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CHESAPEAKE BAY WATER QUALITY MONITORING PROGRAM

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

JULY 1984—DECEMBER 2000
VOLUME 1

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Annapolis, Maryland

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 2000)*, was prepared by Versar, Inc. at the request of Dr. Robert Magnien of the Maryland Department of Natural Resources under Cooperative Agreement CA-00-02/07-4-30608-3734 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 2000 and evaluates their responses to changes in water quality.

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1.0 INTRODUCTION

1.1 BACKGROUND

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

- quantify the types and extent of water quality problems (i.e., characterize the "state-of-the-bay");
- determine the response of key water quality measures to pollution abatement and resource management actions;
- identify processes and mechanisms controlling the bay's water quality; and
- define linkages between water quality and living resources.

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

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 hypoxia 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 seventeenth 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 current sampling year and provide a limited examination of how conditions in the current year differ from conditions in previous years of the study, as well as how data from the present 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. The Tidal Freshwater Goals that were developed in 1999, were refined, statistically validated (Alden et al. In Press), and applied as modified to tidal freshwater and oligohaline sites. In Chapter 4, which describes baywide benthic community condition, estimates of degraded condition are presented for at least five years for all sub-regions of the Bay, and community measures that contribute to Restoration Goal failure are used to diagnose the causes of failure. Additionally, this information is supplemented this year by two new analyses. The first analysis, described in Chapter 5, takes application of the Benthic Community Restoration Goals a step further into the management realm by setting an acreage goal for the extent of "healthy" benthic communities in the Bay. The analysis quantifies the relationships between dissolved oxygen and benthic community condition, and estimates the area for which we should see improvements in benthic condition with improvements in water quality. The second analysis, presented in Chapter 6, provides a more focused assessment of benthic community degradation by Chesapeake Bay Program segment and water depth. The results of this analysis were presented at the 2001 EMAP Symposium in Pensacola Beach and are included here in the form of a manuscript submitted to *Environmental Monitoring and Assessment*.

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. Techniques were developed for combining all types of input into a single electronic file, permitting production of the report in Adobe Acrobat format to facilitate distribution across the internet; previously, reports were compiled by xeroxing output of several diverse software packages or "original figures" prepared several years previously. This year, an improved world-wide-web site (http://www.esm.versar.com/VCB/Benthos/CBBENhome.htm) has been made available to the general public. This web site provides reports, data, and information about the benthic monitoring programs. The 2000 data can now be downloaded from this site. This site represents the culmination of collaborative efforts between Versar, Maryland DNR, and the U.S. EPA-sponsored Chesapeake Information Management System (CIMS). The activities that Versar will undertake as a partner of the CIMS were recorded in a Memorandum of Agreement signed October 28, 1999.

1.3 ORGANIZATION OF REPORT

This report is organized into seven 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 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 describes the area goal study. Chapter 6 is the manuscript submitted to *Environmental Monitoring and Assessment*. Chapter 7 lists literature cited throughout the report. Appendix A amplifies information presented in Table 3-2 by providing p-values and rates of change for the 1985-2000 fixed site community attribute trend analysis. Finally, Appendices B and C present the B-IBI values for fixed and random sites, respectively, sampled in summer 2000.

