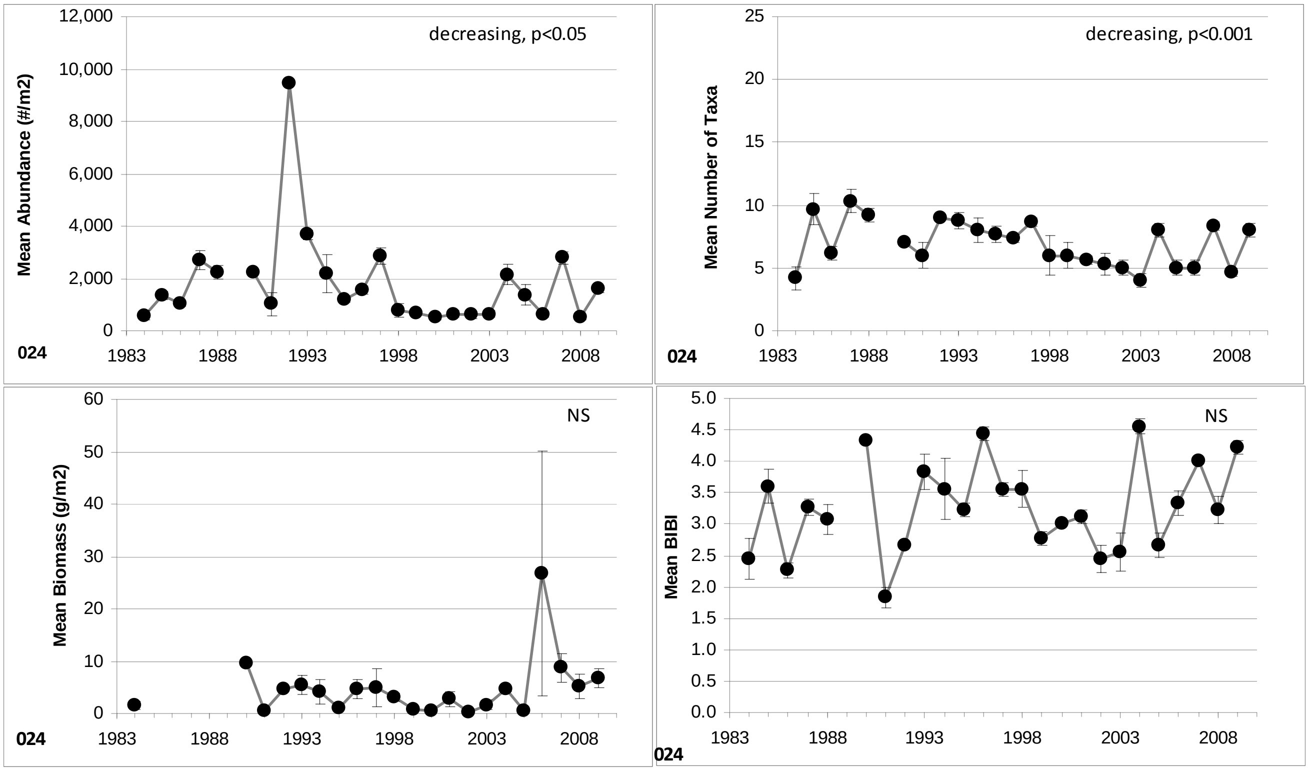

Figure 3-3. Trends in abundance, biomass, number of species, and B-IBI (±1 SE) at long-term fixed stations. See text for details. Station 24 = Chesapeake mainstem (5-8 m) near the mouth of the Patapsco River estuary.

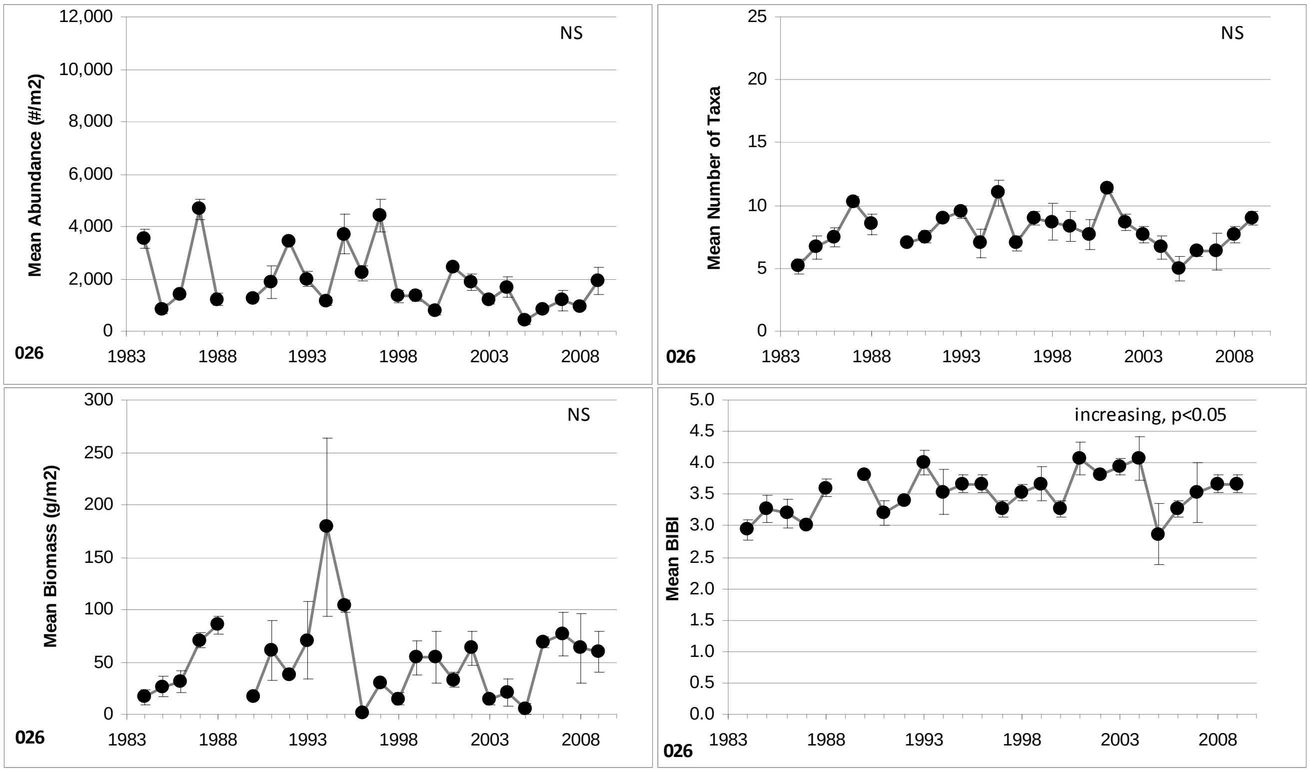

Figure 3-4. Trends in abundance, biomass, number of species, and B-IBI (± 1 SE) at long-term fixed stations. See text for details. Station 26 = Chesapeake Bay mainstem (2-5 m) near Pooles Island.

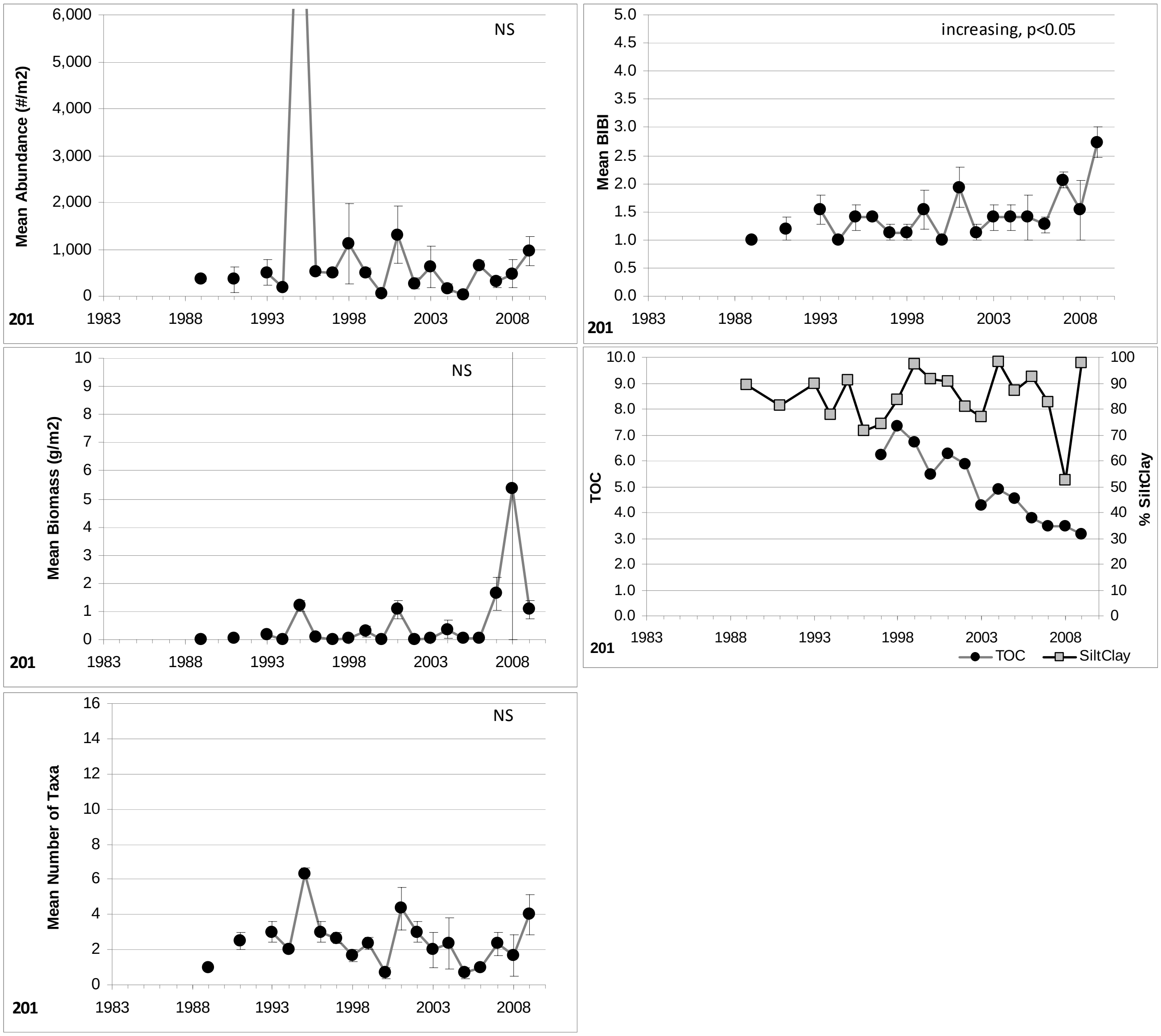

Figure 3-5. Trends in abundance, biomass, number of species, and B-IBI (±1 SE) at long-term fixed stations. See text for details. Station 201 = Bear Creek. Percent total organic carbon and silt-clay of sediments also shown.

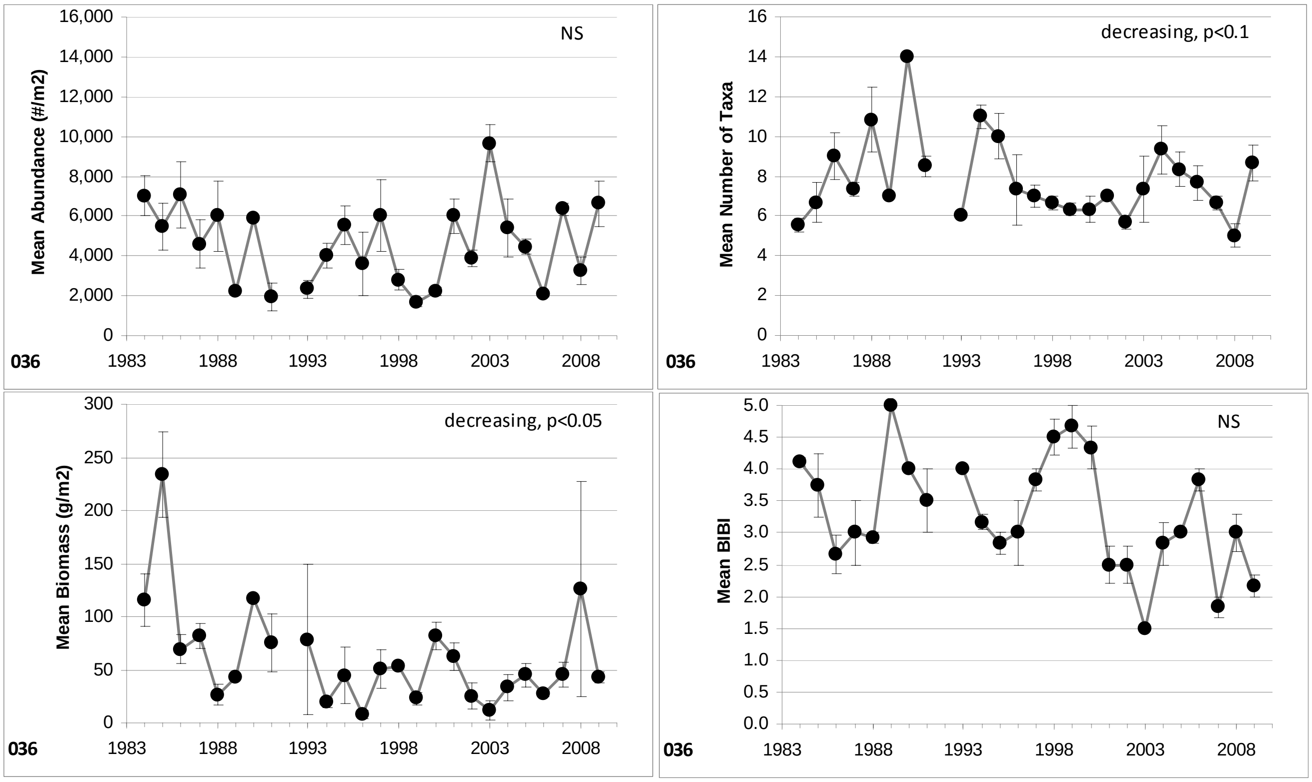

Figure 3-6. Trends in abundance, biomass, number of species, and B-IBI (±1 SE) at long-term fixed stations. See text for details. Station 36 = Tidal fresh Potomac River.

