CHESAPEAKE BAY WATER QUALITY MONITORING PROGRAM

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

JULY 1984—DECEMBER 2001 (VOLUME 1)

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Prepared by

Roberto J. Llansó
Lisa C. Scott
Frederick S. Kelley

Versar, Inc.
9200 Rumsey Road
Columbia, Maryland 21045

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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 2001), was prepared by Versar, Inc. at the request of Dr. Robert Magnien of the Maryland Department of Natural Resources under Cooperative Agreement CA-02-01/07-4-30722-3734 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 2001 and evaluates their responses to changes in water quality.

ACKNOWLEDGMENTS

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The development of the area-based restoration goals (Chapter 5) was supported in part by a grant from the Chesapeake Bay Program. Marcia Olson (Chesapeake Bay Program) and Daniel M. Dauer (Old Dominion University) collaborated in the project, and Ananda Ranasinghe (currently at the Southern California Coastal Water Research Program) contributed to much of the original ideas and to securing funding.

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 the eighteenth 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 2001 and compared to results from previous years. A study to develop area-based restoration goals in relation to dissolved oxygen levels is included in this report.

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 have been 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 17-year B-IBI trends were detected at ten of the 27 sites currently monitored. Benthic community condition declined at three sites and improved at seven sites. Trends detected through 1999 and 2000 were still present in 2001 with the exception of a degrading trend in the Patuxent River at Chalk Point (Sta. 74), which was no longer significant. Sites with improving trends still present in 2001 were located in the main stem of the Bay (3 sites) and the Potomac River at Rosier Bluff (Sta. 36) and St. Clements Island (Sta. 51). Sites with declining trends still present in 2001 were located in the Patuxent River at Broomes Island (Sta. 71) and Holland Cliff (Sta. 77), and in the Nanticoke River (Sta. 62). New trends were found at two sites, the Chester (Sta. 68) and Elk (Sta. 29) rivers, and both were improving. 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.

The new improving trend in the Chester River was associated with a decrease in abundance of organisms below the upper reference level, and is possibly linked to a reduction in organic enrichment. The trend in the Elk River was associated with changes in the abundance of pollution-indicative organisms, and may reflect an observed general improving trend in nutrient, chlorophyll, and sediment concentrations in this system. Improving trends continuing in 2001 were attributed to an increase in faunal abundance possibly related to baywide improvements in water quality (mainstem sites), a decrease in overabundance of bivalves in the tidal fresh Potomac River (Sta. 36), and an improvement in the diversity and general condition of the benthic community in the lower shallow Potomac River (Sta. 51) suggesting improvements in water quality in this region of the river.

Degrading trends continuing through 2001 were attributed to a decrease in the abundance of the bivalve *Macoma balthica* in relation to long-term changes in salinity and freshwater flow in the upper Patuxent River (Sta. 77), declines in total community abundance and biomass associated with very low dissolved oxygen concentrations in the deep, lower portion of the Patuxent River (Sta. 71), and a decrease in diversity, abundance, and biomass possibly linked to high sediment loads in the Nanticoke River. Low biomass is a problem common to Maryland lower eastern tributaries. Lower eastern tributaries have high sediment loads.

It is difficult to relate fixed-site trends with probability-based sampling results. However, it appears that degradation trends in Patuxent River sites were consistent with a pronounced increase in degraded area as determined from probability-based sampling.

Baywide Benthic Community Condition

The overall benthic condition of Chesapeake Bay has remained unchanged since 1999. In 2001, about half of the Bay and nearly 60% of the Maryland portion of the Bay failed to meet the benthic community restoration goals. A small improvement in the condition of the Maryland Bay was observed in 2001. Forty-four percent of the area failing the restoration goals in Chesapeake Bay was marginally to moderately impaired and should respond quickly to moderate improvements in water quality. Baywide, the Potomac and York rivers were in worst condition in 2001, both with 80% of the bottom area failing the restoration goals. The mid-Bay mainstem and the Potomac and Patuxent rivers were in the poorest condition among the six Maryland strata. The mid-Bay mainstem continued to have the largest area of degraded bottom (~ 2000 km^2) among the strata, with well over half the area, including the deep trough, severely degraded. Since 1994 more than half of the Potomac area has consistently failed the restoration goals. In 2001, the Patuxent River experienced the largest percent of degradation ever observed for this basin. The condition of the upper western tributaries, however, improved substantially relative to previous years. The eastern shore tributaries continued to have the smallest area with severely degraded condition over the assessment period, although an increase in this area was noted in 2001.

As in previous years, restoration goal failure due to severely degraded and depauperate benthic fauna was more common than failure due to excess abundance or biomass of benthic organisms. Over the period 1996-2001, the highest percentages of severely degraded sites failing the restoration goals due to insufficient abundance or biomass were found in the mainstem of the Chesapeake Bay and the Potomac River. Sites with a high incidence of failure due to excess abundance or biomass were most frequently located in eastern shore tributaries. 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 mid-bay Maryland mainstem, and 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.

Area-Based Restoration Goals

A method for setting area-based benthic restoration goals in relation to improvements in dissolved oxygen predicted for various nutrient reduction scenarios was established. Results from the 1996-1998 random benthic sampling effort were combined with water quality model simulation runs to establish the tool and the restoration goals for one scenario. The development of area goals is expected to provide Bay managers with targets for restoration that link water quality to living resources. The area with degraded benthos that is associated with low dissolved oxygen was estimated for three segments in the Maryland mainstem, and the Potomac, Rappahannock, and York river mesohaline zones. Estimates were produced for various probability levels of degradation. Changes to the area were then estimated on the basis of increases in dissolved oxygen concentrations predicted by the Chesapeake Bay Program Limit of Technology (LOT) scenario. This modeling scenario projects changes to water quality from future possible changes to land use, best management practices, point sources, and atmospheric deposition loads resulting from management actions directed at reducing nutrients and sediments delivered to the Bay.

The largest change in area was predicted for segment CB5MH of the Maryland mainstem, with 36% (525 km^2) of the segment area changing from high to low probabilities of benthic degradation. The smallest change was predicted for the Rappahannock River, with 11% (35 km^2) of the segment area changing from high to low probabilities of degradation. Most of the hypoxia in the Rappahannock River was restricted to deep water where little improvement in dissolved oxygen concentrations and benthic community condition was expected. The most significant improvement was predicted for the Potomac River where the percent total area supporting benthos with greater than 50% chance of severe impairment was expected to decline from 52% to 22% under the LOT scenario.

The improvements in benthic community condition predicted from the LOT scenario are large and should be viewed with caution. The estimates provided by the LOT scenario represent some of the highest bottom summer dissolved oxygen concentrations among the modeling scenarios. Applications of the method to more achievable model scenarios is recommended. With further refinement, area-based benthic community restoration goals should prove very useful to Bay managers to evaluate recovery of the biological community relative to water quality criteria.

Summary

This report assesses the status of Chesapeake Bay benthic communities in 2001 and evaluates their response to changes in water quality. Assessment of benthic community condition is possible through application of the benthic index of biotic integrity. Seventeen-year trends at fixed monitoring sites indicated significant improvements at seven sites and increasing degradation at three sites. Improving trends in the Chester, Elk, and Potomac rivers were consistent with observed reductions in nutrient, chlorophyll, and sediment concentrations in these systems. Degrading trends were associated with changes in freshwater flow and hypoxia in the Patuxent River, and with high sediment loads in the Nanticoke River. The overall benthic condition in the Bay remained unchanged since 1999. However, in much of the Bay benthic communities are marginally to moderately impaired and are expected to respond quickly to moderate improvements in water quality. The strata with the highest areal estimates of degraded benthic community condition had higher frequency of low dissolved oxygen events. Benthic community condition is expected to improve substantially with increases in dissolved oxygen concentrations predicted by the LOT nutrient reduction model scenario.

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VOLUME 1

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; and
- define linkages between water quality and living resources.

The program includes elements to measure water quality, sediment quality, phytoplankton, zooplankton, 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 oysters and clams, are economically important. Others, such as polychaete worms 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 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).

Factors that contribute to the development and spatial variation of hypoxia in the Chesapeake Bay are freshwater inflow (Holland et al. 1987), salinity, temperature, wind stress, and tidal circulation (Tuttle et al. 1987). 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. 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), albeit not the only one. Biological processes contribute to deep water oxygen depletion. 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).

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 the eighteenth in 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 in Chapter 3 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 described in the Chesapeake Bay Basin Summaries. The Tidal Freshwater Goals that were developed in 1999, were refined, statistically validated (Alden et al. 2002), and applied to tidal freshwater and oligohaline sites. In Chapter 4, which describes baywide benthic community condition, estimates of degraded condition are presented for at least six years for all subregions of the Bay, and community measures that contribute to Restoration Goal failure are used to diagnose the causes of failure. In addition, we present in Chapter 5 results of the area-based restoration goals study. The objective of this study was to set area-based restoration goals for benthic communities in the Chesapeake Bay relative to improvements in dissolved oxygen predicted by water quality modeling scenarios. The area-based restoration goals represent a new step in the development of quantitative goals that link water quality to living resources.

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 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. The site has been substantially improved over the past year. The 2001 data, as well as the data from previous years, can be downloaded from this site. 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 six chapters and three appendices. Chapter 2 presents the field, laboratory, and data analysis methods used to collect, process, and evaluate LTB samples. Chapter 3 presents an assessment of trends in benthic community condition at sites sampled annually by LTB in the Maryland Chesapeake Bay. Chapter 4 presents an assessment of the area of the Bay that meets the Chesapeake Bay Benthic Community Restoration Goals. Chapter 5 is the area-based restoration goal study, and Chapter 6 lists the Literature cited in the report. Appendix A amplifies information presented in Table 3-2 by providing rates of change for the 1985-2001 fixed site trend analysis. Finally, Appendices B and C present the B-IBI values for the 2001 fixed and random samples, respectively. Volume 2 consists of the raw 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 2001 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).

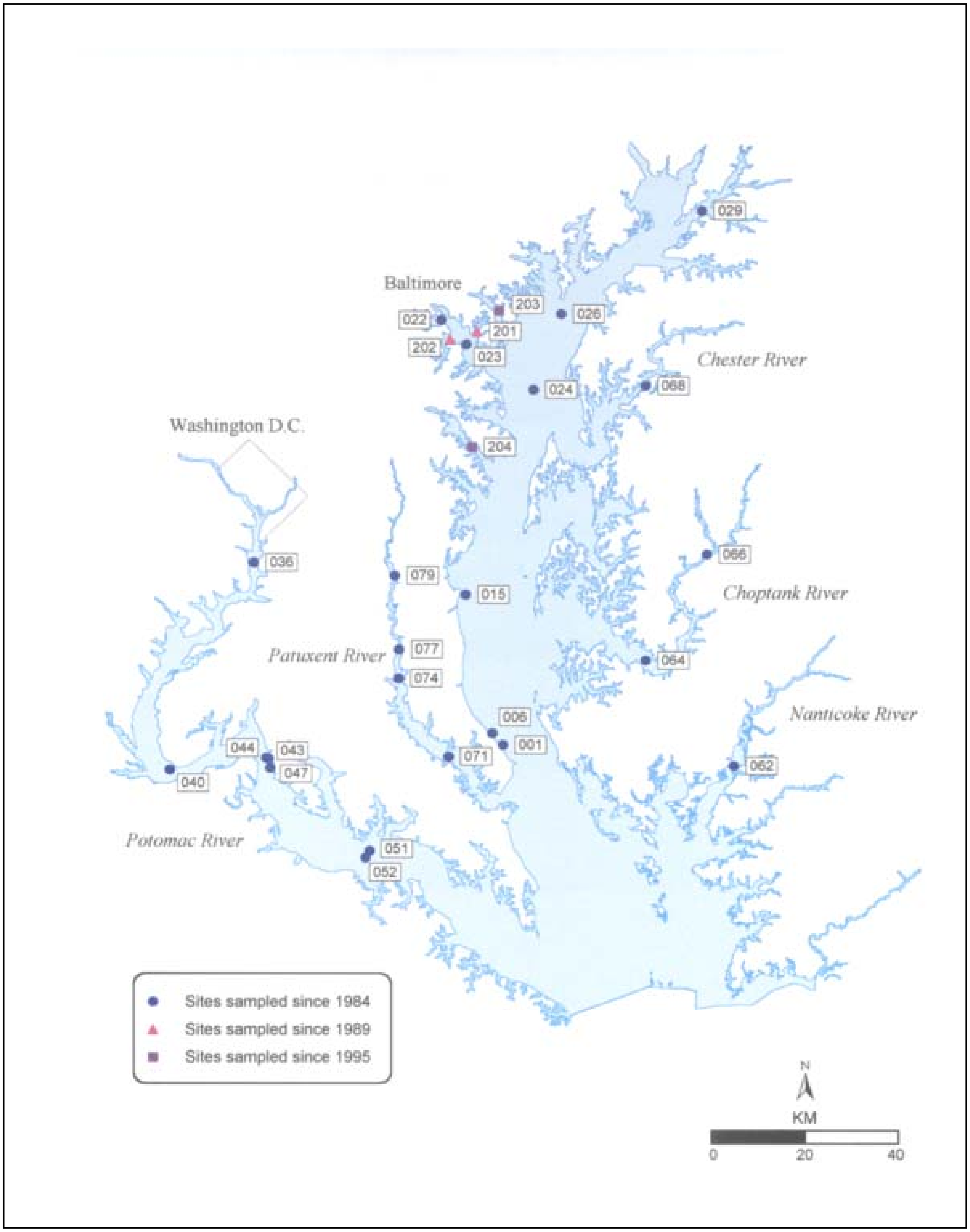

Figure 2-1. Fixed sites sampled in 2001

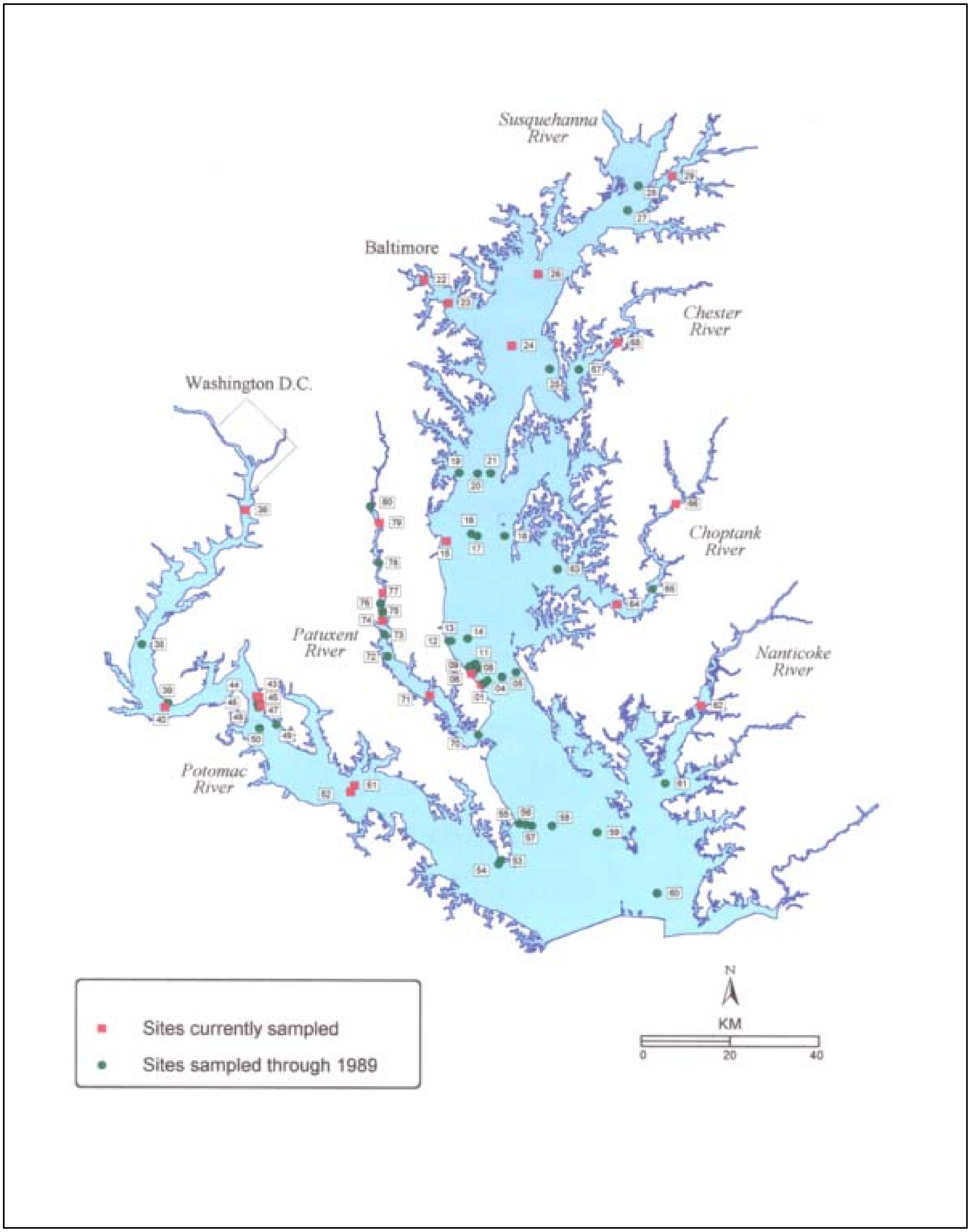

Figure 2-2. Fixed sites sampled from 1984 to 1989; some of these sites are part of the current design

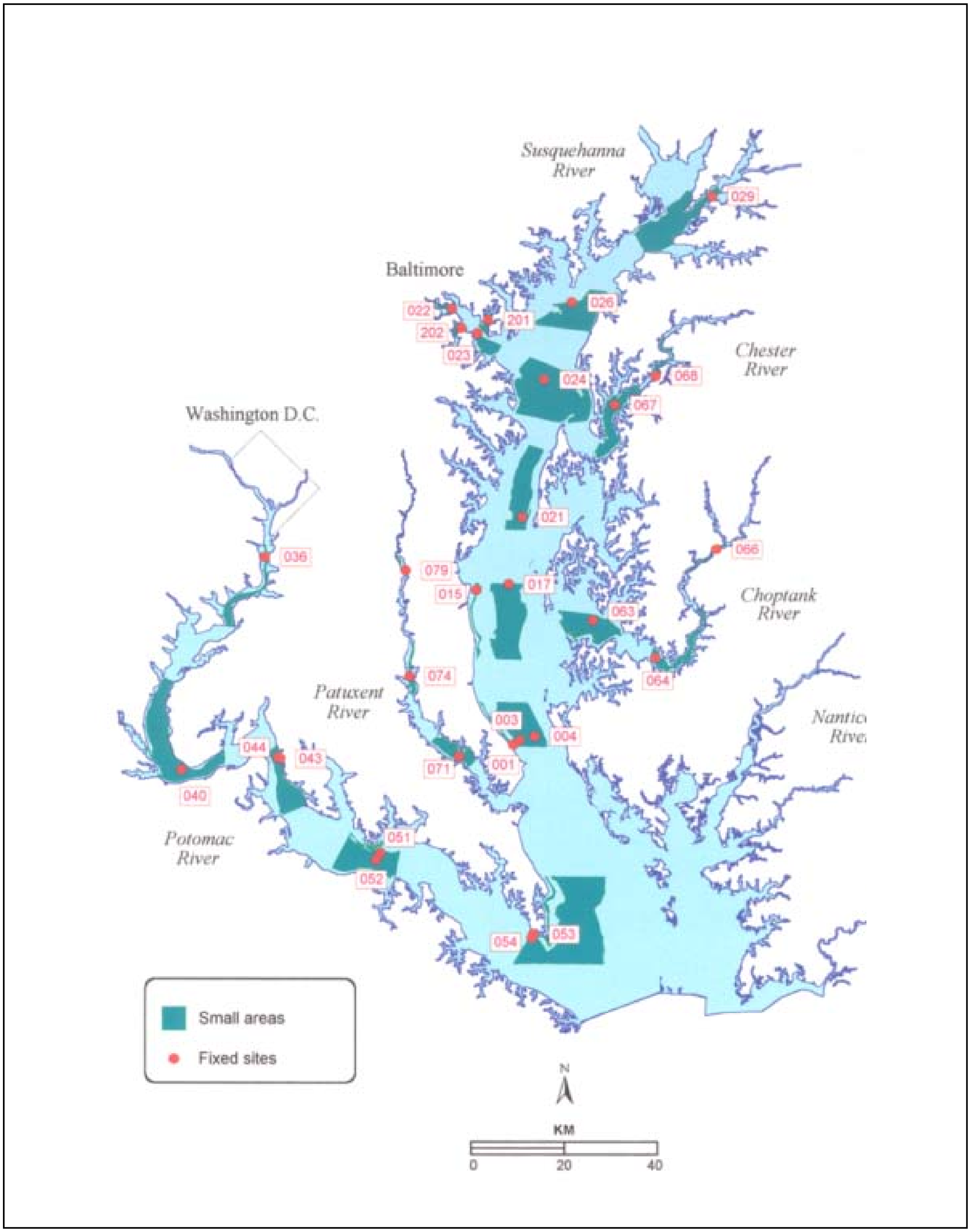

Figure 2-3. Small areas and fixed sites sampled from 1989 to 1994

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	Longitude	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**	**Longitude**	**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)	3611	55.5	27
Potomac River	1850	28.4	28
Other tributaries and embayments	1050	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 2001. 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

