CHESAPEAKE BAY WATER QUALITY MONITORING PROGRAM

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

JULY 1984—DECEMBER 2004 (VOLUME 1)

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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 2005), was prepared by Versar, Inc., at the request of Mr. Bruce Michael of the Maryland Department of Natural Resources under Cooperative Agreement CA-05-01/07-4-30884-3734 between Versar, Inc., and the University of Maryland Center for Environmental and Estuarine Studies. The report assesses the status of Chesapeake Bay benthic communities in 2004 and evaluates their responses to changes in water quality.

ACKNOWLEDGEMENTS

We are grateful to the State of Maryland’s Environmental Trust Fund which partially funded this work. The benthic studies discussed in this report were conducted from the University of Maryland's research vessels and we appreciate the efforts of their captains and crew. We thank Nancy Mountford and Tim Morris of Cove Corporation who identified benthos in many of the samples from previous years and provided current taxonomic and autecological information. We also thank those at Versar whose efforts helped produce this report: the field crews who collected samples, including Martin Berlett, Craig Bruce, Donna Croson, Katherine Dillow, and Brenda Morgan; the laboratory technicians for processing samples, Dawn Hendrickson, Bobbi Mayer, Lay Nwe, Theresa Panzer, Diana Thaung, and Josh Vanderwagen; Suzanne Arcuri and Michael Winnel for taxonomic identifications; Jody Dew for managing and analyzing data; Allison Brindley for GIS support; Dr. Don Strebel for web-page development; and Sherian George and Gail Lucas for document production.

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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. This report is one in a series of annual reports that summarize data up to the current sampling year. Benthic community condition and trends in the Chesapeake Bay are assessed for 2004 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 the 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 twice a year, in May and in late August or September. Three replicate sediment samples for benthos are collected at each fixed site with 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 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 for the entire Chesapeake Bay. The largest portion of the Chesapeake Bay, the mainstem, is divided into three strata, and five strata consist of the major tributaries (Patuxent, Potomac, Rappahannock, York, and James rivers). Two additional strata include the remaining smaller tributaries of the Maryland upper western shore and Maryland eastern shore. The strata sampled represent the entire tidal region of the Chesapeake Bay from freshwater to polyhaline zones. Probability sites are sampled once a year in late August or September. One sample is collected at each probability site using a Young grab with a surface area of 440 cm^2.

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 20-year B-IBI trends were detected at 8 of the 27 sites currently monitored. Trends in benthic community condition declined at 3 sites and improved at 5 sites. Trends detected through 2003 were still present in 2004 at 6 sites, and disappeared at 4 sites. The trends that were no longer significant with the addition of the 2004 data were trends which rate of increase has been diminishing over the past few years (Mainstem Sta. 01 and 06, Elk River Sta. 29) or a degrading trend in the Potomac River at Morgantown (Sta. 44), which has improved. Two new trends were detected in 2004 (Baltimore Harbor Sta. 23, Choptank River Sta. 64), both improving. The Choptank River trend is back from 2002.

Sites with improving B-IBI trends were located in the main stem of the Bay (Sta. 15 and 26), Baltimore Harbor (Sta. 23), Choptank River (Sta. 64), and Potomac River at St. Clements Island (Sta. 51). Sites with degrading B-IBI trends were located in the Severn River (Sta. 204), Patuxent River at Holland Cliff (Sta. 77), and Nanticoke River (Sta. 62). 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.

Improving trends were attributed to an increase in faunal abundance and a decrease in the abundance of pollution-indicative organisms at one mainstem site (Sta. 15), increases in diversity and a general improvement of the condition of the benthic community in the lower shallow Potomac River (Sta. 51), and increases in the abundance and biomass of pollution-sensitive organisms in Baltimore Harbor (Sta. 23).

Degrading trends were attributed to a decrease in biomass in the Severn River (Sta. 204), an increase in abundance (over the upper threshold) and decrease in biomass in the Patuxent River at Holland Cliff (Sta. 77), and an increase in abundance (over the upper threshold) and decreases in biomass and diversity in the Nanticoke River (Sta. 62). The upper portion of the Severn River is affected by severe hypoxia. The Nanticoke River is affected by high sediment loads. Low biomass relative to reference conditions is a problem common in the Nanticoke River and the other tributaries of the lower eastern shore of Maryland.

B-IBI trends for abundance and biomass in the Patuxent River at Sta. 77 reversed direction with the addition of the 2004 data. Positive trends in the Patuxent River are observed, but signs of recovery at Sta. 77 during the past few years may have been confounded by changes in river flow resulting from drier than normal years between 1999 and 2002.

Baywide Benthic Community Condition

The area of Chesapeake Bay estimated to fail the restoration goals decreased from 59% in 2003 to 47% in 2004. The higher estimates for 2003 were associated with high flow conditions in the Bay, which were responsible for high nutrient and sediment run off, strong water column density stratification events, and widespread hypoxia. River flow was still above normal in 2004, but the heavy precipitation occurred in September, after the summer period that usually influences most benthic community condition. Over the past decade, benthic community condition varied with changes in hydrology (dry versus wet years) and year-to-year fluctuations in dissolved oxygen concentrations. However, benthic community degradation in Chesapeake Bay continued to be large in any given year. In the Maryland portion of the Bay, 65% of the tidal waters failed the Chesapeake Bay benthic community restoration goals in 2003, and 52% in 2004.

Forty-seven percent of the degraded Chesapeake Bay bottom in 2004 (2,590 km^2) was marginally to moderately degraded and 53% was severely degraded. In the Maryland portion of the Bay, 37% of the degraded bottom (1,211 km^2) was marginally to moderately degraded and 63% was severely degraded. No obvious trends in the percentage of area with marginal or moderate degradation were observed over the time series.

The Potomac and Patuxent rivers, and the Maryland western shore tributaries, were in the poorest condition among the ten bay strata in 2004. The bottom area failing the restoration goals for each of these three systems was 64%. The Potomac River had the largest percent severely degraded condition. The upper Bay mainstem and the Maryland eastern shore tributaries were in best condition overall. In general, Chesapeake Bay tributaries exhibited levels of degradation in 2004 that were similar to those of 2002. This contrasts with the unusually high levels of degradation recorded in 2003 for most strata.

There was good agreement between the status and trends for water quality parameters and the benthic community condition. Over the period 1996-2004, high percentages of severely degraded sites failing the restoration goals due to insufficient abundance or biomass occurred in the Potomac River, Patuxent River, and the mainstem of the Chesapeake Bay. Sites with high incidence of failure due to excess abundance were most frequently located in the Maryland eastern shore tributaries, upper Bay mainstem, the James River, and the York River. Severely degraded and depauperate benthic communities are symptomatic of prolonged oxygen stress while excess abundance and biomass 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.

Despite substantial restoration efforts, significant changes in benthic condition that would indicate widespread improvements in abundance, diversity, or biomass of organisms, many of which are the base for fisheries species, were not observed. Even if the effect of hydrology (dry versus wet years) is factor out, the residual degradation is still large for any given year. It will probably take sustained management efforts over an extended period of time to bring back a more balanced community of benthic organisms to Chesapeake Bay.

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1.0 INTRODUCTION

1.1 BACKGROUND

Monitoring is a necessary part of environmental management because it provides the means for assessing the effectiveness of previous management actions and the information necessary to focus future actions (NRC 1990). Towards these ends, the State of Maryland has maintained an ecological 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; 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 are 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. 1994a 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 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 chemical and biological oxygen demand (Malone 1987). Winter to spring accumulation of phytoplankton biomass has been linked to depletion of bottom water oxygen in 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 (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 (no oxygen) events may 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 and nutrient inputs are critical factors in the health of the resources of the Chesapeake Bay region, monitoring that evaluates benthic community 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 report on how species contribute to changes in condition and discuss results in relation to changes in water quality. The 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 at least eight years 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. This report is produced in Adobe Acrobat format to facilitate distribution across the internet. 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 2004 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 four 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 2004, and consists of two assessments: an assessment of trends in benthic community condition at 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 1985-2004 fixed site trend analysis. Finally, Appendices B and C present the B-IBI values for the 2004 fixed and random sampling components, respectively. 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. 1994a, 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 2004 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 to the present, 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).

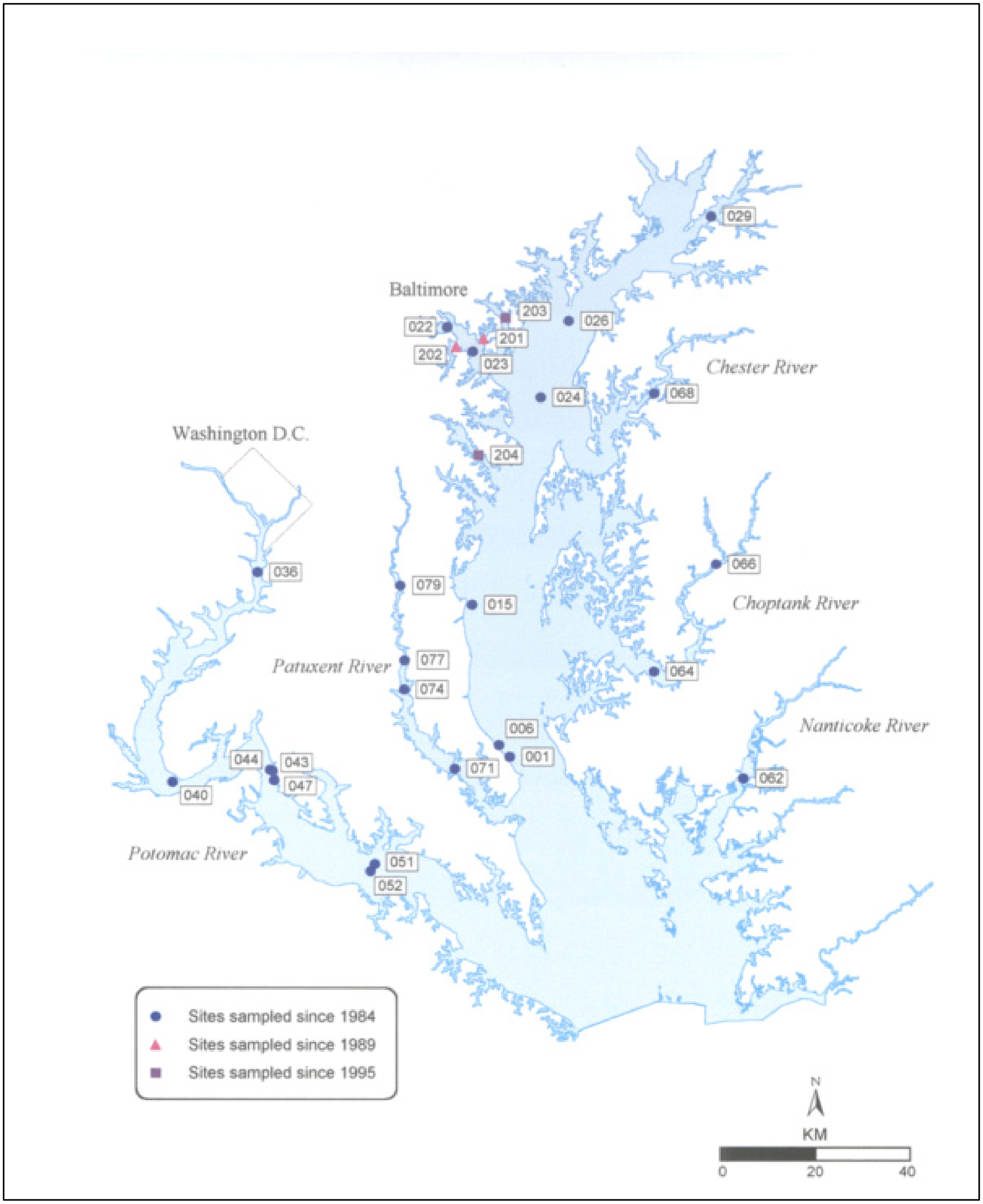

Figure 2-1. Fixed sites sampled in 2004

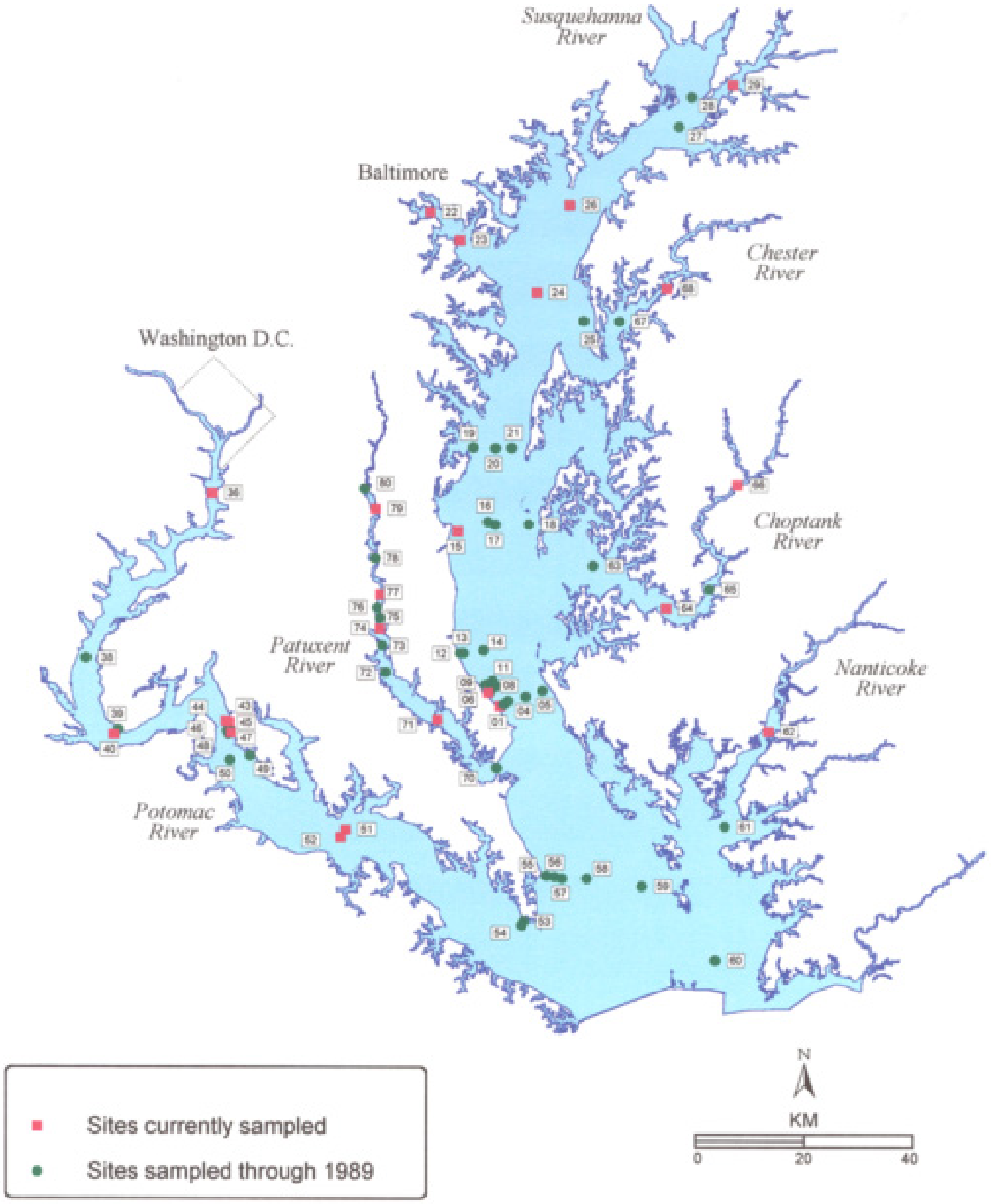

Figure 2-2. Fixed sites sampled from 1984 to 1989; some of these sites are part of the current design