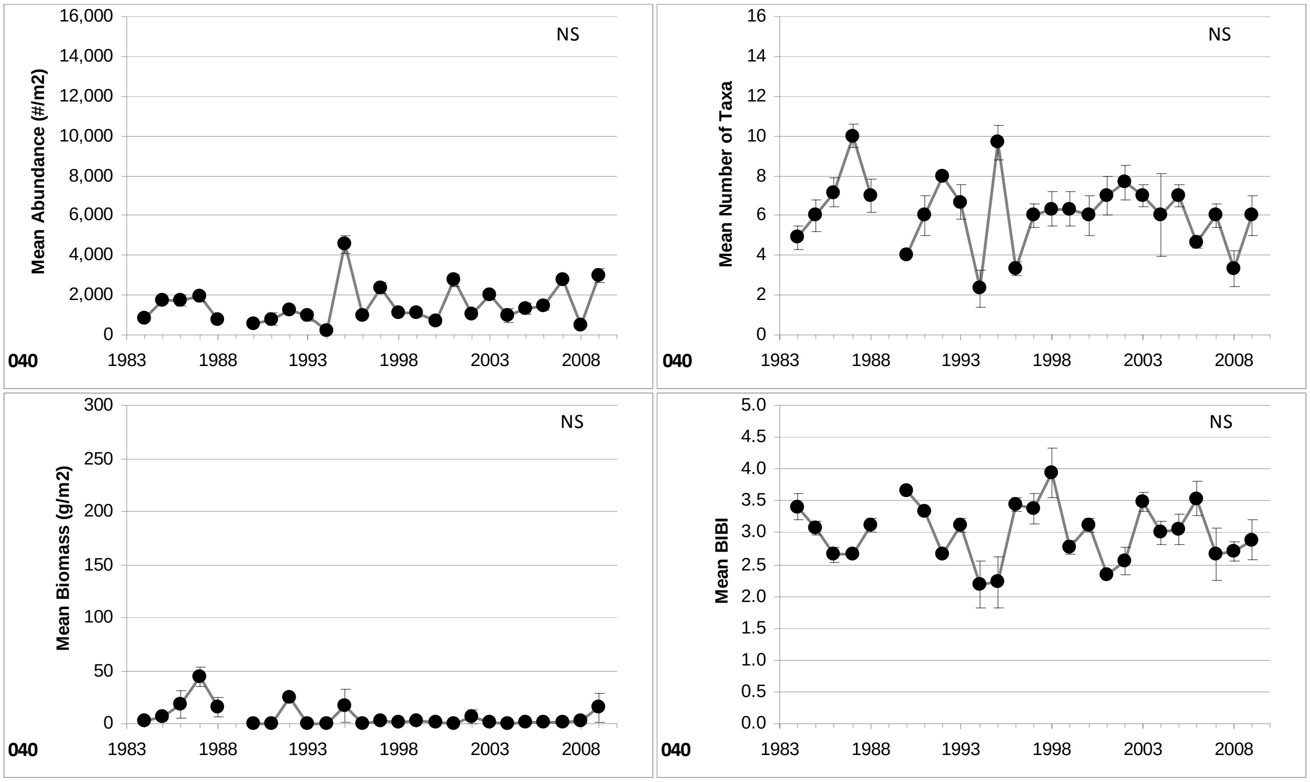

Figure 3-7. Trends in abundance, biomass, number of species, and B-IBI (± 1 SE) at long-term fixed stations. See text for details. Station 40 = Oligohaline Potomac River.

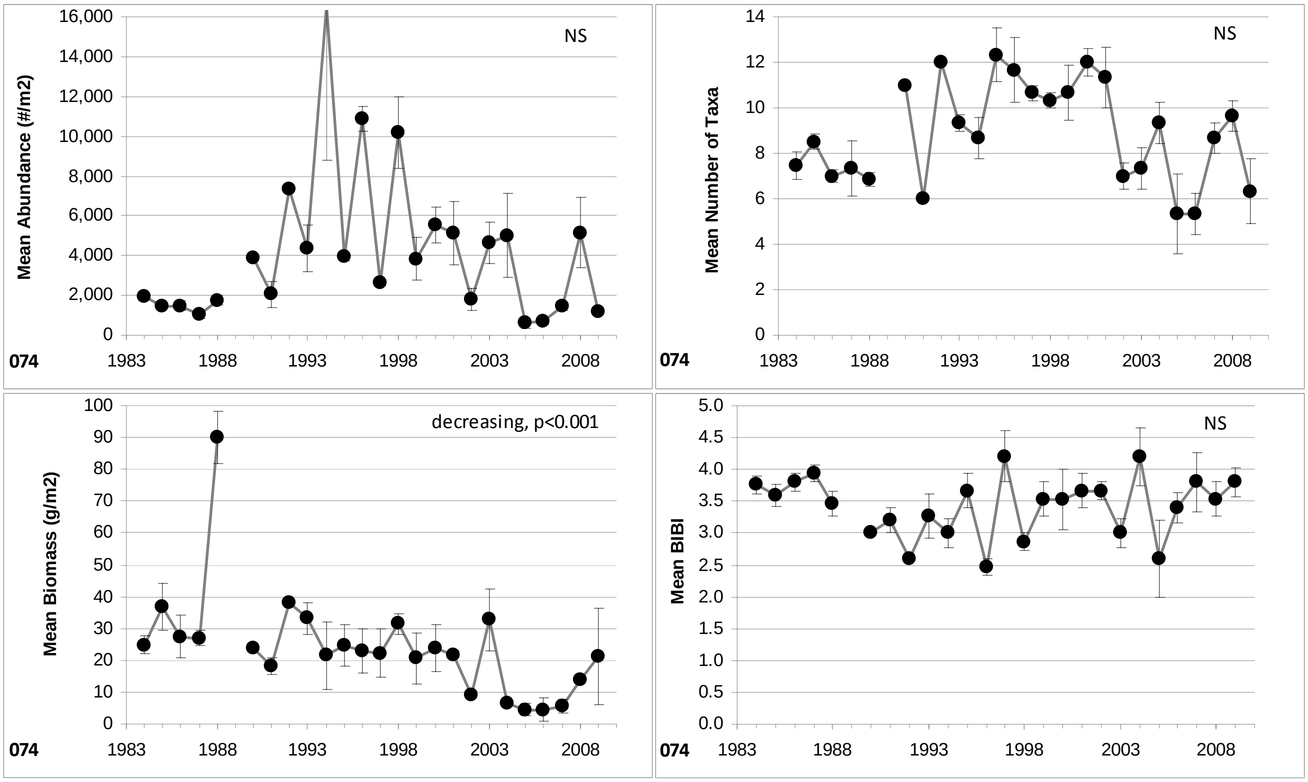

Figure 3-8. Trends in abundance, biomass, number of species, and B-IBI (±1 SE) at long-term fixed stations. See text for details. Station 74 = Patuxent River at Chalk Point.

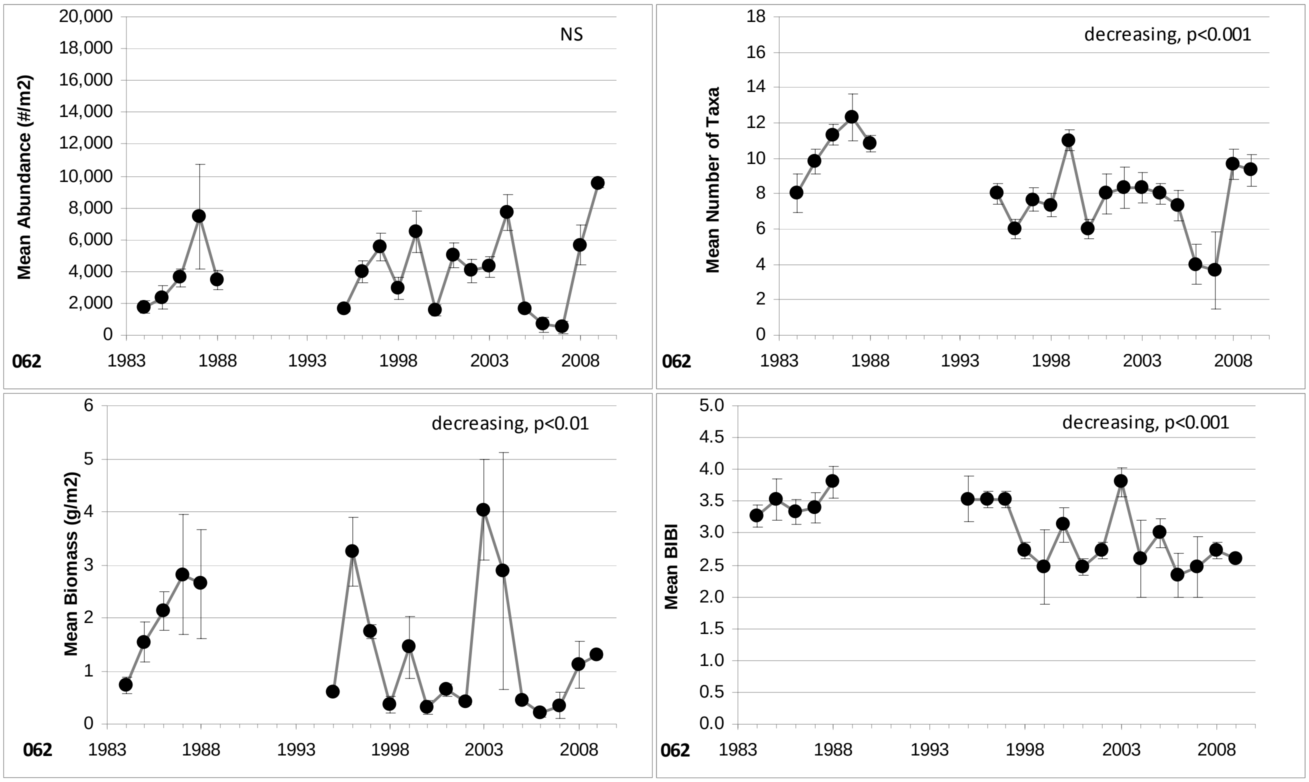

Figure 3-9. Trends in abundance, biomass, number of species, and B-IBI (±1 SE) at long-term fixed stations. See text for details. Station 62 = Nanticoke River.

3.2 BAYWIDE BOTTOM COMMUNITY CONDITION

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

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

Probability-based sampling has been employed previously by LTB, but the sampled area included only 16% of the Maryland Bay (Ranasinghe et al. 1994) which was insufficient to characterize the entire Bay. Probability-based sampling was also used in the Maryland Bay by the U.S. EPA Environmental Monitoring and Assessment Program (EMAP), and most recently by the U.S. EPA National Coastal Assessment, but at a sampling density too low to develop precise condition estimates for the Maryland Bay. The 2009 sampling continues with efforts initiated in 1994 to develop area-based bottom condition statements for the Maryland Bay.

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

This section presents the results of the 2009 Maryland and Virginia probability-based sampling and provides sixteen years (1994-2009) 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 2009, 70 met and 80 failed the Chesapeake Bay benthic community restoration goals (Figure 3-10), an increase in the number of samples meeting the goals relative to 2007 and 2008. Of the 250 probability samples collected in the entire Chesapeake Bay in 2009, 118 met and 132 failed the restoration goals. The Virginia sampling results are presented in Figure 3-11. In terms of number of sites meeting the goals in Chesapeake Bay, more sites met the goals in 2009 than in 2008 and 2007 (47% vs. 39% and 36%, respectively).

The area with degraded benthos in the Maryland Bay decreased substantially in 2009 (Maryland Tidal Waters, Figure 3-12). The magnitude of the severely degraded condition also decreased for the fifth consecutive year (Figure 3-12). 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 2009, 58% (±5% SE) of the Maryland Bay was estimated to fail the restoration goals (Figure 3-12). In 2008, the estimate was 70% (±4% SE). Expressed as area, 3,605 ±299 km^2 of the tidal Maryland Chesapeake Bay remained to be restored in 2009 (Table 3-4).

In 2009, the Patuxent River and Maryland mid-Bay mainstem were in the poorest condition among the six Maryland strata (Figures 3-13 and 3-15). The bottom area failing the restoration goals for the Patuxent River was the largest of the time series (Figure 3-13). There were statistically significant increases in degradation in the Patuxent River (ANOVA, $p = 0.0005$) and Maryland Eastern tributaries ($p = 0.0229$), and no change in the Maryland Western tributaries (Figure 3-13). However, there were substantial improvements in the benthic condition of the Chesapeake Bay mainstem and the Potomac River. Percent degradation declined in the Maryland Upper Bay mainstem, Maryland Mid-bay mainstem, and the Virginia mainstem (Figures 3-13 and 3-14). In the Potomac River, degradation declined for the third consecutive year (Figure 3-13). The improvements were in the upper oligohaline and tidal fresh region of the river. The area with healthy benthic communities in this region was 83% in 2009. The lower Potomac River, however, showed continuing degradation, with only 8% of the area meeting the restoration goals. Over the 1995-2009 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, Table 3-4), was severely degraded. Severely degraded condition typically occurs in the lower Potomac River in deep muddy habitats.

In Virginia, percent degraded area in 2009 declined in all strata relative to 2008 (Table 3-4, Figure 3-14). The most significant improvements were in the Rappahannock River and in the Virginia mainstem, both in percent degraded and severely degraded condition.

For the Chesapeake Bay, the estimate of degradation in 2009 was the lowest of the 1996-2009 time series (Figure 3-12). Weighting results from the 250 probability sites in Maryland and Virginia, 44% (±4%) or 5,094±436 km^2 of the tidal Chesapeake Bay was estimated to fail the restoration goals in 2009, and 62% of that area (3,164 km^2) was severely degraded (Table 3-4). An increasing trend in the percent degraded area of the Chesapeake Bay in the last few years was no longer statistically significant with the addition of the 2009 data (ANOVA, $p = 0.4097$). The extent of the severely degraded condition also declined in 2009 and has been declining since 2005 (Figure 3-12).

The improvements in benthic condition observed in Chesapeake Bay in 2009 were associated with low flow conditions in Chesapeake Bay. Although rainfall was high in Maryland and Virginia in spring and early summer, monthly discharge at Conowingo was well below average in 2009. Susquehanna River flow can influence mainstem hypoxia and benthic condition. Compared to the 1996-2008 average, Maryland mainstem sites in 2009 had more species per sample (13.2 versus 9.9), higher abundance (30,722 versus 7,113 individuals per m^2), and higher biomass (10.3 versus 1.6), although slightly less H' (2.06 versus 2.13). 2009 also had higher average B-IBI score (2.68 versus 2.54). The Upper Bay mainstem had the same number of species (8.4), lower abundance (1,772 versus 2,453), slightly higher H' (2.23 versus 2.16), higher biomass (26.7 versus 23.8), and higher B-IBI average (3.48 versus 3.10). Compared to the 1996-2008 average, Virginia mainstem sites in 2009 had more species per sample (22.5 versus 19.2) and higher H′ (3.41 versus 2.97), although less abundance (3,105 versus 4,122) and slightly less biomass (2.0 versus 2.2).

Figure 3-16 summarizes changes in benthic condition in 2009. Improvements in benthic condition bay wide were mostly due to the lower (Virginia) mainstem, where percent failing went from a 13-year average of 38% (1996-2008) to 16% in 2009. In Maryland, changes were due to improvements in the Potomac River and the mid-Bay mainstem.