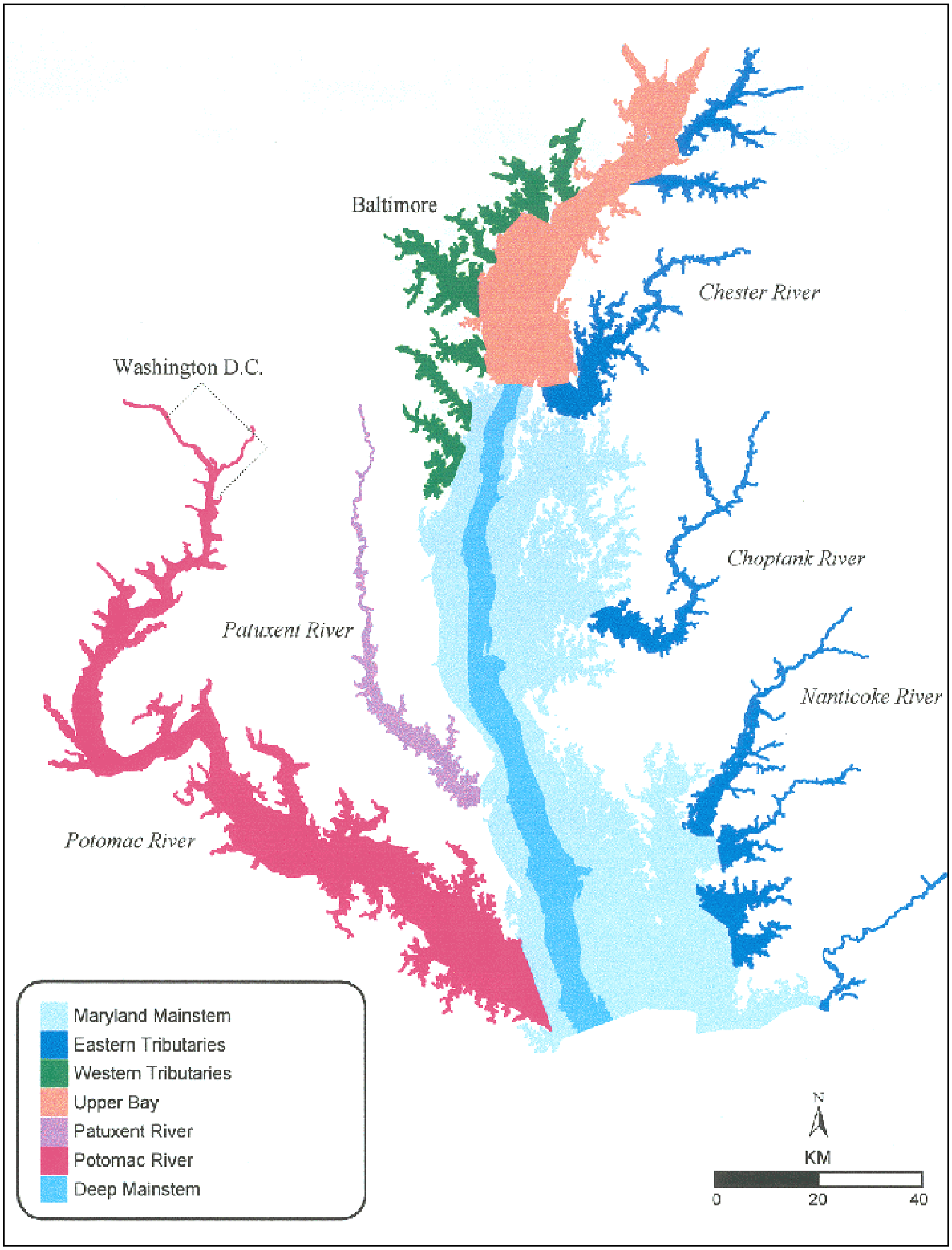

Figure 2-4. Maryland baywide sampling strata in and after 1995

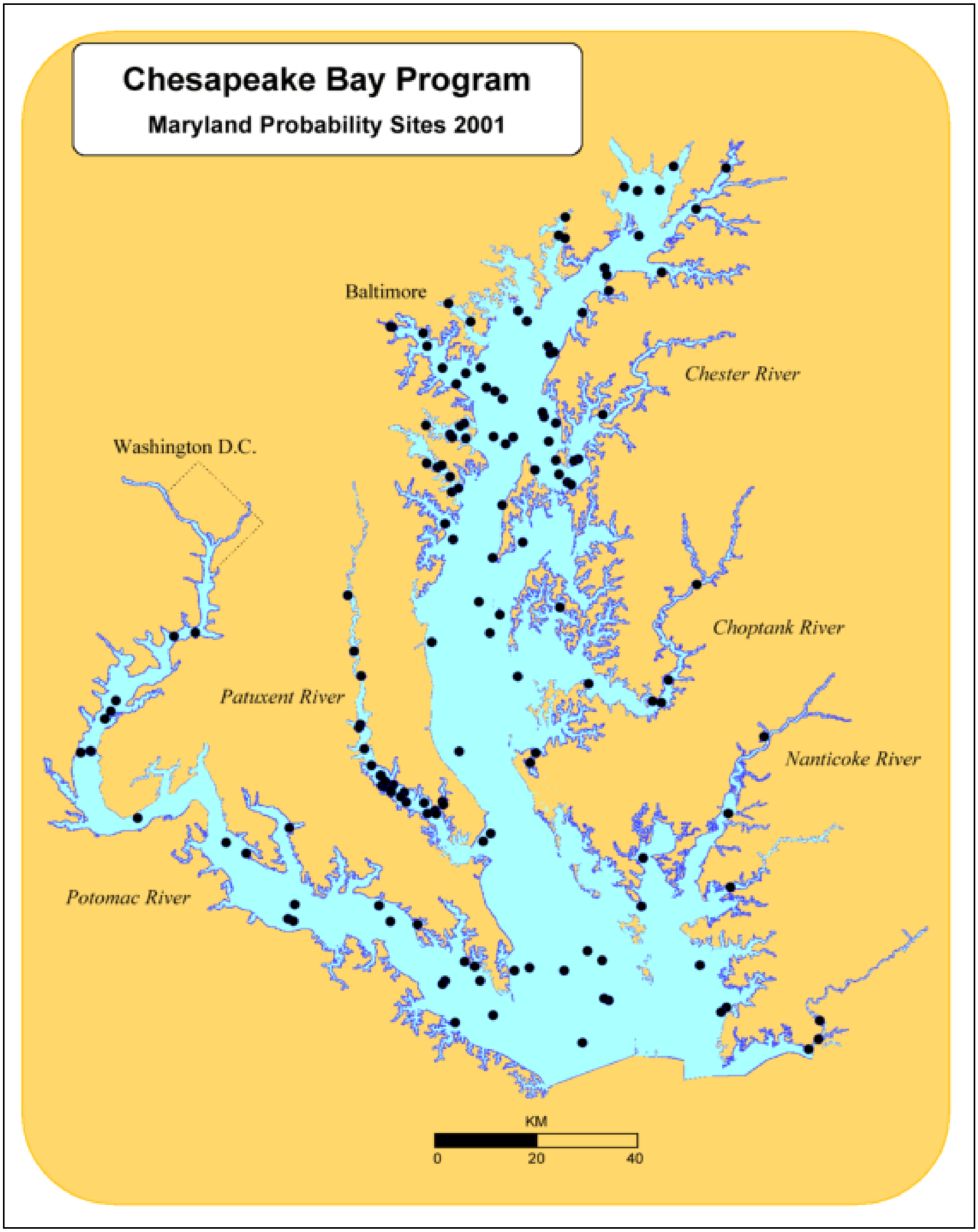

Figure 2-5. Maryland probability-based sampling sites for 2001

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.

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

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

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 NAD83 coordinate system is currently used.

2.2.2 Water Column Measurements

Water column vertical profiles of temperature, conductivity, salinity, dissolved oxygen concentration (DO), oxidation reduction potential (ORP), and pH were measured at each site. For fixed sites, profiles consisted of water quality

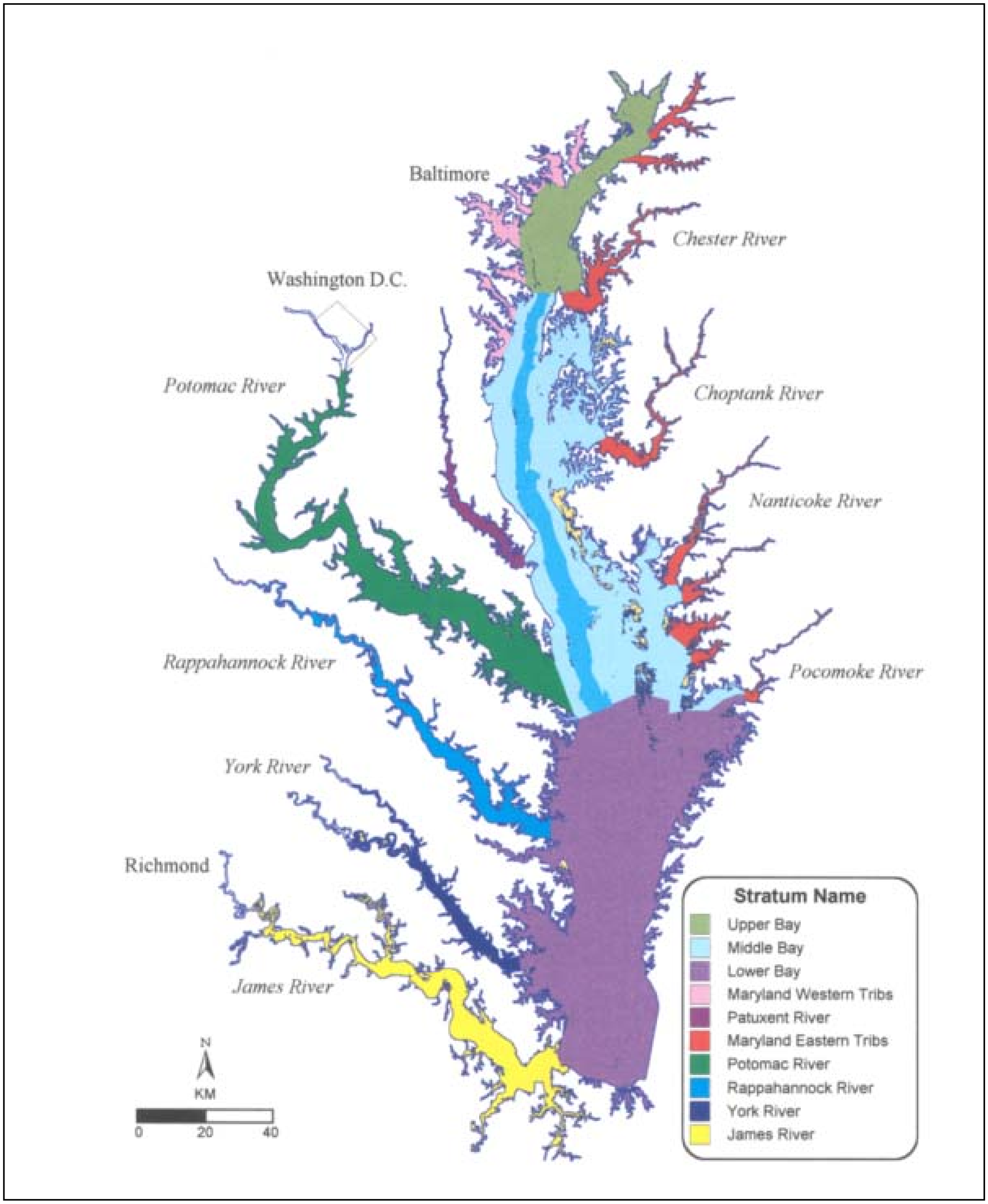

Figure 2-6. Chesapeake Bay stratification scheme

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.

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.

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 Hydrolab H2O
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 Hydrolab H2O 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 Hydrolab H2O 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 Hydrolab H2O 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

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 60EC and ashing in a muffle furnace at 500EC 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 60EC and ashing in a muffle furnace at 500EC for four hours.

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

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

Silt-clay composition and carbon and nitrogen content were determined for one of the two sediment sub-samples collected at each sampling site. The other sample was archived for quality assurance purposes (Scott et al. 1988). Sand and silt-clay particles were separated by wet-sieving through a 63-Fm, 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 CE440 analyzer in and after 1995. The results from both instruments are comparable.

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 were classified as severely degraded; values from 2 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 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 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

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

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:

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

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 TRENDS IN FIXED SITE BENTHIC CONDITION

Trend analysis is conducted on twenty-seven 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. This chapter presents trend analysis results for all fixed sites.

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 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.

This chapter presents trends in benthic 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.

Seventeen-year (1985-2001) trends are presented for 23 of the 27 trend sites. Thirteen-year trends are presented for two sites in Baltimore Harbor (Stations 201 and 202) first sampled in 1989. Seven-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 presented in Figure 2-1.

B-IBI calculations and trend analysis for six sites located in areas with oligohaline or tidal freshwater salinities were updated in 2001 using the index metrics developed by Alden et al. (2002). The last of the updates were conducted for this report and resulted in revised initial conditions for the six sites (Stations 29, 36, 40, 66, 79, and 203). Although the revised initial conditions did not appear to have influenced the trends significantly, comparisons to previous years' status and trends for these sites should be avoided.

3.1 RESULTS

Statistically significant B-IBI trends ($p<0.1$) were detected at 10 of the 27 sites (Table 3-1). Benthic community condition declined at three of these sites (significantly decreasing B-IBI trend) and improved at seven sites. Currently, 12 stations meet the goals and 15 fail the goals. Initially, 10 stations met the goals and 17 failed the goals (Table 3-1). Seven stations with a significant trend have changed status since 1985. Stations 01, 06 (mainstem), 29 (Elk River) and 51 (Potomac River, St. Clements Island) have improved from initial failure to currently meeting the goals (Table 3-1). Stations 77 (upper Patuxent River, Holland Cliff) and 62 (Nanticoke River) have declined in status from initially meeting the goals to currently failing the goals (Table 3-1). Station 71 (lower Patuxent River, Broomes Island) has declined from a degraded to a severely degraded condition. The status of these stations have not changed from those reported last year except for Station 29, which has improved significantly with the addition of the 2001 data.

Significant trends present with the analysis of 1999 and 2000 data were still present with the addition of the 2001 data except for Station 74. Station 74 (Patuxent River, Chalk Point) had a significantly degrading trend through 2000 (Llansó et al. 2001) but with the addition of summer 2001 data, the station no longer has a significant trend (Table 3-1). In addition, new trends are reported this year for Station 29 (Elk River) and Station 68 (Chester River). Both stations showed significant improvements in the B-IBI.

Since the majority of the trends detected through 1999 and 2000 were still present with the addition of summer 2001 data, the sections below will emphasize changes in attributes and rates (i.e., slopes) from those presented in Llansó et al. (2001) and will discuss the new trends. 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. Basin summaries information provided by the Tidal Monitoring and Analysis Workgroup (TMAW) of the Chesapeake Bay Program Monitoring Subcommittee will be included in the discussion where appropriate.

3.1.1 Declining Trends

Degrading trends (declining B-IBI values) at three sites were identified with the analysis of the 1985-2001data: two sites were located in the Patuxent River (Stations 71 and 77) and one site was located in the Nanticoke River (Station 62).

As noted previously (Llansó et al. 2000, 2001), the declining Patuxent River sites vary in benthic condition and degree of change (Table 3-1). Station 77, in the vicinity of Holland Cliff in the upper mesohaline portion of the river, is the most problematic of the sites. It previously met the Restoration Goals but now fails (Table 3-1). Station 71 in the deep, lower mesohaline portion (Broomes Island) is severely degraded and has failed the goals since the program's inception. Station 74 at Chalk Point shows good benthic community condition and no significant trend in 2001.

Table 3-1. Summer trends in benthic community condition, 1985-2001. Trends were identified using the van Belle and Hughes (1984) procedure. Current mean B-IBI and condition are based on 1999-2001 values. Initial mean B-IBI and condition are based on 1985-1987 values. NS: not significant; (a): 1989-1991 initial condition; (b): 1995-1997 initial condition.

Station	**Trend Significance**	**Median Slope (B-IBI units/yr)**	**Current Condition (1999-2001)**	**Initial Condition (1985-1987 unless otherwise noted)**
Potomac River				
36	$p < 0.05$	0.05	3.83 (Meets Goal)	3.14 (Meets Goal)
40	NS	0.00	2.74 (Marginal)	2.80 (Marginal)
43	NS	0.00	3.62 (Meets Goal)	3.76 (Meets Goal)
44	NS	0.00	1.80 (Severely Degraded)	2.80 (Marginal)
47	NS	0.00	4.02 (Meets Goal)	3.89 (Meets Goal)
51	$p < 0.001$	0.06	3.30 (Meets Goal)	2.43 (Degraded)
52	NS	0.00	1.11 (Severely Degraded)	1.37 (Severely Degraded)
Patuxent River				
71	$p < 0.05$	-0.03	1.93 (Severely Degraded)	2.59 (Degraded)
74	NS	0.00	3.58 (Meets Goal)	3.78 (Meets Goal)
77	$p < 0.001$	-0.10	2.73 (Marginal)	3.76 (Meets Goal)
79	NS	0.00	2.55 (Degraded)	2.75 (Marginal)
Choptank River				
64	NS	0.02	2.78 (Marginal)	2.78 (Marginal)
66	NS	0.00	2.89 (Marginal)	2.60 (Degraded)
Maryland Mainstem				
26	$p < 0.05$	0.00	3.67 (Meets Goal)	3.16 (Meets Goal)
24	NS	0.00	3.00 (Meets Goal)	3.04 (Meets Goal)
15	NS	0.02	2.52 (Degraded)	2.22 (Degraded)
06	$p < 0.05$	0.04	3.22 (Meets Goal)	2.56 (Degraded)
01	$p < 0.01$	0.03	3.74 (Meets Goal)	2.93 (Marginal)
Maryland Western Shore Tributaries				
22	NS	0.00	1.22 (Severely Degraded)	2.08 (Degraded)
23	NS	0.00	2.64 (Degraded)	2.49 (Degraded)
201	NS	0.00	1.49 (Severely Degraded)	1.10 (Severely Degraded) (a)
202	NS	0.00	1.80 (Severely Degraded)	1.40 (Severely Degraded) (a)
203	NS	0.04	2.19 (Degraded)	2.08 (Degraded) (b)
204	NS	0.00	3.59 (Meets Goal)	3.67 (Meets Goal) (b)
Maryland Eastern Shore Tributaries				
29	$p < 0.001$	0.05	3.26 (Meets Goal)	2.38 (Degraded)
62	$p < 0.01$	-0.03	2.69 (Marginal)	3.42 (Meets Goal)
68	$p < 0.01$	0.03	4.02 (Meets Goal)	3.51 (Meets Goal)

Table 3-2. Summer trends in benthic community attributes at mesohaline stations 1985-2001. 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 1989-2001 data; (b): trends based on 1995-2001 data; (c): attribute trend based on 1990-2001 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 1985-2001. 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 1995-2001 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	

Station 77 had the most pronounced decline of the two river stations, with a slope of -0.10 B-IBI units per year (Table 3-1). However, the magnitude of the decline has diminished from that reported in Llansó et al. (2001) and the current condition has improved through 1999 and 2000 from degraded (B-IBI = 2.11) to marginally degraded in 2001 (B-IBI = 2.73). Trends in several community attributes contributed to the declining trend in the overall B-IBI. Total biomass is significantly decreasing over time with large organisms being replaced by small, abundant opportunist organisms indicative of pollution (Table 3-2).