2.0 METHODS

2.1 SAMPLING DESIGN

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

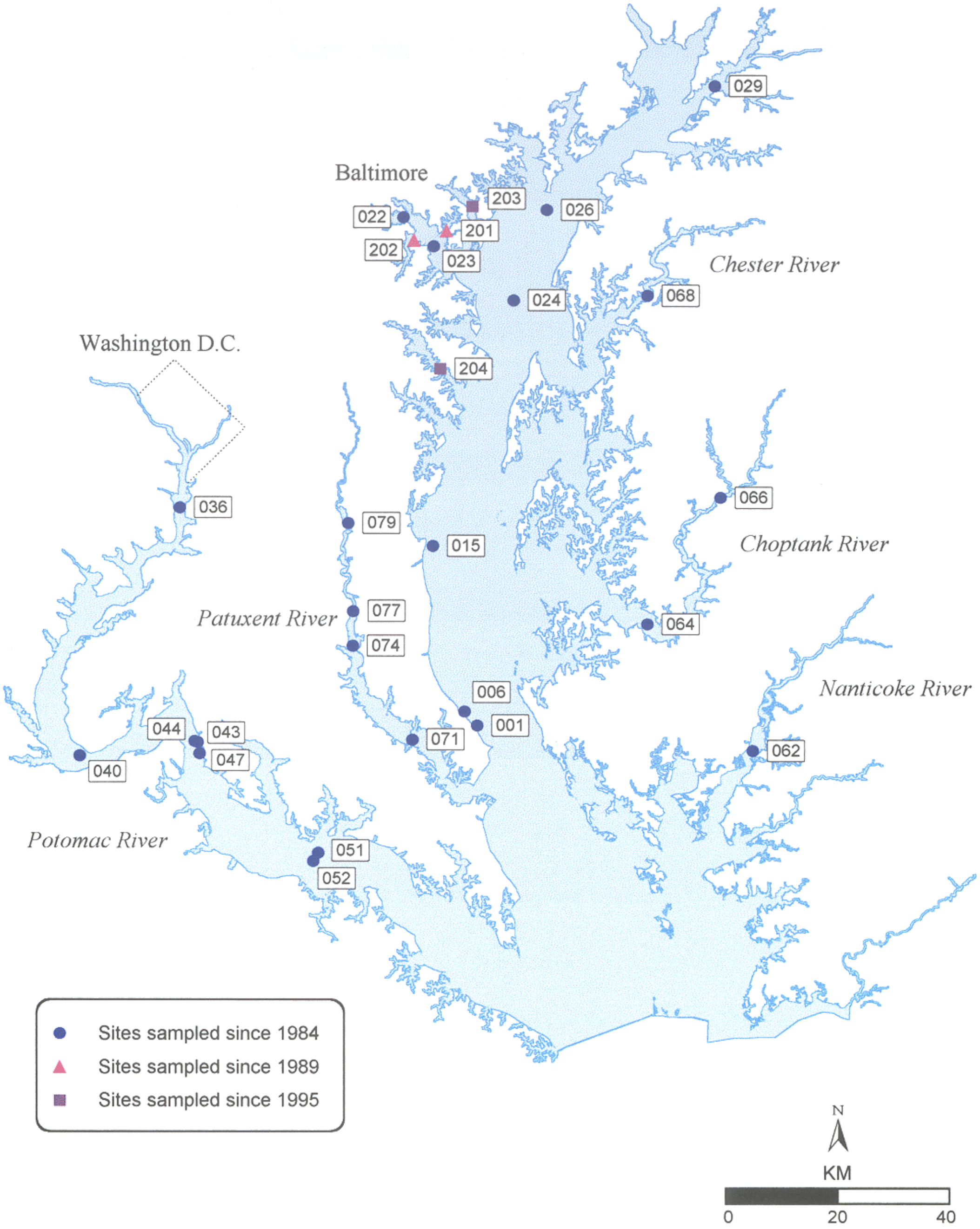
2.1.1 Fixed Site Sampling

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 2000 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 in1995,Table 2-1, Fig. 2-1). This sampling regime was selected as being most


Baltimore
Washington D.C.
Chester River
Choptank River
Patuxent River
Nanticoke River
Potomac River
029
203
026
022
201
202
023
024
068
204
036
066
079
015
077
074
064
006
001
071
062
044
043
047
040
051
052
● Sites sampled since 1984
▲ Sites sampled since 1989
■ Sites sampled since 1995
N
KM
0
20
40