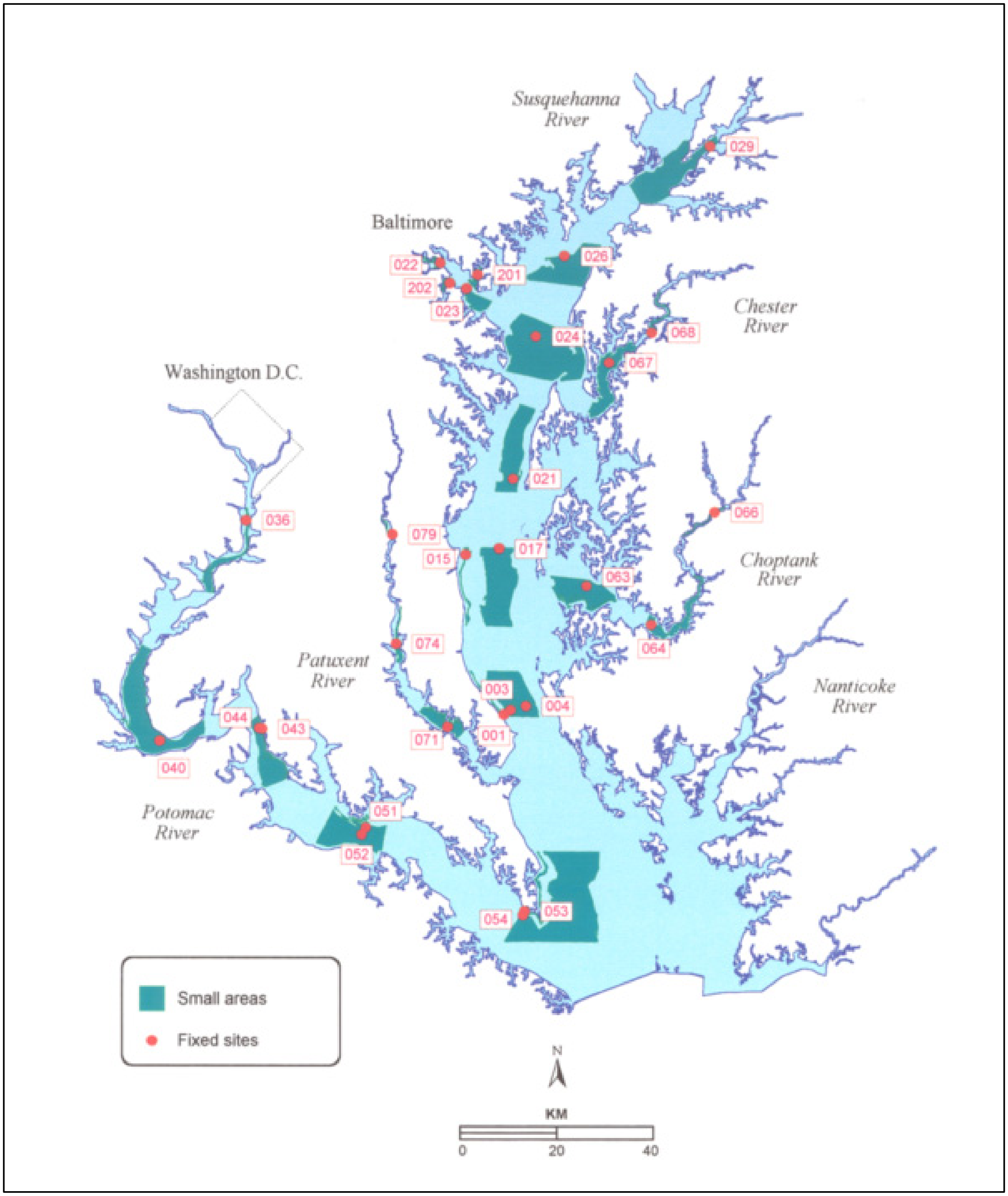

Figure 2-3. Small areas and fixed sites sampled from 1989 to 1994

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. 1994a, 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 2004. 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.

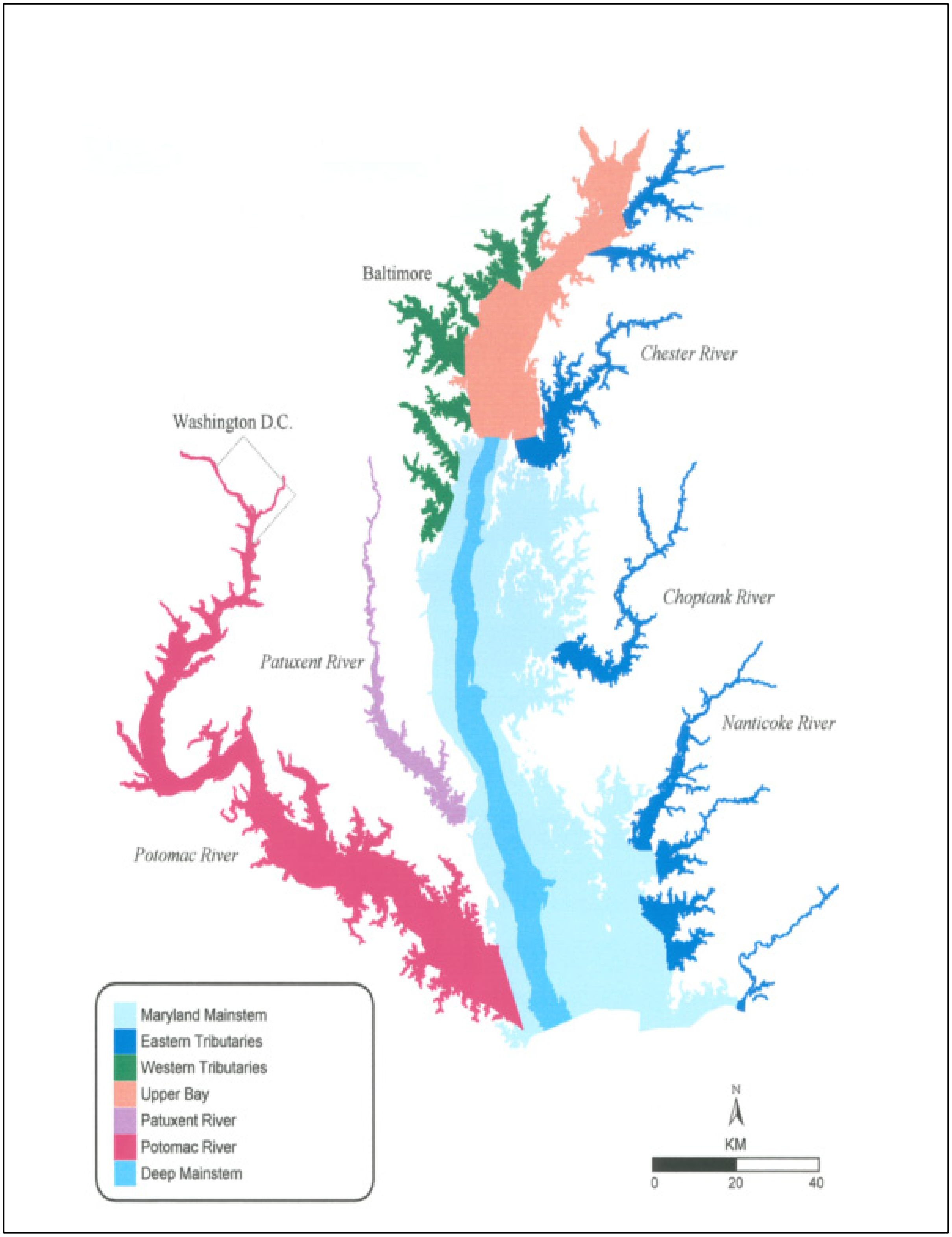

Figure 2-4. Maryland baywide sampling strata in and after 1995

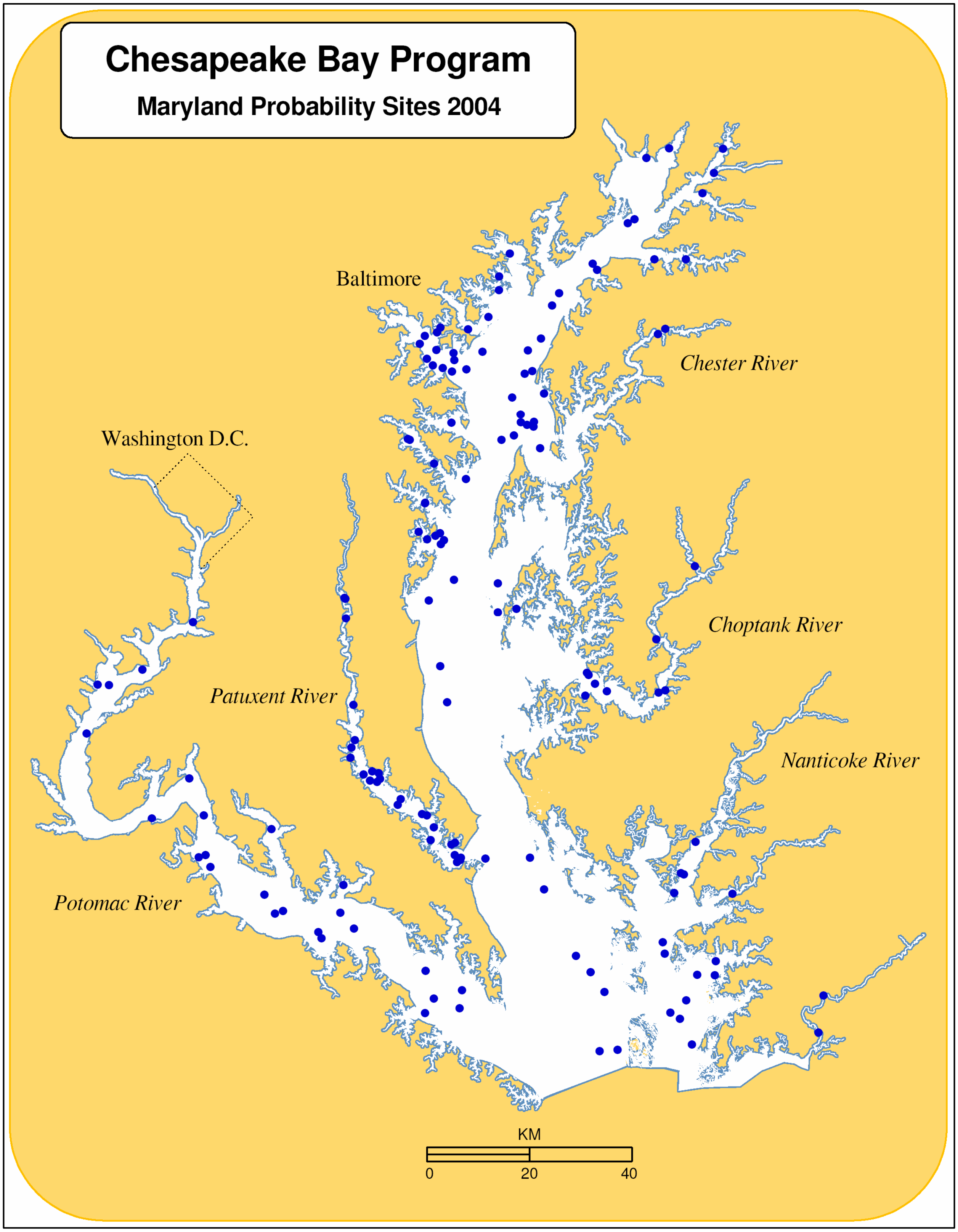

Figure 2-5. Maryland probability-based sampling sites for 2004

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 km2	Area State %	Area Bay %	Number of Samples
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.

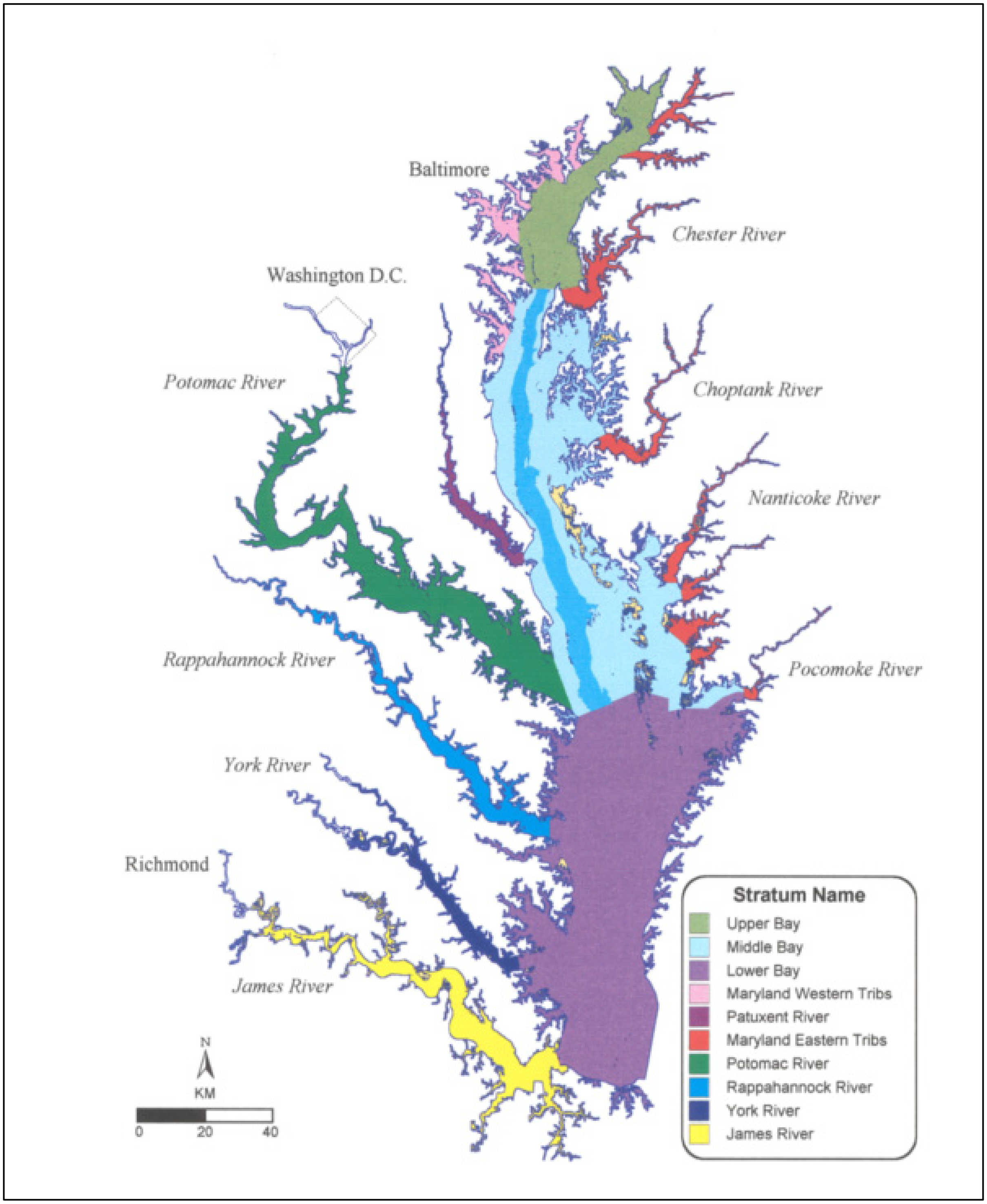

Figure 2-6. Chesapeake Bay stratification scheme

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 Hydrolab DataSonde 3 or (currently) YSI-6600 Sonde
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	Hydrolab DataSonde 3 or (currently) YSI-6600 Sonde nickel six-pin electrode-salt water cell block combination 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	Hydrolab DataSonde 3 or (currently) YSI-6600 Sonde membrane design probe 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	Hydrolab DataSonde 3 or (currently) YSI-6600 Sonde glass pH electrode and standard reference (STDREF) electrode automatically compensated for temperature
Oxidation Reduction Potential	December 1984 to December 1995	Hydrolab Surveyor II platinum banded glass ORP electrode

2.2.3 Benthic Samples

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

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

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

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

2.3 LABORATORY PROCESSING

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

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

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

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

Silt-clay composition and carbon and nitrogen content were determined for one of the two sediment sub-samples collected at each sampling site. The other sample was archived for quality assurance purposes (Scott et al. 1988). Sand and silt-clay particles were separated by wet-sieving through a 63-µm, stainless steel sieve and weighed using the procedures described in the Versar, Inc., Laboratory Standard Operating Procedures (Versar 1999). Carbon and nitrogen content of dried sediments was determined using an elemental analyzer. Sediment carbon content was measured with a Perkin-Elmer Model 240B analyzer from 1984 to 1988, and an Exeter Analytical Inc., Model CE-440 analyzer in and after 1995. The results from both instruments are comparable. Samples are combusted at high temperature (975 °C) and the carbon dioxide and nitrogen produced are measured by thermal conductivity detection. Prior to combustion, each sample is homogenized and oven-dried.

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. 1994a, updated by Weisberg et al. 1997; Alden et al. 2002). The B-IBI provides a means for comparing relative condition of benthic invertebrate assemblages across habitat types. It also provides a validated mechanism for integrating several benthic community attributes indicative of habitat "health" into a single number that measures overall benthic community condition.

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

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

2.4.2 Fixed Site Trend Analysis

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

2.4.3 Probability-Based Estimation

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

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

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

and

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

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

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

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

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

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

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. The sites are 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-year (1985-2004) trends are presented for 23 of the 27 trend sites, 16-year trends are presented for two sites in Baltimore Harbor (Stations 201 and 202) first sampled in 1989, and 10-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 8 of the 27 sites (Table 3-1). Trends in benthic community condition declined at 3 sites (significantly decreasing B-IBI trend) and improved at 5 sites. Currently, 13 stations meet the goals and 14 fail the goals. Initially, 10 stations met the goals and 17 failed the goals (Table 3-1). Seven stations changed status in 2004 relative to the previous year, improving from failing the goals to meeting the goals (Table 3-1 shaded areas; Stations 15, 24, 40, 51), or from a severely degraded or degraded condition to a degraded or marginal condition (Stations 22, 44, 79). Improvements in status at these stations suggest improvements in water quality in Chesapeake Bay in the last three years despite very wet conditions and widespread hypoxia in 2003. However, there were some declines in status in 2004 relative to the previous year. Mainstem Stations 01 and 06 declined from meeting the goals to marginal, and Elk River Station 29 declined from marginal to degraded (Table 3-1 shaded areas).