The decrease in total biomass at Station 77 has been attributed to a decrease in the abundance of the bivalve *Macoma balthica*. Llansó et al. (2000, 2001) hypothesized that the decrease in the abundance of *M. balthica* may be related to salinity changes in the river. Our long-term salinity record shows that summer salinity has decreased below 7 ppt, the approximate limit of the distribution of *M. balthica* in Chesapeake Bay, and spring values decreased below 1 ppt. These changes in salinity occurred during the recruitment period, and may have been caused by a 57% flow increase measured at the fall line of the Patuxent River since 1985, as reported by TMAW. Another factor that can potentially affect bivalve densities is a change in the amount and type of predators in the area. At this time, changes in predators are unknown and unquantified but should be investigated further.

Station 71 is located in a deep area of the Patuxent River near Broomes Island that usually has low bottom water dissolved oxygen (DO) concentrations in the summer and, as a result, has failed the goals since program inception (Table 3-1). The declining trend in B-IBI at Station 71 can most likely be attributed to increasing stress from low DO, possibly influenced by the very low DO values that were recorded in the lower Patuxent River during the Summer of 2000. Total community abundance and biomass have highly significantly declining trends (Table 3-2), factors that are usually linked to stress from low DO. Benthic community condition in the mesohaline portion of the Patuxent River varies according to year, but the percentage of samples failing the B-IBI (from probability-based sampling) during the period 1995-2000 was strongly and negatively correlated with DO concentration (R^2 = 0.91). In this portion of the river, TMAW has reported a significant increase in Chlorophyll a concentrations in both surface and bottom layer waters since 1985, which may be a contributing factor to hypoxia in the lower Patuxent River.

One other site in the Patuxent River that had a significant degrading trend through 2000, Station 74 in the vicinity of Chalk Point, had no longer a trend with the addition of the 2001 data. Station 74 is located in shallow water where low DO has historically not been a problem. A previous decline in the B-IBI at this station was attributed to increases in abundance above reference levels in a pattern symptomatic of intermediate levels of eutrophication. This abundance trend is still present (Table 3-2). An oil spill that occurred in April 2000 in Swanson Creek just below Station 74 did not reveal an impact on the benthic community at this site (Llansó and Vølstad 2001). The disappearance of the degrading trend may be linked to ongoing nutrient reduction efforts in the Patuxent and it is good news.

The degrading B-IBI trend detected at Station 62 in the Nanticoke River was newly reported in Llansó et al. (2000). With the addition of 2001 data the trend was highly significant, although the rate of decline remained the same as that reported in 2000. This station initially met the goals but now fails marginally (Table 3-1). Attributes contributing to the declining condition included a decrease in Shannon diversity, a decrease in total biomass, and decreases in the percentages of pollution-sensitive species abundance and biomass (Table 3-2). Low biomass is a problem affecting lower eastern shore tributaries, and may be linked to high sediment loads (TMAW Basin Summaries). A link between high sediment loads and degraded benthic community condition can be hypothesized either through impacts of siltation on benthic fauna or reductions in food from the plankton. A decrease in phytoplankton productivity would be expected to limit suspension feeding productivity and biomass.

3.1.2 Improving Trends

Three sites with improving trends were located in the mainstem of the Bay (Stations 01, 06, and 26), two sites were located in the Potomac River (Stations 36 and 51), and two additional sites were located in eastern shore tributaries, the Elk River (Station 29) and the Chester River (Station 68). The trends for the Elk and Chester rivers are new with the addition of the 2001 data. The improving trend for the Elk River is particularly welcome since the status for Station 29 was initially degraded and now meets the Restoration Goals. There were no substantial changes in the slopes of trends reported in Llansó et al. (2001).

Mainstem stations (Stations 01, 06, and 26) show good benthic community status (Table 3-1). Increasing B-IBI values at these stations probably represent a general improving trend in water quality baywide. Station 26, located in the upper portion of the Maryland Bay, is a good indicator of water quality in a region that is influenced by discharges from the Susquehanna River and the upper western shore tributaries. Total abundance at this station has a significant positive trend (Table 3-2).

Potomac River stations (Station 36 and 51) showed trends that have been reported and discussed previously. Station 36 is located in the tidal freshwater portion of the Potomac River at Rosier Bluff. Most of the improvements at this site can be attributed to a substantial decrease in the abundance of the dominant bivalve *Corbicula fluminea*, which has been decreasing from high densities since its peak in the late 1980s. Previous trends reported for oligochaete abundance, percent pollution-indicative taxa, and percent deep-deposit feeders, disappeared with the addition of the 2001 data. Improving trends in benthic community condition in the upper Potomac River are probably linked to significant reductions in nutrient loads in recent years (TMAW Potomac River Basin Summary). At Station 51, located near St. Clements Island, improving trends were due to significant increases in diversity, pollution-sensitive abundance, and carnivore-omnivore abundance, and to significant decreases in pollution-indicative abundance (Table 3-2), which suggest a positive response of shallow water benthos to improving water quality in the mesohaline Potomac River.

The improving trend for Station 68 in the Chester River is good news because the probability of observing degraded benthos in the Chester River is high. However, most of the random sites failing the B-IBI are concentrated in the lower portion of the estuary, around Eastern Neck Island. Poor benthic community condition in this region of the river is attributed to eutrophic conditions. Station 68 is located mid-river above the region where a majority of the sites from the random monitoring component failed the B-IBI. The new improving trend in the Chester River was associated with a decrease in abundance of organisms below the upper reference level possibly linked to a reduction in organic enrichment.

The improving trend in the Elk River (Station 29) was associated with changes in the abundance of pollution-indicative organisms (Table 3-2). There is insufficient benthic data to discuss this trend in relation to water quality at this time; however improving trends in this region have been observed for nutrients, Chlorophyll, and sediment concentrations (TMAW Basin Summaries).

4.0 BAYWIDE BOTTOM COMMUNITY CONDITION

4.1 INTRODUCTION

The fixed site monitoring presented in Chapter 3.0 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 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 2001 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 chapter presents the results of the 2001 Maryland and Virginia tidal waters probability-based sampling and adds an eighth year of results to LTB's

Maryland Bay time series. The analytical methods for estimating the areal extent of bay bottom meeting the Restoration Goals were presented in Chapter 2.0. The physical data associated with the benthic samples (bottom salinity, DO, etc.) can be found in the appendices (Volume 2).

Estimates presented in this report include tidal freshwater samples. Tidal freshwater and oligohaline samples were analyzed using new and statistically optimized metrics described in Alden et al. (2002).

4.2 RESULTS

Of the 150 Maryland samples collected with the probability-based design in 2001, 71 met and 79 failed the Chesapeake Bay Benthic Community Restoration Goals (Figure 4-1). Of the 250 probability samples collected in the entire Chesapeake Bay in 2001, 119 met and 131 failed the Restoration Goals. The Virginia sampling results are presented in Figure 4-2.

The improvement in the Maryland Bay condition observed since 1998 continued with the addition of the 2001 data (Figure 4-3). The change in condition, however, was within the uncertainty margin of the estimate. 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 2001, 56% (±5% SE) of the Maryland Bay was estimated to fail the Restoration Goals. This percentage is at the low end of the range (56-69%) of previous years. Expressed as area, 3,517±160 km^2 of the tidal Maryland Chesapeake Bay remained to be restored in 2001.

As with last year's results, the Potomac River, the Patuxent River, and the mid-Bay mainstem were in the poorest condition among the six Maryland strata (Figure 4-4). The condition of the upper western tributaries improved substantially in 2001 relative to previous years, with levels of degradation reduced to those observed in 1995 (Figure 4-5). The Patuxent River had a very large percentage of degradation in 2001, the largest increase in degradation observed thus far for this basin. The upper Bay mainstem and the eastern tributaries continued to be in good condition. Over the eight-year time series (1994-2001), more than half of the tidal Potomac River (714-1,173 km^2) failed the Restoration Goals each year (Figure 4-5) and a large portion of that area, ranging from 48-93% (510-793 km^2, Table 4-1), was severely degraded. The mid-Bay Maryland mainstem continued to have the largest amount of degraded area among the strata, just short of 2,000 km^2 in 2001 (Table 4-1), and well over half of this area (including the deep trough) was severely degraded. The eastern shore tributaries had the smallest amount of area with severely degraded condition over the eight year period, although an increase in this area was noted for 2001 (Table 4-1).

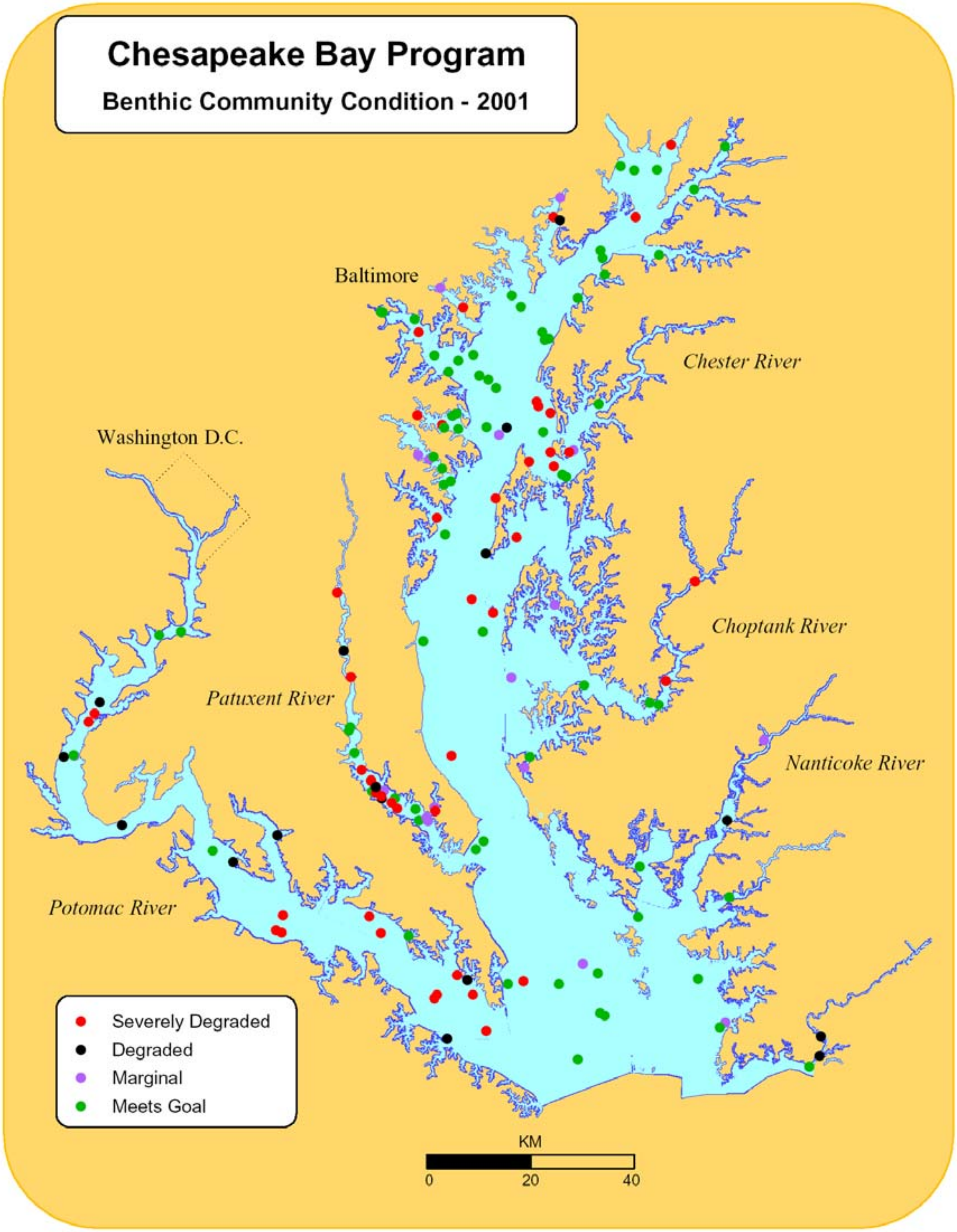

Figure 4-1. Results of probability-based benthic sampling of the Maryland Chesapeake Bay and its tidal tributaries in 2001. Each sample was evaluated in context of the Chesapeake Bay Benthic Community Restoration Goals.

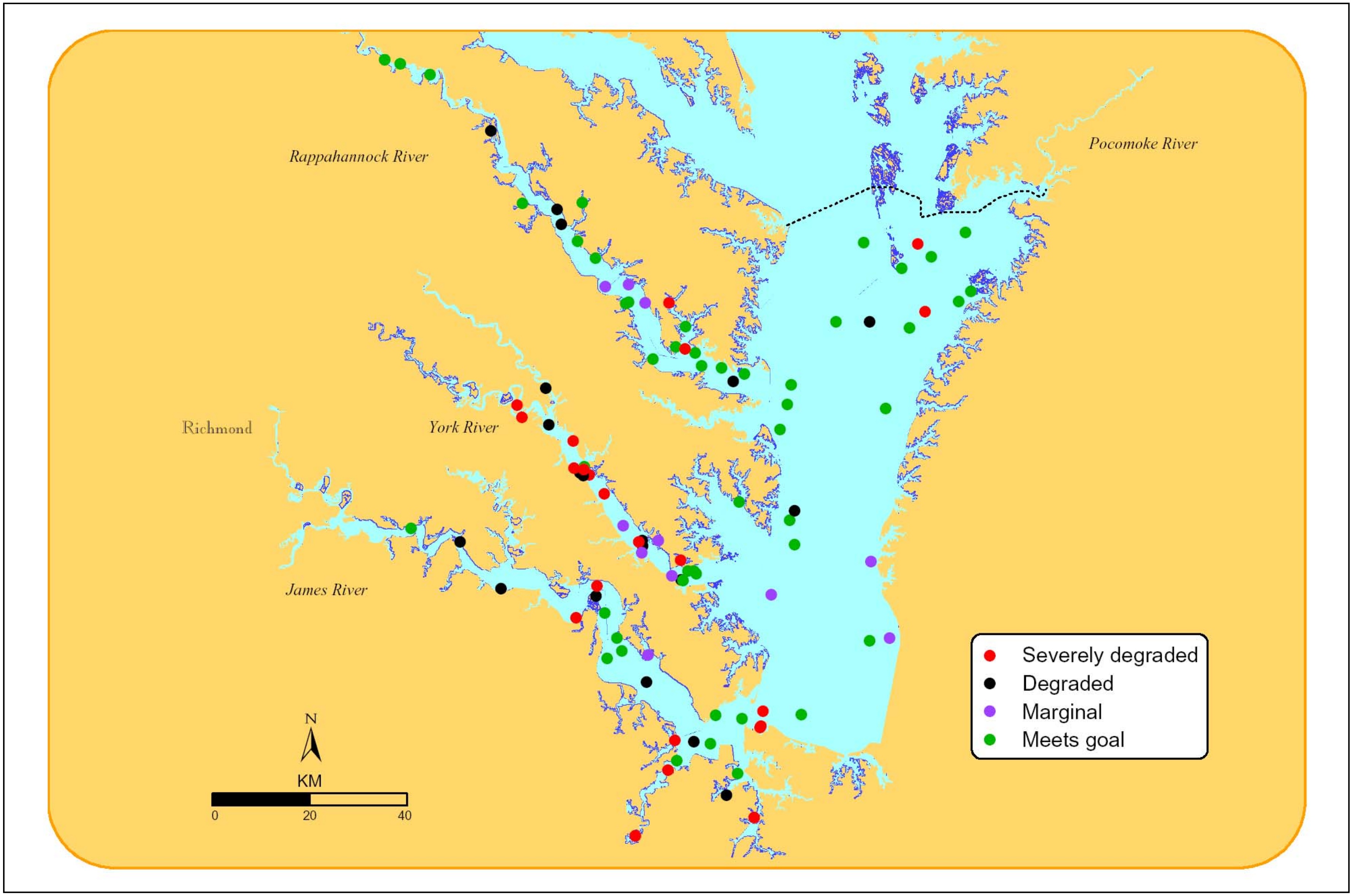

Figure 4-2. Results of probability-based benthic sampling of the Virginia Chesapeake Bay and its tidal tributaries in 2001. Each sample was evaluated in context of the Chesapeake Bay Benthic Community Restoration Goals.

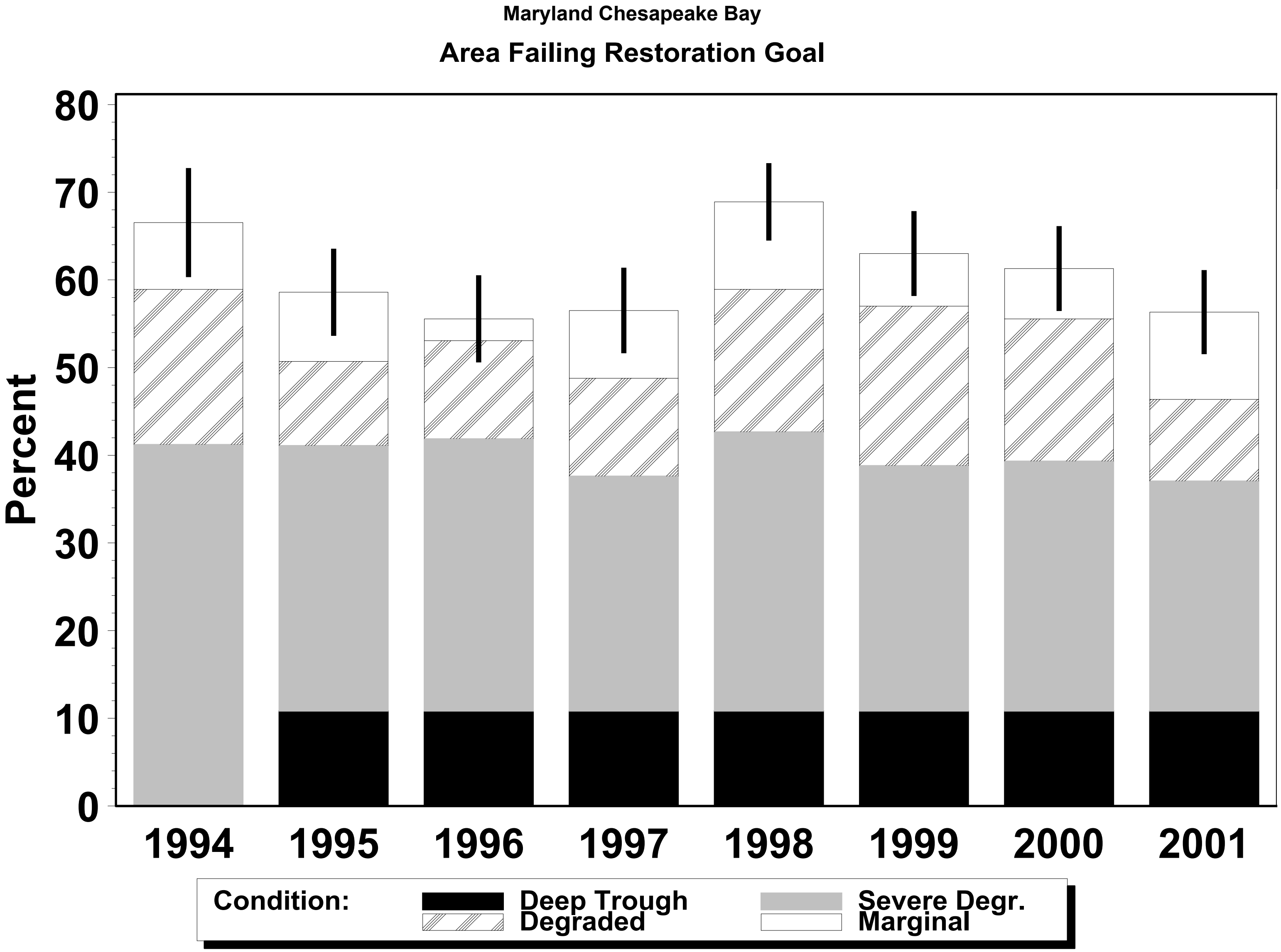

Figure 4-3. Proportion of the Maryland Bay failing the Chesapeake Bay Benthic Community Restoration Goals from 1994 to 2001. The error bars indicate ± 1 standard error. The mainstem deep trough was sampled in 1994 and found to be mostly azoic; it is included in the severely degraded condition in 1994, but was excluded from sampling in subsequent years.