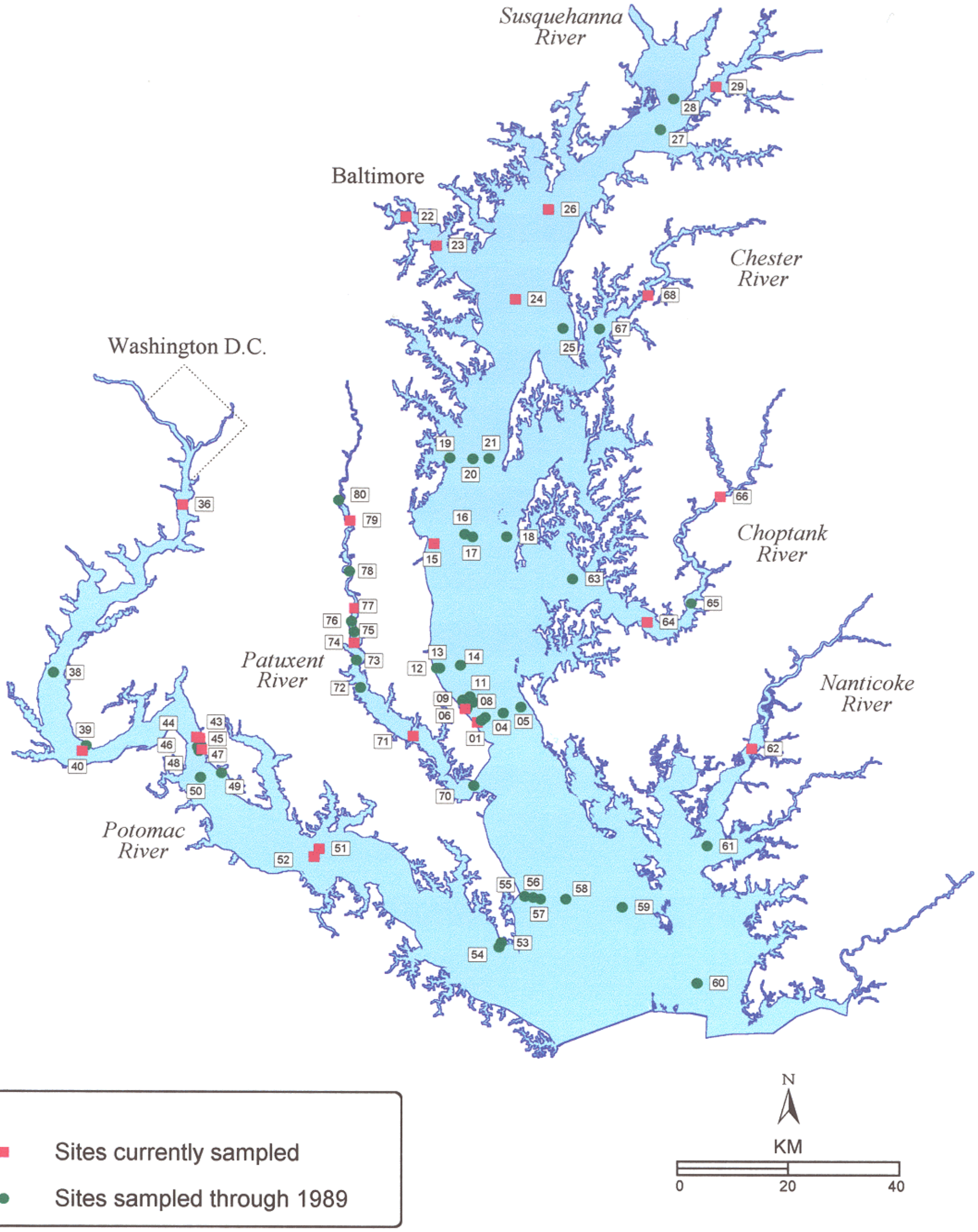


Figure 2-1. Fixed sites sampled in 2000.