Significant trends present with the analysis of 2003 data were still present with the addition of the 2004 data at 6 sites. Trends at 4 sites (Mainstem Stations 01 and 06, Elk River Station 29, Potomac River Morgantown Station 44) disappeared with the addition of the 2004 data. New trends are reported this year for Baltimore Harbor (Station 23) and the Choptank River (Station 64), both improving. The Choptank River trend is back from 2002.

Sites with improving B-IBI trends (Table 3) were located in the main stem of the Bay (Stations 15 and 26), Baltimore Harbor (Station 23), Choptank River (Station 64), and Potomac River at St. Clements Island (Station 51). Sites with degrading B-IBI trends (Table 3) were located in the Severn River (Station 204), Patuxent River at Holland Cliff (Station 77), and Nanticoke River (Station 62).

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.

3.2 BAYWIDE BOTTOM COMMUNITY CONDITION

The fixed site monitoring provides useful information about trends in the condition of benthic biological resources 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.

Probability-based sampling has been employed previously by LTB, but the sampled area included only 16% of the Maryland Bay (Ranasinghe et al. 1994a) 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), but at a sampling density too low to develop precise condition estimates for the

Maryland Bay. The 2004 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 2004 Maryland and Virginia probability-based sampling and provides eleven years (1994-2004) 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, DO, 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 2004, 74 met and 76 failed the Chesapeake Bay benthic community restoration goals (Figure 3-1). Of the 250 probability samples collected in the entire Chesapeake Bay in 2004, 128 met and 122 failed the restoration goals. The Virginia sampling results are presented in Figure 3-2. In terms of number of sites meeting the goals in Chesapeake Bay, 2004 was a good year (> 50% of the sites met the restoration goals), while 2003 was the worst year since probability-based sampling started in 1994 (only about 40% of the sites met the restoration goals).

The area with degraded benthos in the Maryland Bay declined in 2004 relative to 2003, with the lowest estimate since 1994 (Figure 3-3). The magnitude of the severely degraded condition also declined. Previously, there had been no appreciable changes in the magnitude of the severely degraded condition over the time series. 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 both 2002 and 2003, 65% (±5% SE) of the Maryland Bay was estimated to fail the restoration goals. In 2004, the estimate was 52% (±5% SE). Expressed as area, 3,247±300 km^2 of the tidal Maryland Chesapeake Bay remained to be restored in 2004.

In 2004, the Potomac and Patuxent Rivers, and the Maryland western shore tributaries were in the poorest condition among the six Maryland strata (Figure 3-4). The bottom area failing the restoration goals for each of these systems was 64%. The Potomac River had the largest percent severely degraded condition (Figure 3-4). Over the 1995-2004 time series, more than half of the tidal Potomac River (714-1,173 km^2) failed the restoration goals each year (Figure 3–5) and a large portion of that area, ranging from 48-93% (510-867 km^2, Table 3-4), was severely degraded.

The level of degradation in the Maryland mid-Bay mainstem continued to be high in 2004. The mid-Bay mainstem continued to have the largest amount of degraded area among the strata: 1,697 km^2 in 2004 (Table 3-4). On the other hand, the upper Bay mainstem and the eastern shore tributaries of Maryland exhibited low levels of degradation (Figure 3-4). These two strata generally have good benthic community condition relative to the other bay strata, except in 2003 where unusually high levels of degradation were observed throughout the Bay (Figure 3-5).

In Virginia, percent degraded area in 2004 was similar among strata (Figure 3-4, Table 3-4) and lower than in 2003 (Figure 3-6), in tune with the more benign conditions observed throughout the Chesapeake Bay in 2004.

The area of Chesapeake Bay estimated to fail the restoration goals decreased substantially from a record high of 59% in 2003 to 47% in 2004 (Figure 3-7). The high estimates for 2003 were associated with high flow conditions in the Bay and widespread hypoxia. Weighting results from the 250 probability sites in Maryland and Virginia, 47% (±4%) or 5,492±516 km^2 of the tidal Chesapeake Bay was estimated to fail the restoration goals in 2004 (Table 3-4). The percentage for previous years ranged from 45% (±4%) in 1996 to 59% (± 4%) in 2003 (Table 3-4). About 25% of the Chesapeake Bay continued to exhibit severely degraded benthic condition. No obvious trends in the percentage of area with marginal, moderate, or severe degradation were observed over the time series.

As reported in previous years, and for the period 1996-2004, five strata (Potomac River, Patuxent River, mid-Bay mainstem, Virginia mainstem, and the Maryland upper western tributaries) had a large percentage (>60%) of sites failing the goals because of insufficient abundance or biomass of organisms relative to reference conditions (Table 3-5). Except for the Virginia mainstem, these strata also had a high percentage (>50%) of failing sites classified as severely degraded (Table 3-5). The Potomac and Patuxent rivers had the largest percentage of depauperate sites, failing for insufficient abundance or biomass. The Virginia mainstem also had a large percentage of depauperate sites, but this percentage was based on a comparatively small number of sites failing the restoration goals. The York and James rivers had the lowest percentages of depauperate sites. Low abundance, low biomass, and the level of widespread failure in most metrics necessary to classify a site as severely degraded would be expected on exposure to catastrophic events such as prolonged oxygen stress.

The Maryland eastern tributaries, James and York rivers, and the upper Bay mainstem, had excess abundance, excess biomass, or both in over 25% of the failing sites (Table 3-6). 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.

Table 3-1. Summer trends in benthic community condition, 1985-2004. Trends were identified using the van Belle and Hughes (1984) procedure. Current mean B-IBI and condition are based on 2002-2004 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 trend or condition over those reported for 2003.

Station	Trend Significance	Median Slope (B-IBI units/yr)	Current Condition (2002-2004)	Initial Condition (1985-1987 unless otherwise noted)
Potomac River				
36	NS	0.00	2.28 Degraded)	3.14 (Meets Goal)
40	NS	0.00	3.01 (Meets Goal)	2.80 (Marginal)
43	NS	0.00	3.58 (Meets Goal)	3.76 (Meets Goal)
44	NS	0.00	2.56 (Degraded)	2.80 (Marginal)
47	NS	0.00	3.40 (Meets Goal)	3.89 (Meets Goal)
51	$p < 0.001$	0.04	3.07 (Meets Goal)	2.43 (Degraded)
52	NS	0.00	1.22 (Severely Degraded)	1.37 (Severely Degraded)
Patuxent River				
71	NS	0.00	2.41 (Degraded)	2.59 (Degraded)
74	NS	0.00	3.62 (Meets Goal)	3.78 (Meets Goal)
77	$p < 0.01$	–0.06	3.18 (Meets Goal)	3.76 (Meets Goal)
79	NS	0.00	2.83 (Marginal)	2.75 (Marginal)
Choptank River				
64	$P < 0.1$	0.03	3.37 (Meets Goal)	2.78 (Marginal)
66	NS	0.00	2.73 (Marginal)	2.60 (Degraded)
Maryland Mainstem				
26	$p < 0.001$	0.03	3.93 (Meets Goal)	3.16 (Meets Goal)
24	NS	0.00	3.19 (Meets Goal)	3.04 (Meets Goal)
15	$p < 0.01$	0.04	3.04 (Meets Goal)	2.22 (Degraded)
06	NS	0.00	2.89 (Marginal)	2.56 (Degraded)
01	NS	0.02	2.93 (Marginal)	2.93 (Marginal)
Maryland Western Shore Tributaries				
22	NS	0.00	2.24 (Degraded)	2.08 (Degraded)
23	$P < 0.1$	0.02	3.09 (Meets Goal)	2.49 (Degraded)
201	NS	0.00	1.31 (Severely Degraded)	1.10 (Severely Degraded) (a)
202	NS	0.00	1.44 (Severely Degraded)	1.40 (Severely Degraded) (a)
203	NS	0.02	2.26 (Degraded)	2.08 (Degraded) (b)
204	$p < 0.01$	–0.17	2.30 (Degraded)	3.67 (Meets Goal) (b)
Maryland Eastern Shore Tributaries				
29	NS	0.00	2.15 (Degraded)	2.38 (Degraded)
62	$p < 0.05$	–0.03	3.04 (Meets Goal)	3.42 (Meets Goal)
68	NS	0.00	3.13 (Meets Goal)	3.51 (Meets Goal)

Table 3-2. Summer trends in benthic community attributes at mesohaline stations 1985-2004. 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 improving conditions; (a): trends based on 1989-2004 data; (b): trends based on 1995-2004 data; (c): attribute trend based on 1990-2004 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	NA	⇑***
52		⇓ **	⇓ **	⇓ *	(d)	(d)			⇓ *
Patuxent River									
71		⇓ ***	⇓ ***		⇓ ***(d)	(d)	⇓ **		⇑***
74		⇑ ***	⇓ ***	⇓ *	⇑ *	⇓***(d)	NA	⇓*	NA
77	⇓ ***	⇑ **	⇓ **		⇑ ***	⇓ *(d)	NA	⇑ **	NA
Choptank River									
64	⇑ *	⇑ **			(d)	(d)	⇑ *	⇓ *	
Maryland Mainstem									
01							NA	NA	
06		⇑ ***					NA	NA	
15	⇑ ***	⇑ **			⇓ ***		NA	NA	⇑ **
24		⇓ **		⇓ ***	⇓ ***(d)	⇑ **(d)			⇑ ***
26	⇑ ***					(d)	NA		NA
Maryland Western Shore Tributaries									
22			⇓ *	⇓ *	⇑***	(d)	NA		NA
23	⇑ *	⇓ ***				⇑***(d)	NA	⇑ **	NA
201(a)		⇓ *				(d)	NA		NA
202(a)			⇑**	⇑ *	⇓ **	⇑*(d)	NA	⇑ ***	NA
204(b)	⇓***		⇓ ***		⇑**(d)	(d)	⇑ ***	⇓ ***	
Maryland Eastern Shore Tributaries									
62	⇓ **	⇑ **	⇓*	⇓***	⇓*	⇓**(d)	NA		NA
68			⇑ ***			⇑***(d)	NA		NA

Table 3-3. Summer trends in benthic community attributes at oligohaline and tidal freshwater stations 1985-2004. 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 improving conditions; (a): trends based on 1995-2004 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	⇑**

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	2,998	1,154	1,098	5,250	45.2
	1997	2,884	1,757	1,199	5,841	50.3
	1998	3,709	1,810	1,224	6,743	58.1
	1999	3,121	1,648	681	5,450	47.0
	2000	2,684	1,503	1,439	5,626	48.5
	2001	3,123	1,187	1,240	5,551	47.8
	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
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
Virginia Tidal Waters	1996	384	454	943	1,781	33.2
	1997	535	1,060	716	2,312	43.1
	1998	1,045	794	601	2,441	45.5
	1999	698	510	306	1,515	28.3
	2000	229	366	1,203	1,798	33.5
	2001	810	606	596	2,012	37.5
	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
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

Table 3-4. (Continued)

Region	Year	Severely Degraded	Degraded	Marginal	Total Failing	% Failing
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
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
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
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

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
Virginia Mainstem	1996	165	330	824	1,318	32.0
	1997	165	824	659	1,648	40.0
	1998	824	330	494	1,648	40.0
	1999	494	165	165	824	20.0
	2000	0	165	1,154	1,318	32.0
	2001	494	330	494	1,318	32.0
	2002	659	659	165	1,483	36.0
	2003	494	824	659	1,977	48.0
	2004	659	659	330	1,648	40.0
Rappahannock River	1996	119	60	0	179	48.0
	1997	134	74	15	223	60.0
	1998	60	119	45	223	60.0
	1999	74	104	45	223	60.0
	2000	164	89	15	268	72.0
	2001	30	60	45	134	36.0
	2002	134	45	0	179	48.0
	2003	89	104	0	194	52.0
	2004	60	89	30	179	48.0
York River	1996	45	37	37	120	64.0
	1997	45	52	15	112	60.0
	1998	52	45	7	105	56.0
	1999	75	22	15	112	60.0
	2000	37	30	7	75	40.0
	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
James River	1996	55	27	82	164	24.0
	1997	191	109	27	328	48.0
	1998	109	301	55	465	68.0
	1999	55	219	82	355	52.0
	2000	27	82	27	137	20.0
	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

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 2004. 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	114	69.5	128	78.0
Patuxent River	63	50.4	92	73.6
Mid Bay Mainstem	67	53.2	89	70.6
Virginia Mainstem	24	30.0	53	66.3
Western Tributaries	73	57.0	78	60.9
Rappahannock River	58	47.9	72	59.5
Upper Bay Mainstem	43	53.8	46	57.5
Eastern Tributaries	28	29.2	45	46.9
York River	59	41.3	50	35.0
James River	39	35.8	33	30.3

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 2004. Strata are listed in decreasing percentage order.

Stratum	**Number of Sites**	**As Percentage of Sites Failing the Goals**
Eastern Tributaries	30	31.3
James River	32	29.4
York River	39	27.3
Upper Bay Mainstem	21	26.3
Western Tributaries	31	24.2
Rappahannock River	24	19.8
Mid Bay Mainstem	21	16.7
Potomac River	22	13.4
Patuxent River	16	12.8
Virginia Mainstem	8	10.0

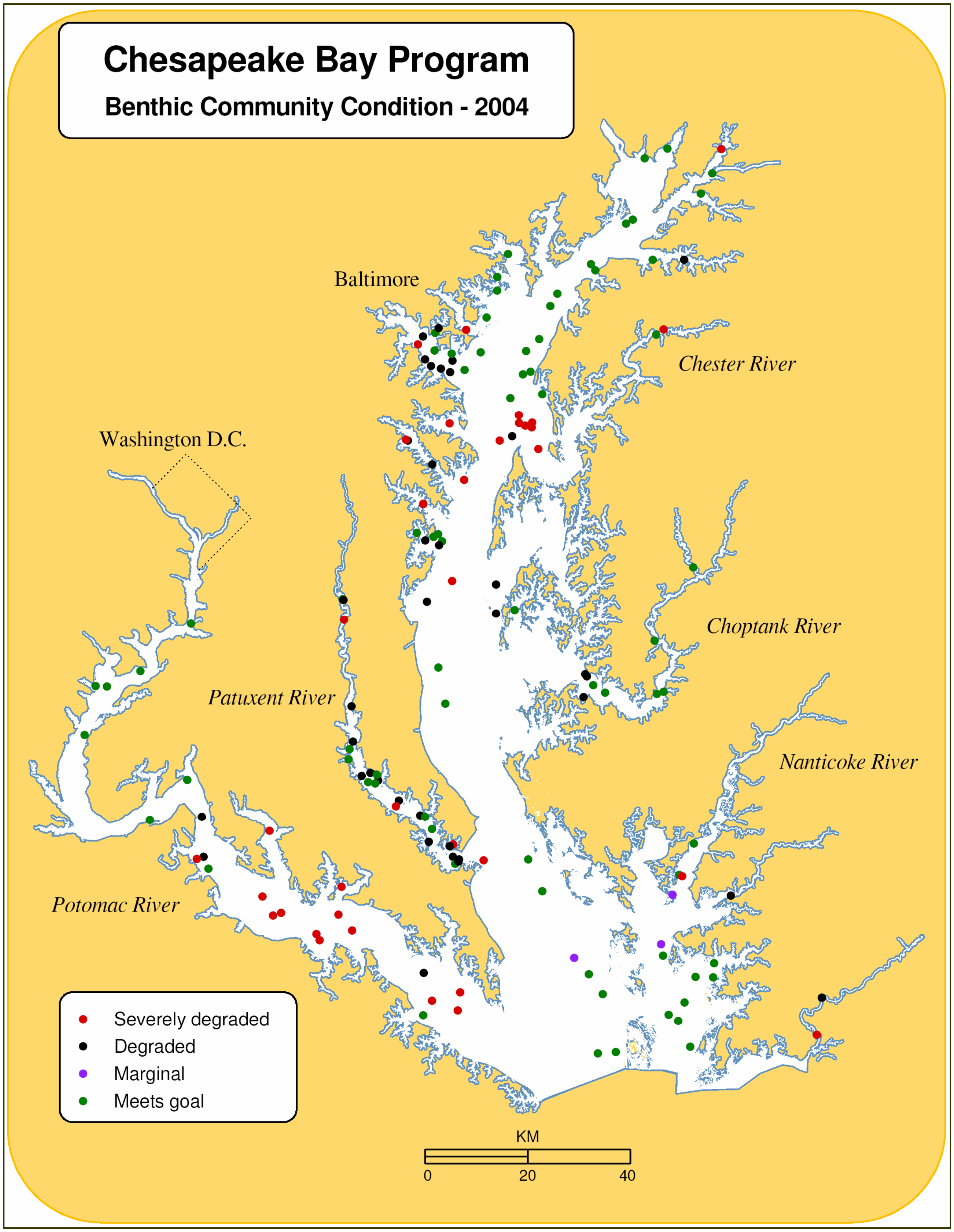

Figure 3-1. Results of probability-based benthic sampling of the Maryland Chesapeake Bay and its tidal tributaries in 2004. Each sample was evaluated in context of the Chesapeake Bay benthic community restoration goals.