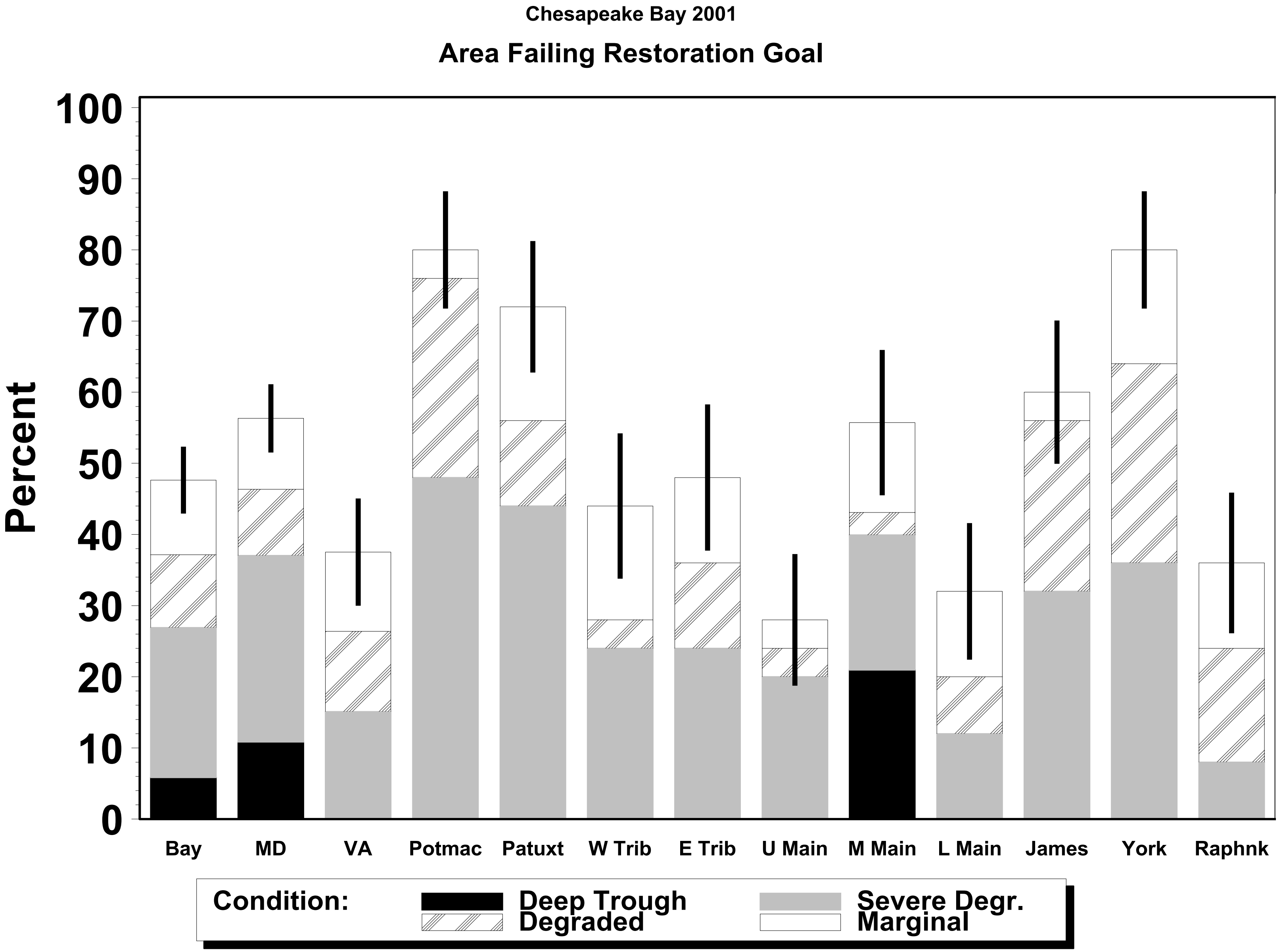

Figure 4-4. Proportion of the Chesapeake Bay, Maryland, Virginia, and the 10 sampling strata failing the Chesapeake Bay Benthic Community Restoration Goals in 2001. The error bars indicate + 1 standard error.

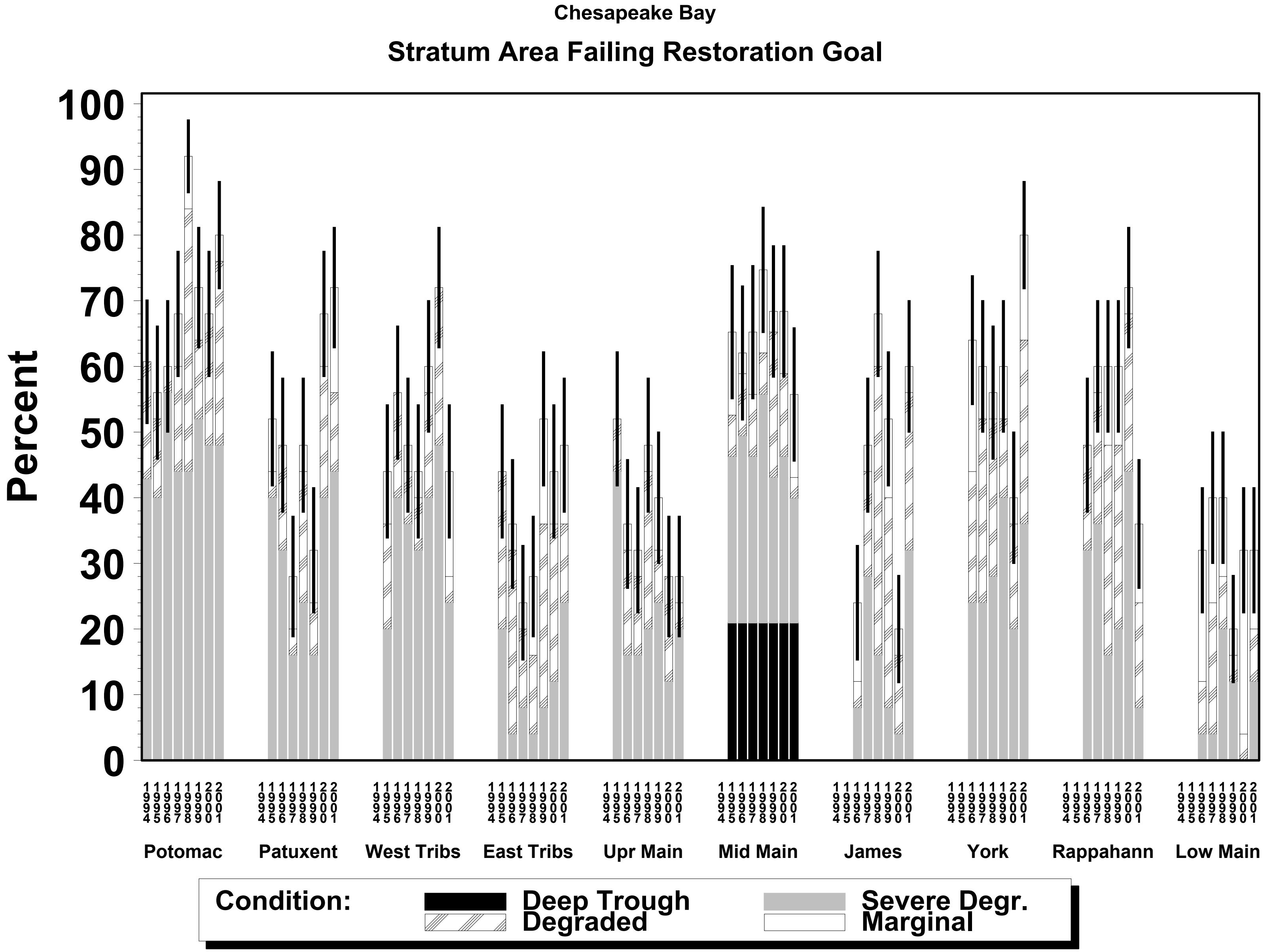

Figure 4-5. Proportion of the sampling strata failing the Chesapeake Bay Benthic Community Restoration Goals, 1994 to 2001. The error bars indicate ± 1 standard error.

Table 4-1. 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	1,379	1,563	5,626	48.5
	2001	3,123	1,187	1,219	5,529	47.6
Maryland Tidal Waters	1994	2,684	1,152	497	4,333	66.5
	1995	2,565	600	493	3,659	58.6
	1996	2,615	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	1,013	359	3,828	61.3
	2001	2,313	582	622	3,517	56.3
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	28.2
	2000	229	366	1,203	1,798	33.5
	2001	810	606	596	2,012	37.5
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	67.9
	1998	561	510	102	1,173	91.9
	1999	663	153	102	918	71.9
	2000	612	255	0	867	67.9
	2001	612	357	51	1020	79.9

Table 4-1. (Continued)

Region	Year	Severely Degraded	Degraded	Marginal	Total Failing	% Failing
Patuxent River	1995	51	5	10	67	52.3
	1996	41	20	0	61	47.7
	1997	20	5	10	36	28.1
	1998	31	26	5	61	47.7
	1999	20	10	10	41	32.0
	2000	51	26	10	87	68.0
	2001	56	15	20	92	71.9
Maryland Upper Western Tributaries	1995	58	47	23	129	44.2
	1996	117	47	0	164	56.2
	1997	105	23	12	140	47.9
	1998	94	23	12	129	44.2
	1999	117	47	12	175	59.9
	2000	140	70	0	211	72.3
	2001	70	12	47	129	44.2
Maryland Eastern Tributaries	1995	107	128	0	235	44.0
	1996	21	150	21	192	36.0
	1997	43	64	21	128	24.0
	1998	21	64	64	150	28.1
	1999	43	150	86	278	52.1
	2000	64	128	43	235	44.0
	2001	128	64	64	257	48.1
Maryland Upper Bay Mainstem	1995	345	63	0	408	52.0
	1996	126	126	31	283	36.1
	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
Maryland Mid Bay Mainstem	1995	1,493	204	408	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	408	306	2,208	68.4
	2001	1,289	102	408	1,799	55.7

Table 4-1. (Continued)

Region	Year	Severely Degraded	Degraded	Marginal	Total Failing	% Failing
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
Rappahannock River	1996	119	60	0	179	48.1
	1997	134	74	15	223	59.9
	1998	60	119	45	223	59.9
	1999	74	104	45	223	59.9
	2000	164	89	15	268	72.0
	2001	30	60	45	134	36.0
York River	1996	45	37	37	120	64.2
	1997	45	52	15	112	59.9
	1998	52	45	7	105	56.1
	1999	75	22	15	112	59.9
	2000	37	30	7	75	40.1
	2001	67	52	30	150	80.2
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	51.9
	2000	27	82	27	137	20.0
	2001	219	164	27	410	59.9

The area of Chesapeake Bay estimated to fail the Restoration Goals in 2001 did not change appreciably from the 1999 and 2000 estimates (Figure 4-6). About 25% of the Chesapeake Bay continued to exhibit severely degraded benthic condition. Weighting results from the 250 probability sites in Maryland and Virginia, 48% (±4%) or 5,529±237 km^2 of the tidal Chesapeake Bay was estimated to fail the Restoration Goals in 2001 (Table 4-1). The percentage for previous years ranged from 45% (±5%) in 1996 to 58% (± 5%) in 1998 (Table 4-1).

Baywide, the Potomac River and the York River were in worst condition in 2001 (Figure 4-4), both with 80% of the bottom area failing the Restoration Goals. Benthic community condition in the three Virginia tributaries changed substantially in 2001 relative to 2000. While the percentage of bottom area failing the Restoration Goals in the

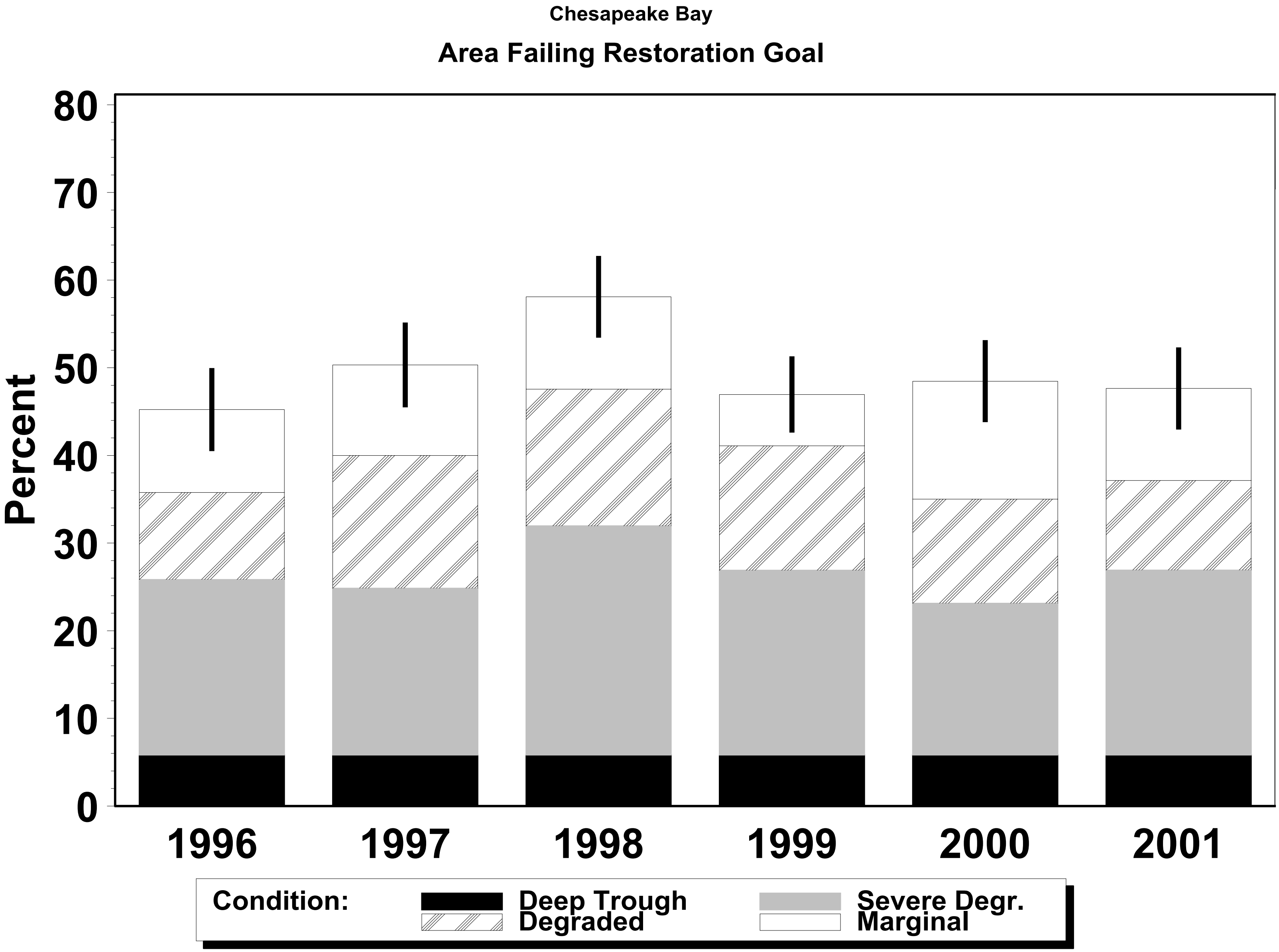

Figure 4-6. Proportion of the Chesapeake Bay failing the Chesapeake Bay Benthic Community Restoration Goals, 1996 to 2001. The error bars indicate ± 1 standard error.

Rappahannock River decreased significantly in 2001, the percentage of bottom area failing the goals in the York and James rivers increased significantly (Figure 4-5). The improvements in benthic community condition observed in the York and James rivers in 2000 disappeared in 2001 and the general condition became more similar to that observed in previous years (Figure 4-5). Over the 1996-1999 period, 56-64% of the tidal bottom area of the York River failed the Restoration Goals; the estimate for 2001 increased to 80%. In the James River, 24-68% of the tidal bottom area failed the Restoration Goals over the 1996-1999 period; the estimate for 2001 was of 60% (Table 4-1). Baywide, and over the time series, the lower (Virginia) mainstem was in best condition overall. The percentage of failure in the Virginia mainstem in 2001 did not change from the 2000 estimate, although the area with severely degraded bottom increased from 0 km^2 in 2000 to 494 km^2 in 2001 (Table 4-1).

As reported in previous years, and for the period 1996-2001, five strata (Patuxent River, Potomac River, mid-Bay mainstem, Virginia mainstem, and upper western tributaries) had a large percentage (>67%) of sites failing the goals because of insufficient abundance or biomass of organisms relative to reference conditions (Table 4-2). Except for the Virginia mainstem, these strata also had a high percentage (>57%) of failing sites classified as severely degraded (Table 4-2). 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 upper Bay mainstem, James River, York River, and the Maryland eastern tributaries had excess abundance, excess biomass, or both in more than 25% of the failing sites (Table 4-3). Excess abundance and excess biomass are phenomena usually associated with eutrophic conditions and organic enrichment of the sediment.

4.3 DISCUSSION

Estimates of benthic community condition for the Chesapeake Bay and the Maryland Bay in 2001 were similar to those reported for 2000 (Llansó et al. 2001). About half of the Chesapeake Bay and nearly sixty percent of the Maryland Bay failed the Chesapeake Bay Benthic Community Restoration Goals. While a small improvement in the Maryland portion of the Bay was observed in 2001, the Chesapeake Bay overall condition remained unchanged since 1999. A large portion of the area failing the Restoration Goals in Chesapeake Bay had B-IBI values greater than 2.0, indicating mild degradation that should respond quickly to moderate improvements in water quality. Forty-four percent of the degraded Chesapeake Bay bottom in 2001 (2,406 km^2) was marginally to moderately impaired. In the Maryland portion of the Bay, a third (34%) of the degraded bottom (1,204 km^2)

Table 4-2. Sites severely degraded (B-IBI$\leq$2) and failing the Restoration Goals (scored at 1.0) for insufficient abundance, insufficient biomass, or both as a percentage of site failing the goals (B-IBI<3), 1996 to 2001. Strata are listed in decreasing order of severely degraded failure percentage.

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
Western Tributaries	55	67.9	55	67.9
Potomac River	73	66.4	84	76.4
Patuxent River	43	58.1	59	79.7
Mid Bay Mainstem	49	57.6	62	72.9
Upper Bay Mainstem	27	50.9	29	54.7
York River	43	47.8	38	42.2
Rappahannock River	39	46.4	48	57.1
James River	24	35.3	24	35.3
Virginia Mainstem	13	26.5	35	71.4
Eastern Tributaries	15	25.9	29	50.0

Table 4-3. 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 2001. Strata are listed in decreasing percentage order.

Stratum	Number of Sites	As Percentage of Sites Failing the Goals
Upper Bay Mainstem	15	28.3
James River	19	27.9
York River	25	27.8
Eastern Tributaries	16	27.6
Rappahannock River	18	21.4
Western Tributaries	16	19.8
Mid Bay Mainstem	15	17.6
Potomac River	17	15.5
Patuxent River	10	13.5
Lower Bay	3	6.1

was marginally to moderately impaired. Of the additional 2,313 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 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 (Figure 4-5). Some exceptions, however, should be noted. The estimated degraded area for the Potomac River in 1998 was exceptionally high. This result can be explained by the clumping of the random sites in perennially degraded areas such as those typically affected by summer hypoxia. Also, estimates for the Patuxent River increased substantially in 2000 and 2001 relative to previous years. The estimate for the Maryland upper western tributaries was also high in 2000. Large annual changes in benthic community degradation may be related to flow patterns. 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 1994, 1998, and 2000. In addition to flow, other factors contribute to summer hypoxia. One such factor, the amount of decaying organic matter from phytoplankton blooms, might be linked to the extent of benthic degradation in the Patuxent River. The lower Patuxent River suffers from poor water clarity and high algal concentrations (TMAW Basin Summaries, unpublished data). Years with large phytoplankton blooms may result in more extensive hypoxia and increased benthic degradation.