In addition to 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 1996-2009, four strata (Potomac River, Patuxent River, Mid Bay mainstem, and the Maryland upper western tributaries) had a large percentage (>68%) 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 (>50%) of failing sites classified as severely degraded (Table 3-5). These results contrast with those of Maryland eastern tributaries, James River, and York River strata, which were at the bottom of the list for depauperate sites but at the top of the list for excess abundance, excess biomass, or both in >22% 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
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

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
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

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
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

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
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

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
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

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
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

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

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 2009. 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	185	72.0	213	82.9
Patuxent River	115	52.3	175	79.5
Mid Bay Mainstem	117	54.2	159	73.6
Western Tributaries	125	62.8	136	68.3
Upper Bay Mainstem	61	54.0	76	67.3
Virginia Mainstem	45	35.2	83	64.8
Rappahannock River	126	55.5	137	60.4
Eastern Tributaries	56	34.6	82	50.6
York River	111	50.5	74	33.6
James River	76	38.8	54	27.6

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 2009. 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	61	31.1
Eastern Tributaries	39	24.1
York River	50	22.7
Upper Bay Mainstem	22	19.5
Western Tributaries	36	18.1
Rappahannock River	38	16.7
Mid Bay Mainstem	34	15.7
Patuxent River	23	10.5
Potomac River	26	10.1
Virginia Mainstem	10	7.8

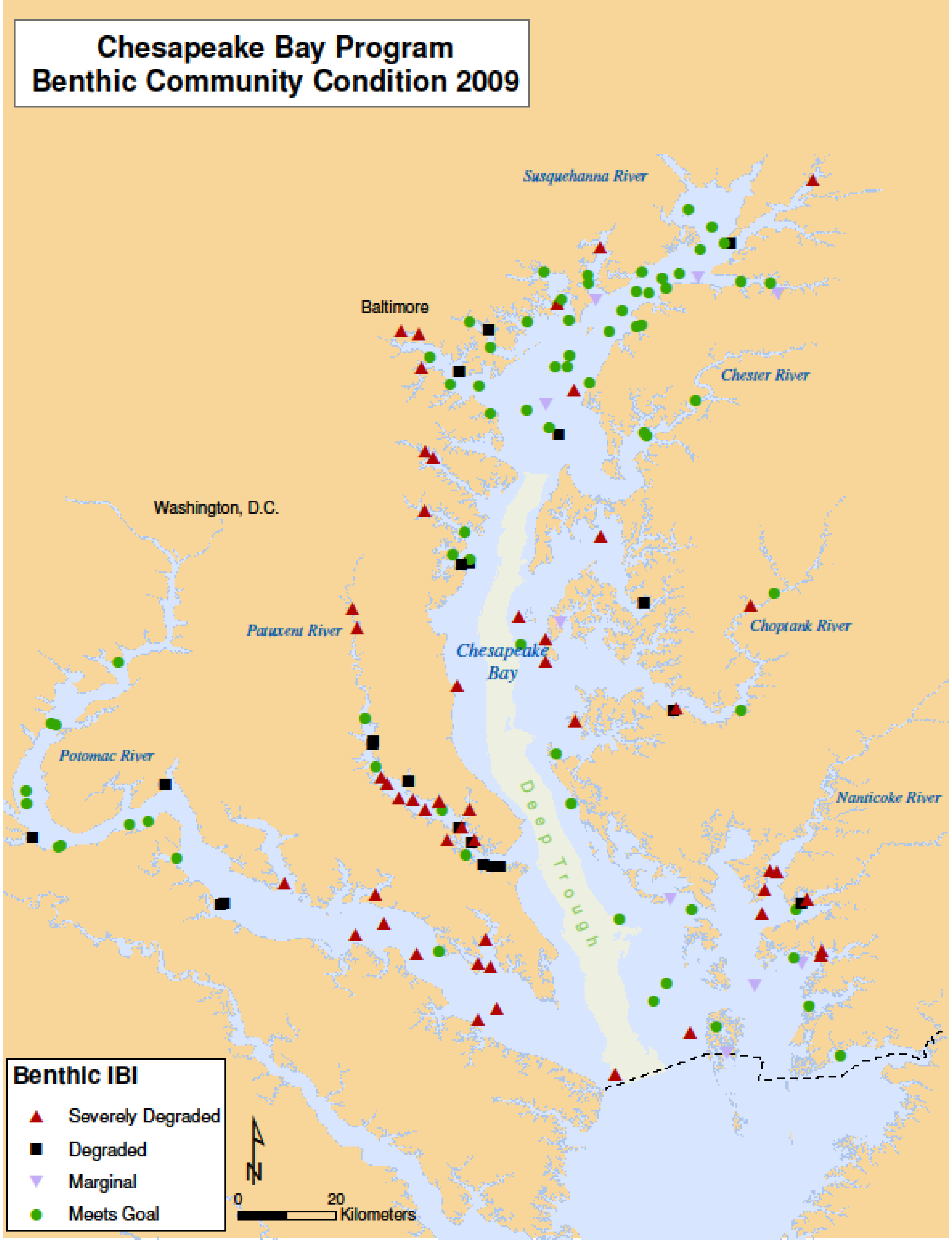

Figure 3-10. Results of probability-based benthic sampling of the Maryland Chesapeake Bay and its tidal tributaries in 2009. Each sample was evaluated in context of the Chesapeake Bay benthic community restoration goals.

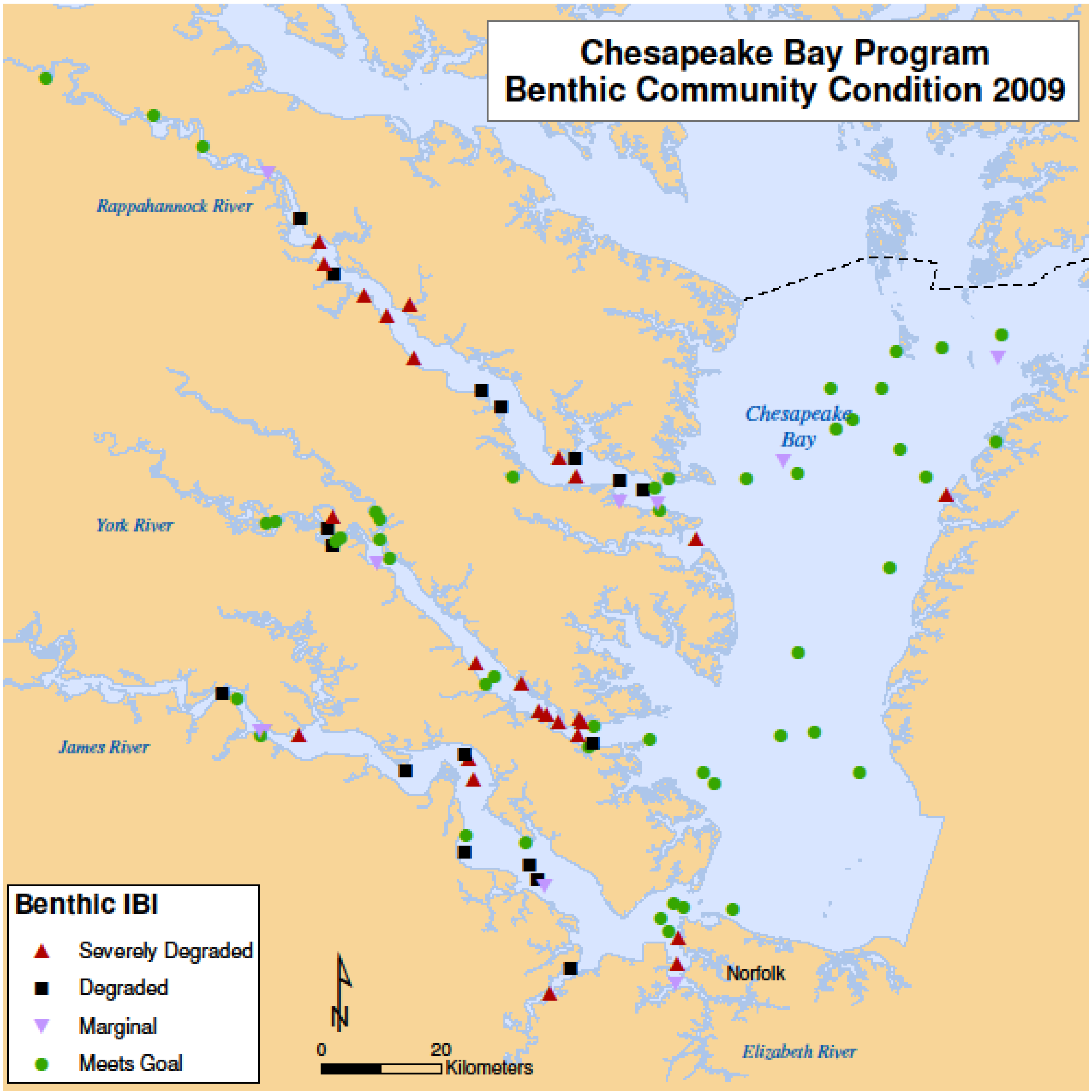

Figure 3-11. Results of probability-based benthic sampling of the Virginia Chesapeake Bay and its tidal tributaries in 2009. Each sample was evaluated in context of the Chesapeake Bay benthic community restoration goals.

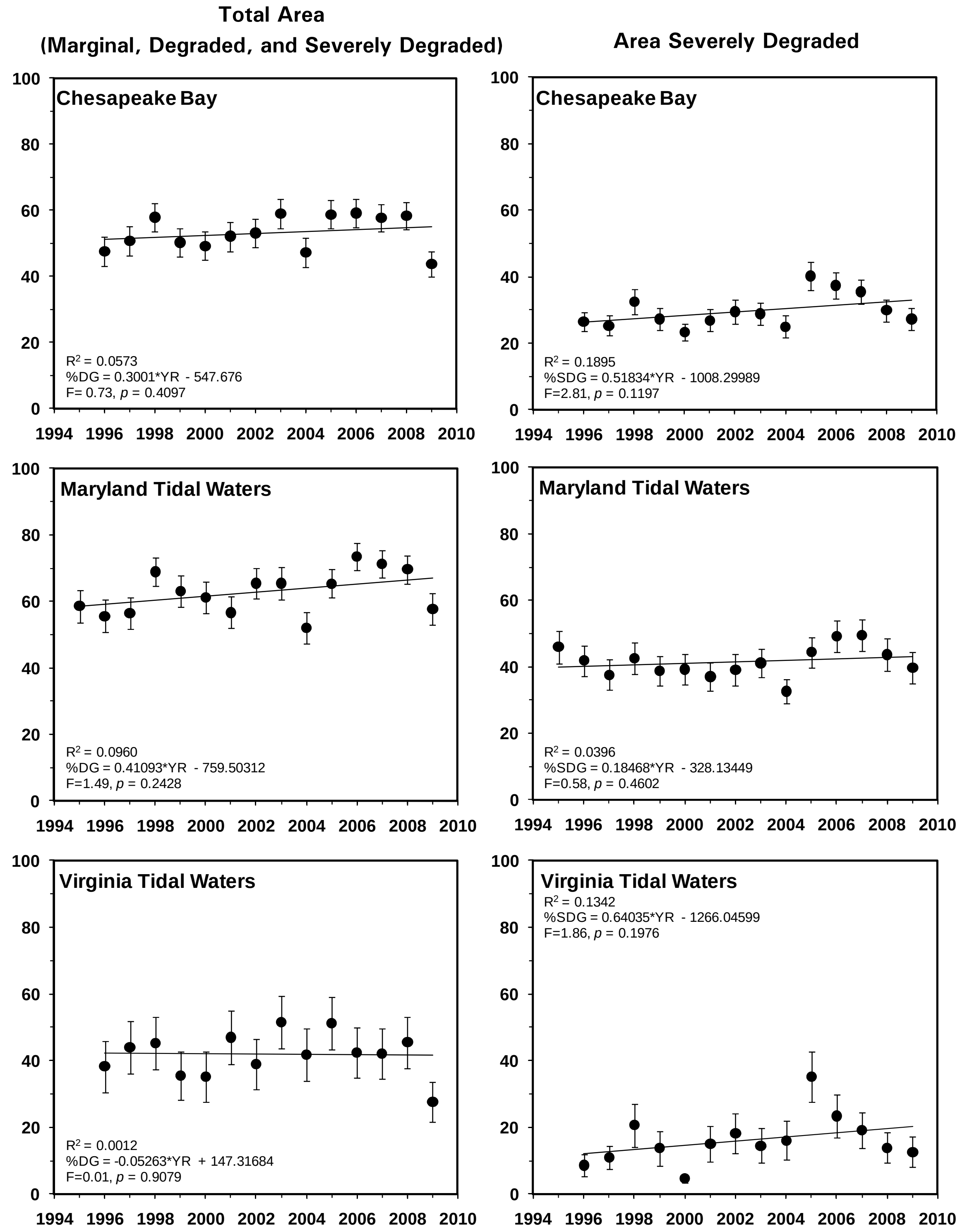

Figure 3-12. Proportion of the Chesapeake Bay, Maryland tidal waters, and Virginia tidal waters failing the Chesapeake Bay benthic community restoration goals, 1996 to 2009 (1995-2009 for Maryland). Panels on left show percent total area degraded (B-IBI <3.0); panels on right show percent area severely degraded (B-IBI ≤2.0). Error bars indicate ± 1 SE. The mainstem deep trough is included in the severely degraded condition estimates.

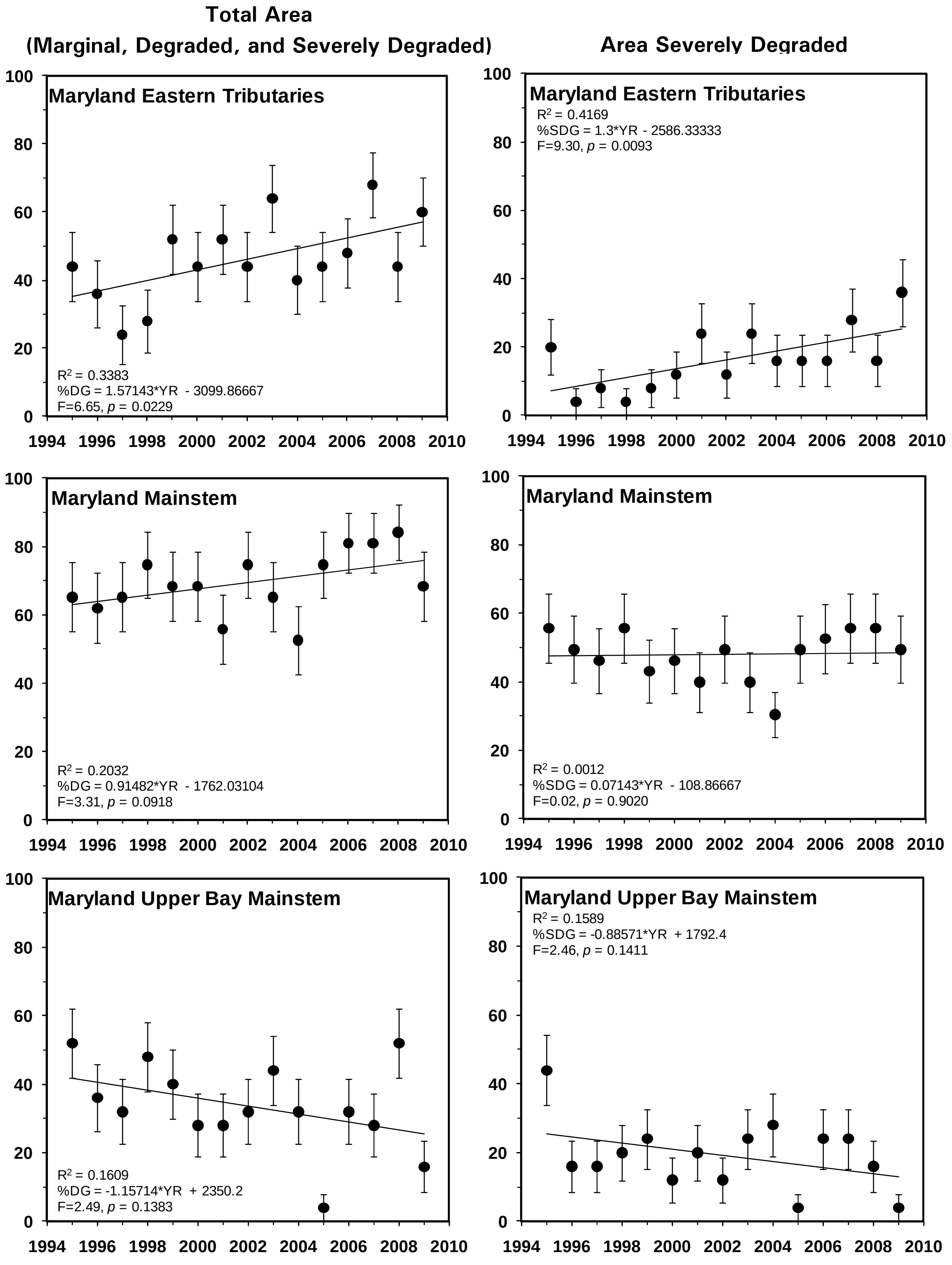

Figure 3-13. Proportion of the Maryland sampling strata failing the Chesapeake Bay benthic community restoration goals, 1995 to 2009. Panels on left show percent total area degraded (B-IBI <3.0); panels on right show percent area severely degraded (B-IBI ≤ 2.0). Error bars indicate ± 1 SE. The deep trough is included in the Maryland mainstem stratum estimates.