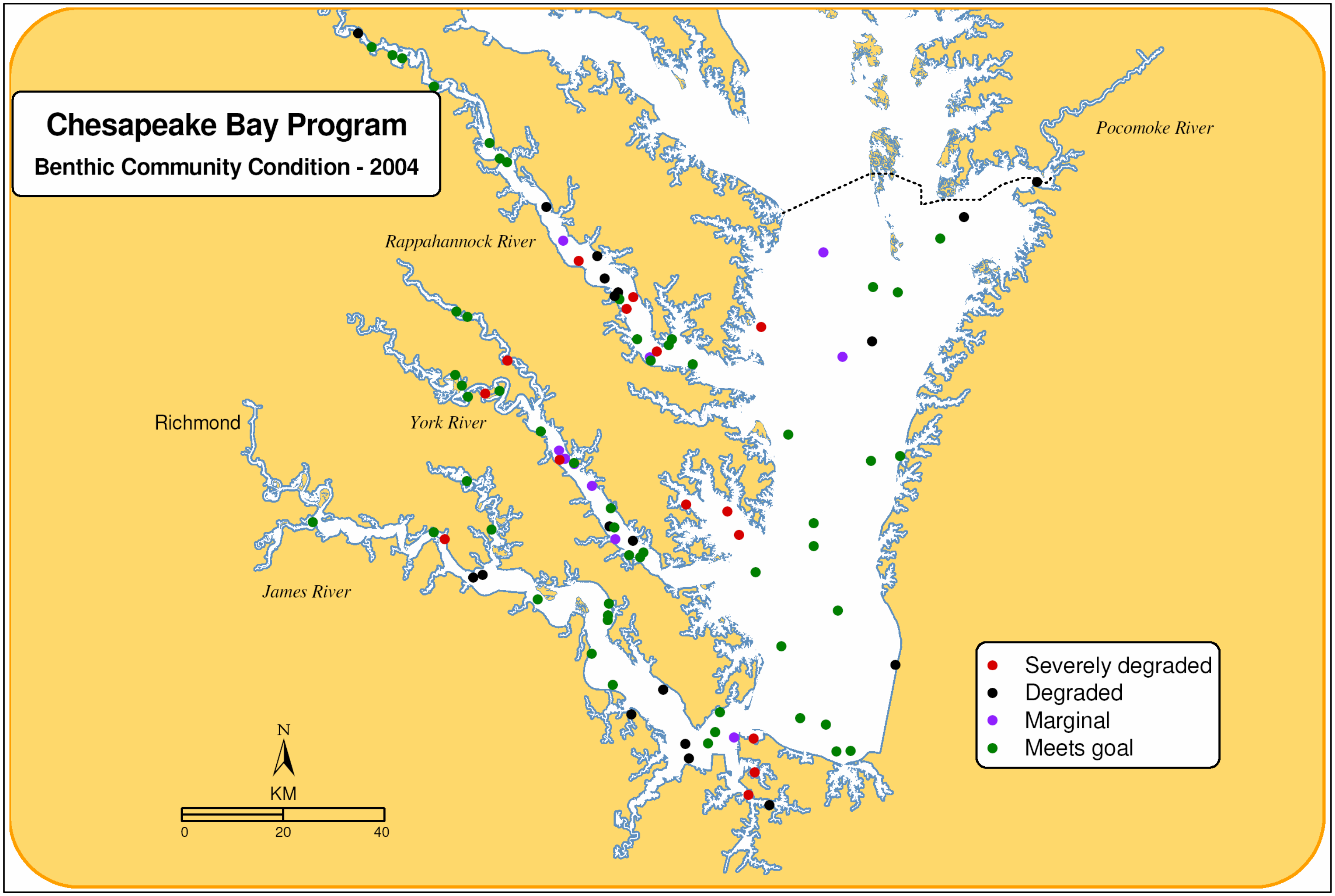

Figure 3-2. Results of probability-based benthic sampling of the Virginia Chesapeake Bay and its tidal tributaries in 2004. Each sample was evaluated in context of the Chesapeake Bay benthic community restoration goals.

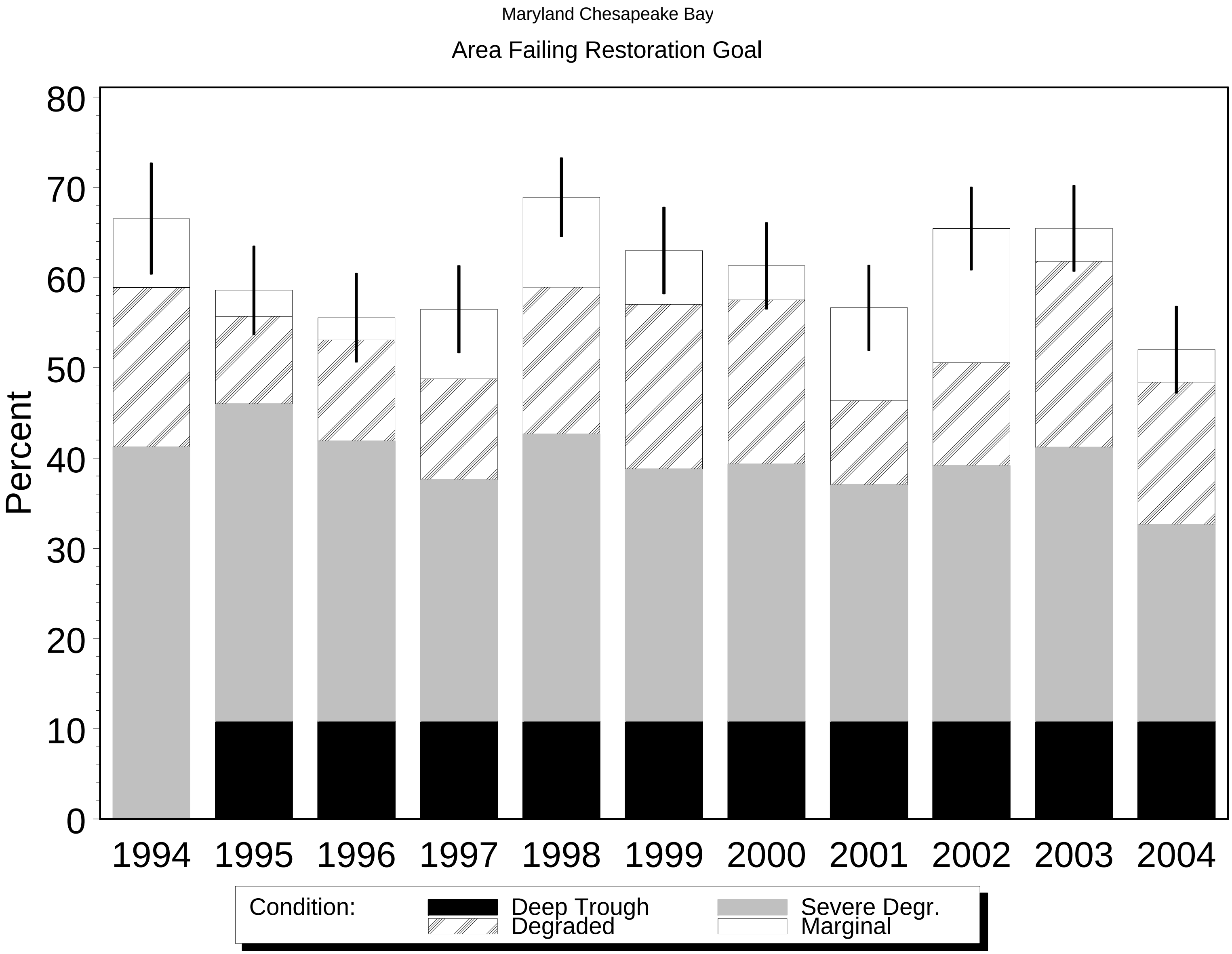

Figure 3-3. Proportion of the Maryland Bay failing the Chesapeake Bay benthic community restoration goals from 1994 to 2004. The error bars indicate + 1 standard error. The mainstem deep trough was sampled in 1994 and found to be mostly azoic; it is included in the severely degraded condition in 1994, but was excluded from sampling in subsequent years.

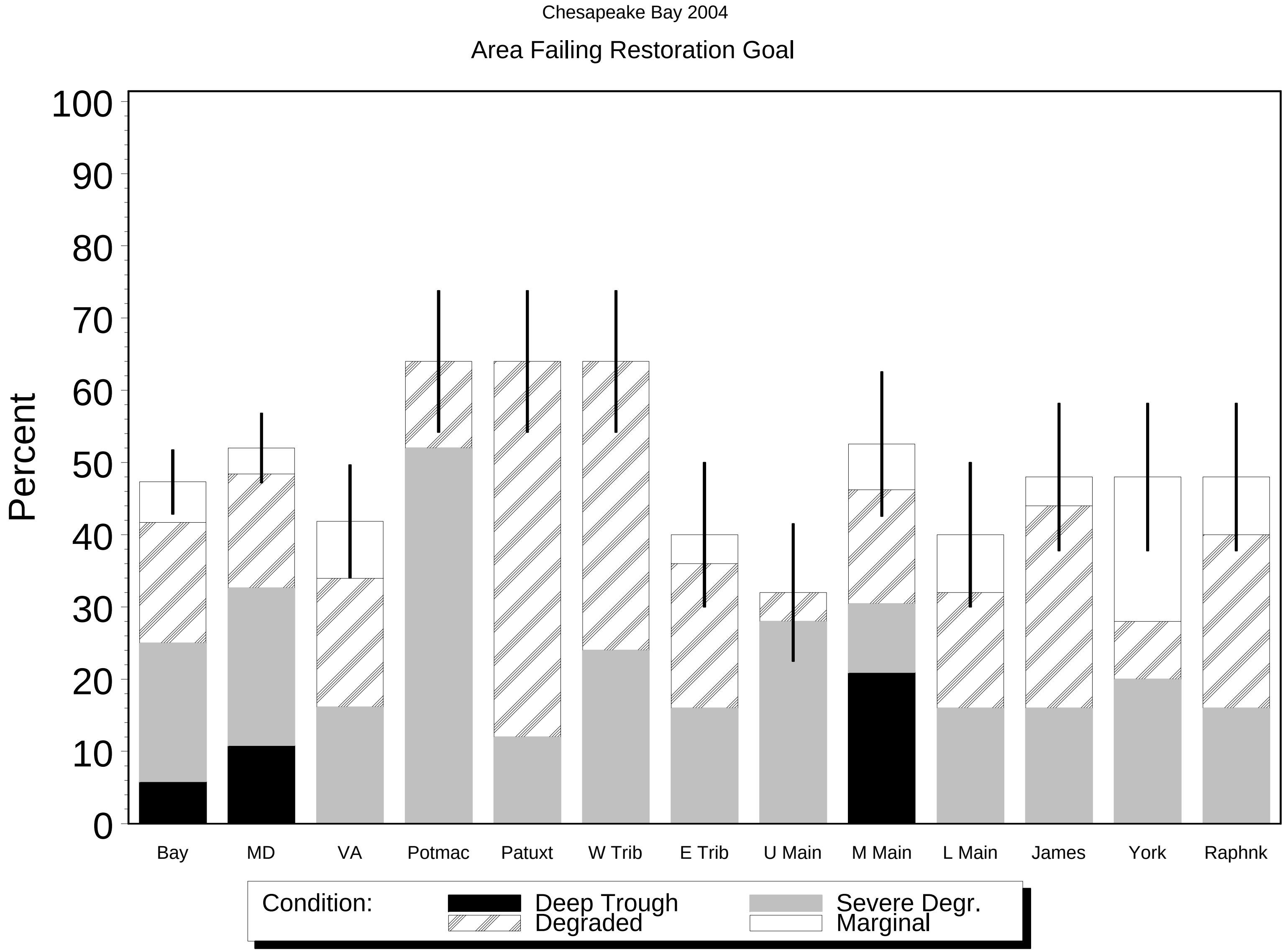

Figure 3-4. Proportion of the Chesapeake Bay, Maryland, Virginia, and the 10 sampling strata failing the Chesapeake Bay benthic community restoration goals in 2004. The error bars indicate ± 1 standard error.

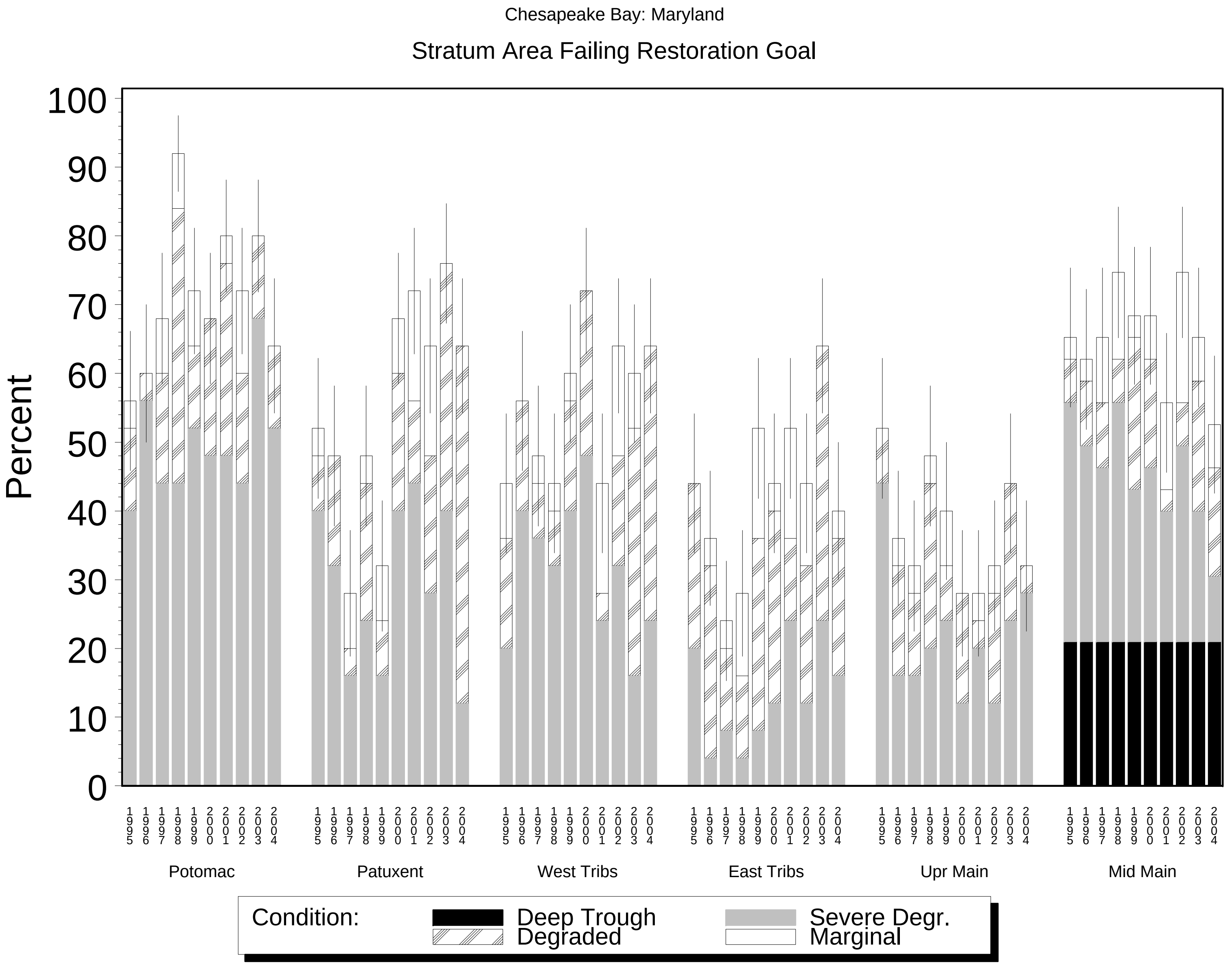

Figure 3-5. Proportion of the Maryland sampling strata failing the Chesapeake Bay benthic community restoration goals, 1995 to 2004. The error bars indicate ± 1 standard error.