The James and the York rivers exhibited increases in the estimated degraded area in 2001. The levels bounced back from 2000, which had the lowest extent of degradation observed in these two systems since 1996. The James and York rivers do not normally experience hypoxia, except for periods of intermittent hypoxia associated with spring-neap tidal cycles in the lower York River (Hass 1977). Therefore, stratum-wide changes in community condition for these two systems cannot be attributed to effects from low dissolved oxygen. In the James River, patterns in benthic community condition among years can be partially explained by the clumping of samples in areas with local contamination problems. For example, of the 25 random samples allocated to the James River stratum in 2001, several fell in the Nansemond and Elizabeth rivers. These tributaries have significantly higher levels of degradation compared to the James River mainstem. Because pollution sources are spatially variable in these systems, comparisons in patterns of benthic community condition should be interpreted with caution and include assessments at various spatial scales of variability (Dauer and Llansó in press). Goal failure in the York River was previously linked to eutrophication, especially because of the relatively high percentage of sites with excess abundance (Table 4-3). The upper Bay mainstem also had a high percentage of sites with excess abundance. While organic enrichment may lead to changes in abundance, such as large increases in the density of opportunistic species, problems associated with anthropogenic nutrient inputs to the York River are inconclusive. We suggest that benthic condition in the York River is partially related to physical disturbance. Radioisotope dating of sediments in the York River shows strong sediment erosion and deposition events associated with tidal exchange and river flow (Schaffner et al. 2002). These events are likely to exert a significant stress on the benthic community, masking potential effects from other sources.

As in previous years, Restoration Goals failure due to depauperate benthic fauna and severe degradation was more common within strata and occurred at higher levels in more strata than failure due to excess numbers or biomass of benthic fauna (Tables 4-2 and 4-3). 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 (e.g., Pearson and Rosenberg 1978). Low dissolved oxygen events are common and severe in the Potomac River and the mid-bay Maryland mainstem (Dauer et al. 2000), and the Patuxent River experiences variable annual events. Over the period 1996-2001, these three strata had the highest percentage of sites failing the Restoration Goals because of insufficient abundance or biomass (Table 4-2). Over the same period, the Potomac River and the mid-bay Maryland mainstem had the highest areal estimates of severely degraded condition, 48-56% and 40-56% of the total stratum area, respectively. In contrast, the Maryland eastern tributaries had values of 4-24% for the severely degraded condition, with the exceptional value of 24% recorded in 2001. Maryland eastern tributaries have high agricultural land use, high nutrient input, high chlorophyll values but low frequencies of low dissolved oxygen events (TMAW Basin Summaries, unpublished data; Dauer et al. 2000). A high incidence of failure of Restoration Goals due to excess abundance or biomass of organisms is observed for these tributaries (Table 4-3), as well as for the upper Bay mainstem, likely influenced by Susquehanna River nutrient inputs, and the James and York rivers.

In addition to low dissolved oxygen and organic enrichment, other stresses to the Bay benthos include toxic contamination, but these are for the most part limited to small areas such as those associated with urban and industrial centers (e.g., Anacostia River, Baltimore Harbor, Elizabeth River). With sufficient data, it should be possible to focus on small regions with specific pollution problems and examine trends in benthic condition over time to assess progress toward Bay management goals. Time-series analysis is usually possible with ten years of data, which will be available soon for the Maryland strata. Currently, no obvious trend in benthic community status was discernible for the Bay as a whole or for any of its subdivisions.

The probability-based Chesapeake Bay-wide estimates developed in this chapter 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 the condition of benthic communities 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 muds to polyhaline sands in the Chesapeake Bay, and this is an important and useful feature of the index because it allows characterization of locations close to human activities that may be widespread throughout the estuary.

As baywide application of the Benthic Community Restoration Goals enters its seventh year, an assessment of sediment quality independent of benthic indicators should be conducted to verify B-IBI performance beyond the results of the initial calibration and validation studies. This was a recommendation in Llansó et al. (2000), and it is re-emphasized here. Independent assessments should provide with the evidence that the B-IBI is performing in the expected way. 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.

5.0 AREA-BASED RESTORATION GOALS

5.1 INTRODUCTION

The Chesapeake Bay Program successfully developed Benthic Community Restoration Goals for the Chesapeake Bay in 1993 (Ranasinghe et al. 1994a). The Restoration Goals are quantitative expectations based on relatively unimpacted benthic communities in Chesapeake Bay. The effort set the Restoration Goals and developed a benthic index of biotic integrity (B-IBI) to measure how well the goals are being met (Weisberg et al. 1997). The Chesapeake Bay Program currently uses this B-IBI to monitor benthic community health bay-wide (see previous chapters of this report).

The Restoration Goals and the B-IBI are useful in two ways. First, they provide objective, validated thresholds for distinguishing degraded from reference benthic assemblages. These thresholds provide context for evaluating effectiveness of Bay management activities and for measuring status and trends in benthic community condition. Second, because the goals are habitat specific, the B-IBI provides a uniform scale applicable across habitat boundaries. The goals are critical elements for conducting managerially relevant assessments of benthic monitoring data. They establish criteria with which to determine the extent of degraded habitats in Chesapeake Bay and identify those bottom habitats most in need of restoration. The goals also provide a well-defined endpoint for restoration activities and permit intermediate determinations of progress (or lack thereof) in meeting water quality criteria.

Several issues were identified during the initial B-IBI development project. The first issue was the lack of sufficient data to establish reliable Restoration Goals for tidal freshwaters. Following recommendations from Chesapeake Bay managers, the Chesapeake Bay Program funded a sampling effort in FY96 to develop and establish tidal freshwater goals for Chesapeake Bay. Collection and analysis of data conducted in FY97 resulted in the expansion of the Chesapeake Bay B-IBI to tidal fresh and oligohaline waters. The expanded B-IBI was applied throughout the Bay in the 1998 assessment and in subsequent years. The metrics, thresholds, and performance of the tidal freshwater and oligohaline B-IBI are described in Alden et al. (2002).

Other issues identified in the initial B-IBI development project were addressed in an effort funded by the Chesapeake Bay Program in FY99. These issues were related to various aspects of the performance of the index, such as minimum data requirements for the B-IBI and how large a deviation from the goals is ecologically meaningful or statistically significant. The effort was necessary to define limitations, clarify uncertainties, and investigate potential enhancements of the B-IBI. Detailed statistical and simulation analyses of data indicated that the B-IBI is sensitive, stable, robust, and statistically sound. Results were published by Alden et al. (2000, 2002).

Subsequently, and with a robust indicator in place, the Bay Program expressed interest in the development of methods for the application of the B-IBI. For example, the identification of problem areas in Chesapeake Bay at high levels of spatial resolution, especially in the context of basin summaries, became priority. In response to this interest, and in conjunction with the 2001 EMAP Symposium "Coastal Monitoring Through Partnerships", we applied the B-IBI to various small spatial scales, such as watersheds and small tidal creeks, and developed a method for assessing benthic community condition by Chesapeake Bay Program segment and water depth. This work was published by Dauer and Llansó (In press) and Llansó et al. (In press). Earlier on, Bay Program managers had also indicated the need to establish area-based restoration goals linking living resources to dissolved oxygen criteria. In light of the 2000 Bay Agreement, establishing restoration goals for living resources on an area basis was deemed critical to evaluating attainment of water quality criteria. In particular, as nutrient and sediment reduction strategies are being implemented, dissolved oxygen levels are expected to improve in the Bay resulting in the recovery of degraded benthic communities. We worked with the Bay Program to address this need, for which an effort was funded in FY00. Below we report on this effort.

The objective of the present study was to develop a method for setting area-based restoration goals for benthic communities in Chesapeake Bay in relation to improvements in dissolved oxygen predicted for various nutrient reduction scenarios. We combined results from the 1996-1998 random benthic sampling effort with Bay water quality model simulation runs to establish the tool and the restoration goals for one scenario. The development of area goals is expected to provide Bay managers with targets for restoration that link water quality to living resources, and a new tool for evaluating progress toward program commitments.

5.2 METHODS

5.2.1 Approach

The approach taken to derive area-based restoration goals consisted of five general steps: (1) quantify the relationships between dissolved oxygen (DO) and benthic community condition from existing data; (2) estimate the area currently supporting healthy benthic communities (or alternatively, degraded benthos) from these relationships; (3) evaluate the extent of area likely to be released from low DO stress on the basis of results from Chesapeake Bay estuary model scenarios; (4) estimate the extent of area likely to be populated by healthy (or degraded) benthic communities under a selected model scenario; and (5) identify how the predicted and current area estimates differ in terms of acreage.

Data used in this project were collected by the benthic monitoring program (1996-1998 bay-wide random site collections) and the water quality monitoring program (1984-1999 bay-wide dissolved oxygen measurements). Several measures of DO stress were explored to identify the best DO predictor of benthic community condition. Results from the 2010 Limit of Technology (LOT) model scenario were considered. LOT represents maximum practical levels of nutrient and sediment reductions given unlimited resources, unlimited cost share, and 100% bay-wide participation. The 2010 LOT scenario uses 2010 land use, point source flows, and animal population estimates as input data.

5.2.2 Data

Benthic data from 750 stratified random sites (one sample per site) sampled throughout the Bay during 1996-1998 were available for this project. For each benthic site, four DO measures were obtained: (1) the bottom DO concentration measured at the time of the benthic sampling, (2) the bottom DO concentration measured by the water quality monitoring program for each of four summer months (June-September), (3) an estimate of the percentage of time each site was below 2 ppm based on the DO concentration measured at the time of the benthic sampling, and (4) an estimate of the percentage of time each site was below 2 ppm for each of the four summer months based on DO concentrations measured by the water quality monitoring program.

An empirical model was used to estimate the percentage of time each benthic site was below a DO concentration of 2 ppm (hereafter referred as the "estimating model"). The estimating model was developed by Marcia Olson (Chesapeake Bay Program Office) independently of this project. Data in the model consisted of bottom DO readings collected fortnightly by the Chesapeake Bay water quality monitoring program at stations located at the center of basins and tributaries. The estimating model was developed using DO measurements from 1984 to1999. From this data base, the Bay Program found that on a segment-by segment basis, there is a predictable relationship between the average DO concentration for a particular depth and the percentage of time below selected thresholds: 1 ppm, 2 ppm, etc. Since DO has not yet significantly changed in the Bay as result of management action, it is assumed that the current relationships are approximately the same as during model development. The new 1998 Bay segmentation (TMAW 1999) was used in this model.

Data derived from Chesapeake Bay estuary model simulations consisted of summer bottom-cell DO concentrations for 25 modeling segments. The old Bay segmentation (see TMAW 1999) was used in the simulations. DO concentrations consisted of 10-day averages for each of four summer months (June-September). These values were available for each of the 10 years used in the simulation (1985-1994), as well as for the 10-year average DO concentration reflecting the mean over varying hydrology. These DO concentrations were predicted values for the 2010 LOT scenario described above.

5.2.3 Procedures

The first step in deriving area-based restoration goals was estimating the percentage of time that DO was below 2 ppm for each of four summer months (June through September) at each benthic site. The period of analysis was 1996-1998. Two separate estimates were made: one using the monthly water quality monitoring DO measurements and a second using the DO concentration obtained with the benthic sample. To accomplish this, the DO measured by the water quality monitoring cruises during the period of analysis was first averaged over the segment for the depth of the benthic site and each of the four summer months. The average DO was then submitted to the estimating model for (1) the month in which the benthic sample was collected (usually August or September), and (2) for each of the preceding summer months. The model yielded an estimate of the percentage of time that the benthic site, for that depth and segment, was below 2 ppm in each summer month, given the particular month of the year and the observed DO concentration at the time of the monitoring cruise. Then, although the DO concentration measured at the time of the benthic sampling represents one snap shot in time, this measurement was also submitted to the model and an estimate of the percentage of time DO was below 2 ppm was obtained based on the segment, depth, and month of the benthic sample.

After the above first step, four types of DO measures were available for further analysis. Two were estimates of the percentage of time each site was below 2 ppm as explained above, and two were actual bottom DO concentrations: the concentration measured at the time of the benthic sampling, and the concentration measured by the water quality monitoring program for each of the four summer months.

In the second part of the analysis, the relationships between the B-IBI and each of the four DO measures were examined using linear regression. Summer data were averaged, and the average was calculated including the month of September if the site was sampled after September 15. Otherwise, the month of September was excluded from the average under the assumption that DO conditions during this month would probably have minimum or no effects on benthic assessments conducted earlier in the month. Based on these regressions, percent time below 2 ppm based on water quality monitoring data was selected as best overall predictor of benthic community condition. Logistic regression models (Hosmer and Lameshow 2000) were then used to further describe the relationships between percent time below 2 ppm and the probability of degraded condition. Degradation was defined alternatively as sites having B-IBI values below 3.0 and sites having B-IBI values equal to or less than 2.0. Segments for which the logistic regression model resulted in a significant fit were selected. Segments with toxic contamination (e.g., Patapsco River) or insufficient data were excluded. Segments were also combined for some basins (Maryland mainstem, Patuxent River, Potomac River, and Rappahannock River) for which we hypothesized the relationships would be strongest. Using the parameters of the regression model, percent time thresholds for each of three probabilities defining four probability ranges of degradation ($p<0.25$, $0.25<p<0.50$, $0.50<p<0.75$, and $p>0.75$) were obtained. The estimating model was then used in an inverse sense to convert these percent time thresholds into the corresponding depths at which they occurred. The results were used to produce a map and current area estimates for four probability levels of benthic degradation. The logistic regression models were fitted using SUDAAN (RTI 2001), taking into account the stratified random survey design.

Lastly, results from the Chesapeake Bay simulation model were used to assess the depth at which each of the percent time thresholds identified as B-IBI predictors are expected to be met under the LOT Scenario. These depths were used to produced a map and predicted area estimates for the four probability levels of degradation. The analysis was conducted as follows. The model data consisted of 10-day DO concentrations for bottom cells, June-September, 1985-1994. The cells had specific depths, such as 3.5 m, 7.5 m, 13.5 m, etc. A segment monthly average DO by depth was first calculated for the LOT and for a Reference Scenario representing current loadings and land base use. The difference in monthly DO between the two scenarios (the “improvement” in DO) was then calculated for each depth and each of the segments being evaluated. The “improvement” was added to the observed DO of the water quality monitoring data for each depth and then applied to the estimating model to obtain the percent time below 2 ppm and the depth (by segment) at which each of the thresholds will be expected to be met. Since Bay model simulation data for the period of analysis of this study (1996-1998) were not available, the results used here are for the summer of 1994 (July and August averaged) using the old segmentation scheme.

5.3 RESULTS

For the period of analysis (1996-1998), relationships between DO measures and benthic community condition were strongest for segments in the Maryland mainstem, the Potomac River, and the Rappahannock River. Most other segments had infrequent hypoxic events or low sample size. For the Patuxent River, the B-IBI appeared to be uncorrelated with the DO measures. Comparisons among DO measures revealed slightly better relationships between B-IBI and percent time below 2 ppm than between B-IBI and summer DO concentration averages. Figures 5-1 and 5-2 illustrate these relationships for the Maryland mainstem. Plotting the B-IBI as a function of the DO concentration at the time of the benthic sampling did not reveal improvements in the relationship for the Maryland mainstem (Figure 5-3), although the strength of the relationship varied among segments. Based on these results, and as mentioned before, percent time below 2 ppm based on water quality monitoring data was selected as overall best predictor of benthic community condition.

In examining the results, it was noted that the B-IBI was highly variable at high DO concentrations (Figure 5-2) or when percent time below 2 ppm was low (Figure 5-1). That is, the B-IBI exhibited a broad range of values at sites expected to have little or no stress from low DO. However, as DO concentrations decreased below 2 ppm or the percentage of time a site was under low DO increased above 40% (Potomac) or 60% (mainstem), B-IBI values declined below the benchmark of 3.0, indicating failure to meet the Restoration Goals and impairment of the benthic community. Therefore, it appears that there is a DO threshold below which the benthic community shows always signs of impairment. Low DO impacts were more often associated with deep water than with shallow water. For example, for the lower (mesohaline) Potomac River, changes in the B-IBI with depth (Figure 5-4) were clearly associated with changes in DO (Figure 5-5). In shallow water, stress from low DO appeared to be the cause of B-IBI failure at some sites, but stress from low DO could not be attributed to all B-IBI failures. Presumably, other factors contribute to benthic community impairment. This becomes clear when benthic community degradation is expressed in terms of probability and this probability is plotted as a function of percent time below 2 ppm using logistic regression (Figure 5-6). The regression model shows that there is a probability of observing degraded benthos near the intercept at percent time values close to zero. The relationship was stronger when a B-IBI value of 2.0 or less, indicating severely degraded conditions, was selected to define degradation. Using this approach and this B-IBI range, significant relationships ($p<0.05$) for sites in the Maryland mainstem, Potomac River, and Rappahannock River were found both at the basin and at the segment levels.

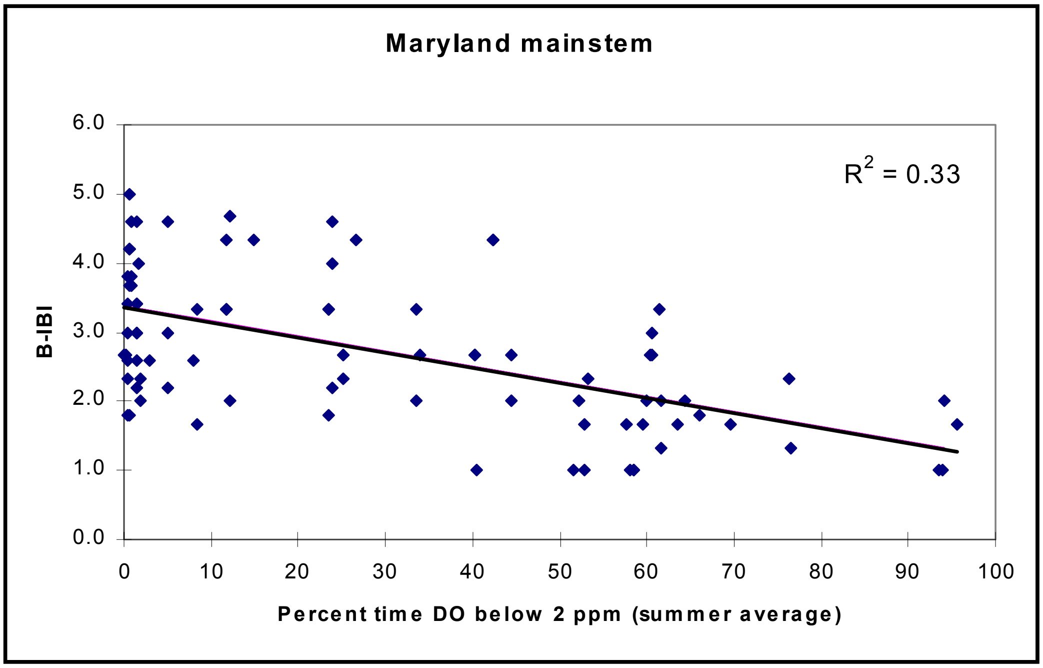

Figure 5-1. Relationship of benthic index of biotic integrity to percent time dissolved oxygen below 2 ppm.

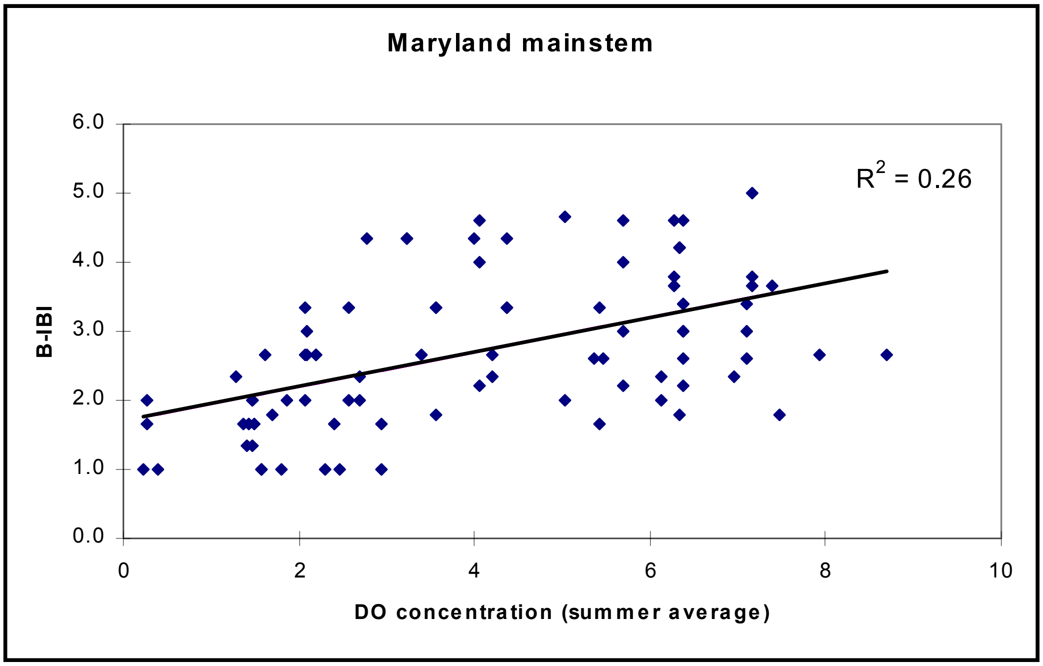

Figure 5-2. Relationship of benthic index of biotic integrity to dissolved oxygen concentration.