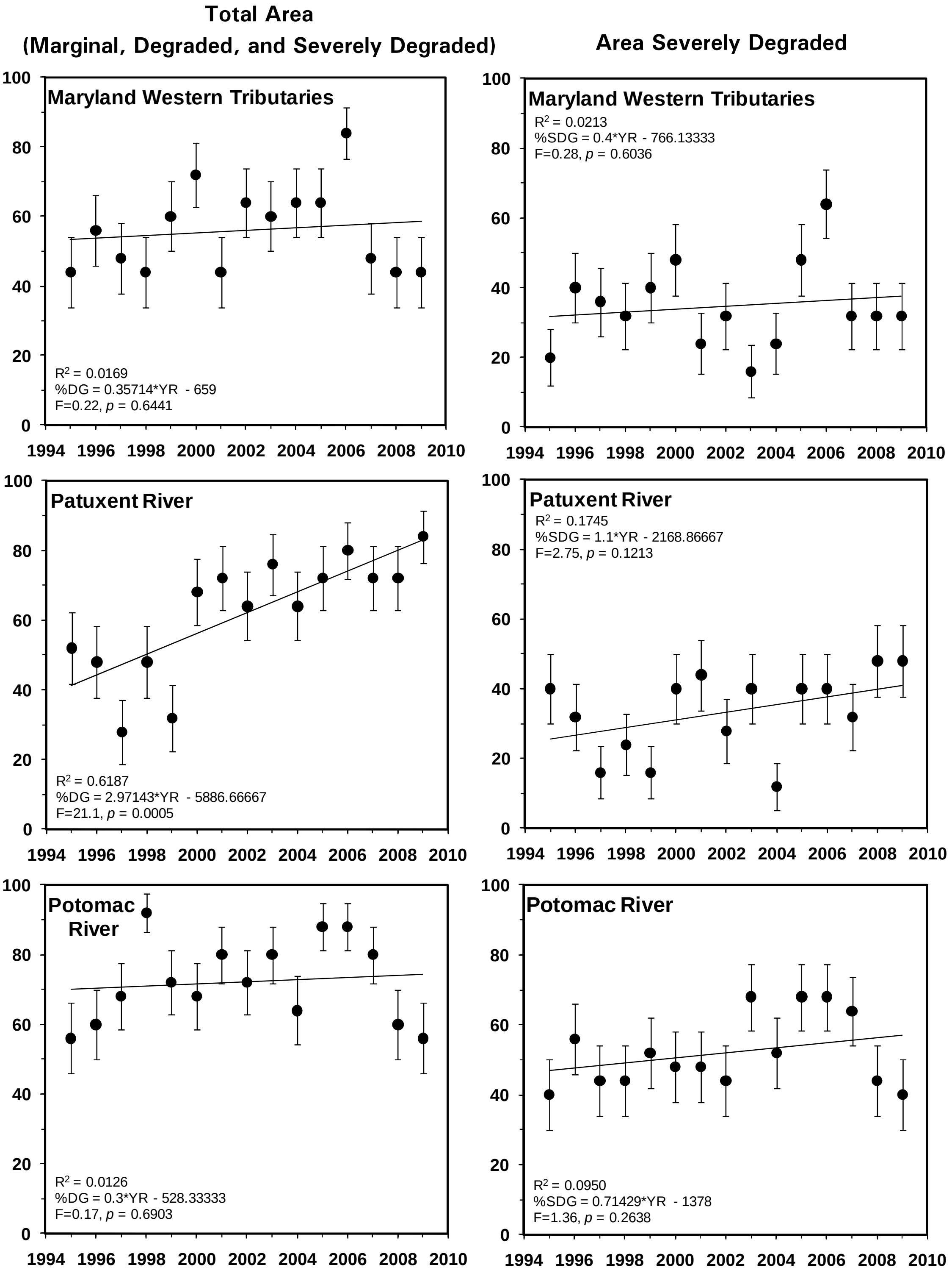

Figure 3-13. (Continued)

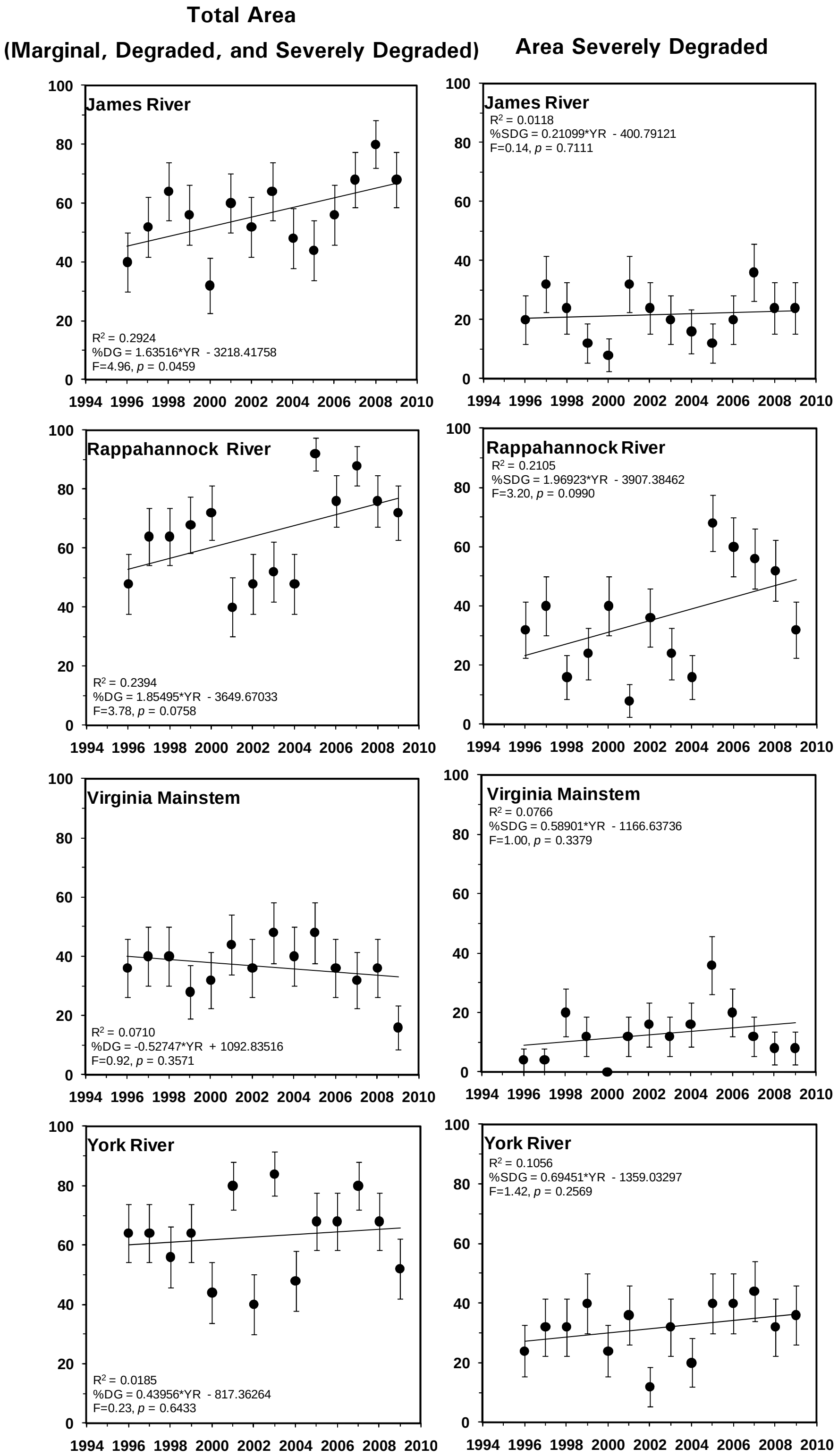

Figure 3-14. Proportion of the Virginia sampling strata failing the Chesapeake Bay benthic community restoration goals, 1996 to 2009. Panels on left show percent total area degraded (B-IBI <3.0); panels on right show percent area severely degraded (B-IBI ≤2.0). Error bars indicate ± 1 SE.

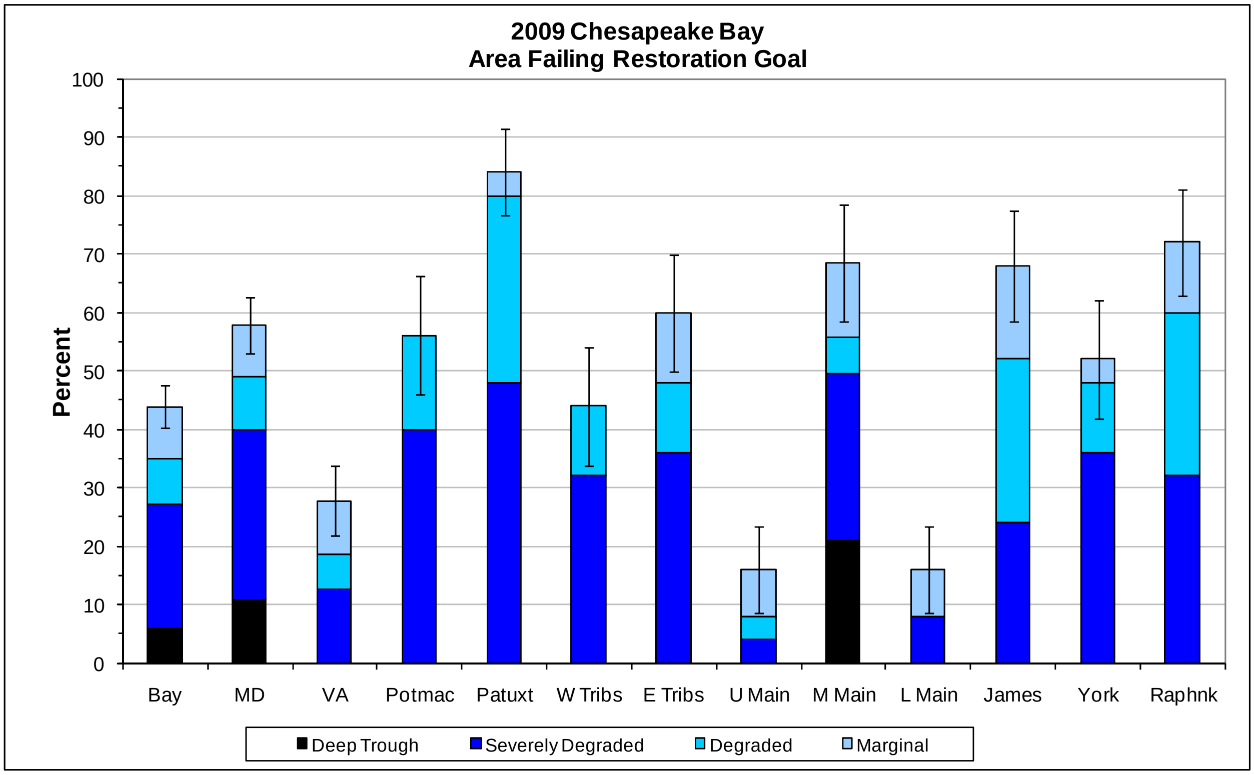

Figure 3-15. Proportion of the Chesapeake Bay, Maryland, Virginia, and the 10 sampling strata failing the Chesapeake Bay benthic community restorations goals in 2009. Error bars indicate ± 1 SE.

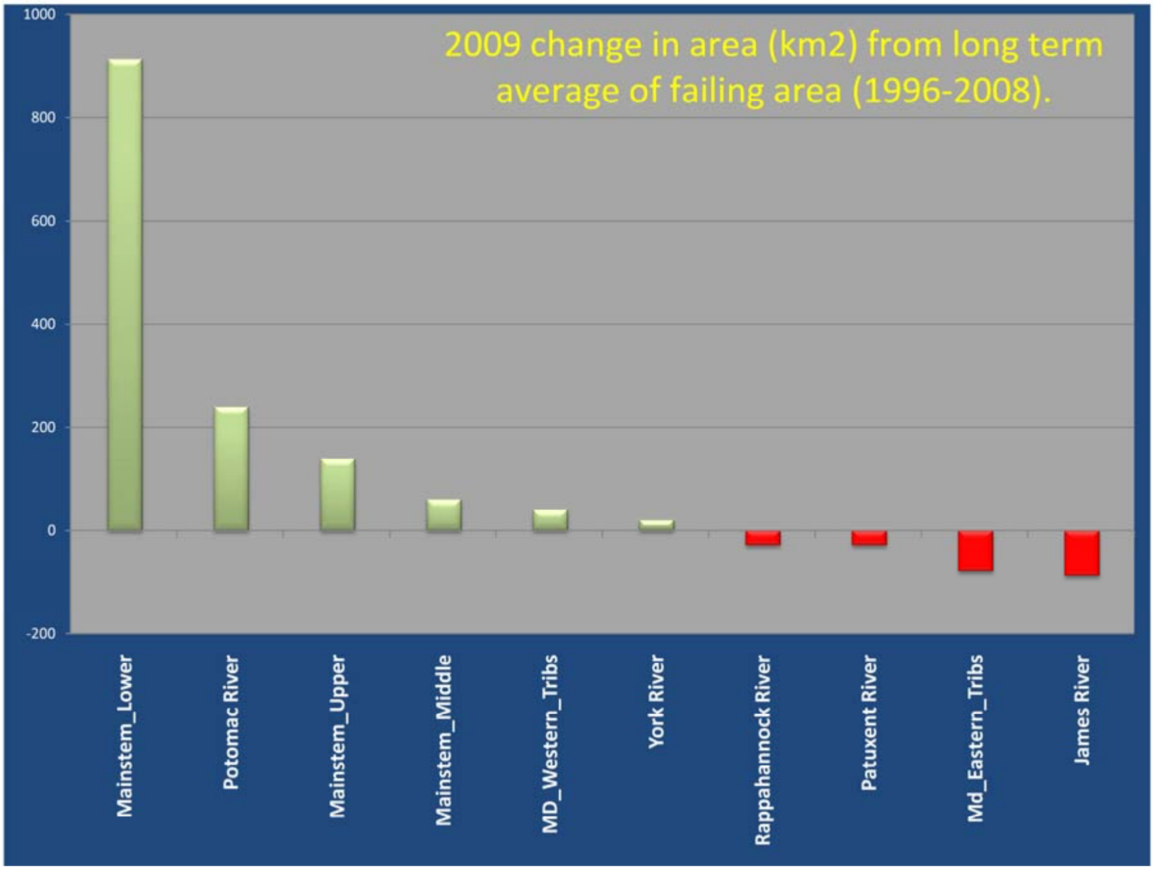

Figure 3-16. Change in area (km^2) in 2009 from the long-term average of failing area (percent degraded area) by sampling strata. Figure courtesy of Old Dominion University.

3.3 BASIN-LEVEL BOTTOM COMMUNITY CONDITION

Probability-based sampling can be used to produce areal estimates of degradation for regions of interest. The 2009 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 3-17). The Bay Program conducts an annual integrated assessment for the Bay and its tidal tributaries using indicators of water quality conditions (chlorophyll *a*, dissolved oxygen, and water clarity), living resources (plankton and benthos), and habitat (Bay grasses) combined into a Bay Health Index (Williams et al. 2009). Reporting regions align with Tributary Strategy basins, for which benthic community condition is also summarized on a regular basis. Tributary Teams consider basin summaries that synthesize monitoring information from several sources, including watershed, ambient water quality, habitat, and living resources components. This information is linked to nutrient and sediment pollution sources and is intended to provide the Tributary Teams with resources to consult in setting Tributary Strategy goals.

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

By basin, the Maryland Upper Western Shore, Upper Bay, and Lower Bay were in best condition, with 25% or less of the bottom area estimated to fail the restoration goals in 2009 (Table 3-7). The Patuxent River, Rappahannock River, and Maryland Upper Eastern Shore basin were in worst condition, with >70% of the bottom area estimated to fail the restoration goals. The Elizabeth River basin did not have sufficient data in 2009 for a reliable determination of degradation. The remaining of the basins exhibited 46-68% degradation. Note that the uncertainty associated with the estimates is generally large because of small sample size or poor data coverage in sub-regions. Thus, at the basin level, large changes in benthic condition are likely to occur, and this should be taken into account when comparing basins and years.

Table 3-7. Estimated tidal area failing to meet the Chesapeake Bay benthic community restoration goals in 2009 by Bay Health Index Reporting Region and Tributary Strategy basin. The Elizabeth River Biological Monitoring Program was not conducted in 2009, thus no additional sites from that program are included in the Elizabeth River estimate below. See Figure 3-17 for reporting regions.