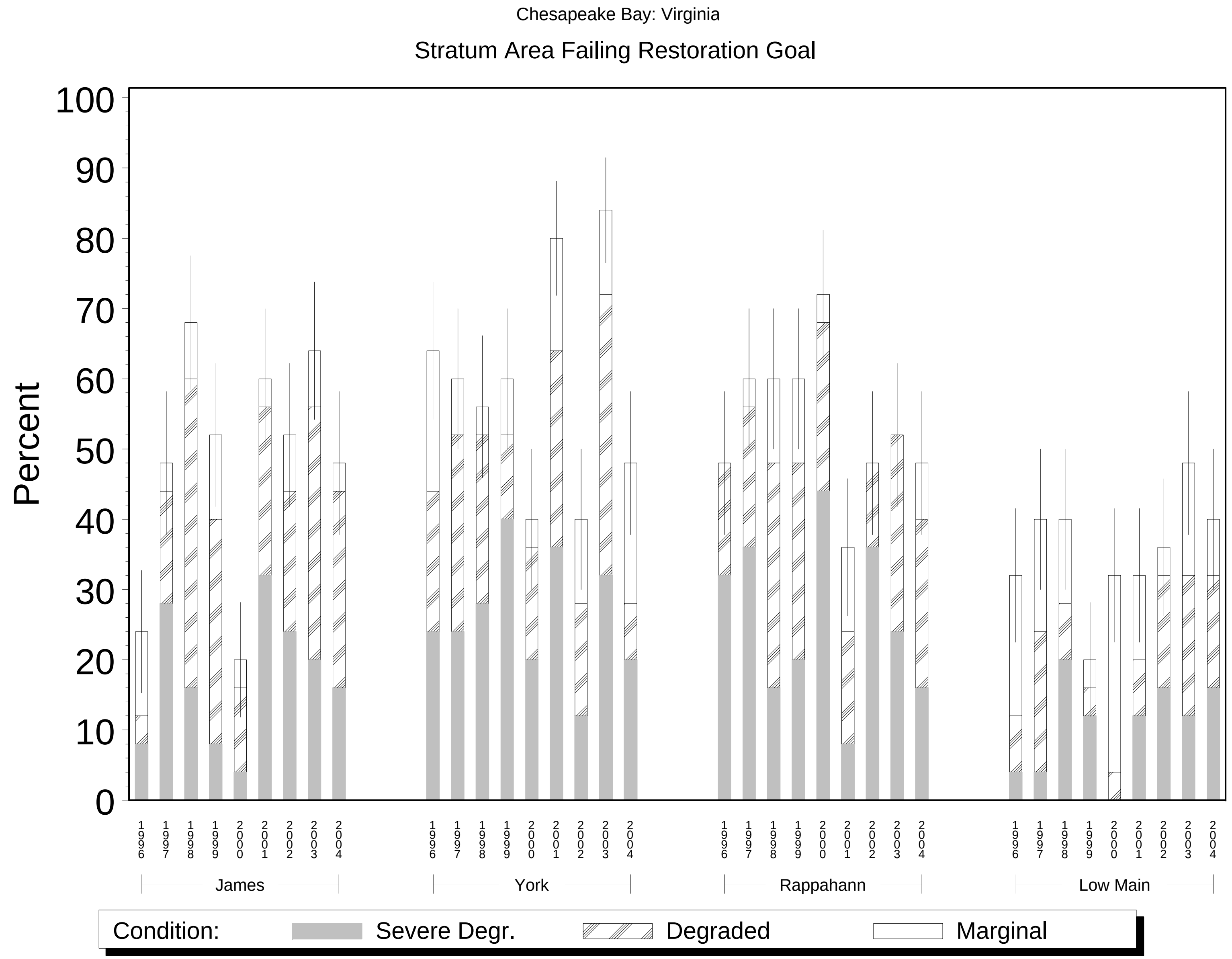

Figure 3-6. Proportion of the Virginia sampling strata failing the Chesapeake Bay benthic community restoration goals, 1996 to 2004. The error bars indicate ± 1 standard error.

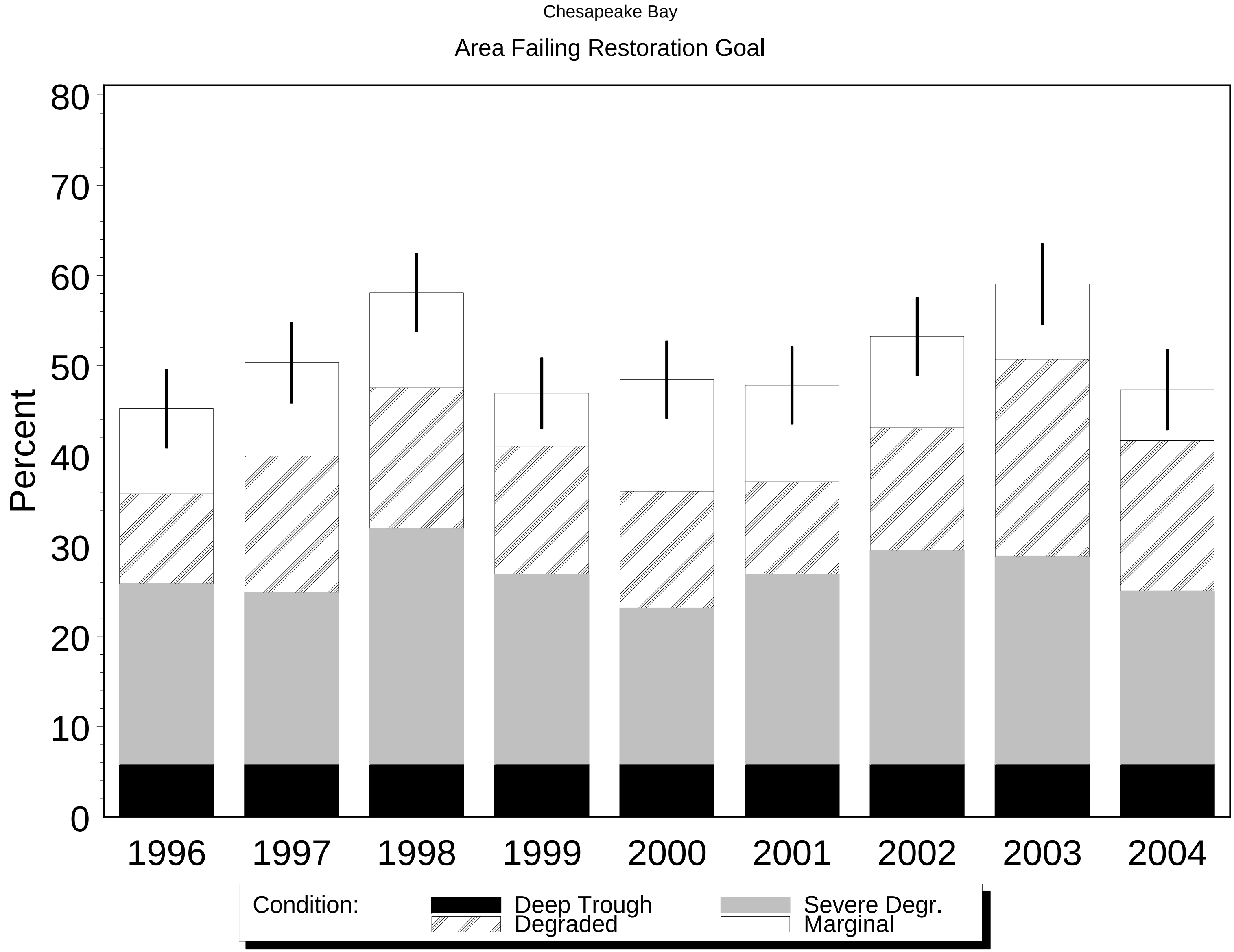

Figure 3-7. Proportion of the Chesapeake Bay failing the Chesapeake Bay benthic community restoration goals, 1996 to 2004. The error bars indicate ± 1 standard error.

4.0 DISCUSSION

Estimates of benthic community degradation for the Maryland Bay were the lowest since monitoring began in 1994. Overall, 52% of the Maryland tidal waters failed the Chesapeake Bay benthic community restoration goals in 2004. The lower estimate in 2004 contrasts with high estimates of 65% in 2002 and 2003. For the Chesapeake Bay, the area estimated to fail the restoration goals decreased from 59% in 2003 to 47% in 2004. The higher estimates for 2003 were associated with high flow conditions in the Bay, which were responsible for high nutrient and sediment run off, strong water column density stratification events, and widespread hypoxia. River flow was still above normal in 2004 (Figure 4-1), but the heaviest precipitation occurred in September, after the summer period that usually influences most benthic community condition in the Bay. Over the past decade, the area with degraded benthic community condition has varied with changes in hydrology (dry versus wet years) and year-to-year fluctuations in the frequency, severity, and extent of hypoxia. Although years with low run-off fare better for aquatic resources in Chesapeake Bay than wet years, the area with degraded benthic communities in Chesapeake Bay continues to be large in any given year. For example, even though 2002 was a drought year and hypoxic conditions were mild, some monitoring strata had large levels of degradation (Llansó et al. 2003). As we have stated elsewhere, it will probably take sustained management efforts over an extended period of time to bring back a more balanced community of benthic organisms and see significant baywide improvements in benthic condition. Excess organic matter from phytoplankton blooms in combination with hypoxia primarily enhances the growth and reproduction of small pollution tolerant organisms. It is the excess of nutrients in sediments that may continue to be a problem in many areas of the Bay even after improvements in dissolved oxygen conditions occur.

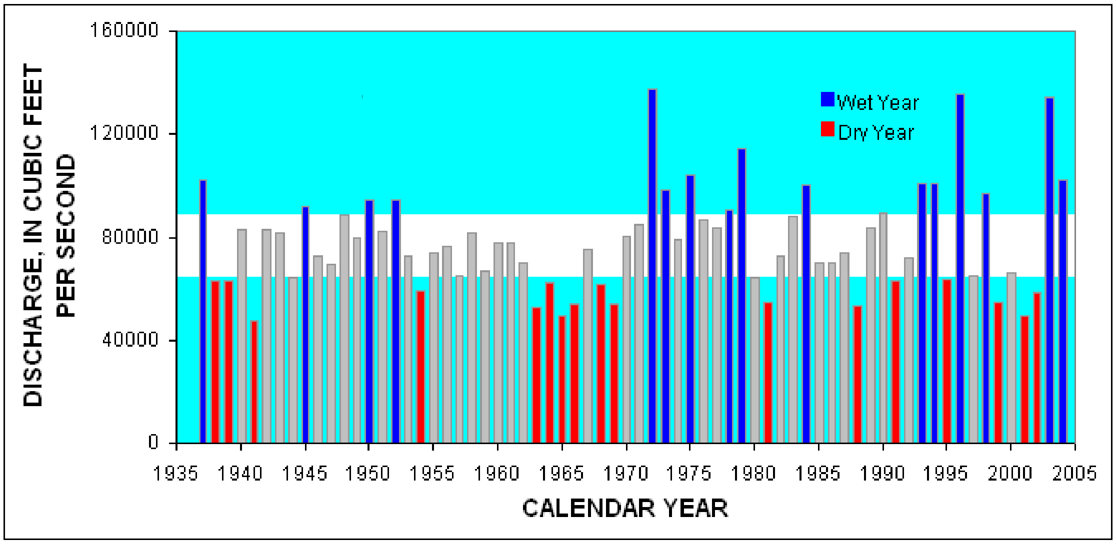

Figure 4-1. Annual mean flow into Chesapeake Bay, 1937-2004. Unshaded area shows normal range of annual mean flows (25th to 75th percentile). Chart from the USGS website: http//md.water.usgs.gov/monthly/bay.html.

Forty-seven percent of the degraded Chesapeake Bay bottom in 2004 (2,590 km^2) was marginally to moderately impaired. In the Maryland portion of the Bay, 37% of the degraded bottom (1,211 km^2) was marginally to moderately impaired. Of the additional 2,037 km^2 of Maryland Bay bottom supporting severely degraded benthic communities, 676 km^2 were located in the deep (>12m) mainstem that is perennially anoxic and probably beyond the scope of present mitigation efforts. The area with marginal to moderate degradation would be expected to show the first signs of improvement as nutrient reduction efforts are implemented baywide. However, no obvious trends in the percentage of area with marginal or moderate degradation were observed over the time series.

The estimates of degraded area for regions measured in multiple years were generally similar between years, with most estimates included within the confidence interval of other years. Exceptions can be explained by the clumping of the random sites in either deep areas that are perennially hypoxic (e.g., the exceptionally high estimate of degraded area for the Potomac River in 1998) or shallow areas that are not typically affected by summer hypoxia (e.g., the low estimates of degraded area for the Patuxent River in 1997 and 1999). In addition, inter-annual variability in river flow patterns influences water quality and benthic community condition. High spring flows, for example, have been theorized to cause earlier and spatially more extensive stratification within the Bay, leading to more extensive hypoxia (Tuttle et al. 1987). Patterns of degradation between years, although subtle, were in the direction expected from abnormally strong spring freshets. In 2004, the heaviest precipitation did not occur in spring but in September, and consequently hypoxia was not as severe.

Below we discuss the patterns of degradation and sources of stress affecting benthic communities in each of the six Maryland Bay strata (see Figure 2-4) and the Virginia tributaries. Inferences for specific systems were based on post-stratification of the random sites by Chesapeake Bay segments and analysis of the 2000-2004 B-IBI data using methods developed for the identification of impaired waters in Chesapeake Bay (Llansó et al. 2005). The method development and analysis was conducted for the States of Maryland and Virginia for reporting overall condition and identification of impaired waters (305b report) under the Clean Water Act. Water quality trends are based on the annual results of the Maryland Water Quality Monitoring Program. The patterns described below for the Patuxent and Potomac rivers were presented in previous reports. However, we discuss any changes resulting from the addition of the data for the current year.

4.1 PATUXENT RIVER

Benthic community degradation in the Patuxent River is probably the result of mixed sources of stress, including contamination, eutrophication, and low dissolved oxygen stress. Benthic diagnostic tool analyses (Llansó et al. 2005) for the 2000-2004 period indicated moderate to high probabilities of contaminant effects for 46% of the sites failing the restoration goals in the lower Patuxent River. The remaining of the sites were classified as being affected by other sources of stress. The lower Patuxent River is affected by summer hypoxia, although the intensity of hypoxic events varies annually. There is a positive relationship between the percentage of samples failing the restoration goals (B-IBI scores less than 3.0) and summer hypoxia, expressed as percent observations in the mesohaline Patuxent River with bottom DO concentrations below 2 mg/L, as measured at long-term monitoring stations by the Water Quality Monitoring Program, June through September (Figure 4-2). Hypoxia was severe in 2003, and thus a majority of samples (82%) in the lower Patuxent River failed the restoration goals. Hypoxia was moderate in 2004 and the percentage of samples failing the restoration goals (62%) was more typical. A strong relationship was also observed for the 1995-2002 time series when the average DO concentration measured at the time of the benthic sampling was plotted against the percentage of samples failing the restoration goals (Llansó et al. 2003). That relationship explained 76% of the variability in the B-IBI data. With the addition of the 2003 and 2004 data, the strength of the relationship decreased substantially (Figure 4-3) due to higher DO concentrations at the time of the benthic sampling (late August to mid September) than during the preceding months in those two years. Baywide, hypoxia was more extensive and severe in July in both years. Mortality of benthic organisms probably occurred at that time, with little recovery of the community during the following months.

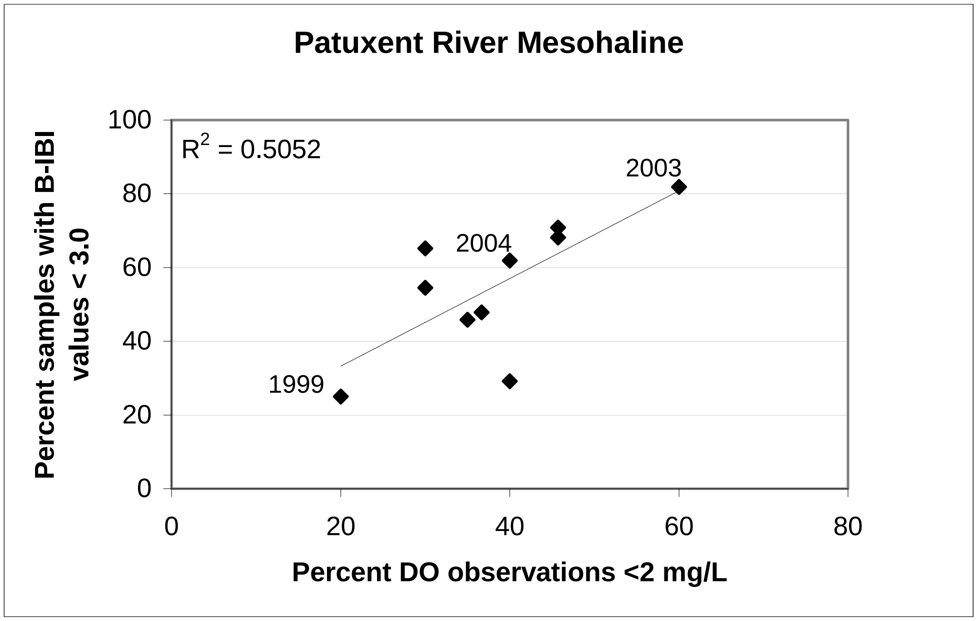

Figure 4-2. Relationship of benthic index of biotic integrity to percent dissolved oxygen observations below 2 mg/L (June-September) in the mesohaline Patuxent River. Each point represents a different year, 1995-2004. Dissolved oxygen data are fortnight near-bottom observations from Chesapeake Bay Water Quality Monitoring Program stations RET1.1, and LE1.1 through LE1.4.