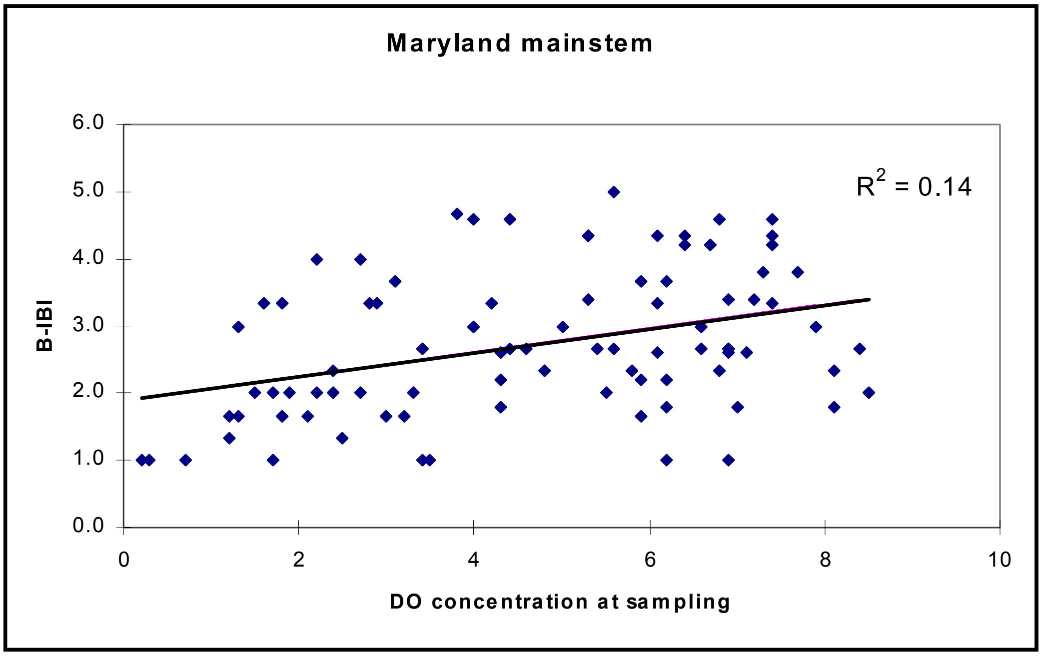

Figure 5-3. Relationship of benthic index of biotic integrity to dissolved oxygen concentration at the time of benthic sample collection.

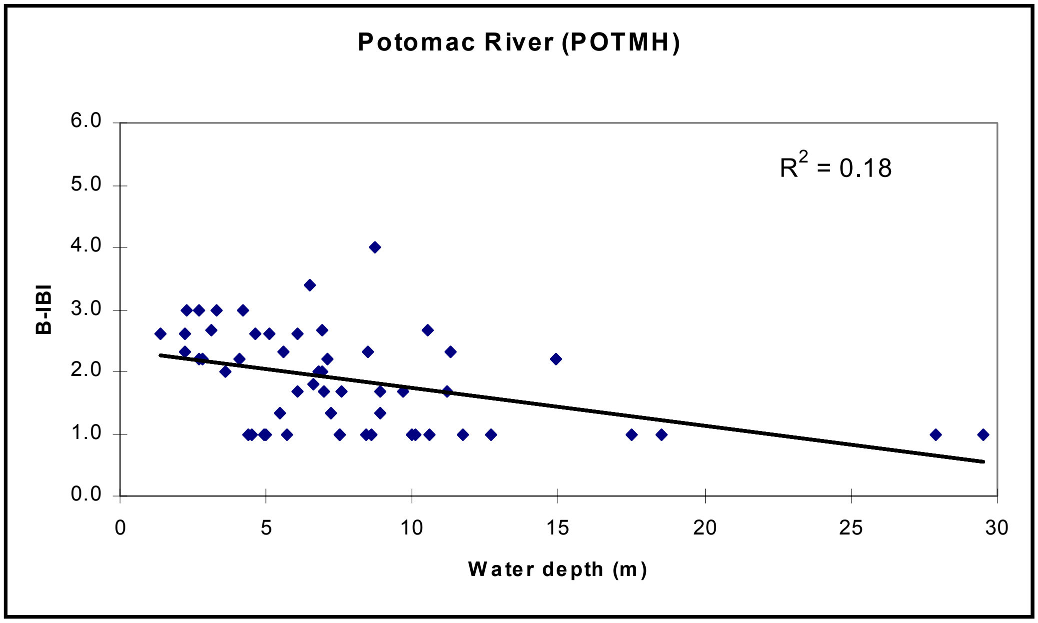

Figure 5-4. Relationship of benthic index of biotic integrity to water depth.

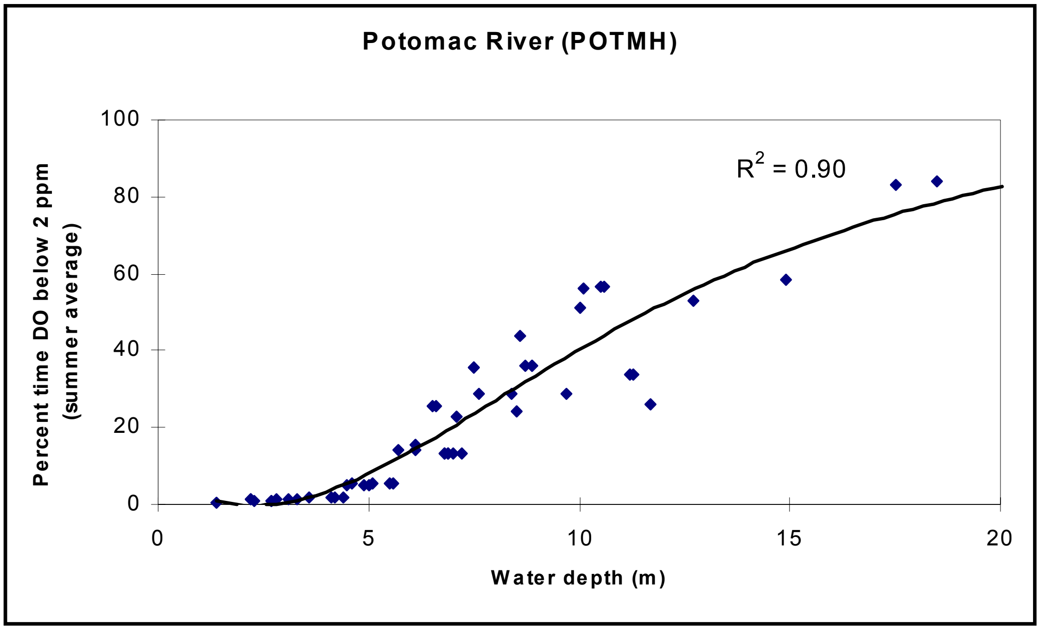

Figure 5-5. Relationship of percent time dissolved oxygen below 2 ppm to water depth.

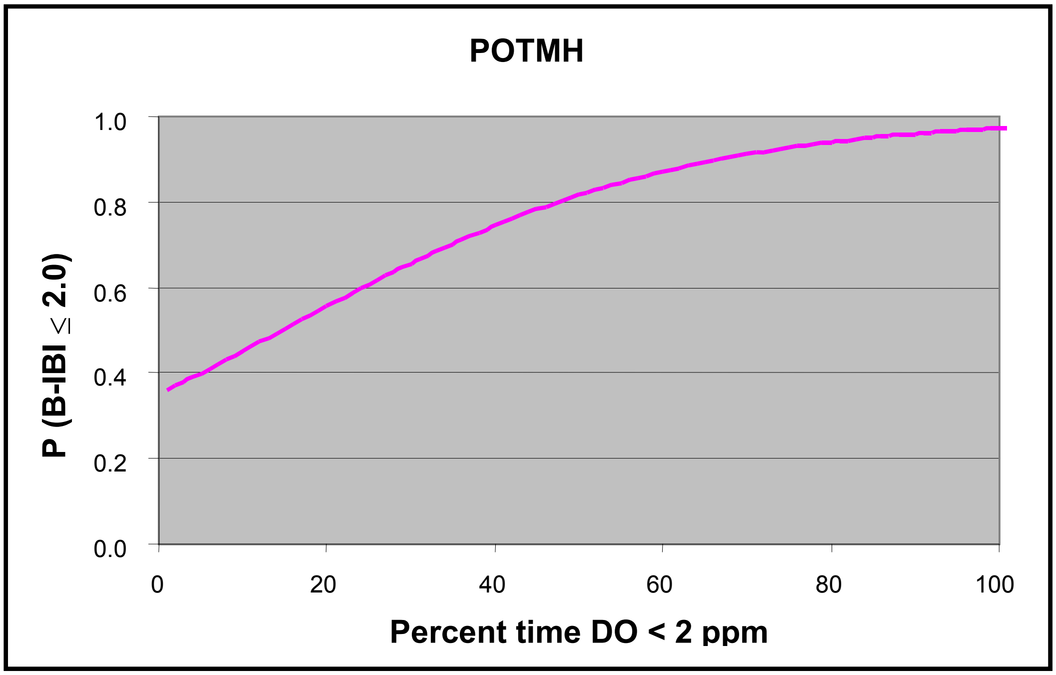

Figure 5-6. Probability of observing benthic index of biotic integrity values less than or equal to 2.0 as a function of percent time dissolved oxygen below 2 ppm

The next step in the analysis is illustrated in Figure 5-7 (see Methods for detail). Percent time thresholds for each of three probabilities defining four probability ranges of degradation were obtained from the parameters of the regression model, and the depths at which these thresholds are met were found and used to produce a map of observed condition. Similarly, the depths at which the thresholds are expected to be met under the LOT scenario were found and used to produce a map of predicted or improved condition. Figures 5-8 through 5-12 show observed and improved conditions for three segments of the Maryland mainstem (CBMH3, CBMH4, and CBMH5) and the two mesohaline segments of the Potomac (POTMH) and Rappahannock (RPPMH) Rivers. Only the mesohaline portions of the Potomac and Rappahannock Rivers were analyzed using these last procedures because the majority of the DO problem in these rivers was restricted to the mesohaline region. The depths for each segment and condition are given in Table 5-1, and the area estimates are presented in Table 5-2. The areas of the improved condition are the area-based restoration goals. These results are based on 1994 water quality and hydrological data, as this was the latest year available in the Chesapeake Bay model data.

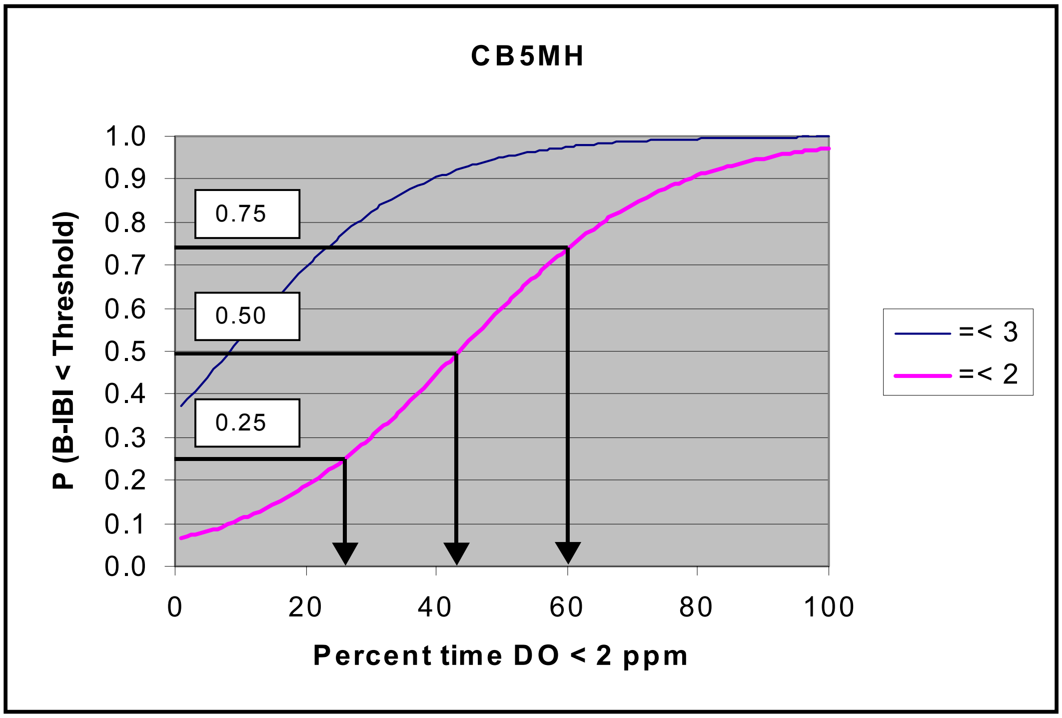

Figure 5-7. Illustration of method to derive percent time dissolved oxygen thresholds for each of three probabilities of degradation.

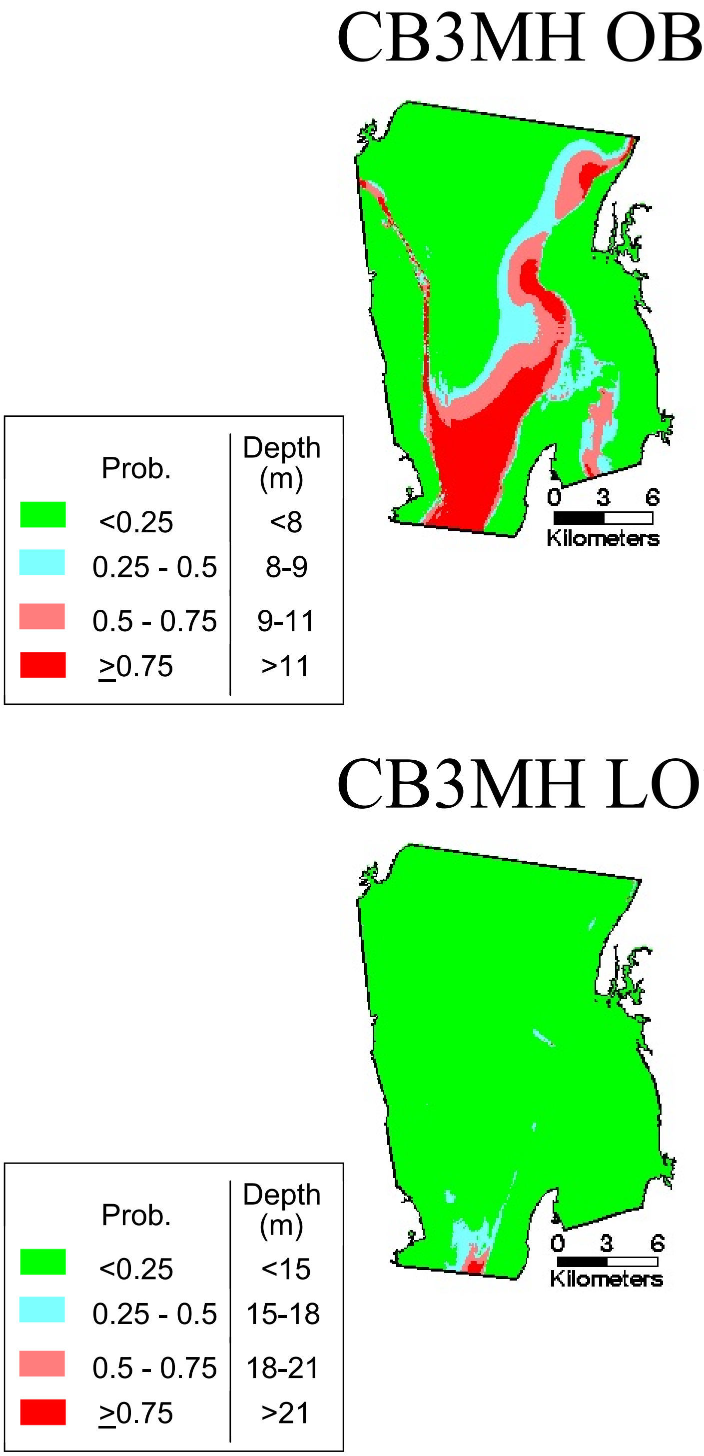

Figure 5-8. Probabilities of observing degraded benthos in the observed data and for improvements predicted by the Limit of Technology (LOT) scenario for segment CB3MH.

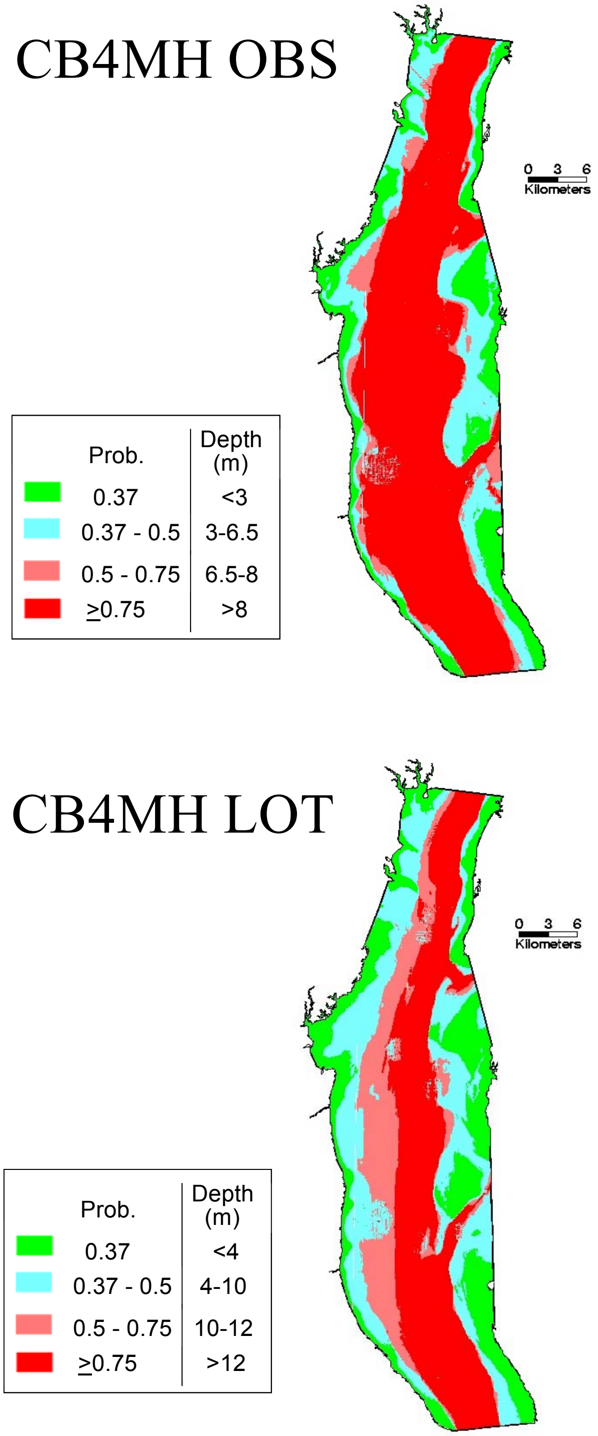

Figure 5-9. Probabilities of observing degraded benthos in the observed data and for improvements predicted by the Limit of Technology (LOT) scenario for segment CB4MH.