Region/Basin	Percent Failing	Km^2 Failing	SE	N
Elizabeth River	100	47	-	2
Patuxent River	84	108	7.5	25
Maryland Upper Eastern Shore	73	334	8.6	11
Rappahannock River	72	268	9.2	25
Maryland Lower Western Shore	68	67	21.1	6
James River	65	417	10.2	25
Choptank River	65	280	26.3	8
Potomac River	56	714	10.1	25
Mid Bay*	55	1,308	8.0	12
York River	52	97	10.2	25
Maryland Lower Eastern Shore	49	723	12.5	24
Patapsco/Back Rivers	46	50	15.8	11
Maryland Upper Western Shore	25	22	16.4	8
Upper Bay	16	126	7.5	25
Lower Bay	15	466	8.2	20

*Region SE estimated using 2000-2009 data.

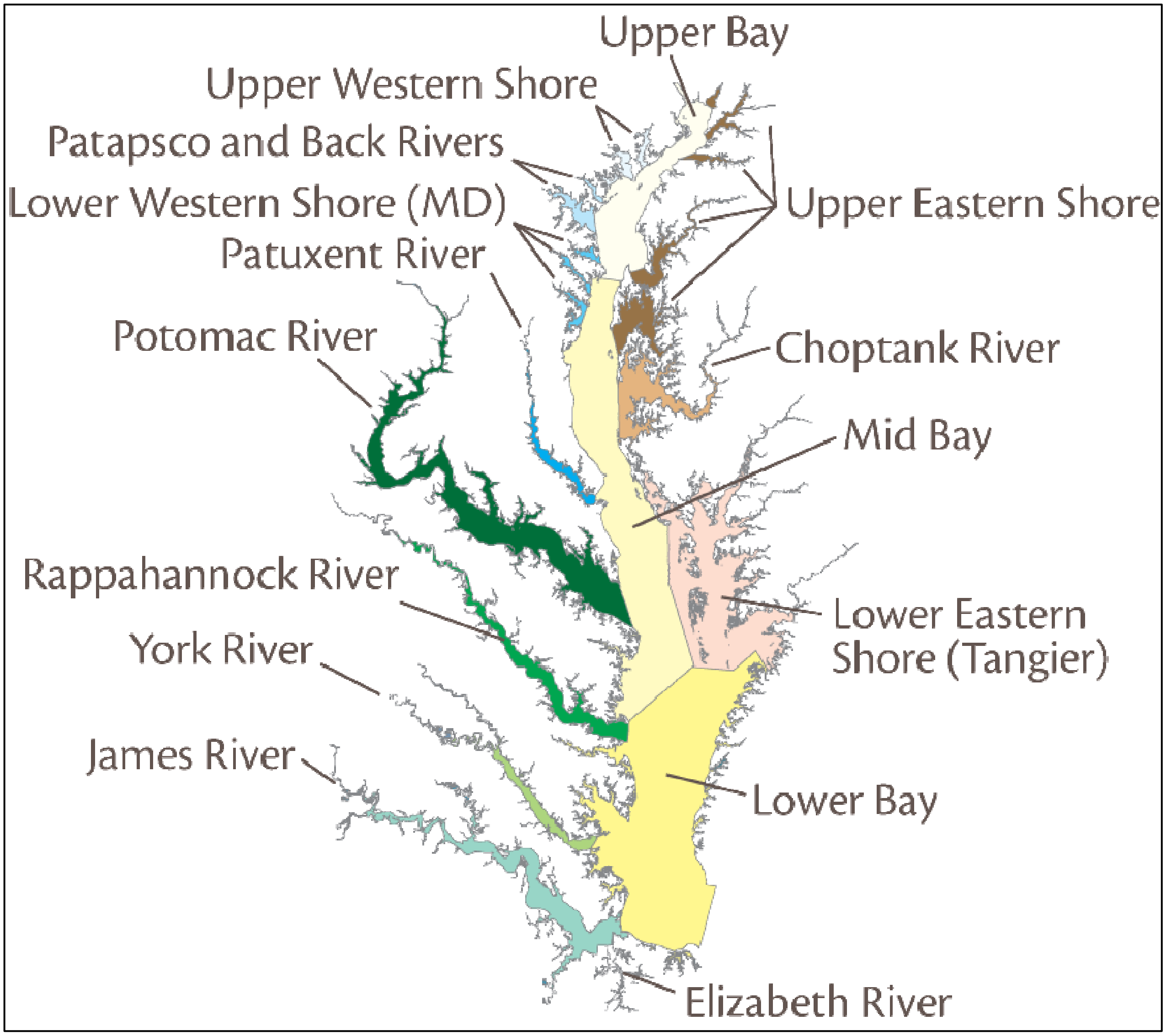

Figure 3-17. Bay Health Index Reporting Regions and Tributary Strategy basins. Figure courtesy of EcoCheck, NOAA-UMCES Partnership.

3.4 FLOW ANALYSIS

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

To address the question of whether river flow influences patterns of benthic degradation in Chesapeake Bay, we conducted two separate analyses. First we described trends in mean B-IBI values and each of the index components at long-term fixed sites while accounting for the effects of freshwater flow. A second-order polynomial regression model was used. The regression included linear (Time) and non-linear (Time squared) trend effects with time represented as number of years, 1985-2007. A second-order polynomial was selected under the assumption that only one inflection point in the parameters of interest was likely to occur over the monitoring period of record for this study. The model included a freshwater flow term. Flow was represented by spring (March-June), summer (July-September), and annual averages of daily fall-line gage measurements from the Susquehanna River at Conowingo for mainstem sites, and from the Choptank, Patuxent, and Potomac rivers for tributary sites. River flow data were accessed on the World Wide Web at the USGS National Water Information System.

Second, we conducted analyses of covariance with year and flow as independent variables and percent fail (percentage of sites with B-IBI values <3.0) and percent severely degraded condition (percentage of sites with B-IBI values ≤ 2.0) as the dependent variable, using the random-site data of each of the monitoring strata. The period of record for the B-IBI at the time of the analysis was 1995-2007. Flow was represented by spring (March-June) and summer (July-September) averages of daily fall-line gage measurements from the Susquehanna River at Conowingo, and alternatively from the Patuxent, Potomac, Rappahannock, York, and James rivers, but in this analysis flow was used as a categorical variable. Spring (or summer) mean flows above the 75 percentile of the normal range of spring (or summer) mean flows for the 1985-2007 baseline period were categorized as high; otherwise, flows were categorized as normal or low. Figure 3-18 shows mean flows for the Susquehanna River and the Potomac River.

Significant ($p< 0.05$) linear or non-linear trends in the B-IBI were detected at two of the 17 Maryland fixed sites tested, and freshwater flow was significant at six sites using annual averages, one site using summer averages, and none using spring averages (Table 3-8). For the random-site data, freshwater flow was significant for the spring but not the summer, when using Susquehanna River flow and data summarized at the Chesapeake Bay level (Table 3-9). Interestingly, there were year*flow interactions indicating that percent degradation, for both the degraded (percent fail) and the severely degraded condition, varied with flow but that these differences depended on year. Percent degradation exhibited contrasting trends in high and normal-low flow years (Figure 3-19). These trends were more pronounced in the Maryland mainstem (Table 3-10, Figure 3-20), but were not significant (not significant year*flow interactions) for tributary strata.

Table 3-8. Summary of results of second-order polynomial regressions of B-IBI versus time and river flow at fixed trend stations. The regression included linear (Time) and non-linear (Time^2) trend effects with time represented as number of years, 1985-2007. Significant ($p < 0.05$) negative and positive trends are indicated in the table. NS = not significant. Freshwater flow was represented by the annual, summer (July-September), or spring (March-June) average of daily fall-line gage measurements from the Susquehanna River at Conowingo (Stations 01-26), Potomac River (Stations 36-52), Choptank River (Stations 64-66) and Patuxent River (Stations 71-74).

			Annual				Summer				Spring			
STATION	**PARAMETER**	**MODEL**	**R^2**	**LINEAR**	**NON LINEAR**	**FLOW**	**R^2**	**LINEAR**	**NON LINEAR**	**FLOW**	**R^2**	**LINEAR**	**NON LINEAR**	**FLOW**
01	B_IBI	Full Model	0.310	NS	NEG	NS	0.391	NS	NEG	NS	0.284	NS	NEG	NS
06	B_IBI	Full Model	0.394	NS	NEG	NS	0.466	NS	NEG	NS	0.396	NS	NEG	NS
15	B_IBI	Full Model	0.392	NS	NS	POS	0.238	NS	NS	NS	0.267	NS	NS	NS
24	B_IBI	Full Model	0.221	NS	NS	POS	0.165	NS	NS	NS	0.068	NS	NS	NS
26	B_IBI	Full Model	0.242	NS	NS	NS	0.282	NS	NS	NS	0.227	NS	NS	NS
36	B_IBI	Full Model	0.254	NS	NS	NS	0.261	NS	NS	NS	0.252	NS	NS	NS
40	B_IBI	Full Model	0.176	NS	NS	NS	0.068	NS	NS	NS	0.052	NS	NS	NS
43	B_IBI	Full Model	0.104	NS	NS	NS	0.162	NS	NS	NS	0.038	NS	NS	NS
44	B_IBI	Full Model	0.233	NS	NS	NS	0.144	NS	NS	NS	0.212	NS	NS	NS
47	B_IBI	Full Model	0.125	NS	NS	NS	0.099	NS	NS	NS	0.109	NS	NS	NS
51	B_IBI	Full Model	0.108	NS	NS	NS	0.135	NS	NS	NS	0.109	NS	NS	NS
52	B_IBI	Full Model	0.070	NS	NS	NS	0.058	NS	NS	NS	0.061	NS	NS	NS
64	B_IBI	Full Model	0.177	NS	NS	NS	0.256	NS	NS	NS	0.181	NS	NS	NS
66	B_IBI	Full Model	0.381	NS	NS	POS	0.337	NS	NS	POS	0.297	NS	NS	NS
71	B_IBI	Full Model	0.128	NS	NS	NS	0.112	NS	NS	NS	0.157	NS	NS	NS
74	B_IBI	Full Model	0.278	NS	NS	NEG	0.227	NS	NS	NS	0.194	NS	NS	NS
77	B_IBI	Full Model	0.249	NS	NS	NS	0.300	NS	NS	NS	0.249	NS	NS	NS

Table 3-9. Results of analysis of covariance between percent degraded condition (% Fail) or percent severely degraded condition (% Sev Deg) for Chesapeake Bay and year (1995-2007) plus river flow. River flow was the average of spring (March-June) or summer (July-September) daily fall-line gage measurements from the Susquehanna River at Conowingo, or from all the major Bay tributaries combined. H = High flow; L = Normal or low flow (see text for flow classification). Shaded cells are *P* values <0.05.

Stratum	Flow From	Flow Classification	Variable	Season	P-Value			P-Value		# Years	
					Year	Flow Class	Year*Flow Class	Year	Flow Class	H	L
CH Bay	All	H >= 75%	% Fail	Mar-June	0.0274	0.5918	0.5898	0.0153	0.0941	3	9
CH Bay	All	H >= 75%	% Sev Deg	Mar-June	0.1511	0.2262	0.2267	0.0247	0.3928	3	9
CH Bay	All	H >= 75%	% Fail	Jul-Sept	0.0733	0.7535	0.7542	0.0605	0.61	4	8
CH Bay	All	H >= 75%	% Sev Deg	Jul-Sept	0.0496	0.5798	0.5791	0.0307	0.5546	4	8
CH Bay	Susquehanna	H >= 75%	% Fail	Mar-June	0.9023	0.0174	0.0174	0.0684	0.6369	3	9
CH Bay	Susquehanna	H >= 75%	% Sev Deg	Mar-June	0.7943	0.0159	0.0159	0.034	0.6023	3	9
CH Bay	Susquehanna	H >= 75%	% Fail	Jul-Sept	0.0733	0.7535	0.7542	0.0605	0.61	4	8
CH Bay	Susquehanna	H >= 75%	% Sev Deg	Jul-Sept	0.0496	0.5798	0.5791	0.0307	0.5546	4	8

Table 3-10. As in Table 3-9 but for the Maryland mainstem stratum using Susquehanna River flow. Shaded cells are *P* values <0.05.

Stratum	Flow From	Flow Classification	Variable	Season	P-Value			P-Value		# Years	
					Year	Flow Class	Year*Flow Class	Year	Flow Class	H	L
MMS	Susquehanna	H >= 75%	% Fail	Mar-June	0.2582	0.0079	0.0078	0.1525	0.2763	3	10
MMS	Susquehanna	H >= 75%	% Sev Deg	Mar-June	0.0153	0.0075	0.0075	0.7184	0.2122	3	10
MMS	Susquehanna	H >= 75%	% Fail	Jul-Sept	0.1664	0.9509	0.9491	0.1171	0.2261	4	9
MMS	Susquehanna	H >= 75%	% Sev Deg	Jul-Sept	0.74	0.667	0.6654	0.8383	0.243	4	9

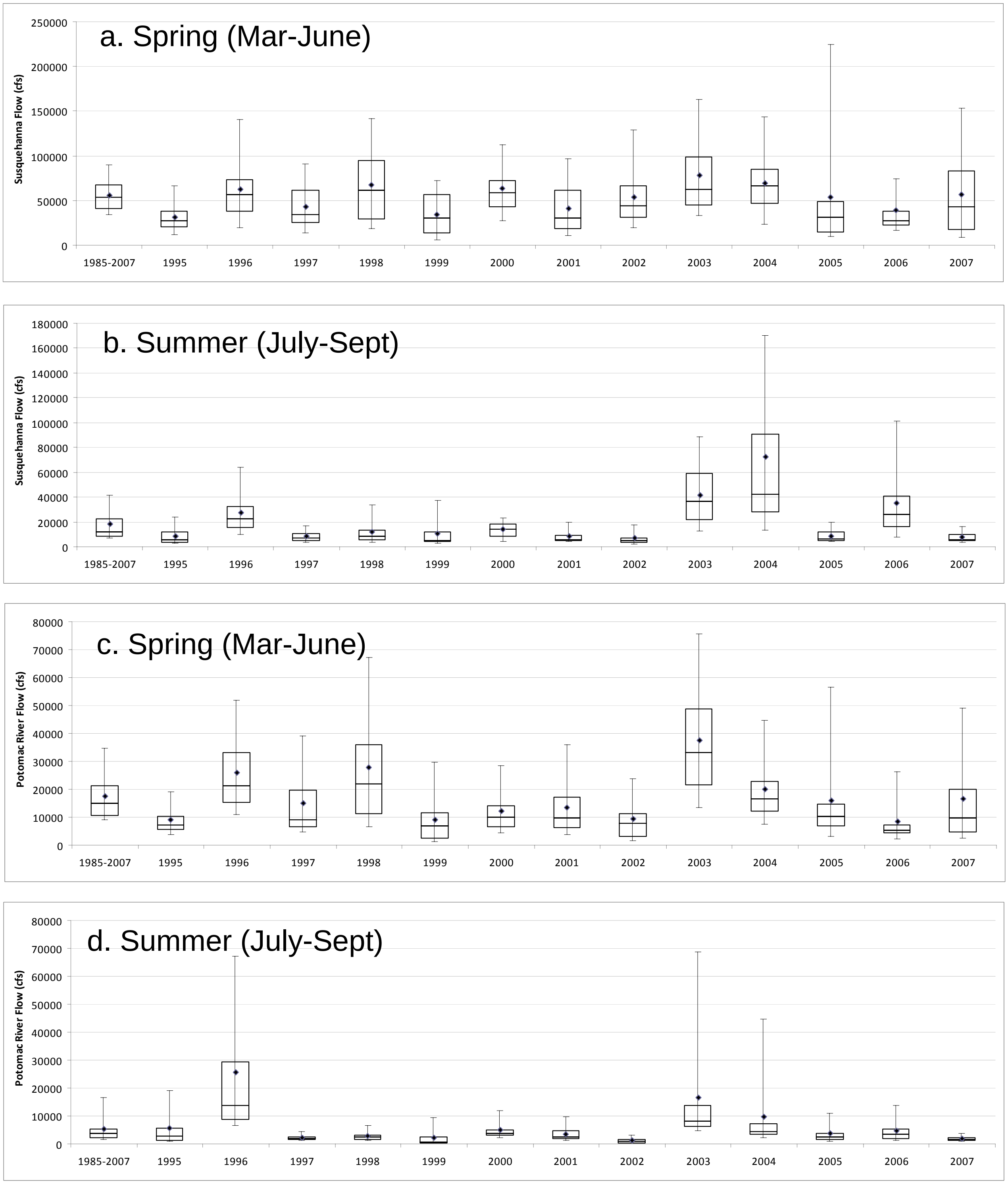

Figure 3-18. Spring and summer mean flow (dots within boxes) into Chesapeake Bay from the Susquehanna (a, b) and Potomac rivers (c, d) by year, 1995-2007. The average range of spring and summer flows used as baseline to categorize the years in the analysis is shown in the first box of each plot.