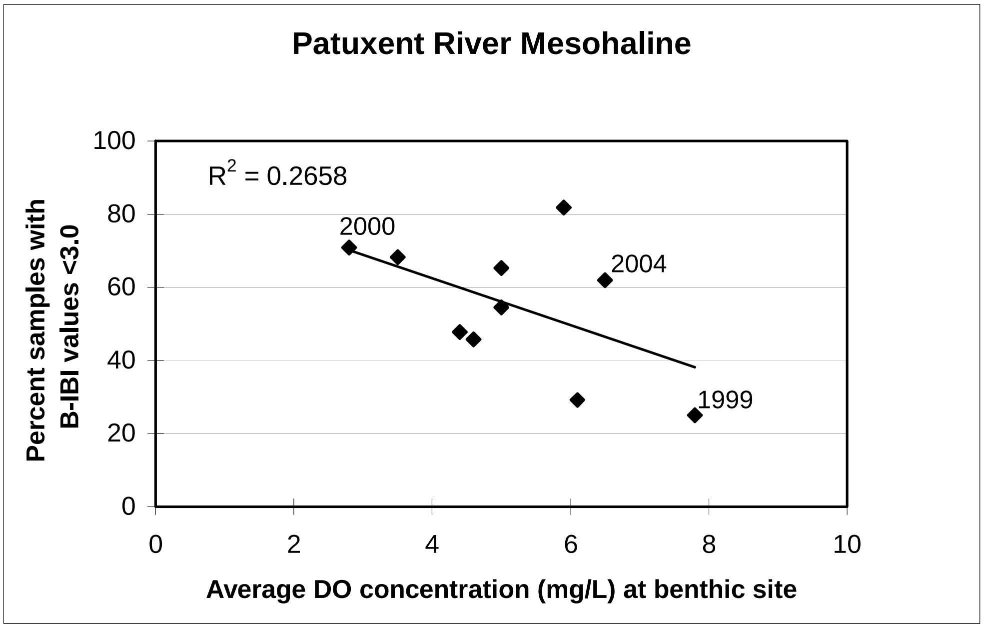

Figure 4-3. Relationship of benthic index of biotic integrity to dissolved oxygen concentration at the time of benthic sample collection in the mesohaline Patuxent River. Each point represents a different year, 1995-2004.

One factor linked to hypoxia is the amount of decaying organic matter from phytoplankton blooms. Years with large phytoplankton blooms are likely to result in more extensive hypoxia and increased benthic degradation. The lower Patuxent River had poor to fair water clarity and high algal concentrations with degrading trends in 2003, but low algal concentrations and no significant trends in 2004. This difference between the two years was correlated with the benthic community condition. A positive association was observed between the percentage of samples with severely degraded benthic condition and the average chlorophyll a concentration in the lower Patuxent River (Figure 4-4). There were strong relationships for average chlorophyll concentrations below the pycnocline for quarter 2 (April-June), quarter 3 (July-September), and the combined quarters 1-3. Above the pycnocline, chlorophyll concentrations in the lower Patuxent River were highest in 2003, with a maximum observed concentration of 723 μg/L. In 2004, the maximum observed chlorophyll concentration above the pycnocline was 135 μg/L.

Fixed monitoring stations in the Patuxent River did not show changes in benthic community status in 2004 except for an improvement from degraded to marginally degraded condition at Station 79 (tidal freshwater at Lyons Creek). The status of Station 77 (Holland Cliff) and Station 74 (Chalk Point) continued to be good, while the status of Station 71 (Broomes Island) continued to be degraded. This last station, located in the deep mainstem of the lower Patuxent River, is affected by low dissolved oxygen conditions. The status for any given year is calculated by averaging the B-IBI scores of the

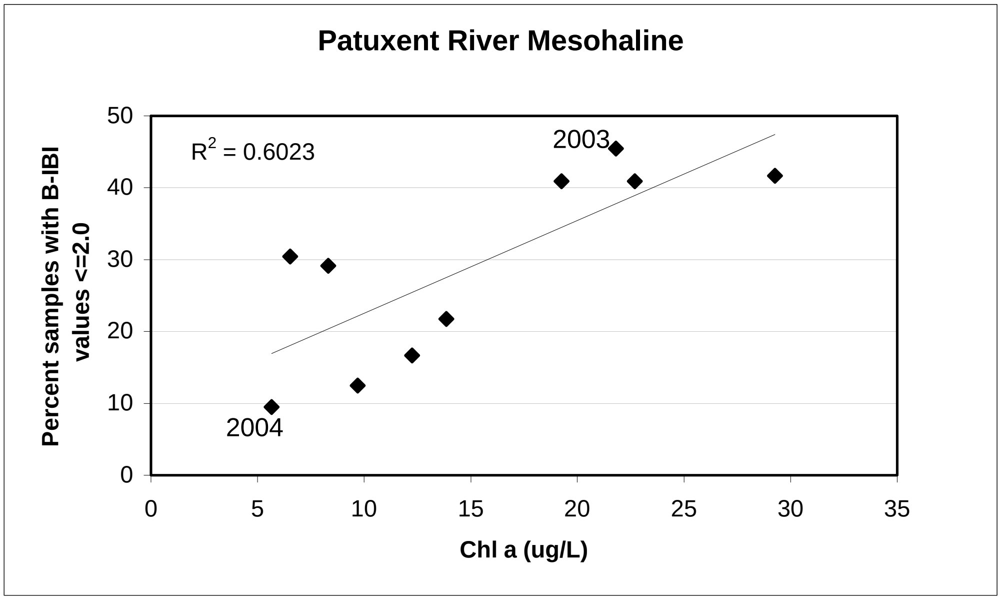

Figure 4-4. Relationship of benthic index of biotic integrity to average chlorophyll a concentration in the mesohaline Patuxent River. Each point represents a different year, 1995-2004. Chlorophyll data are below pycnocline, April through June fortnight observations from Chesapeake Bay Water Quality Monitoring Program stations RET1.1, and LE1.1 through LE1.4.

last three years. The B-IBI scores for Stations 79, 74, and 71 were better in 2004 than in 2003, reflecting recovery of the community from the severe hypoxia events and high river flow conditions of 2003.

The most significant change in trends at the Patuxent River stations in 2004 was a reverse in direction of trends for abundance and biomass (increasing degradation) at Station 77 (Holland Cliff). As a consequence, the magnitude of the degrading B-IBI trend at this station increased. We reported recovery (decreasing magnitude in the trend) in the last three years. The recovery was predominantly associated with increases in densities and biomass of the bivalves *Macoma balthica* and *Rangia cuneata*. Signs of recovery in previous years may have been confounded by changes in river flow resulting from drier than normal years between 1999 and 2002. Flow-induced changes in salinity typically limit the distribution of bivalves in the Chesapeake Bay (Holland et al. 1987) and are likely to play a major role in structuring benthic communities in transitional salinity regions. We will continue to monitor changes in the bivalve community of the oligohaline Patuxent River to attempt to dissociate changes due to pollution from those caused by natural phenomena.

4.2 POTOMAC RIVER

The Potomac River has one of the largest areas with degraded benthic community in the Chesapeake Bay. However, there was a decrease in the total area degraded in 2004. Tidal fresh and oligohaline sites in 2004 met the restoration goals. Sites failing the restoration goals were located in the mesohaline portion of the river. Much of the problem in the Potomac River is severe oxygen depletion in the lower deep mainstem. Over the period 1996-2004, this stratum had the highest percentage of sites failing the restoration goals because of insufficient abundance or biomass. On the other hand, algal abundance showed good status and no significant trend in 2004. Benthic diagnostic tool analysis indicated low probability of contaminant effects. Unlike with the Patuxent River, no significant relationship was observed when the percentage of samples failing the restoration goals was plotted against the percentage of observations with DO concentrations below 2 mg/L, June through September. This is because hypoxia in the Potomac River is a perennial problem that affects waters below the pycnocline, with little inter-annual variability. The average bottom DO concentration at water quality monitoring stations in the lower Potomac River from 1994 to 2004 was 2 mg/L, and 62% of the observations were below this concentration. In 2004, 61% of the bottom DO observations were below 2 mg/L, and 57% were below 1 mg/L.

A relationship was observed when the average DO concentration at the benthic sites was plotted against the percentage of samples failing the restoration goals (Figure 4-5). Hypoxic events tend to be long lasting in the main stem of the Potomac River and thus, DO concentrations tend to remain low throughout the summer. Eighty-nine percent of the sites sampled in the mesohaline Potomac River in 2004 failed the restoration goals. In 2003, 100% of the sites failed the restoration goals, reflecting the more severe hypoxic events of 2003. Relationships between the B-IBI and DO in the Potomac River, however, are best explored as a function of depth. The frequency of low DO events in the Potomac River is strongly associated with water depth (Figure 4-6), and so is the probability of observing severely degraded benthos (Figure 4-7). No relationships were observed between the B-IBI and chlorophyll concentrations in the lower Potomac River.

Of the seven long-term monitoring stations in the Potomac River, only Station 51 in shallow water near St. Clements Island exhibited a significant trend (improving) in the B-IBI. A degrading B-IBI trend at Station 44 in Morgantown disappeared with the addition of the 2004 data. All stations with changes in status indicated improving conditions in 2004. This is all good news. Water quality has improved in the Potomac River. Trends for total nitrogen, total phosphorus, and chlorophyll a were improving in 2004. Secchi depth was significantly increasing in the tidal freshwater region, although decreasing in the oligohaline region. Notwithstanding these improvements, total nitrogen and Secchi depth remained in poor status in most of the Potomac River, and benthic community condition was degraded at the tidal fresh Station 36 (Rosier Bluff), and at Stations 44 (Morgantown) and 52 (St. Clements Island). The lower Potomac River was included in the 303(d) list of impaired waters for benthos. Clearly, more work remains to be done in the Potomac River.

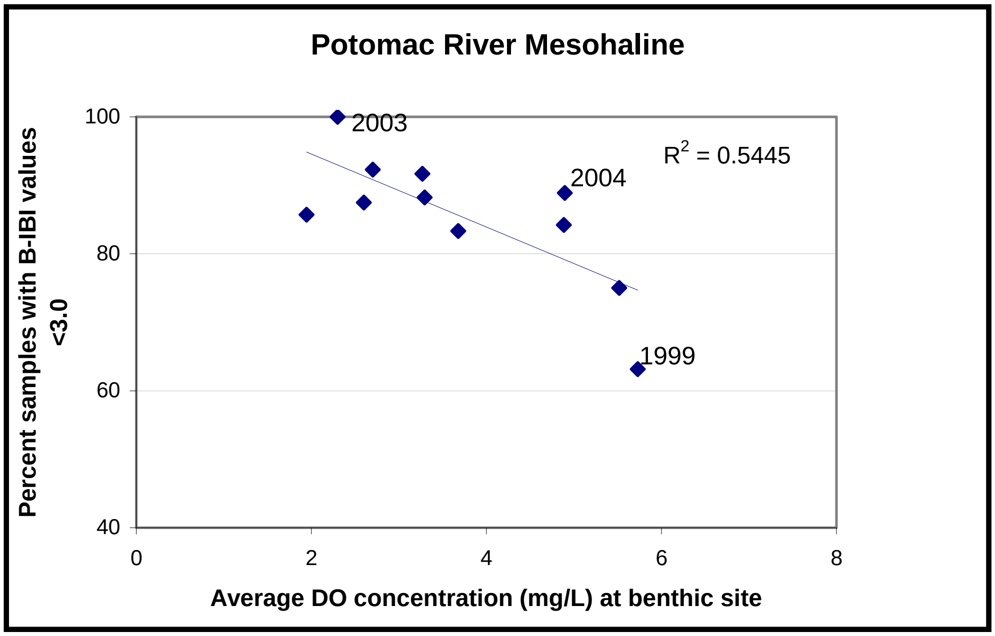

Figure 4-5. Relationship of benthic index of biotic integrity to dissolved oxygen concentration at the time of benthic sample collection in the mesohaline Potomac River. Each point represents a different year, 1994-2004.

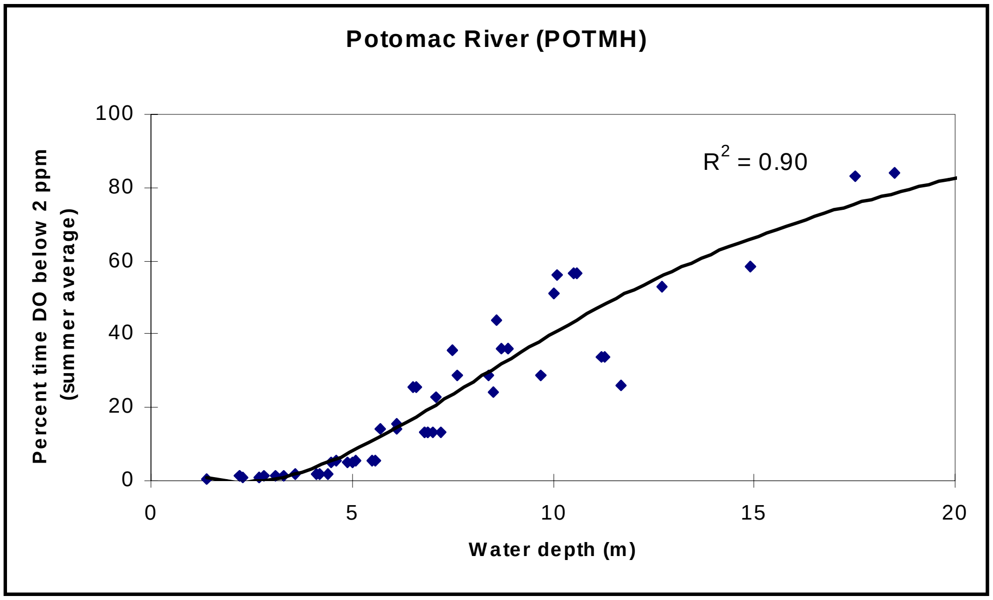

Figure 4-6. Relationship between percent DO observations below 2 mg/L and water depth in the mesohaline Potomac River (1996-1998 data).

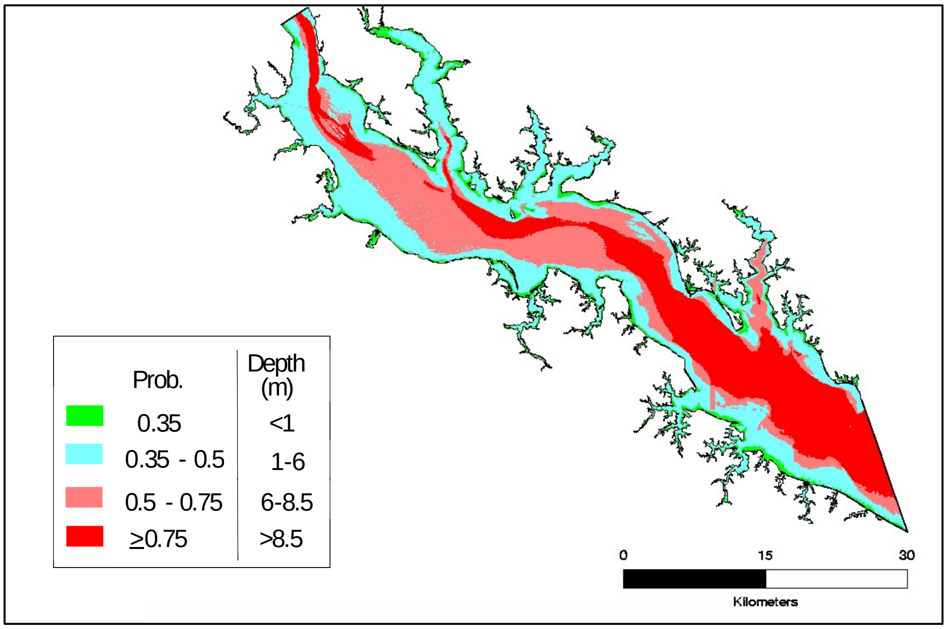

Figure 4-7. Probability of observing severely degraded benthos (B-IBI < = 2.0) as a function of water depth in the mesohaline Potomac River. A logistic regression model was used to obtain the probabilities (1996-1998 data).