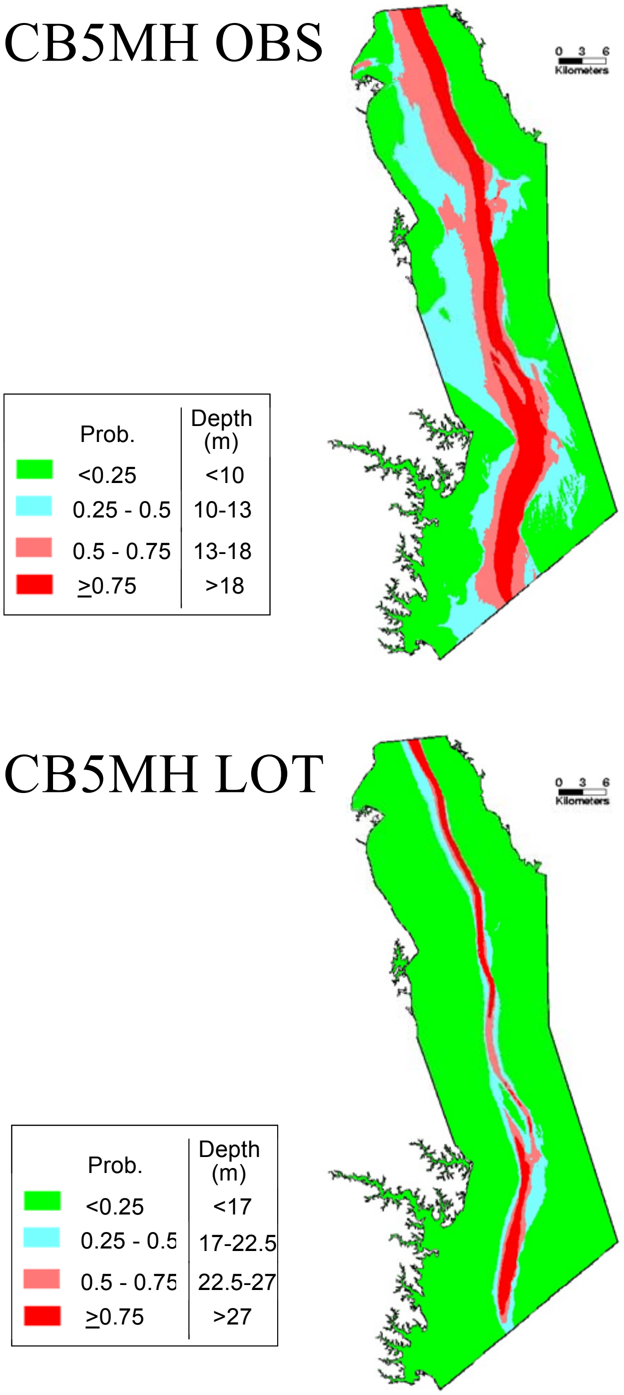

Figure 5-10. Probabilities of observing degraded benthos in the observed data and for improvements predicted by the Limit of Technology (LOT) scenario for segment CB5MH.

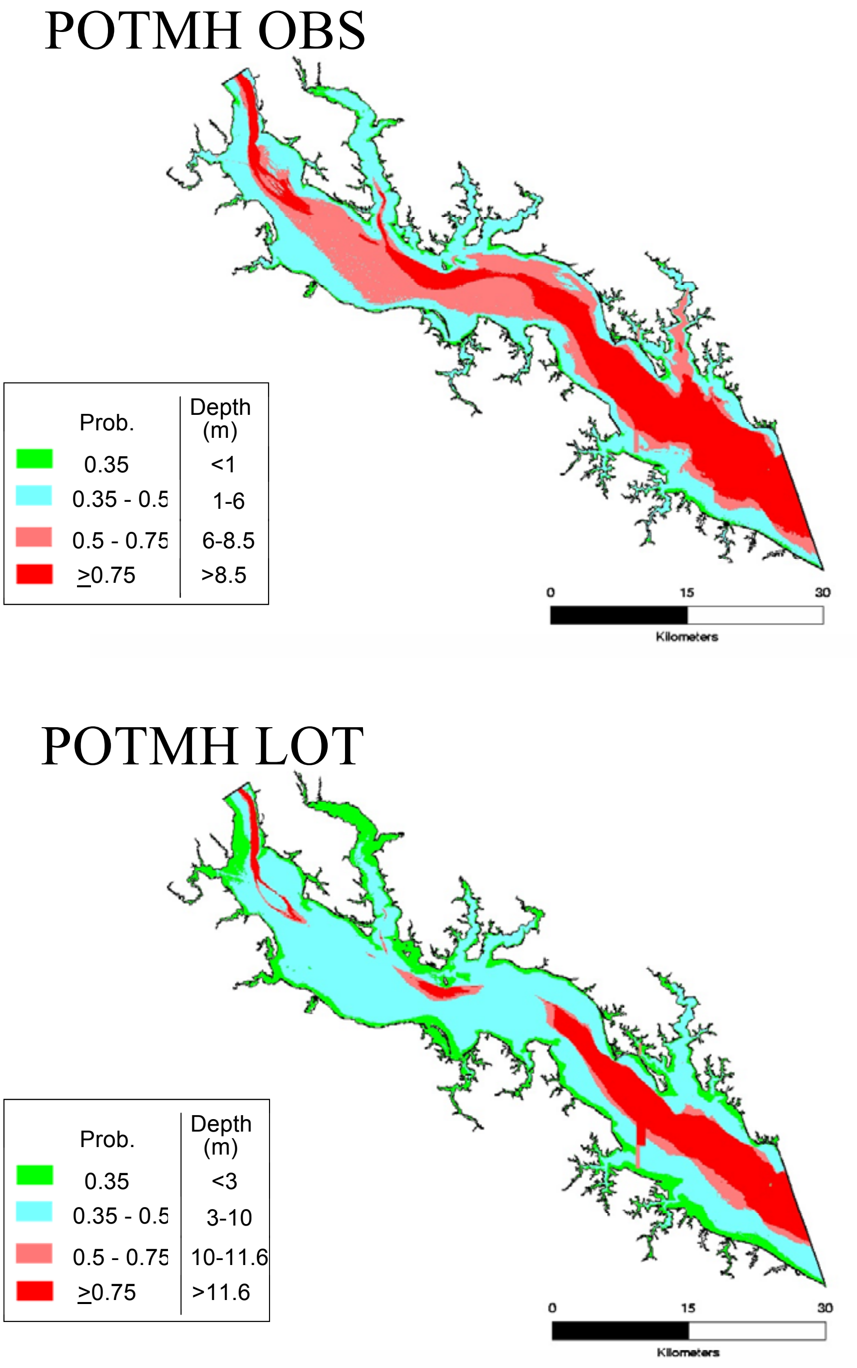

Figure 5-11. Probabilities of observing degraded benthos in the observed data and for improvements predicted by the Limit of Technology (LOT) scenario for segment POTMH.

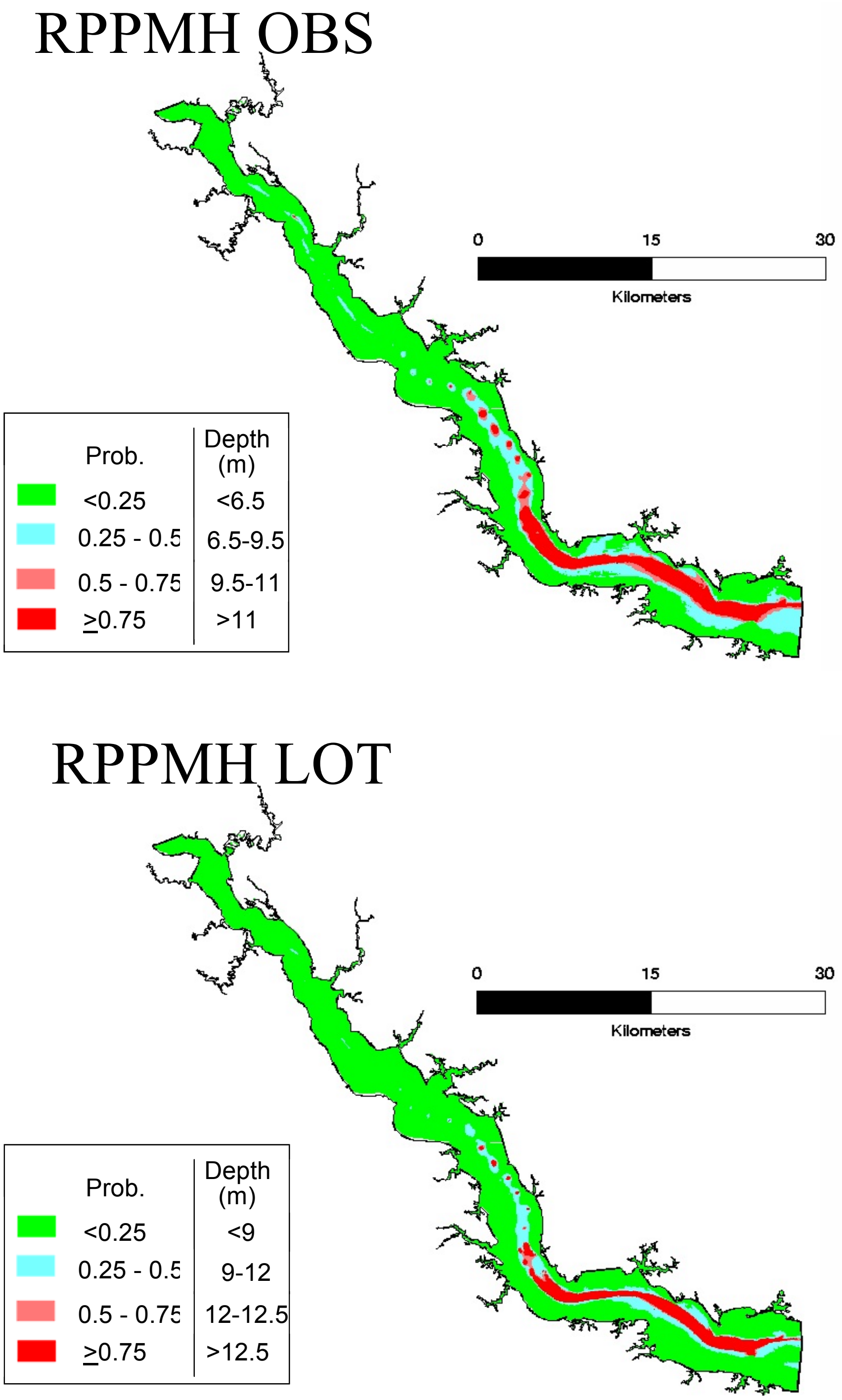

Figure 5-12. Probabilities of observing degraded benthos in the observed data and for improvements predicted by the Limit of Technology (LOT) scenario for segment RPPMH.

Table 5-1. Depths (m) in the observed data and as adjusted for improvements predicted by the Limit of Technology (LOT) scenario for each of three probabilities of benthic community degradation.

Segment	Probability	Percent time DO <2 ppm	Observed Depth	Depth for LOT Improvement
CB3MH	0.25	37.8	8.0	15.0
	0.50	56.1	9.0	18.0
	0.75	74.4	11.0	20.9
CB4MH	0.25	0.5	3.0	4.3
	0.50	7.9	6.5	9.8
	0.75	24.3	8.0	12.0
CB5MH	0.25	25.9	10.0	17.3
	0.50	43.4	13.0	22.5
	0.75	61.0	18.0	26.9
POTMH	0.25	0.5	1.0	2.8
	0.50	13.6	6.0	9.9
	0.75	39.6	8.5	11.6
RPPMH	0.25	7.6	6.5	8.8
	0.50	39.5	9.5	11.9
	0.75	71.3	11.0	12.5

Table 5-2. Estimated tidal area (km^2) with degraded benthic condition (B-IBI $\leq$ 2.0) at four probability levels of degradation for each of five Chesapeake Bay segments. OBS = Observed condition; LOT = Improved condition predicted from the Limit of Technology scenario. Percent change is shown in parenthesis, with negative values indicating decreases in area.

Segment	Probability (B-IBI $\leq$ 2.0)			
	<0.25	0.25-0.5	0.5-0.75	>0.75
CB3MH OBS	246.1	34.7	37.3	43.9
CB3MH LOT	353.6 (29.7)	6.3 (-7.8)	1.3 (-9.9)	0.6 (-11.9)
CB4MH OBS	150.9	162.2	65.2	528.7
CB4MH LOT	206.9 (6.2)	241.4 (8.7)	154.8 (9.9)	303.9 (-24.8)
CB5MH OBS	753.3	317.6	226.9	175.9
CB5MH LOT	1,278.5 (35.6)	94.9 (-15.1)	45.5 (-12.3)	54.9 (-8.2)
POTMH OBS	97.5	329.5	212.2	243.4
POTMH LOT	230.3 (15.0)	461.3 (14.9)	45.4 (-18.9)	145.6 (-11.1)
RPPMH OBS	231.1	43.5	10.9	31.6
RPPMH LOT	265.7 (10.9)	26.3 (-5.4)	3.0 (-2.5)	22.1 (-3.0)

5.4 DISCUSSION

The present analysis is the second of two extensive studies funded by the Bay Program to link benthic community condition to summer DO measures in Chesapeake Bay on a segment-by-segment basis. A previous study by Ranasinghe et al. (1994b), published in the scientific literature by Dauer et al. (2000), examined the relationships between the B-IBI and a variety of measures of land use, water column, and sediment exposure, including frequency of low dissolved oxygen events, but the main objective of that study was to characterize segment conditions and describe relationships. The present analysis went a step further to estimate for six segments the area with degraded benthos that is associated with low DO stress, and to predict changes to this area anticipated to occur from improvements in water quality. Estimates were produced for various probability levels of degradation.

The largest change is expected to occur in segment CB5MH of the Maryland mainstem, with an estimated 36% (525 km^2) of the total segment area changing from high to low probability levels of degradation. The improvement is expected to occur in regions deeper than 10 m. The smallest change is expected to occur in the mesohaline portion of the Rappahannock River, with an estimated 11% (35 km^2) of the total segment area changing from high to low probability levels of degradation in regions deeper than 6.5 m. Most of the hypoxia in the Rappahannock River is restricted to deep water where little improvement in dissolved oxygen concentrations and benthic community condition is expected. The most significant improvement is predicted for the mesohaline Potomac River where the percentage of total area supporting benthos with a greater than 50% chance of severe impairment is expected to decline from the current estimate of 52% (456 km^2) to the predicted 22% (191 km^2) under the Limit of Technology nutrient reduction scenario.

While the methods developed in this study provide a powerful tool that allows quantification of the benthic community condition in relation to low DO stress for current and predictive model scenarios, a number of assumptions have been made that warrant validation in future refinements of the study. First of all, current DO conditions were assumed to have no measurement error. This assumption is intrinsic to all regression models where the independent variable is assumed to accurately represent the conditions upon which the predictions are made. In the present study, an empirical model was used to estimate the percentage of time that each benthic site was below a DO concentration of 2 ppm. The model output has been validated with data from continuous monitoring, and on a segment-by-segment basis there was a predictable relationship between the average DO concentration for a particular depth and the percentage of time below the threshold. However, the estimating model is based on mid-channel fixed station data, which may underestimate the extent of hypoxia in peripheral areas such as flanks, creeks, and small coves. For example, upon examining the data in detail we found sites in the Potomac River that had B-IBI values and point-in-time DO measurements that suggested exposure of the community to severe oxygen stress, yet the estimating model did not indicate a DO problem. Sites for which the estimating model failed to predict low DO events were generally located in water shallower than 6 m. Shallow water areas above the pycnocline often exhibit high spatial and temporal DO variability and therefore are difficult to model. Continuous monitoring in these areas is needed and should help improve the estimating model. Also, short-term DO excursions that may have devastating effects on the benthic community are not taken into account by the model.

A second assumption was that the status of the benthic community at the time of sampling reflected the average DO condition of the preceding summer months. This assumption seems reasonable in light of a wide variety of studies which suggest that the benthos respond predictably to low DO stress and integrate changes in environmental conditions over time (Holland et al. 1977, 1987; Phil et al. 1991; Dauer et al. 1992, 1993; Dauer 1993; Diaz and Rosenberg 1995). This is probably true in systems that experience persistent hypoxia. However, in systems that experience periodic hypoxia, both the intensity and the frequency of the low DO events are important determinants of benthic community condition (Llansó 1992; Diaz and Rosenberg 1995). The maximum value (i.e., the lowest DO concentration on record or the longest continuous hypoxic event) may turn out to be a better predictor of benthic condition than the average. In this study, the frequency of low DO events, expressed as the summer average of the percentage of time a site was under low DO, was significantly correlated with benthic community condition, with higher probabilities of degradation associated with higher percentages. However, a better fit in the regression model might be achieved if information on intensity were combined with information on frequency of summer hypoxic events. The timing of the disturbance is also an important factor for which we do not have information. The coincidence of hypoxic events with benthic recruitment processes in early summer may have devastating effects on the benthic community which are likely to be long-lasting (Holland et al. 1987; Llansó 1992) and affect the outcome of community measures later in the year.

In the present study, we used all the benthic data available for the period of analysis. Segments where toxic contamination is known to be a problem were excluded from consideration. Otherwise, the assumption was made that for selected segments most of the variability in benthic community condition is reflective of changes in DO concentrations occurring during the summer period (June-September). Obviously, there was a large amount of variability that could not be explained in terms of changes in the percentage of time a site was under low DO. Some of this residual variation may be explained in terms of the limitations of the estimating DO model discussed above. However, it must be recognized that failure of the B-IBI to meet the Restoration Goals is probably due to a variety of factors, although stress from low DO emerges as the overriding factor for many regions of the Chesapeake Bay. The results of the logistic regression analysis suggest that there is a baseline probability of degradation that is unrelated to low DO. This baseline is influenced by sampling and analytical error (e.g., error in the B-IBI to accurately describe the benthic condition), but it is likely to be driven by other factors, natural or anthropogenic, that affect benthic community condition. Organic enrichment of the sediment, for example, is often associated with eutrophication of the water column and may be responsible for excess abundance and biomass as well as species compositional changes in the benthic community compared to reference conditions (Pearson and Rosenberg 1978; Dauer and Conner 1980; Ferraro et al. 1991; Diaz and Rosenberg 1995). Sites with excess abundance or biomass (indicated by scores of 1 for these metrics in the benthic index) were not excluded from the data in the present study because in some instances excess abundance or biomass may also be indicators of dominance patterns in communities recovering from hypoxia. Natural factors also play an important role in structuring benthic communities and in determining benthic community condition; however, most of the variability due to natural factors has been presumably accounted for in the B-IBI, by using reference data distributions that integrate a variety of natural situations. The point being made here is that even if DO conditions were to substantially improve in the Bay, a certain amount of benthic degradation would still be expected, especially in shallow areas of river banks and creeks where stressors other than low DO may play an important role.

The relationships between DO and benthic community condition were established using data from stratified random benthic monitoring sites and fixed water quality monitoring stations sampled 1996-1998. No additional bay-wide data were available when the study was initiated. Data now available for 1999-2001 might help strengthen the relationships, and should be used in further refinements of the study. The area-based goals are based on 1994 data, since this was the last year available from Bay model simulation runs. That means that the DO thresholds corresponding to the three probabilities of degradation (see Methods) were derived using the 1996-1998 data, while the depths at which each of these thresholds are met or are predicted to be met were calculated from 1994 water quality monitoring data. For the predicted condition, the hydrology used in the simulation data is that of 1994. While mapping benthic community condition outside the interval for which relationships were generated may be problematic, 1994 was hydrologically similar to 1996 and 1998 in the sense that these were wet years with average flows above the normal range of annual mean flows delivered to the Chesapeake Bay. Wet years are considered to be bad for the Bay because heavy rains drive large amounts of nutrients off the land and the increased freshwater flow strengthens the density stratification of the water column, processes both that magnify the low DO problem in the Bay. Nevertheless, because data across years may be highly variable (1998, for example, had the largest expanse of oxygen-depleted water ever seen in the Chesapeake Bay), future refinements of this study should include a variety of years reflecting varying hydrology and partition the data into wet and dry years to examine best and worst-case scenarios.

One further limitation of the Chesapeake Bay Program model data is that they are based on the old segmentation scheme. The difference between the old and the new segments, albeit small, may generate conflicting results. For the mid-bay basin, the old segments CB4 and CB5 and the new segments CB4MH and CB5MH include the same water quality monitoring stations. CB3 and CB3MH, however, don't quite share the same monitoring stations. This is the only place where the estimating model may produce results (observed versus improved condition) that differ partially because of the way the data were aggregated. As for the Potomac and Rappahannock Rivers, LE2 and LE3 results should be very similar to POTMH and RPPMH results because both the old and the new segments include the mesohaline reaches of the river where the majority of the low DO problem occurs. In the future, it is strongly recommended that the new segmentation scheme be used in Chesapeake Bay simulation runs.

Finally, the area-based goals presented in this study are based on results from the 2010 Limit of Technology (LOT) scenario. This Chesapeake Bay Program modeling scenario projects impacts on water quality from future possible changes to land use, BMP implementations, point sources, and atmospheric deposition loads resulting from management actions directed at reducing nutrients and sediments delivered to the Bay. The data provided by the LOT scenario represent some of the highest bottom summer DO concentrations achievable among the Bay Program modeling scenarios. LOT represents maximum practical level of nutrient and sediment reductions given unlimited resources, unlimited cost share, and one hundred percent participation. This may be overly optimistic and the results are clear from our analysis. The improvements in benthic community condition predicted from LOT nutrient reduction implementations are large and should be viewed with caution. However, with further refinement and applications to more realistic modeling scenarios, the tool presented in this study should prove very useful to Bay managers to evaluate status of key biological communities relative to management goals and to measure progress toward meeting water quality criteria in support of Bay agreements. Although area-based restoration goals for one scenario have been developed in this study, the focus has been on the method. It is recommended that further refinements to the method and derivation of more realistic goals based on achievable scenarios be conducted.