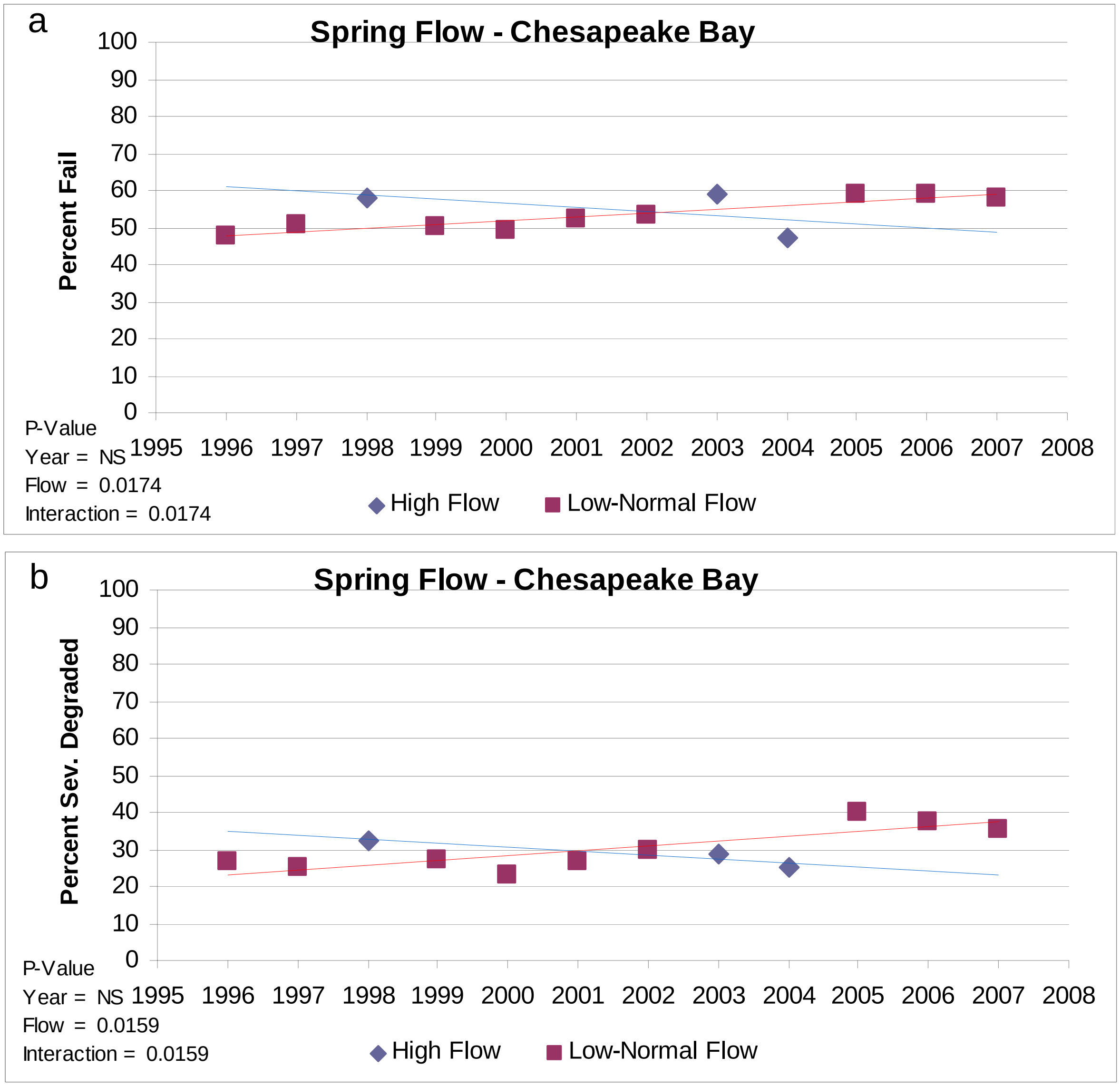

Figure 3-19. Relationship between percent degraded (percent fail) and percent severely degraded condition and year for high and low-normal spring (March-June) flow into Chesapeake Bay from the Susquehanna River. *P* values are for the analysis of covariance, see Table 3-9.

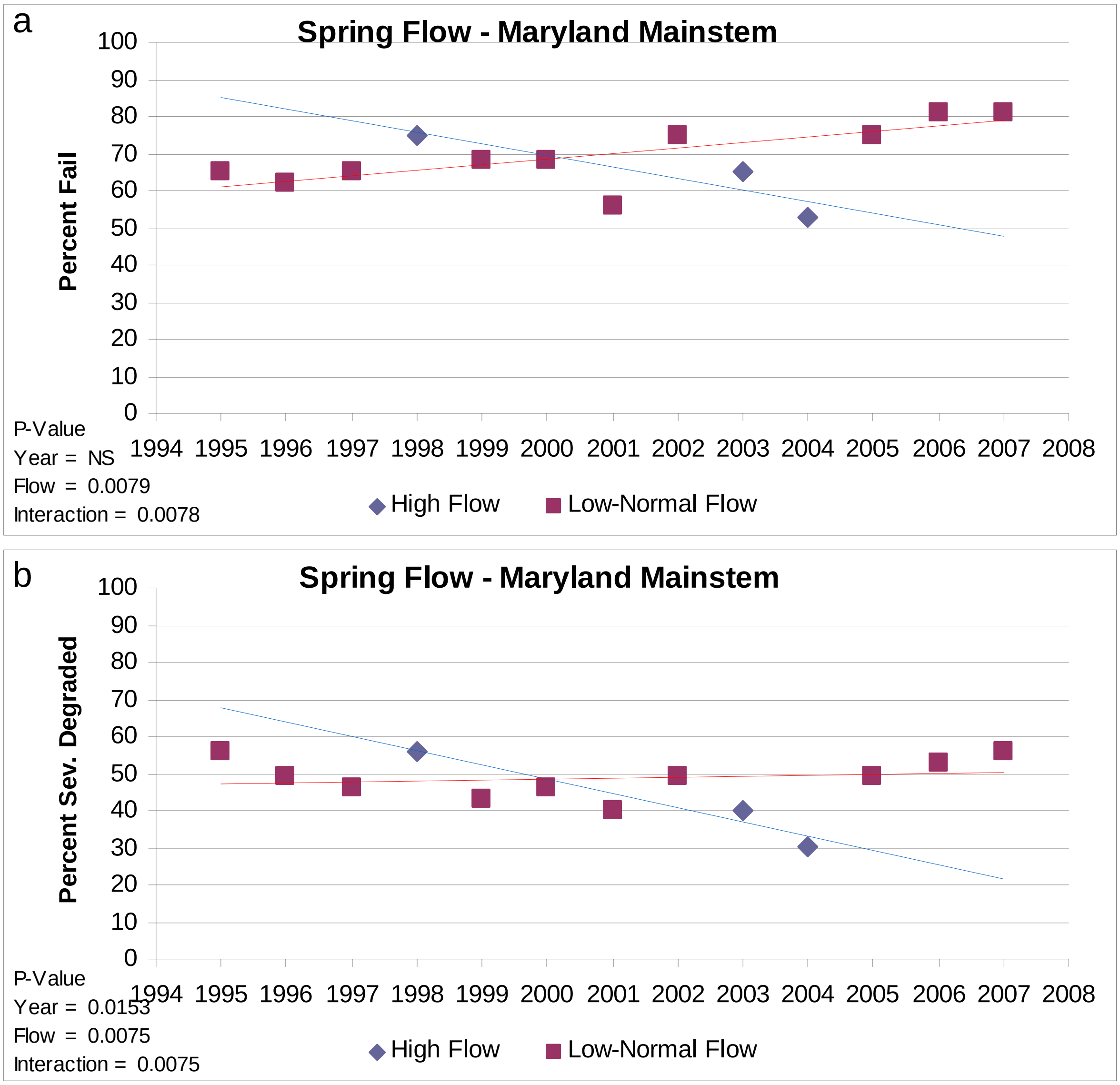

Figure 3-20. Relationship between percent degraded (percent fail) and percent severely degraded condition in the mainstem and year for high and low-normal spring (March-June) flow into Chesapeake Bay from the Susquehanna River. *P* values are for the analysis of covariance, see Table 3-10.

4.0 DISCUSSION

The highlights for 2009 are: (1) Improvements in benthic condition throughout the Maryland mainstem and the Potomac River, but statistically significant increases in degradation in the Patuxent River and the Maryland eastern tributaries; (2) an increase in the area of the Chesapeake Bay meeting the restoration goals, with the lower (Virginia) mainstem showing the largest increase; and (3) positive changes in trend direction and magnitude at several of the Maryland fixed sites, but still with overall declining trends in abundance and species richness at many sites.

In 2009 the benthos throughout the mainstem of the Chesapeake Bay improved from the Susquehanna Flats to the mouth of the Bay. Fifty-six percent of the Bay's tidal waters in 2009 met the benthic community restoration goals, compared to 41-42% in the last four years. The greatest improvement in benthic condition was in the Lower Bay, which consistently has the healthiest benthos for all tidal waters. When water quality conditions are sufficiently improved, it is expected that the Lower Bay benthos will respond first. However, these results should be interpreted with caution because they are based on a single year's change. Several years of consistent change will provide the robustness needed to support accolades or concerns.

In the Maryland portion of the Bay, 58% of the tidal waters failed the Chesapeake Bay restoration goals in 2009. This is one of the lowest estimates of degradation for the 1995-2009 period of record. The severely degraded condition in both the Chesapeake Bay and the Maryland waters has steadily decreased during the last four years. These results contrast with high levels of degradation in 2002 and 2003, and 2005 through 2008. However, despite the improvements, 5,000 km^2 of Bay bottom (3,600 km^2 in Maryland) remained to be restored in 2009.

It has been hypothesized that high estimates of degradation in Chesapeake Bay are associated with high spring flow in the Bay's tributaries. The Bay has experienced higher than normal spring flows (March-April) in most recent years except 2004. High spring flows are responsible for high nutrient runoff and earlier and spatially more extensive stratification within the Bay, factors that usually lead to more extensive hypoxia (Tuttle et al. 1987). In 2009, Susquehanna River flow was lower than average throughout the spring and the summer months. However, tributaries in Maryland and Virginia, such as the Potomac River, had higher-than-normal flow. Most of the rainfall in 2009 occurred in the lower Chesapeake watershed. The Susquehanna River provides 50% of the freshwater flow to the mainstem, so improvements in benthic condition would be expected mostly in the mainstem of the Bay. Indeed, the largest improvements in 2009, as measured by the benthic index of biotic integrity, occurred in the mainstem of the Bay. Although the Potomac River also showed improvements, good benthic community condition in the Potomac River was almost exclusively associated with the upper tidal freshwater and oligohaline portions of the river. Major reductions in runoff entering the upper tidal Potomac River have resulted in reduced nitrogen levels, fewer algal blooms, improved water clarity, and increases in seagrass cover. In contrast, the lower Potomac River is perennially hypoxic.

We examined the influence of freshwater flow on benthic community condition using polynomial regression models and analysis of covariance. The results suggested that freshwater flow does influence benthic condition in the mainstem of the Bay and that percent degradation (percent fail and percent severely degraded condition) follows different trajectories for years of high and normal or low flow. However, when freshwater flow was used as a continuous variable, as in the polynomial regressions of fixed site data, it was not a significant variable for any of the spring model runs. Thus, the intensity of the spring flow, rather than the annual mean flow, appeared to be the factor most closely associated with summer benthic community condition. High spring flows and rain events are usually associated with high nutrient runoff and more extensive hypoxia (Tuttle et al. 1987). We will continue to explore river flow relative to benthic condition, salinity, and dissolved oxygen trends in future analyses.

Fixed-site benthic condition remained unchanged in 2009 for many of the stations that exhibited significant trends in the previous year. However, two improving trends were new this year. Sites with improving benthic condition were located in the mainstem of the Bay, Elk River, lower Choptank River, Bear Creek, and Back River. B-IBI trend direction and magnitude at fixed sites changed for the first time since 2006, with changes reflecting improvements in the Maryland portion of the Bay. Nevertheless, major effects of hypoxia in the last few years were suggested by a decline in species richness at most stations, which is consistent and significant bay wide (See last year’s report, Seitz et al. 2009). The improving B-IBI trend in Bear Creek was accompanied by a decrease in the total organic carbon concentration of the sediments. This station is influenced by historical sources of pollution into the Patapsco River estuary, but the reason for the decline in the organic carbon concentration is not yet known.

Although hypoxia continues to be one of the major driving factors in determining benthic community condition in the Chesapeake Bay, such as in the lower Potomac River and the mainstem of the Bay, excess organic matter and nutrients in sediments is a contributing factor. Mixed sources of stress, including contamination, nutrient over-enrichment, and low dissolved oxygen stress affect the Patuxent River and the Maryland western tributaries, and high sediment loads and excess nutrient inputs affect the Maryland eastern tributaries (Dauer et al. 2000). Despite substantial restoration efforts, significant changes in benthic condition that would indicate widespread improvements in abundance, diversity, or biomass of organisms remain to be observed.

Post-stratification and probability-based sampling allow determination of levels of benthic community degradation at multiple spatial scales, from Bay Program 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 allow for a validated, unambiguous approach to characterizing conditions in the Chesapeake Bay. The Chesapeake Bay 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 study revealed good classification performance of the B-IBI, balanced Type I and Type II errors, and the influence of a variety of metrics in the final B-IBI score, characteristics that made assessments in Chesapeake Bay more reliable with the B-IBI than with any of the alternative benthic indicators.

5.0 REFERENCES

Alden, R.W. III, D.M. Dauer, J.A. Ranasinghe, L.C. Scott, and R.J. Llansó. 2002. Statistical verification of the Chesapeake Bay benthic index of biotic integrity. *Environmetrics* 13:473-498.

Alden, R.W. III, S.B. Weisberg, J.A. Ranasinghe, and D.M. Dauer. 1997. Optimizing temporal sampling strategies for benthic environmental monitoring programs. *Marine Pollution Bulletin* 34:913-922.

Baird, D. and R.E. Ulanowicz. 1989. The seasonal dynamics of the Chesapeake Bay Ecosystem. *Ecological Monographs* 59:329-364.

Boicourt, W.C. 1992. Influences of circulation processes on dissolved oxygen in the Chesapeake Bay. Pages 7-59. *In*: D.E. Smith, M. Leffler, and G. Mackiernan (eds.), Oxygen Dynamics in the Chesapeake Bay: A Synthesis of Recent Results. Maryland Sea Grant Program, College Park, Maryland.

Boynton, W.R. and W.M. Kemp. 2000. Influence of river flow and nutrient loads on selected ecosystem processes: A synthesis of Chesapeake Bay data. Pages 269-298. *In*: J.E. Hobbie, ed., Estuarine Science: A Synthetic Approach to Research and Practice. Island Press, Washington, D.C.