Hypoxia in the deep mainstem of the Potomac River influences benthic community condition in Stations 44 (Morgantown) and 52 (St. Clements Island). Both stations are located on the slope of the deep channel (10-17 m). Benthic condition at Station 52 is severely degraded and has shown no improvement since monitoring began in 1984. Benthic condition at Station 44 varies depending on the hydrographic characteristics of the year (dry vs. wet) and tilts of the pycnocline bringing episodic fluctuations in salinity and DO. Abrupt changes in flow and salinity during the benthic reproductive season may determine benthic community condition later in the year. For example, in May 1998 (a wet year) salinity at Station 44 was 1.5 psu, while in May 2002 (a dry year), salinity was 21 psu. In September 2002 (a dry year) DO was 5 mg/L while in late August 2003 (a wet year) DO was 1.8 mg/L. Interestingly, salinity at Station 44 was only 0.6 psu in September 2004 but DO was high around 4 mg/L, and benthic community condition met the restoration goals. 2004 was a wet year but most of the precipitation came late in September, suggesting that the timing of precipitation and river flow events is an important factor in determining benthic community condition in the Potomac River.

4.3 UPPER WESTERN TRIBUTARIES

Benthic degradation in the upper western tributaries of the Bay was high in 2004, with 64% of the area exhibiting degraded condition. The level of degradation in the upper western tributaries is generally high, reflecting various sources of stress, including toxic contamination, low dissolved oxygen, excess phytoplankton growth, lack of water clarity, and nutrient runoff. These factors vary greatly among systems and so does the stress to the benthic communities. The patterns described in previous years were reinforced with the addition of the 2004 data. Results indicate good agreement between the status and trends for the water quality parameters and the benthic community condition.

Benthic diagnostic tool analyses for the period 2000-2004 indicated high probability of contaminant effects for the Patapsco and South rivers. Fifty-two percent of the Patapsco River estuary was estimated to be degraded during this period, and the estuary was included in the lists of impaired waters for benthos. Eighty-eight percent of the South River was estimated to have degraded benthic community, but this estuary was not included in the list of impaired waters because of small sample size. Benthic community condition is severely degraded in the upper part of the Patapsco River estuary, above the Francis Scott Key Bridge and at sites in Curtis Creek, Stony Creek, and along the deep channel south of Sparrows Point, areas that are affected by very low DO concentrations and by toxic contamination. Excess abundance, indicating eutrophic conditions, is common in the lower portion of the estuary in areas that are not affected by hypoxia. The Back River shows moderately degraded benthic condition with total densities of organisms that are either within the good range or in excess of reference conditions, in agreement with pollution related to excess algal growth and high particulate organic deposition. Both the Patapsco and the Back River estuaries had poor total nitrogen, total phosphorus, Secchi depth, and chlorophyll a status in 2004, although improving trends for nitrogen, phosphorus, and chlorophyll were detected.

Good benthic community condition was observed in the Middle, Bush, and Gunpowder rivers. To the south, the Magothy River exhibited degradation that appeared to respond to a mixture of over-enrichment and hypoxia. This is consistent with excess algal abundance and observations of low DO concentrations at the water quality monitoring station in this river, although no significant trends were observed in 2004 for these parameters. The Magothy River was included in the list of impaired waters for benthos. The Severn River exhibited patterns of degradation that were consistent with severe hypoxia or anoxia problems in the upper half of the estuary. The long-term monitoring station in the Severn River (Station 204) had degrading trends for abundance, biomass, pollution-indicative biomass, pollution-sensitive biomass, and the B-IBI. The degrading B-IBI trend increased in magnitude with the addition of the 2004 data. The trend was new in 2003, and possibly signals an increase in the extent of the low DO area. The Rhode and West rivers exhibited low degradation predominately due to excess abundance indicative of over-enrichment.

4.4 EASTERN TRIBUTARIES

The Maryland eastern tributaries usually have some of the smallest extent of degraded area in the Chesapeake Bay. Benthic community degradation decreased from 64% in 2003 to 40% in 2004. Degradation in 2003 was exceptionally high and affected predominately the lower Chester River and the rivers emptying in Tangier Sound, with the exception of the Wicomico River. The lower mesohaline regions of the Chester and

Choptank rivers have been included in the list of impaired waters for benthos. The lower Choptank River and the Pocomoke River were also identified by the benthic diagnostic tool as having high probability of contaminant effects.

A majority of the sites with failing B-IBI in the Chester River were concentrated in the lower portion of the river, around Eastern Neck Island. This region exhibited excess abundance of organisms, which is consistent with poor water clarity and excess algal growth, although degrading trends for these two water quality parameters disappeared in 2004. A long-term station (Station 68) located mid-river above the region where a majority of the random samples fail the B-IBI, continued to have good status in 2004 with no significant B-IBI trend. In the lower Choptank River, 40% of the bottom area was degraded during the period 2000-2004. However, the long-term monitoring station in the mesohaline region of the river (Station 64) exhibited good benthic community condition and no significant trend in the B-IBI. The long-term station in the oligohaline portion of the river (Station 66) exhibited marginally degraded condition and a small but significant improving trend in the B-IBI.

Maryland eastern tributaries have high agricultural land use, high nutrient input, high chlorophyll values but low frequencies of low dissolved oxygen events (Dauer et al. 2000). A high incidence of failure of restoration goals due to excess abundance of organisms was observed for these tributaries. In the lower eastern shore basin, low biomass relative to reference conditions was a problem, particularly in the Manokin River and Tangier Sound. The major problem affecting water quality in the lower eastern shore basin is high sediment loads, which may reduce the amount of food that is available from the water column to the benthos. Poor water clarity affected all systems in the lower eastern shore basin in 2004, and degrading trends in Secchi depth were observed for the Manokin River, Big Annemessex River, Pocomoke Sound, and Tangier Sound. The long-term monitoring station in the Nanticoke River (Station 62) exhibited a degrading trend in the B-IBI, and significantly decreasing trends in biomass, diversity, and abundance of pollution-sensitive organisms, and increasing densities of organisms over the upper threshold. High sediment, nitrogen, and phosphorus loads continued to be major problems in the lower Nanticoke River in 2004.

A small positive B-IBI trend in the Elk River (Station 29) disappeared with the addition of the 2004 data, and benthic community status decreased from marginal to degraded. Although improving trends in this region were reported for nutrients and chlorophyll a in 2004, patterns in river flow and the associated salinity fluctuations are likely to influence benthic community dynamics in the Elk River, with wet years enhancing the abundance of pollution-tolerant oligochaete worms, and dry years enhancing the abundance of bivalves.

4.5 MARYLAND MID BAY AND UPPER BAY MAINSTEMS

Low DO events are common and severe in the mid-bay Maryland mainstem (Dauer et al. 2000). Anoxia is a common feature of the mid-bay deep channel. The Maryland mainstem stratum has the largest extent of severely degraded benthic community condition in the Bay, although the estimates of area degraded decreased from 65% in 2003 to 53% in 2004. We attribute this decrease to the higher dissolved oxygen concentrations in the Bay in 2004.

The upper Maryland mainstem receives discharges from the Susquehanna River; therefore, water quality in this region is a good indicator of inputs from the Susquehanna River watershed. A high incidence of failure of restoration goals due to excess abundance or biomass of organisms is a common feature in the tidal freshwater portion of this region. This is indicative of effects on benthos resulting from nutrient enrichment. However, further down in the oligohaline portion of the mainstem, all probability sites for the period 2000-2004 met the restoration goals, suggesting good water quality condition in this region of the Chesapeake Bay. Sites failing the restoration goals in the upper bay stratum were generally concentrated in deeper water at the mouth of the Chester River, which indicates a local problem.

Three of the long-term monitoring stations are located in shallow, sandy habitats of the mainstem (Stations 01, 06, and 15). Improving B-IBI trends at the Calvert Cliff stations (Stations 01 and 06) disappeared with the addition of the 2004 data, and benthic community status decreased from meeting the goals to marginal. B-IBI scores for these two stations decreased substantially in 2004. These changes in benthic condition are worrisome and will be scrutinized closely over the upcoming monitoring year. Positive trends in the B-IBI continued in North Beach (Station 15) and in the upper bay (Station 26). Benthic community condition met the goals at Station 15 and at the two upper bay stations (Station 24 and 26).

4.6 VIRGINIA TRIBUTARIES

Virginia tributaries showed a decrease in benthic degradation in 2004 relative to 2003, commensurate with the improvements seen elsewhere. A component of degradation in the Virginia tributaries and mainstem is certainly due to low DO, but hypoxia does not extensively affect the Virginia tributaries. The York River does not normally experience hypoxia, except for periods of intermittent hypoxia associated with spring-neap tidal cycles (Haas 1977) in the deep channel near the mouth of the river. Likewise, the Rappahannock River experiences hypoxia near the mouth of the river. Predominant stressors in these rivers appear to be contaminants, eutrophication, and strong tidal flow. Many sites throughout the York River exhibited excess abundance of organisms, a condition more often associated with nutrient enrichment. Physical disturbance of the sediments associated with strong erosional and depositional events is also known to structure benthic communities in the York River (Schaffner et al. 2002). These events were documented through radioisotope dating of sediments and were associated with tidal exchange and river flow. The mesohaline York River had a moderately high probability of contaminant effects during the 2000-2004 period and a high incidence of sites with excess abundance or biomass. The Rappahannock River had high probability of contaminant effects, but low incidence of sites with excess abundance or biomass. The lower portion of both rivers (including the mesohaline and polyhaline York River) were included in the list of impaired waters for benthos.

In the James River, patterns in benthic community condition vary among years depending on the random distribution of sites among systems with local contamination problems. Because pollution sources are spatially variable in the James River stratum, comparisons in patterns of benthic community condition should be interpreted with caution and include assessments at various spatial scales of variability (Dauer and Llansó 2003). Patterns of degradation in the James River are driven by significant sediment contamination problems concentrated in the Elizabeth River (Dauer and Llansó 2003). With the exception of the upper polyhaline main stem of the Elizabeth River, all the branches of the Elizabeth River had a high percentage of degraded area and most samples were classified as contaminated by the benthic diagnostic tool. The mesohaline and oligohaline James River had also a high probability of contaminant effects. Both regions of the James River, plus the Elizabeth River, were included in the list of impaired waters.

4.7 CONCLUSIONS

Baywide estimates of degradation were considerably lower in 2004 than in 2003, and some regions of the Bay had some of the lowest percent degraded area of the monitoring time series. Positive trends in benthic community condition continued to be detected at some fixed long-term monitoring stations, most notably in the Patuxent and Potomac river estuaries. Other stations, such as the Calvert Cliff stations, require close monitoring over the next year because of recent increased degradation. Local areas with identifiable point sources of pollution may be the first ones to respond to pollution abatement and are more likely to show recovery at fixed stations. Hence, the importance of long-term monitoring at fixed stations. Nevertheless, benthic community degradation continued to be large in the Chesapeake Bay.

Much of the problem is excess organic matter from phytoplankton blooms and hypoxia. Although not as large as in 2002 and 2003, the level of benthic community degradation in the Bay was near 50% in 2004 relative to reference conditions. Despite substantial restoration efforts, we haven’t seen significant changes in benthic condition that would indicate widespread improvements in abundance, diversity, or biomass of organisms, many of which are the base for fisheries species. Patterns of degradation between years appear to vary with changes in hydrology (dry versus wet years) and the associated year-to-year fluctuations in the severity and extent of hypoxia. But even if the effect of hydrology is factor out, the residual degradation is still large for any given year. It will probably take sustained management efforts over an extended period of time to bring back a more balanced community of benthic organisms and see significant baywide improvements in benthic condition.

4.8 METHOD DEVELOPMENT AND REFINEMENT

The probability-based estimates developed for this report are the result of reviews conducted jointly by the Maryland and Virginia Chesapeake Bay benthic monitoring programs. A program review in 1996 examined program objectives, analysis techniques, and power to detect trends. One objective that emerged from the program review process was a goal of producing a baywide area estimate of degraded benthic communities with known and acceptable uncertainty. That goal is now an inherent part of benthic monitoring activities in Chesapeake Bay.

Baywide estimates are dependent on fully validated thresholds for assessing the condition of the benthic community in each sample collected. The thresholds were established and validated by Ranasinghe et al. (1994a) and updated by Weisberg et al. (1997). The B-IBI and the stratified random sampling design allow 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. The B-IBI is also applicable to a wide range of habitats, from tidal freshwater mud to polyhaline sand in the Chesapeake Bay, and this is an important and useful feature of the index because it allows characterization of local gradients of pollution and conditions across habitats. A study to develop diagnostic tools that differentiate between low dissolved oxygen impacts on benthos and those from toxic contamination was recently conducted by Dauer et al. (2002) and further augmented the usefulness of the B-IBI to management.

Although a continuing evolution of the B-IBI may lead to changes in estimates of the area of the Bay meeting the restoration goals, these revisions should amount to fine-tuning and not to significant changes in the estimates. One strength of the probability-based sampling element is that the amount of area meeting the goals can be recalculated as the index continues to be improved, so that trends in the area meeting the goals can be compared in a consistent and rigorous fashion.

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APPENDIX A

FIXED SITE COMMUNITY ATTRIBUTE
1985-2004 TREND ANALYSIS RESULTS

Appendix Table A-1. Summer trends in benthic community attributes at mesohaline stations 1985-2004. 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 1989-2004 data; (b): trends based on 1995-2004 data; (c): attribute trend based on 1990-2004 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.

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	-52.82	-0.81	0.003	0.39	-0.60 (d)	0.074 (e)	-0.11	-0.08 (e)
44	0.00	-28.89	-0.10	0.02	-0.42	-0.24(d)	0.004 (e)	-1.21	0.57 (e)
47	0.00	-14.29	0.21	0.02	0.42	-1.26 (d)	0.003 (e)	-0.70	-0.31 (e)
51	0.04	-3.64	-0.16	0.02	-1.03	0.65	0.03 (e)	-0.25 (e)	0.68
52	0.00	-4.44	-0.00	-0.00	0.00 (d)	0.00 (d)	0.00	0.00	-0.00
Patuxent River									
71	0.00	-45.45	-0.07	0.01	-2.57 (d)	0.00 (d)	-2.31	0.00	1.23
74	0.00	173.33	-1.10	-0.02	0.25	-1.35 (d)	-0.001 (e)	-0.11	-0.55 (e)
77	-0.06	64.97	-0.15	-0.001	1.73	-0.57 (d)	-2.59(e)	4.96	-0.62 (e)
Choptank River									
64	0.03	45.86	0.07	0.01	-0.45 (d)	0.33 (d)	0.07	-0.88	-0.12
Maryland Mainstem									
01	0.02	9.71	0.03	-0.01	-0.33	0.62	-0.06 (e)	-0.18 (e)	0.15
06	0.00	43.64	0.01	0.01	0.00	0.68	0.04 (e)	-1.73 (e)	0.32
15	0.04	35.00	-0.01	0.001	-1.02	0.11	-0.01 (e)	0.25 (e)	0.39
24	0.00	-43.49	-0.12	-0.03	-0.63 (d)	0.63 (d)	-0.01	0.38	1.28
26	0.03	17.88	-0.54	0.01	0.00	0.56 (d)	0.00 (e)	-0.02	0.37 (e)
Maryland Western Shore Tributaries									
22	0.00	-12.44	-0.03	-0.03	1.85	0.00 (d)	0.51 (e)	0.00	-0.59 (e)
23	0.02	-79.71	-0.03	0.003	-0.12	0.65 (d)	-0.05 (e)	1.96	0.49 (e)
201(a)	0.00	-20.04	-0.00	0.002	0.00	0.00 (d)	2.08 (e)	0.00	0.00 (e)
202(a)	0.00	-28.26	0.003	0.06	-1.74	0.00 (d)	-1.08 (e)	0.00	0.85 (e)
204(b)	-0.17	71.20	-0.36	0.01	2.14 (d)	-0.37 (d)	0.18	-4.99	-0.62
Maryland Eastern Shore Tributaries									
62	-0.03	110.00	-0.04	-0.06	-0.11	-0.35 (d)	0.00 (e)	-0.04	-0.37 (e)
68	0.00	68.53	0.64	0.002	0.18	1.13 (d)	-0.00 (e)	-0.05	0.48 (e)

Appendix Table A-2. Summer trends in benthic community attributes at oligohaline and tidal freshwater stations 1985-2004. 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 1989-2004 data; NA: attribute not calculated.