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APPENDIX A

FIXED SITE COMMUNITY ATTRIBUTE
1985-2001 TREND ANALYSIS RESULTS

Appendix Table A-1. Summer trends in benthic community attributes at mesohaline stations 1985-2001. 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 1989-2001 data; (b): trends based on 1995-2001 data; (c): attribute trend based on 1990-2001 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	-54.17	-0.42	0.00	0.28	-0.80 (d)	0.00 (e)	0.08	-0.13 (e)
44	0.00	-33.45	-0.11	0.03	-0.44	-0.41(d)	0.00 (e)	-5.26	0.65 (e)
47	0.00	-5.74	1.94	0.03	0.16	-1.11 (d)	-0.005 (e)	-0.84	-0.47 (e)
51	0.06	13.3	-0.22	0.03	-1.30	0.62	0.24 (e)	-1.96 (e)	0.70
52	0.00	0.00	-0.00	0.00	0.00(d)	0.00(d)	0.00	0.00	0.00
Patuxent River									
71	-0.03	-55.58	-0.10	0.01	-2.09 (d)	-0.10(d)	-0.06	0.10	0.91
74	0.00	300.84	-0.83	-0.00	0.35	-1.62 (d)	0.01 (e)	-0.12	-0.52 (e)
77	-0.10	54.91	-0.30	-0.01	3.01	-1.02 (d)	-4.16 (e)	7.64	-0.35 (e)
Choptank River									
64	0.02	20.84	0.00	0.03	0.03(d)	0.66(d)	0.37	-1.72	-0.07
Maryland Mainstem									
01	0.03	14.55	0.03	0.01	-0.63	1.20	-0.17 (e)	-0.78 (e)	1.12
06	0.04	42.97	-0.01	0.00	-0.63	1.92	0.00 (e)	-0.37 (e)	1.75
15	0.02	30.00	-0.04	0.01	-0.76	0.17	0.36 (e)	-1.40 (e)	0.28
24	0.00	-43.67	-0.22	-0.02	-0.62 (d)	0.41(d)	-0.01	0.00	1.85
26	0.00	37.33	0.27	0.02	0.20	0.47(d)	0.00 (e)	-0.03	0.35 (e)
Maryland Western Shore Tributaries									
22	0.00	-13.77	-0.04	-0.04	2.22	0.00 (d)	1.74 (e)	-1.49	-0.64 (e)
23	0.00	-97.58	-0.02	0.00	-0.38	0.46 (d)	-0.01 (e)	0.31	0.60 (e)
201(a)	0.00	-2.53	-0.00	0.00	0.00	0.00(d)	4.17 (e)	0.00	0.00 (e)
202(a)	0.00	12.99	0.002	0.04	-0.44	0.00(d)	-1.85 (e)	0.00	0.83 (e)
204(b)	0.00	-363.64	-0.34	0.05	0.00(d)	2.24 (d)	0.00	1.17	2.54
Maryland Eastern Shore Tributaries									
62	-0.03	83.21	-0.08	-0.06	-0.25	-0.41 (d)	0.00 (e)	-6.23	-0.26 (e)
68	0.03	-63.90	0.87	0.02	-0.23	2.60 (d)	-0.01 (e)	0.05	1.79 (e)

Appendix Table A-2. Summer trends in benthic community attributes at oligohaline and tidal freshwater stations 1985-2001. 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 1989-2001 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	0.05	-107.01	-0.02	-0.35	NA	NA	NA	-0.37	NA
40	0.00	-20.94	0.00	NA	-0.73	0.00	0.00	NA	0.71
Patuxent River									
79	0.00	165.15	-0.00	0.00	NA	NA	NA	-0.33	NA
Choptank River									
66	0.00	102.18	0.16	NA	-0.37	0.00	6.11	NA	1.94
Maryland Western Shore Tributaries									
203(a)	0.04	242.42	0.00	NA	0.00	0.00	0.00	NA	0.00
Maryland Eastern Shore Tributaries									
29	0.05	-63.43	-0.16	NA	-3.84	0.17	0.00	NA	0.10

APPENDIX B

FIXED SITE B-IBI VALUES, SUMMER 2001

Appendix Table B-1. Fixed site B-IBI values, Summer 2001

Station	Sampling Date	Latitude (NAD83 Decimal Degrees)	Longitude (NAD83 Decimal Degrees)	B-IBI	Status
001	04-Sep-01	38.41983	76.41700	4.11	Meets Goal
006	04-Sep-01	38.44233	76.44333	3.44	Meets Goal
015	04-Sep-01	38.71500	76.51400	2.22	Degraded
022	11-Sep-01	39.25483	76.58767	1.00	Severely Degraded
023	11-Sep-01	39.20817	76.52367	3.67	Meets Goal
024	11-Sep-01	39.12200	76.35567	3.11	Meets Goal
026	11-Sep-01	39.27133	76.29033	4.07	Meets Goal
029	18-Sep-01	39.47950	75.94483	3.60	Meets Goal
036	17-Sep-01	38.76967	77.03783	2.50	Degraded
040	17-Sep-01	38.35733	77.23083	2.33	Degraded
043	06-Sep-01	38.38400	76.98933	3.93	Meets Goal
044	06-Sep-01	38.38550	76.99600	1.80	Severely Degraded
047	06-Sep-01	38.36500	76.98500	3.93	Meets Goal
051	06-Sep-01	38.20533	76.73833	2.89	Marginal
052	06-Sep-01	38.19217	76.74800	1.00	Severely Degraded
062	24-Sep-01	38.38383	75.85033	2.47	Degraded
064	04-Sep-01	38.59033	76.06967	3.00	Meets Goal
066	24-Sep-01	38.80133	75.92217	2.78	Marginal
068	10-Sep-01	39.13283	76.07900	4.20	Meets Goal
071	07-Sep-01	38.39500	76.54917	2.33	Degraded
074	07-Sep-01	38.54883	76.67650	3.67	Meets Goal
077	07-Sep-01	38.60433	76.67533	2.33	Degraded
079*	21-Sep-01	38.75033	76.68933	2.00	Severely Degraded
201	11-Sep-01	39.23417	76.49750	1.93	Severely Degraded
202	11-Sep-01	39.21783	76.56417	3.00	Meets Goal
203	21-Sep-01	39.27500	76.44450	2.00	Severely Degraded
204	12-Sep-01	39.00667	76.50500	3.67	Meets Goal

*Station 079 B-IBI mean based on two replicates

APPENDIX C

RANDOM SITE B-IBI VALUES, SUMMER 2001

Appendix Table C-1. Random site B-IBI values, Summer 2001

Station	Sampling Date	Latitude (NAD83 Decimal Degrees)	Longitude (NAD83 Decimal Degrees)	B-IBI	Status
MET-08401	24-Sep-01	37.96074	75.65701	3.40	Meets Goal
MET-08402	24-Sep-01	37.97851	75.63484	2.60	Degraded
MET-08403	24-Sep-01	38.01286	75.63229	2.60	Degraded
MET-08405	05-Sep-01	38.02692	75.85377	3.00	Meets Goal
MET-08406	05-Sep-01	38.03551	75.84233	2.67	Marginal
MET-08407	05-Sep-01	38.11145	75.90301	4.67	Meets Goal
MET-08408	05-Sep-01	38.25395	75.83599	3.40	Meets Goal
MET-08409	24-Sep-01	38.38728	75.84253	2.60	Degraded
MET-08410	24-Sep-01	38.52764	75.76213	2.67	Marginal
MET-08411	04-Sep-01	38.58796	75.99608	3.80	Meets Goal
MET-08413	04-Sep-01	38.62036	76.16137	3.33	Meets Goal
MET-08414	04-Sep-01	38.62876	75.98034	1.80	Severely Degraded
MET-08415	24-Sep-01	38.80308	75.91844	1.00	Severely Degraded
MET-08416	10-Sep-01	38.98189	76.20714	3.33	Meets Goal
MET-08417	10-Sep-01	38.98580	76.21562	4.67	Meets Goal
MET-08418	10-Sep-01	39.00005	76.23472	1.33	Severely Degraded
MET-08419	10-Sep-01	39.02504	76.20142	2.00	Severely Degraded
MET-08420	10-Sep-01	39.02523	76.24248	2.00	Severely Degraded
MET-08421	10-Sep-01	39.02757	76.19120	2.67	Marginal
MET-08422	10-Sep-01	39.10937	76.13685	4.60	Meets Goal
MET-08423	11-Sep-01	39.36880	76.00629	3.00	Meets Goal
MET-08424	18-Sep-01	39.48476	75.92906	3.00	Meets Goal
MET-08425	18-Sep-01	39.55913	75.86061	3.00	Meets Goal
MET-08426	10-Sep-01	39.00708	76.28988	1.33	Severely Degraded
MET-08427	04-Sep-01	38.59069	76.01569	4.20	Meets Goal
MMS-08501	05-Sep-01	37.96876	76.16497	3.00	Meets Goal
MMS-08502	05-Sep-01	38.04596	76.10660	4.33	Meets Goal
MMS-08503	05-Sep-01	38.04921	76.11770	4.00	Meets Goal
MMS-08504	05-Sep-01	38.09813	76.32032	4.33	Meets Goal
MMS-08505	05-Sep-01	38.09917	76.20801	3.33	Meets Goal
MMS-08506	05-Sep-01	38.10381	76.28671	1.00	Severely Degraded
MMS-08507	05-Sep-01	38.11841	76.12262	4.00	Meets Goal
MMS-08508	05-Sep-01	38.13522	76.15603	2.67	Marginal
MMS-08509	05-Sep-01	38.21764	76.03566	3.33	Meets Goal
MMS-08510	05-Sep-01	38.30539	76.03379	4.00	Meets Goal
MMS-08511	07-Sep-01	38.33147	76.39480	3.33	Meets Goal
MMS-08512	07-Sep-01	38.34585	76.37790	4.33	Meets Goal
MMS-08513	04-Sep-01	38.47568	76.29123	2.67	Marginal
MMS-08514	04-Sep-01	38.49365	76.27905	3.00	Meets Goal
MMS-08515	04-Sep-01	38.49446	76.45219	1.00	Severely Degraded

Appendix Table C-1. (Continued)

Station	Sampling Date	Latitude (NAD83 Decimal Degrees)	Longitude (NAD83 Decimal Degrees)	B-IBI	Status
MMS-08516	04-Sep-01	38.63171	76.32189	2.67	Marginal
MMS-08517	04-Sep-01	38.69164	76.51842	3.33	Meets Goal
MMS-08518	04-Sep-01	38.70960	76.38753	3.67	Meets Goal
MMS-08519	04-Sep-01	38.74380	76.36523	2.00	Severely Degraded
MMS-08520	04-Sep-01	38.75841	76.22854	2.67	Marginal
MMS-08521	04-Sep-01	38.76687	76.41298	2.00	Severely Degraded
MMS-08522	10-Sep-01	38.84697	76.38360	2.33	Degraded
MMS-08523	10-Sep-01	38.87537	76.31570	1.00	Severely Degraded
MMS-08524	12-Sep-01	38.87896	76.47430	4.00	Meets Goal
MMS-08525	12-Sep-01	38.94307	76.36287	2.00	Severely Degraded
MWT-08301	12-Sep-01	38.90703	76.49241	2.00	Severely Degraded
MWT-08302	12-Sep-01	38.96536	76.47857	3.00	Meets Goal
MWT-08303	12-Sep-01	38.97190	76.46407	3.67	Meets Goal
MWT-08304	12-Sep-01	38.99227	76.48358	3.67	Meets Goal
MWT-08305	12-Sep-01	39.00958	76.51163	2.67	Marginal
MWT-08306	12-Sep-01	39.01340	76.50289	3.33	Meets Goal
MWT-08307	12-Sep-01	39.01599	76.53662	2.67	Marginal
MWT-08308	12-Sep-01	39.06253	76.44792	3.67	Meets Goal
MWT-08309	12-Sep-01	39.06355	76.47961	3.00	Meets Goal
MWT-08310	12-Sep-01	39.06968	76.48504	1.67	Severely Degraded
MWT-08311	12-Sep-01	39.08494	76.46185	3.40	Meets Goal
MWT-08312	12-Sep-01	39.08556	76.54068	1.00	Severely Degraded
MWT-08313	12-Sep-01	39.08978	76.45297	3.33	Meets Goal
MWT-08314	11-Sep-01	39.16147	76.47281	3.40	Meets Goal
MWT-08315	11-Sep-01	39.18054	76.45047	3.40	Meets Goal
MWT-08316	11-Sep-01	39.18995	76.50478	3.80	Meets Goal
MWT-08317	11-Sep-01	39.22913	76.54077	1.00	Severely Degraded
MWT-08318	11-Sep-01	39.25216	76.54937	3.40	Meets Goal
MWT-08319	11-Sep-01	39.26238	76.62102	3.00	Meets Goal
MWT-08320	11-Sep-01	39.26320	76.62527	3.40	Meets Goal
MWT-08321	21-Sep-01	39.27437	76.44244	1.40	Severely Degraded
MWT-08322	21-Sep-01	39.30701	76.49368	2.67	Marginal
MWT-08323	18-Sep-01	39.42830	76.22882	2.33	Degraded
MWT-08324	18-Sep-01	39.43368	76.24299	1.00	Severely Degraded
MWT-08325	18-Sep-01	39.46687	76.22849	2.67	Marginal
PMR-08101	05-Sep-01	38.00217	76.45127	2.33	Degraded
PMR-08102	05-Sep-01	38.01660	76.36693	1.00	Severely Degraded
PMR-08103	05-Sep-01	38.07126	76.48113	1.00	Severely Degraded
PMR-08104	05-Sep-01	38.07735	76.47612	1.33	Severely Degraded
PMR-08105	05-Sep-01	38.07870	76.39679	1.00	Severely Degraded
PMR-08106	05-Sep-01	38.10451	76.40969	2.33	Degraded

Appendix Table C-1. (Continued)

Station	Sampling Date	Latitude (NAD83 Decimal Degrees)	Longitude (NAD83 Decimal Degrees)	B-IBI	Status
PMR-08107	05-Sep-01	38.11319	76.43263	1.00	Severely Degraded
PMR-08108	06-Sep-01	38.17902	76.53991	3.00	Meets Goal
PMR-08109	06-Sep-01	38.18093	76.81933	1.00	Severely Degraded
PMR-08110	06-Sep-01	38.18364	76.60083	1.00	Severely Degraded
PMR-08111	06-Sep-01	38.18521	76.83211	1.00	Severely Degraded
PMR-08112	06-Sep-01	38.21181	76.81718	1.00	Severely Degraded
PMR-08113	06-Sep-01	38.21249	76.62688	1.00	Severely Degraded
PMR-08114	06-Sep-01	38.30266	76.92887	2.60	Degraded
PMR-08115	06-Sep-01	38.32160	76.97487	3.80	Meets Goal
PMR-08116	06-Sep-01	38.35034	76.83307	2.60	Degraded
PMR-08117	17-Sep-01	38.36195	77.17604	2.60	Degraded
PMR-08118	17-Sep-01	38.47827	77.30733	2.33	Degraded
PMR-08119	17-Sep-01	38.48131	77.28451	2.67	Marginal
PMR-08120	17-Sep-01	38.48210	77.28559	3.00	Meets Goal
PMR-08121	17-Sep-01	38.54071	77.25477	2.00	Severely Degraded
PMR-08122	17-Sep-01	38.55469	77.24234	1.67	Severely Degraded
PMR-08123	17-Sep-01	38.57407	77.23147	2.50	Degraded
PMR-08124	17-Sep-01	38.69298	77.10317	3.50	Meets Goal
PMR-08125	17-Sep-01	38.70121	77.05562	3.00	Meets Goal
PXR-08202	07-Sep-01	38.37997	76.50170	2.67	Marginal
PXR-08203	07-Sep-01	38.38070	76.52181	3.33	Meets Goal
PXR-08204	07-Sep-01	38.38586	76.50492	2.67	Marginal
PXR-08205	07-Sep-01	38.39789	76.48610	2.00	Severely Degraded
PXR-08206	07-Sep-01	38.40005	76.52984	3.00	Meets Goal
PXR-08207	07-Sep-01	38.40326	76.48837	2.67	Marginal
PXR-08209	07-Sep-01	38.41766	76.57467	3.00	Meets Goal
PXR-08210	07-Sep-01	38.41838	76.60420	2.33	Degraded
PXR-08211	07-Sep-01	38.42168	76.60578	1.33	Severely Degraded
PXR-08212	07-Sep-01	38.42793	76.61760	1.67	Severely Degraded
PXR-08213	07-Sep-01	38.42963	76.62635	3.00	Meets Goal
PXR-08214	07-Sep-01	38.43144	76.59992	2.67	Marginal
PXR-08215	07-Sep-01	38.43712	76.61835	2.33	Degraded
PXR-08216	07-Sep-01	38.43810	76.61760	1.33	Severely Degraded
PXR-08217	07-Sep-01	38.44734	76.62912	1.00	Severely Degraded
PXR-08218	07-Sep-01	38.44940	76.62886	1.33	Severely Degraded
PXR-08219	07-Sep-01	38.46639	76.64943	1.00	Severely Degraded
PXR-08220	07-Sep-01	38.49602	76.66664	3.00	Meets Goal
PXR-08221	07-Sep-01	38.53437	76.68017	4.20	Meets Goal
PXR-08222	07-Sep-01	38.54046	76.67737	4.20	Meets Goal
PXR-08223	07-Sep-01	38.62838	76.67695	1.67	Severely Degraded
PXR-08224	21-Sep-01	38.67329	76.69413	2.60	Degraded

Appendix Table C-1. (Continued)

Station	Sampling Date	Latitude (NAD83 Decimal Degrees)	Longitude (NAD83 Decimal Degrees)	B-IBI	Status
PXR-08225	21-Sep-01	38.77400	76.71134	1.33	Severely Degraded
PXR-08226	07-Sep-01	38.41064	76.58218	1.67	Severely Degraded
PXR-08227	07-Sep-01	38.40057	76.56977	1.33	Severely Degraded
UPB-08601	11-Sep-01	39.05359	76.35778	2.67	Marginal
UPB-08602	10-Sep-01	39.05959	76.25991	3.00	Meets Goal
UPB-08603	11-Sep-01	39.06615	76.38554	3.33	Meets Goal
UPB-08604	11-Sep-01	39.06658	76.34053	2.33	Degraded
UPB-08605	10-Sep-01	39.09293	76.24415	1.67	Severely Degraded
UPB-08606	10-Sep-01	39.10425	76.27083	2.00	Severely Degraded
UPB-08607	10-Sep-01	39.11216	76.27488	1.33	Severely Degraded
UPB-08608	11-Sep-01	39.13505	76.36629	4.60	Meets Goal
UPB-08609	11-Sep-01	39.14891	76.38309	3.67	Meets Goal
UPB-08610	11-Sep-01	39.15559	76.40337	4.60	Meets Goal
UPB-08611	11-Sep-01	39.19177	76.41737	3.40	Meets Goal
UPB-08612	11-Sep-01	39.21936	76.25906	3.80	Meets Goal
UPB-08613	11-Sep-01	39.22146	76.25060	3.40	Meets Goal
UPB-08615	11-Sep-01	39.23284	76.26494	4.20	Meets Goal
UPB-08617	11-Sep-01	39.27694	76.31367	3.40	Meets Goal
UPB-08618	11-Sep-01	39.29377	76.18645	3.80	Meets Goal
UPB-08619	11-Sep-01	39.33416	76.12726	4.60	Meets Goal
UPB-08620	11-Sep-01	39.36292	76.13251	4.20	Meets Goal
UPB-08621	11-Sep-01	39.37585	76.13766	4.00	Meets Goal
UPB-08622	11-Sep-01	39.43436	76.05916	2.00	Severely Degraded
UPB-08623	18-Sep-01	39.51619	76.06396	3.50	Meets Goal
UPB-08624	18-Sep-01	39.51848	76.01248	3.00	Meets Goal
UPB-08625	18-Sep-01	39.52318	76.09407	4.50	Meets Goal
UPB-08626	11-Sep-01	39.29562	76.33356	3.80	Meets Goal
UPB-08627	18-Sep-01	39.56165	75.98146	2.00	Severely Degraded