Dauer, D.M. 1993. Biological criteria, environmental health and estuarine macrobenthic community structure. *Marine Pollution Bulletin* 26:249-257.

Dauer, D.M. and R.J. Llansó. 2003. Spatial scales and probability based sampling in determining levels of benthic community degradation in the Chesapeake Bay. *Environmental Monitoring and Assessment* 81:175-186.

Dauer, D.M., J.A. Ranasinghe, and S.B. Weisberg. 2000. Relationships between benthic community condition, water quality, sediment quality, nutrient loads, and land use patterns in Chesapeake Bay. *Estuaries* 23:80-96.

Dauer, D.M., A.J. Rodi, Jr., and J.A. Ranasinghe. 1992. Effects of low dissolved oxygen events on the macrobenthos of the lower Chesapeake Bay. *Estuaries* 15:384-391.

Dennison, W.C., R.J. Orth, K.A. Moore, J.C. Stevenson, V. Carter, S. Kollar, P.W. Bergstrom, and R.A. Batiuk. 1993. Assessing water quality with submersed aquatic vegetation. Habitat requirements as barometers of Chesapeake Bay health. *BioScience* 43:86-94.

Diaz, R.J. and R. Rosenberg. 1995. Marine benthic hypoxia: A review of its ecological effects and the behavioural responses of benthic macrofauna. *Oceanography and Marine Biology Annual Review* 33:245-303.

Diaz, R.J. and L.C. Schaffner. 1990. The functional role of estuarine benthos. Pages 25-56. *In:* M. Haire and E. C. Chrome, eds., Perspectives on the Chesapeake Bay, Chapter 2. Chesapeake Research Consortium, Gloucester Point, Virginia. CBP/TRS 41/90.

Flemer, D.A., G.B. Mackiernan, W. Nehlsen, and V.K. Tippie. 1983. Chesapeake Bay: A profile of environmental change. U.S. Environmental Protection Agency, Washington, DC.

Frithsen, J. 1989. The benthic communities within Narragansett Bay. An assessment for the Narragansett Bay Project by the Marine Ecosystems Research Laboratory, Graduate School of Oceanography, University of Rhode Island, Narragansett, Rhode Island.

Gray, J.S. 1979. Pollution-induced changes in populations. *Philosophical Transactions of the Royal Society of London* B286:545-561.

Holland, A.F., N.K. Mountford, M.H. Hiegel, K.R. Kaumeyer, and J.A. Mihursky. 1980. The influence of predation on infaunal abundance in upper Chesapeake Bay. *Marine Biology* 57:221-235.

Holland, A.F., A.T. Shaughnessy, and M.H. Hiegel. 1987. Long-term variation in mesohaline Chesapeake Bay macrobenthos: Spatial and temporal patterns. *Estuaries* 3:227-245.

Holland, A.F., A.T. Shaughnessy, L.C. Scott, V.A. Dickens, J.A. Ranasinghe, and J.K. Summers. 1988. Long-term benthic monitoring and assessment program for the Maryland portion of Chesapeake Bay (July 1986-October 1987). Prepared for Power Plant Research Program, Department of Natural Resources and Maryland Department of the Environment by Versar, Inc., Columbia, Maryland.

Holland, A.F., A.T. Shaughnessy, L.C. Scott, V.A. Dickens, J. Gerritsen, and J.A. Ranasinghe. 1989. Long-term benthic monitoring and assessment program for the Maryland portion of Chesapeake Bay: Interpretive report. Prepared for the Maryland Dept. of Natural Resources by Versar, Inc., Columbia, Maryland. CBRM-LTB/EST-2.

Homer, M. and W.R. Boynton. 1978. Stomach analysis of fish collected in the Calvert Cliffs region, Chesapeake Bay-1977. Final report prepared for the Maryland Power Plant Siting Program by the University of Maryland, Chesapeake Biological Laboratory, Solomons, Maryland. UMCEES 78-154-CBL.

Homer, M., P.W. Jones, R. Bradford, J.M. Scolville, D. Morck, N. Kaumeyer, L. Hoddaway, and D. Elam. 1980. Demersal fish food habits studies near Chalk Point Power Plant, Patuxent estuary, Maryland, 1978-1979. Prepared for the Maryland Department of Natural Resources, Power Plant Siting Program, by the University of Maryland, Center for Environmental and Estuarine Studies, Chesapeake Biological Laboratory, Solomons, Maryland. UMCEES-80-32-CBL.

Llansó, R.J. 1992. Effects of hypoxia on estuarine benthos: The lower Rappahannock River (Chesapeake Bay), a case study. *Estuarine, Coastal, and Shelf Science* 35:491-515.

Llansó, R.J., D.M. Dauer, and J.H. Vølstad. 2009a. Assessing ecological integrity for impaired water decisions in Chesapeake Bay, USA. *Marine Pollution Bulletin*, 59:48-53.

Llansó, R.J., D.M. Dauer, J.H. Vølstad, and L.C. Scott. 2003. Application of the benthic index of biotic integrity to environmental monitoring in Chesapeake Bay. *Environmental Monitoring and Assessment* 81:163-174.

Llansó, R.J., L.C. Scott, and F.S. Kelley. 2005a. Chesapeake Bay water quality monitoring program: Long-term benthic monitoring and assessment component, Level 1 Comprehensive Report (July 1984-December 2004). Prepared for the Maryland Department of Natural Resources by Versar, Inc., Columbia, Maryland.

Llansó, R.J., J.H. Vølstad, D.M. Dauer, and J.R. Dew. 2009b Assessing benthic community condition in Chesapeake Bay: Does the use of different benthic indices matter? *Environmental Monitoring and Assessment*, 150:119-127.

Llansó, R.J., J.H. Vølstad, D.M. Dauer, and M.F. Lane. 2005b. 2006 303(d) Assessment Methods for Chesapeake Bay Benthos. Prepared for Virginia Department of Environmental Quality by Versar, Inc., Columbia, Maryland., and Department of Biological Sciences, Old Dominion University, Norfolk, Virginia.

Malone, T.C. 1987. Seasonal oxygen depletion and phytoplankton production in Chesapeake Bay: Preliminary results of 1985-86 field studies. Pages 54-60. *In:* G.B. Mackiernan, ed., Dissolved Oxygen in the Chesapeake Bay: Processes and Effects. Maryland Sea Grant, College Park, Maryland.

Malone, T.C., L.H. Crocker, S.E. Pile, and B.W. Wendler. 1988. Influences of river flow on the dynamics of phytoplankton production in a partially stratified estuary. *Marine Ecology Progress Series* 48:235-249.

National Research Council (NRC). 1990. Managing Troubled Waters: The Role of Marine Environmental Monitoring. National Academy Press, Washington, DC.

Officer, C.B., R.B. Biggs, J.L. Taft, L.E. Cronin, M.A. Tyler, and W.R. Boynton. 1984. Chesapeake Bay anoxia: Origin, development, and significance. *Science* 223:22-27.

Pearson, T.H. and R. Rosenberg. 1978. Macrobenthic succession in relation to organic enrichment and pollution of the marine environment. *Oceanography and Marine Biology Annual Review* 16:229-311.

Ranasinghe, J.A., L.C. Scott, and S.B. Weisberg. 1993. Chesapeake Bay water quality monitoring program: Long-term benthic monitoring and assessment component, Level 1 Comprehensive Report (July 1984-December 1992). Prepared for Maryland Department of the Environment and Maryland Department of Natural Resources by Versar, Inc., Columbia, Maryland.

Ranasinghe, J.A., S.B. Weisberg, D.M. Dauer, L.C. Schaffner, R.J. Diaz, and J.B. Frithsen. 1994. Chesapeake Bay Benthic Community Restoration Goals. Prepared for the U.S. Environmental Protection Agency Chesapeake Bay Program Office, the Governor's Council on Chesapeake Bay Research Fund, and the Maryland Department of Natural Resources by Versar, Inc., Columbia, Maryland.

Ritter, C. and P.A. Montagna. 1999. Seasonal hypoxia and models of benthic response in a Texas Bay. *Estuaries* 22:7-20.

Seitz, R.D., D.M. Dauer, R.J. Llansó, and W.C. Long. 2009. Broad-scale effects of hypoxia on benthic community structure in Chesapeake Bay, USA. *Journal of Experimental Marine Biology and Ecology* In Press.

Scott, L.C., A.F. Holland, A.T. Shaughnessy, V. Dickens, and J.A. Ranasinghe. 1988. Long-term benthic monitoring and assessment program for the Maryland portion of Chesapeake Bay: Data summary and progress report. Prepared for Maryland Department of Natural Resources, Chesapeake Bay Research and Monitoring Division, and Maryland Department of the Environment by Versar, Inc., Columbia, Maryland. PPRP-LTB/EST-88-2.

Seliger, H.H., J.A. Boggs, and W.H. Biggley. 1985. Catastrophic anoxia in the Chesapeake Bay in 1984. *Science* 228:70-73.

Sen, P.K. 1968. Estimates of the regression coefficient based on Kendall's tau. *Journal of the American Statistical Association* 63:1379-1389.

Tuttle, J.H., R.B. Jonas, and T.C. Malone. 1987. Origin, development and significance of Chesapeake Bay anoxia. Pages 443-472. *In:* S.K. Majumdar, L.W. Hall, Jr., and H.M. Austin, eds., Contaminant Problems and Management of Living Chesapeake Bay Resources. Pennsylvania Academy of Science, Philadelphia, Pennsylvania.

van Belle, G. and J.P. Hughes. 1984. Nonparametric tests for trend in water quality. *Water Resources Research* 20:127-136.

Versar, Inc. 1999. Versar Benthic Laboratory Standard Operating Procedures and Quality Control Procedures. Versar, Inc., Columbia, Maryland.

Virnstein, R.W. 1977. The importance of predation of crabs and fishes on benthic infauna in Chesapeake Bay. *Ecology* 58:1199-1217.

Warwick, R.M. 1986. A new method for detecting pollution effects on marine macrobenthic communities. *Marine Biology* 92:557-562.

Weisberg, S.B., J.A. Ranasinghe, D.M. Dauer, L.C. Schaffner, R.J. Diaz, and J.B. Frithsen. 1997. An estuarine benthic index of biotic integrity (B-IBI) for Chesapeake Bay. *Estuaries* 20:149-158.

Williams, M., B. Longstaff, C. Buchanan, R. Llansó, and W. Dennison. 2009. Development and evaluation of a spatially-explicit index of Chesapeake Bay health. *Marine Pollution Bulletin*, 59:14-25.

Wilson, J.G. and D.W. Jeffrey. 1994. Benthic biological pollution indices in estuaries. Pages 311-327. *In:* J.M. Kramer, ed., Biomonitoring of Coastal Waters and Estuaries. CRC Press, Boca Raton, Florida.

APPENDIX A

FIXED SITE COMMUNITY ATTRIBUTE 1985-2009 TREND ANALYSIS RESULTS

Appendix Table A-1. Summer trends in benthic community attributes at mesohaline stations 1985-2009. Shown is the median slope of the trend. Monotonic trends were identified using the van Belle and Hughes (1984) procedure. Shaded cells indicate increasing degradation; unshaded cells indicate improving conditions; (a): trends based on 1989-2009 data; (b): trends based on 1995-2009 data; (c): attribute trend based on 1990-2009 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	0.00	-80.00	-0.95	-0.01	0.23	-1.03 (d)	0.01 (e)	-1.23	-0.21 (e)
44	0.00	-30.36	-0.06	0.00	-0.32	-0.21 (d)	0.00 (e)	-0.09	0.53 (e)
47	0.00	-72.00	-0.78	0.00	0.14	-1.24 (d)	0.01 (e)	-1.01	-0.27 (e)
51	0.00	-35.43	-0.12	0.01	-0.66	0.27	0.18 (e)	-1.19 (e)	0.29
52	0.00	-3.79	-0.00	0.00	0.00 (d)	0.00 (d)	0.00	0.00	0.00
Patuxent River									
71	-0.03	-45.00	-0.04	-0.02	-1.04 (d)	-0.13 (d)	0.31	0.00	0.12
74	0.00	20.68	-1.21	-0.01	0.18	-0.85 (d)	-0.00 (e)	-0.16	-0.31 (e)
77	-0.04	11.79	-0.09	0.00	0.45	-0.41(d)	-1.30 (e)	1.16	-0.60 (e)
Choptank River									
64	0.02	-18.61	0.07	0.02	-0.24 (d)	0.56 (d)	0.01	-0.70	0.63
Maryland Mainstem									
01	0.00	-40.00	-0.01	-0.01	-0.30	-0.14	-0.04 (e)	-0.42 (e)	-0.40
06	0.00	6.67	0.01	-0.01	0.00	-0.30	0.11 (e)	-1.75 (e)	-0.65
15	0.02	-2.35	-0.02	0.01	-0.58	0.10	0.10 (e)	-0.56 (e)	0.32
24	0.01	-30.29	0.04	-0.02	-0.52 (d)	0.56 (d)	-0.00	1.06	0.74
26	0.00	-12.53	0.09	0.01	0.00	0.09 (d)	-0.00 (e)	-0.00	0.22 (e)
Maryland Western Shore Tributaries									
22	-0.03	-52.76	-0.03	-0.06	2.06	0.00 (d)	1.07 (e)	0.00	-0.50 (e)
23	0.00	-84.42	0.04	-0.02	-0.19	0.86 (d)	-0.03 (e)	1.01	0.11 (e)
201(a)	0.00	-9.05	0.00	0.00	0.00	0.00 (d)	0.00 (e)	0.00	0.00 (e)
202(a)	0.00	-29.72	0.00	0.00	0.00	0.00 (d)	0.00 (e)	0.00	0.00 (e)
204(b)	-0.03	-108.10	-0.12	0.01	0.51 (d)	0.64 (d)	0.01	0.18	0.02
Maryland Eastern Shore Tributaries									
62	-0.04	40.00	-0.05	-0.05	-0.03	-0.40 (d)	0.01 (e)	-2.04	-0.27 (e)
68	0.00	42.50	0.45	-0.02	-0.04	0.29 (d)	0.00 (e)	-0.01	-0.02 (e)

Appendix Table A-2. Summer trends in benthic community attributes at oligohaline and tidal freshwater stations 1985-2009. Shown is the median slope of the trend. Monotonic trends were identified using the van Belle and Hughes (1984) procedure. Shaded cells indicate increasing degradation; unshaded cells indicate improving conditions; (a): trends based on 1989-2009 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	0.00	-4.55	0.02	0.70	NA	NA	NA	0.61	NA
40	0.00	11.16	-0.01	NA	0.20	0.00	0.00	NA	-0.18
Patuxent River									
79	0.00	16.99	-0.01	-0.57	NA	NA	NA	-0.05	NA
Choptank River									
66	0.00	22.50	0.06	NA	0.34	0.00	0.00	NA	0.15
Maryland Western Shore Tributaries									
203(a)	0.07	-22.76	-0.06	NA	0.00	0.00	2.07	NA	2.46
Maryland Eastern Shore Tributaries									
29	0.01	-56.82	-0.05	NA	-1.41	-0.04	0.00	NA	0.22