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	-27.96	0.007	0.59	NA	NA	NA	0.55	NA
40	0.00	-6.49	0.00	NA	-0.64	0.00	0.00	NA	0.59
Patuxent River									
79	0.00	184.44	-0.006	-1.04	NA	NA	NA	-0.19	NA
Choptank River									
66	0.00	76.29	0.12	NA	0.83	0.00	+0.00	NA	0.99
Maryland Western Shore Tributaries									
203(a)	0.05	56.71	-0.03	NA	0.00	0.00	2.60	NA	1.35
Maryland Eastern Shore Tributaries									
29	0.00	-24.71	-0.09	NA	-2.23	0.07	0.00	NA	0.19

APPENDIX B

FIXED SITE B-IBI VALUES, SUMMER 2004

Appendix Table B-1. Fixed site B-IBI values, Summer 2004

Station	Sampling Date	Latitude (WGS84 Decimal Degrees)	Longitude (WGS84 Decimal Degrees)	B-IBI	Status
001	14-Sep-04	38.41967	-76.41917	2.11	Degraded
006	14-Sep-04	38.44203	-76.44422	1.89	Severely Degraded
015	14-Sep-04	38.71510	-76.51398	3.22	Meets Goal
022	2-Sep-04	39.25388	-76.58815	2.47	Degraded
023	2-Sep-04	39.20855	-76.52420	3.93	Meets Goal
024	1-Sep-04	39.12137	-76.35598	4.56	Meets Goal
026	1-Sep-04	39.27092	-76.28965	4.07	Meets Goal
029	17-Sep-04	39.47948	-75.94497	2.00	Severely Degraded
036	20-Sep-04	38.76943	-77.03778	2.83	Marginal
040	15-Sep-04	38.35725	-77.23097	3.00	Meets Goal
043	15-Sep-04	38.38552	-76.99603	3.67	Meets Goal
044	15-Sep-04	38.38552	-76.99603	3.93	Meets Goal
047	15-Sep-04	38.36393	-76.98378	3.53	Meets Goal
051	15-Sep-04	38.20547	-76.73825	3.22	Meets Goal
052	15-Sep-04	38.19223	-76.74875	1.00	Severely Degraded
062	29-Sep-04	38.38420	-75.85080	2.60	Degraded
064	30-Sep-04	38.59040	-76.06967	4.00	Meets Goal
066	29-Sep-04	38.80130	-75.92225	2.78	Marginal
068	30-Sep-04	39.12985	-76.07947	3.40	Meets Goal
071	3-Sep-04	38.39510	-76.54905	2.56	Degraded
074	28-Sep-04	38.55073	-76.67773	4.20	Meets Goal
077	28-Sep-04	38.60435	-76.67527	1.67	Severely Degraded
079	28-Sep-04	38.74965	-76.68967	3.33	Meets Goal
201	2-Sep-04	39.23385	-76.49737	1.40	Severely Degraded
202	2-Sep-04	39.21742	-76.56462	1.67	Severely Degraded
203	24-Sep-04	39.27515	-76.44440	2.56	Degraded
204	14-Sep-04	39.00665	-76.50497	2.78	Marginal

APPENDIX C

RANDOM SITE B-IBI VALUES, SUMMER 2004

Appendix Table C-1. Random site B-IBI values, Summer 2004

Station	Sampling Date	Latitude (WGS84 Decimal Degrees)	Longitude (WGS84 Decimal Degrees)	B-IBI	Status
MET-11401	23-Sep-04	38.00810	-75.62662	2.00	Severely Degraded
MET-11402	23-Sep-04	38.07412	-75.61572	2.50	Degraded
MET-11403	22-Sep-04	38.13292	-75.85618	4.00	Meets Goal
MET-11404	29-Sep-04	38.25198	-75.82028	2.20	Degraded
MET-11405	29-Sep-04	38.25222	-75.95023	2.67	Marginal
MET-11406	29-Sep-04	38.28485	-75.92915	1.80	Severely Degraded
MET-11407	29-Sep-04	38.28697	-75.93593	3.00	Meets Goal
MET-11408	28-Sep-04	38.34235	-75.90402	3.40	Meets Goal
MET-11409	30-Sep-04	38.59805	-76.15443	2.60	Degraded
MET-11411	30-Sep-04	38.60465	-75.99007	3.00	Meets Goal
MET-11412	30-Sep-04	38.60578	-76.10588	3.00	Meets Goal
MET-11413	30-Sep-04	38.60825	-75.97488	3.00	Meets Goal
MET-11414	30-Sep-04	38.61858	-76.13290	3.00	Meets Goal
MET-11415	30-Sep-04	38.69817	-75.99653	3.00	Meets Goal
MET-11416	29-Sep-04	38.82852	-75.91143	3.00	Meets Goal
MET-11419	30-Sep-04	39.23635	-76.00048	3.33	Meets Goal
MET-11420	30-Sep-04	39.24543	-75.98385	2.00	Severely Degraded
MET-11421	17-Sep-04	39.36788	-76.01035	4.00	Meets Goal
MET-11422	17-Sep-04	39.36830	-75.93918	2.50	Degraded
MET-11423	17-Sep-04	39.48568	-75.90253	4.00	Meets Goal
MET-11424	17-Sep-04	39.52118	-75.87738	4.00	Meets Goal
MET-11425	17-Sep-04	39.56395	-75.85715	2.00	Severely Degraded
MET-11426	29-Sep-04	38.63443	-76.14745	2.20	Degraded
MET-11427	22-Sep-04	38.10827	-75.85845	3.33	Meets Goal
MET-11428	22-Sep-04	38.10875	-75.89737	3.33	Meets Goal
MMS-11501	31-Aug-04	37.97200	-76.11247	3.00	Meets Goal
MMS-11502	31-Aug-04	37.97502	-76.07252	3.33	Meets Goal
MMS-11503	31-Aug-04	38.03047	-75.93465	4.00	Meets Goal
MMS-11504	31-Aug-04	38.04178	-75.95620	3.00	Meets Goal
MMS-11505	31-Aug-04	38.06312	-75.92100	3.33	Meets Goal
MMS-11506	31-Aug-04	38.07635	-76.10317	3.67	Meets Goal
MMS-11507	31-Aug-04	38.11095	-76.13475	4.00	Meets Goal
MMS-11508	31-Aug-04	38.13973	-76.16748	2.67	Marginal
MMS-11509	31-Aug-04	38.14493	-75.97042	3.67	Meets Goal
MMS-11510	31-Aug-04	38.16490	-75.97460	2.67	Marginal
MMS-11512	31-Aug-04	38.25533	-76.24087	3.00	Meets Goal
MMS-11513	31-Aug-04	38.30810	-76.37270	2.00	Severely Degraded
MMS-11514	31-Aug-04	38.31055	-76.27328	3.33	Meets Goal

Appendix Table C-1. (Continued)

Station	Sampling Date	Latitude (WGS84 Decimal Degrees)	Longitude (WGS84 Decimal Degrees)	B-IBI	Status
MMS-11515	14-Sep-04	38.58247	-76.46378	3.00	Meets Goal
MMS-11516	29-Sep-04	38.63855	-76.15123	2.20	Degraded
MMS-11517	14-Sep-04	38.64573	-76.48047	3.00	Meets Goal
MMS-11518	28-Sep-04	38.74928	-76.31135	3.40	Meets Goal
MMS-11519	02-Sep-04	38.76182	-76.50867	2.60	Degraded
MMS-11520	02-Sep-04	38.79388	-76.35390	2.60	Degraded
MMS-11521	02-Sep-04	38.79890	-76.45260	1.40	Severely Degraded
MMS-11523	02-Sep-04	38.86140	-76.48352	2.60	Degraded
MMS-11524	02-Sep-04	38.86808	-76.47673	3.40	Meets Goal
MMS-11525	02-Sep-04	38.97628	-76.42923	1.80	Severely Degraded
MMS-11526	31-Aug-04	37.98510	-75.90750	3.33	Meets Goal
MMS-11528	02-Sep-04	38.74247	-76.35307	2.20	Degraded
MWT-11301	02-Sep-04	38.86902	-76.51452	2.20	Degraded
MWT-11302	02-Sep-04	38.87553	-76.49633	3.00	Meets Goal
MWT-11303	02-Sep-04	38.88187	-76.53398	3.80	Meets Goal
MWT-11304	02-Sep-04	38.88040	-76.48592	3.00	Meets Goal
MWT-11305	14-Sep-04	38.93238	-76.52057	1.50	Severely Degraded
MWT-11306	14-Sep-04	38.93377	-76.52027	1.00	Severely Degraded
MWT-11307	14-Sep-04	39.00230	-76.50147	2.50	Degraded
MWT-11308	14-Sep-04	39.04335	-76.55753	2.20	Degraded
MWT-11309	14-Sep-04	39.04517	-76.56168	1.00	Severely Degraded
MWT-11310	14-Sep-04	39.07520	-76.46412	1.00	Severely Degraded
MWT-11311	02-Sep-04	39.16578	-76.46468	2.20	Degraded
MWT-11312	02-Sep-04	39.17192	-76.48595	2.60	Degraded
MWT-11313	02-Sep-04	39.17545	-76.50798	2.60	Degraded
MWT-11314	02-Sep-04	39.18552	-76.45955	2.20	Degraded
MWT-11315	02-Sep-04	39.18740	-76.52195	2.60	Degraded
MWT-11316	02-Sep-04	39.19800	-76.46198	4.20	Meets Goal
MWT-11317	02-Sep-04	39.20302	-76.50067	3.40	Meets Goal
MWT-11318	02-Sep-04	39.21337	-76.53845	1.00	Severely Degraded
MWT-11319	02-Sep-04	39.23402	-76.49970	3.40	Meets Goal
MWT-11320	24-Sep-04	39.24038	-76.42992	1.67	Severely Degraded
MWT-11321	02-Sep-04	39.24267	-76.49230	2.60	Degraded
MWT-11322	24-Sep-04	39.30983	-76.36153	3.00	Meets Goal
MWT-11323	16-Sep-04	39.33395	-76.36120	3.33	Meets Goal
MWT-11324	16-Sep-04	39.37405	-76.33793	3.00	Meets Goal
MWT-11326	02-Sep-04	39.22787	-76.52743	2.60	Degraded
PMR-11101	30-Aug-04	38.03500	-76.50178	3.00	Meets Goal

Appendix Table C-1. (Continued)

Station	Sampling Date	Latitude (WGS84 Decimal Degrees)	Longitude (WGS84 Decimal Degrees)	B-IBI	Status
PMR-11102	30-Aug-04	38.06120	-76.48268	1.00	Severely Degraded
PMR-11103	30-Aug-04	38.07592	-76.42065	1.67	Severely Degraded
PMR-11104	30-Aug-04	38.10927	-76.50208	2.33	Degraded
PMR-11105	30-Aug-04	38.16337	-76.73513	1.80	Severely Degraded
PMR-11106	30-Aug-04	38.17408	-76.74247	1.00	Severely Degraded
PMR-11107	30-Aug-04	38.18177	-76.66292	1.00	Severely Degraded
PMR-11108	30-Aug-04	38.20523	-76.83960	1.00	Severely Degraded
PMR-11109	30-Aug-04	38.20963	-76.82175	1.00	Severely Degraded
PMR-11110	30-Aug-04	38.20868	-76.69407	1.00	Severely Degraded
PMR-11111	30-Aug-04	38.23832	-76.86398	1.00	Severely Degraded
PMR-11112	30-Aug-04	38.25730	-76.68835	1.00	Severely Degraded
PMR-11113	30-Aug-04	38.28477	-76.98590	3.80	Meets Goal
PMR-11114	15-Sep-04	38.30167	-77.01225	1.80	Severely Degraded
PMR-11115	15-Sep-04	38.30518	-76.99738	2.50	Degraded
PMR-11116	15-Sep-04	38.35340	-76.85140	1.00	Severely Degraded
PMR-11117	15-Sep-04	38.36867	-77.11888	4.50	Meets Goal
PMR-11118	15-Sep-04	38.37585	-77.00322	2.60	Degraded
PMR-11120	15-Sep-04	38.44050	-77.03728	5.00	Meets Goal
PMR-11121	15-Sep-04	38.51485	-77.26910	4.00	Meets Goal
PMR-11122	15-Sep-04	38.60120	-77.22167	3.50	Meets Goal
PMR-11123	15-Sep-04	38.60143	-77.24743	5.00	Meets Goal
PMR-11124	20-Sep-04	38.62907	-77.14777	4.00	Meets Goal
PMR-11125	20-Sep-04	38.71527	-77.03667	3.00	Meets Goal
PMR-11127	30-Aug-04	38.04418	-76.42503	1.00	Severely Degraded
PXR-11201	03-Sep-04	38.30152	-76.43588	3.00	Meets Goal
PXR-11202	03-Sep-04	38.30552	-76.42873	2.60	Degraded
PXR-11203	03-Sep-04	38.30888	-76.42750	2.20	Degraded
PXR-11204	03-Sep-04	38.31362	-76.44118	2.60	Degraded
PXR-11206	14-Sep-04	38.33227	-76.44892	2.50	Degraded
PXR-11207	03-Sep-04	38.33970	-76.49552	2.60	Degraded
PXR-11208	03-Sep-04	38.36135	-76.48868	3.40	Meets Goal
PXR-11209	03-Sep-04	38.38318	-76.50492	3.40	Meets Goal
PXR-11210	03-Sep-04	38.38578	-76.51577	2.20	Degraded
PXR-11211	03-Sep-04	38.40130	-76.57045	1.80	Severely Degraded
PXR-11212	03-Sep-04	38.41092	-76.56403	2.60	Degraded
PXR-11213	20-Sep-04	38.44042	-76.61768	3.80	Meets Goal
PXR-11214	20-Sep-04	38.44237	-76.63317	3.00	Meets Goal
PXR-11215	20-Sep-04	38.44558	-76.61117	2.20	Degraded

Appendix Table C-1. (Continued)

Station	Sampling Date	Latitude (WGS84 Decimal Degrees)	Longitude (WGS84 Decimal Degrees)	B-IBI	Status
PXR-11216	20-Sep-04	38.45320	-76.64817	2.60	Degraded
PXR-11217	20-Sep-04	38.45627	-76.61425	3.00	Meets Goal
PXR-11218	20-Sep-04	38.45885	-76.62878	2.60	Degraded
PXR-11219	20-Sep-04	38.48282	-76.67780	3.80	Meets Goal
PXR-11220	20-Sep-04	38.49970	-76.67605	4.60	Meets Goal
PXR-11221	28-Sep-04	38.51330	-76.66885	2.60	Degraded
PXR-11222	28-Sep-04	38.57537	-76.67342	2.60	Degraded
PXR-11223	28-Sep-04	38.72760	-76.69353	2.00	Severely Degraded
PXR-11224	28-Sep-04	38.76210	-76.69570	2.50	Degraded
PXR-11225	28-Sep-04	38.76387	-76.69773	3.50	Meets Goal
PXR-11226	14-Sep-04	38.33512	-76.44120	2.00	Severely Degraded
UPB-11601	01-Sep-04	39.03240	-76.26330	1.80	Severely Degraded
UPB-11602	01-Sep-04	39.04633	-76.35075	2.00	Severely Degraded
UPB-11603	01-Sep-04	39.07030	-76.27852	1.00	Severely Degraded
UPB-11604	01-Sep-04	39.07350	-76.29333	1.40	Severely Degraded
UPB-11605	01-Sep-04	39.07775	-76.30722	1.67	Severely Degraded
UPB-11606	01-Sep-04	39.07870	-76.27810	1.80	Severely Degraded
UPB-11607	01-Sep-04	39.09155	-76.30833	1.40	Severely Degraded
UPB-11608	01-Sep-04	39.12177	-76.32765	3.00	Meets Goal
UPB-11610	01-Sep-04	39.12950	-76.25582	3.00	Meets Goal
UPB-11611	01-Sep-04	39.16347	-76.30053	3.40	Meets Goal
UPB-11612	01-Sep-04	39.16830	-76.28313	3.40	Meets Goal
UPB-11613	02-Sep-04	39.20145	-76.39680	3.80	Meets Goal
UPB-11614	01-Sep-04	39.20460	-76.29420	3.80	Meets Goal
UPB-11616	24-Sep-04	39.26247	-76.38453	3.33	Meets Goal
UPB-11618	01-Sep-04	39.28415	-76.24032	4.20	Meets Goal
UPB-11619	01-Sep-04	39.30640	-76.22488	4.00	Meets Goal
UPB-11620	01-Sep-04	39.34805	-76.13990	4.00	Meets Goal
UPB-11621	01-Sep-04	39.35885	-76.15002	4.50	Meets Goal
UPB-11622	01-Sep-04	39.43030	-76.07158	4.00	Meets Goal
UPB-11623	01-Sep-04	39.43753	-76.05627	4.00	Meets Goal
UPB-11624	17-Sep-04	39.54613	-76.03125	5.00	Meets Goal
UPB-11625	17-Sep-04	39.56360	-75.97958	5.00	Meets Goal
UPB-11626	02-Sep-04	39.16980	-76.43223	3.00	Meets Goal
UPB-11627	01-Sep-04	39.05438	-76.32265	2.60	Degraded
UPB-11628	01-Sep-04	39.22610	-76.26466	3.67	Meets Goal