APPENDIX B

FIXED SITE B-IBI VALUES, SUMMER 2009

Appendix Table B-1. Fixed site B-IBI values, Summer 2009

Station	Sampling Date	Latitude (WGS84 Decimal Degrees)	Longitude (WGS84 Decimal Degrees)	B-IBI	Status
001	9/15/2009	38.41863	-76.4185	2.00	Severely Degraded
006	9/15/2009	38.44082	-76.4444	3.00	Meets Goal
015	9/15/2009	38.71468	-76.5143	1.89	Severely Degraded
022	8/24/2009	39.25462	-76.5876	1.00	Severely Degraded
023	8/24/2009	39.2081	-76.5236	4.07	Meets Goal
024	8/24/2009	39.12182	-76.3558	4.22	Meets Goal
026	8/25/2009	39.27142	-76.2902	3.67	Meets Goal
029	10/6/2009	39.4797	-75.9447	3.00	Meets Goal
036	10/1/2009	38.76967	-77.0377	2.17	Degraded
040	10/1/2009	38.35745	-77.2306	2.89	Marginal
043	9/14/2009	38.38385	-76.9877	3.13	Meets Goal
044	9/14/2009	38.3851	-76.9956	3.40	Meets Goal
047	9/14/2009	38.36395	-76.9839	3.93	Meets Goal
051	9/14/2009	38.2055	-76.7389	1.78	Severely Degraded
052	8/31/2009	38.19205	-76.7481	1.00	Severely Degraded
062	9/8/2009	38.38377	-75.8506	2.60	Degraded
064	9/18/2009	38.59075	-76.0695	3.56	Meets Goal
066	9/8/2009	38.80133	-75.9222	3.56	Meets Goal
068	9/16/2009	39.1329	-76.0791	3.53	Meets Goal
071	9/2/2009	38.39495	-76.5495	1.22	Severely Degraded
074	9/2/2009	38.54902	-76.6763	3.80	Meets Goal
077	9/2/2009	38.60455	-76.6747	2.87	Marginal
079	9/9/2009	38.7505	-76.6894	3.67	Meets Goal
201	8/24/2009	39.23417	-76.4974	2.73	Marginal
202	8/24/2009	39.21787	-76.5641	1.00	Severely Degraded
203	8/25/2009	39.27497	-76.4445	3.22	Meets Goal
204	8/26/2009	39.00667	-76.505	4.22	Meets Goal

APPENDIX C

RANDOM SITE B-IBI VALUES, SUMMER 2009

Appendix Table C-1. Random site B-IBI values, Summer 2009

Station	Sampling Date	Latitude (WGS84 Decimal Degrees)	Longitude (WGS84 Decimal Degrees)	B-IBI	Status
MET-16401	1-Sep-09	38.04403	-75.859	4.00	Meets Goal
MET-16402	1-Sep-09	38.1208	-75.8736	2.67	Marginal
MET-16403	1-Sep-09	38.13212	-75.8873	4.00	Meets Goal
MET-16404	1-Sep-09	38.13647	-75.8373	1.67	Sev. Degraded
MET-16405	1-Sep-09	38.1447	-75.8356	2.00	Sev. Degraded
MET-16407	1-Sep-09	38.21955	-75.883	3.67	Meets Goal
MET-16408	1-Sep-09	38.23135	-75.873	2.33	Degraded
MET-16409	1-Sep-09	38.2401	-75.8632	1.00	Sev. Degraded
MET-16410	1-Sep-09	38.2901	-75.9183	1.67	Sev. Degraded
MET-16411	1-Sep-09	38.29147	-75.9317	1.67	Sev. Degraded
MET-16412	18-Sep-09	38.58532	-76.1088	2.33	Degraded
MET-16413	18-Sep-09	38.58707	-75.9842	3.40	Meets Goal
MET-16414	18-Sep-09	38.58895	-76.1035	1.67	Sev. Degraded
MET-16415	8-Sep-09	38.77983	-75.9672	1.00	Sev. Degraded
MET-16416	8-Sep-09	38.80237	-75.9235	5.00	Meets Goal
MET-16418	16-Sep-09	39.09682	-76.1633	3.40	Meets Goal
MET-16419	16-Sep-09	39.15608	-76.0681	4.20	Meets Goal
MET-16420	6-Oct-09	39.35203	-75.918	2.67	Marginal
MET-16421	6-Oct-09	39.37137	-75.9307	3.33	Meets Goal
MET-16422	6-Oct-09	39.3739	-75.9848	3.33	Meets Goal
MET-16423	6-Oct-09	39.38123	-76.0643	2.67	Marginal
MET-16424	6-Oct-09	39.44528	-76.0045	2.33	Degraded
MET-16425	6-Oct-09	39.559	-75.8524	2.00	Sev. Degraded
MET-16426	16-Sep-09	39.0908	-76.1583	4.33	Meets Goal
MET-16427	1-Sep-09	38.25597	-75.941	2.00	Sev. Degraded
MMS-16501	31-Aug-09	37.91892	-76.2165	2.00	Sev. Degraded
MMS-16502	23-Sep-09	37.952	-75.801	4.33	Meets Goal
MMS-16503	23-Sep-09	37.95668	-76.0107	2.67	Marginal
MMS-16504	1-Sep-09	37.9947	-76.0781	1.67	Sev. Degraded
MMS-16505	23-Sep-09	38.0057	-76.0303	3.00	Meets Goal
MMS-16506	1-Sep-09	38.05198	-76.1456	3.67	Meets Goal
MMS-16507	1-Sep-09	38.08045	-75.96	2.67	Marginal
MMS-16508	1-Sep-09	38.08398	-76.1216	3.33	Meets Goal
MMS-16509	1-Sep-09	38.20387	-76.2081	3.00	Meets Goal
MMS-16510	1-Sep-09	38.21237	-75.9464	1.67	Sev. Degraded
MMS-16511	1-Sep-09	38.22102	-76.0755	3.67	Meets Goal
MMS-16512	1-Sep-09	38.23877	-76.1152	2.67	Marginal
MMS-16513	15-Sep-09	38.41632	-76.2966	3.67	Meets Goal

Appendix Table C-1. (Continued)

Station	Sampling Date	Latitude (WGS84 Decimal Degrees)	Longitude (WGS84 Decimal Degrees)	B-IBI	Status
MMS-16514	15-Sep-09	38.5052	-76.3238	3.33	Meets Goal
MMS-16516	15-Sep-09	38.56728	-76.2895	2.00	Sev. Degraded
MMS-16517	21-Sep-09	38.67467	-76.344	1.67	Sev. Degraded
MMS-16518	21-Sep-09	38.70788	-76.3891	4.00	Meets Goal
MMS-16519	21-Sep-09	38.71755	-76.3442	2.00	Sev. Degraded
MMS-16520	21-Sep-09	38.74632	-76.3178	2.67	Marginal
MMS-16521	21-Sep-09	38.75905	-76.3935	1.67	Sev. Degraded
MMS-16522	24-Sep-09	38.7831	-76.1634	2.33	Degraded
MMS-16523	26-Aug-09	38.85745	-76.4837	2.60	Degraded
MMS-16524	26-Aug-09	38.86203	-76.4829	3.00	Meets Goal
MMS-16525	18-Sep-09	38.90543	-76.2433	1.67	Sev. Degraded
MMS-16527	15-Sep-09	38.63115	-76.5067	2.00	Sev. Degraded
MWT-16301	26-Aug-09	38.85367	-76.4991	2.60	Degraded
MWT-16302	26-Aug-09	38.87067	-76.5142	4.60	Meets Goal
MWT-16303	26-Aug-09	38.91273	-76.4932	3.80	Meets Goal
MWT-16304	26-Aug-09	39.04877	-76.551	1.80	Sev. Degraded
MWT-16305	26-Aug-09	39.06343	-76.5662	1.00	Sev. Degraded
MWT-16306	24-Aug-09	39.1328	-76.4459	3.80	Meets Goal
MWT-16307	24-Aug-09	39.18403	-76.5196	3.40	Meets Goal
MWT-16308	24-Aug-09	39.20705	-76.5024	2.20	Degraded
MWT-16309	24-Aug-09	39.21528	-76.5728	1.00	Sev. Degraded
MWT-16310	24-Aug-09	39.23423	-76.5571	3.40	Meets Goal
MWT-16311	25-Aug-09	39.25242	-76.4458	3.00	Meets Goal
MWT-16312	24-Aug-09	39.27687	-76.5775	1.00	Sev. Degraded
MWT-16313	25-Aug-09	39.2834	-76.4484	2.33	Degraded
MWT-16314	24-Aug-09	39.28438	-76.6098	1.00	Sev. Degraded
MWT-16315	25-Aug-09	39.29833	-76.3775	3.40	Meets Goal
MWT-16316	25-Aug-09	39.30088	-76.4838	3.50	Meets Goal
MWT-16317	13-Sep-09	39.33197	-76.3202	3.80	Meets Goal
MWT-16318	13-Sep-09	39.3327	-76.3224	1.80	Sev. Degraded
MWT-16319	13-Sep-09	39.34192	-76.3149	3.33	Meets Goal
MWT-16320	13-Sep-09	39.37078	-76.2657	3.00	Meets Goal
MWT-16321	13-Sep-09	39.3836	-76.2665	3.00	Meets Goal
MWT-16323	20-Sep-09	39.39202	-76.3474	3.00	Meets Goal
MWT-16325	13-Sep-09	39.4363	-76.2439	2.00	Sev. Degraded
MWT-16326	24-Aug-09	39.18025	-76.466	4.20	Meets Goal
MWT-16327	26-Aug-09	38.95435	-76.5663	1.00	Sev. Degraded
PMR-16101	31-Aug-09	38.0391	-76.4338	1.00	Sev. Degraded

Appendix Table C-1. (Continued)

Station	Sampling Date	Latitude (WGS84 Decimal Degrees)	Longitude (WGS84 Decimal Degrees)	B-IBI	Status
PMR-16102	31-Aug-09	38.11638	-76.4455	1.67	Sev. Degraded
PMR-16103	31-Aug-09	38.12218	-76.4679	1.33	Sev. Degraded
PMR-16104	31-Aug-09	38.14003	-76.5814	1.00	Sev. Degraded
PMR-16105	31-Aug-09	38.14337	-76.54	3.33	Meets Goal
PMR-16106	31-Aug-09	38.1653	-76.4548	1.00	Sev. Degraded
PMR-16107	31-Aug-09	38.17437	-76.6939	1.00	Sev. Degraded
PMR-16108	31-Aug-09	38.19673	-76.642	1.00	Sev. Degraded
PMR-16109	31-Aug-09	38.22838	-76.9423	2.60	Degraded
PMR-16110	31-Aug-09	38.2331	-76.9348	2.20	Degraded
PMR-16111	31-Aug-09	38.24948	-76.6571	1.00	Sev. Degraded
PMR-16112	31-Aug-09	38.26847	-76.8242	1.00	Sev. Degraded
PMR-16113	14-Sep-09	38.3131	-77.0231	3.40	Meets Goal
PMR-16114	1-Oct-09	38.3339	-77.24	3.33	Meets Goal
PMR-16115	1-Oct-09	38.33947	-77.2358	3.80	Meets Goal
PMR-16116	1-Oct-09	38.35158	-77.2874	2.33	Degraded
PMR-16117	14-Sep-09	38.37542	-77.109	3.00	Meets Goal
PMR-16118	14-Sep-09	38.38373	-77.0751	3.80	Meets Goal
PMR-16121	1-Oct-09	38.41482	-77.2983	3.00	Meets Goal
PMR-16122	1-Oct-09	38.43723	-77.2996	3.80	Meets Goal
PMR-16123	28-Sep-09	38.55837	-77.2445	3.00	Meets Goal
PMR-16124	28-Sep-09	38.56182	-77.2533	3.40	Meets Goal
PMR-16125	1-Oct-09	38.67568	-77.1298	4.50	Meets Goal
PMR-16126	14-Sep-09	38.45112	-77.0434	2.60	Degraded
PMR-16127	31-Aug-09	38.01808	-76.4678	1.00	Sev. Degraded
PXR-16201	31-Aug-09	38.29747	-76.4425	2.67	Marginal
PXR-16202	31-Aug-09	38.29815	-76.4281	2.33	Degraded
PXR-16203	2-Sep-09	38.29893	-76.4429	2.33	Degraded
PXR-16204	31-Aug-09	38.30172	-76.4587	2.33	Degraded
PXR-16206	15-Sep-09	38.3217	-76.4913	3.00	Meets Goal
PXR-16207	2-Sep-09	38.34315	-76.4798	2.33	Degraded
PXR-16208	2-Sep-09	38.34748	-76.4748	2.00	Sev. Degraded
PXR-16209	2-Sep-09	38.36987	-76.503	2.33	Degraded
PXR-16210	2-Sep-09	38.37182	-76.4984	2.00	Sev. Degraded
PXR-16211	2-Sep-09	38.40302	-76.4837	1.00	Sev. Degraded
PXR-16212	2-Sep-09	38.40297	-76.5343	3.00	Meets Goal
PXR-16213	2-Sep-09	38.40352	-76.5656	1.00	Sev. Degraded
PXR-16214	2-Sep-09	38.42053	-76.5396	1.67	Sev. Degraded
PXR-16215	2-Sep-09	38.42327	-76.5888	2.00	Sev. Degraded

Appendix Table C-1. (Continued)

Station	Sampling Date	Latitude (WGS84 Decimal Degrees)	Longitude (WGS84 Decimal Degrees)	B-IBI	Status
PXR-16216	2-Sep-09	38.42665	-76.6137	1.67	Sev. Degraded
PXR-16217	2-Sep-09	38.45145	-76.6355	1.00	Sev. Degraded
PXR-16218	2-Sep-09	38.45688	-76.596	2.33	Degraded
PXR-16219	2-Sep-09	38.46243	-76.6466	1.00	Sev. Degraded
PXR-16220	2-Sep-09	38.48405	-76.6563	4.00	Meets Goal
PXR-16221	2-Sep-09	38.5242	-76.6619	2.20	Degraded
PXR-16223	2-Sep-09	38.52897	-76.6612	2.60	Degraded
PXR-16224	2-Sep-09	38.57027	-76.6757	3.40	Meets Goal
PXR-16225	9-Sep-09	38.7728	-76.6993	2.00	Sev. Degraded
PXR-16226	9-Sep-09	38.73655	-76.6906	2.00	Sev. Degraded
PXR-16227	2-Sep-09	38.34798	-76.5257	1.00	Sev. Degraded
UPB-16602	24-Aug-09	39.09343	-76.3195	2.33	Degraded
UPB-16603	24-Aug-09	39.13856	-76.3784	4.20	Meets Goal
UPB-16604	24-Aug-09	39.14732	-76.3435	2.67	Marginal
UPB-16605	25-Aug-09	39.17375	-76.2922	1.67	Sev. Degraded
UPB-16606	25-Aug-09	39.18867	-76.2637	3.40	Meets Goal
UPB-16607	25-Aug-09	39.21613	-76.327	3.80	Meets Goal
UPB-16608	25-Aug-09	39.21772	-76.3036	3.80	Meets Goal
UPB-16610	25-Aug-09	39.23902	-76.2995	3.40	Meets Goal
UPB-16611	25-Aug-09	39.28122	-76.2269	3.80	Meets Goal
UPB-16612	25-Aug-09	39.29155	-76.1767	3.00	Meets Goal
UPB-16613	25-Aug-09	39.29322	-76.1683	3.40	Meets Goal
UPB-16614	13-Sep-09	39.30263	-76.301	3.80	Meets Goal
UPB-16616	25-Aug-09	39.31882	-76.2031	3.33	Meets Goal
UPB-16617	13-Sep-09	39.34002	-76.2525	2.67	Marginal
UPB-16618	6-Oct-09	39.35202	-76.1542	4.20	Meets Goal
UPB-16619	13-Sep-09	39.35508	-76.1766	3.80	Meets Goal
UPB-16620	6-Oct-09	39.36242	-76.123	3.80	Meets Goal
UPB-16621	6-Oct-09	39.37873	-76.1292	3.80	Meets Goal
UPB-16622	13-Sep-09	39.39117	-76.1671	4.20	Meets Goal
UPB-16623	13-Sep-09	39.43308	-76.0596	3.67	Meets Goal
UPB-16624	6-Oct-09	39.44382	-76.0149	3.00	Meets Goal
UPB-16625	6-Oct-09	39.47445	-76.0376	4.50	Meets Goal
UPB-16626	6-Oct-09	39.38943	-76.0982	3.40	Meets Goal
UPB-16627	24-Aug-09	39.10617	-76.3376	3.33	Meets Goal
UPB-16630	6-Oct-09	39.50582	-76.0814	4.00	Meets Goal