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

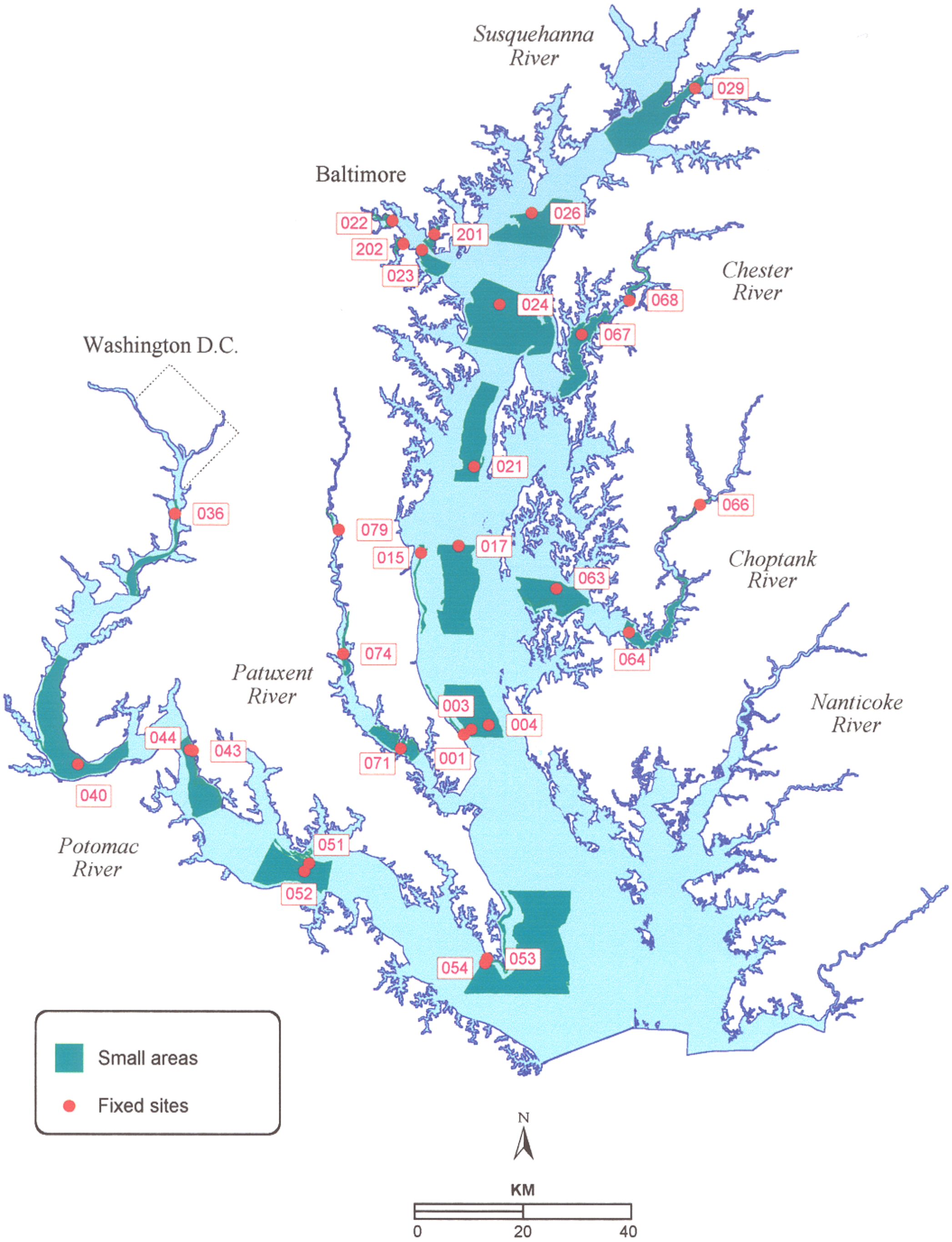

Susquehanna River
029
Baltimore
026
022
201
202
023
Chester River
024
068
067
Washington D.C.
021
066
036
079
015
017
Choptank River
063
064
074
Patuxent River
Nanticoke River
003
004
044
043
001
071
040
Potomac River
051
052
053
054
Small areas
Fixed sites
N
KM
0
20
40

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

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

Stratum	Sub-Estuary	Habitat	Station	Latitude (NAD 27)	Longitude (NAD 27)	Sampling Gear	Habitat Criteria		
							Depth (m)	Siltclay (%)	Distance (km)
Potomac River	Potomac River	Tidal Freshwater	036	38° 46.18'	77° 02.27'	WildCo Box Corer	<=5	>=40	1.0
		Oligohaline	040	38° 21.44'	77° 13.85'	WildCo Box Corer	6.5-10	>=80	1.0
		Low Mesohaline	043	38° 23.04'	76° 59.36'	Modified Box Corer	<=5	<=30	1.0
		Low Mesohaline	047	38° 21.90'	76° 59.10'	Modified Box Corer	<=5	<=30	0.5
		Low Mesohaline	044	38° 23.13'	76° 59.76'	WildCo Box Corer	11-17	>=75	1.0
		High Mesohaline Sand	051	38° 12.32'	76° 44.30'	Modified Box Corer	<=5	<=20	1.0
		High Mesohaline Mud	052	38° 11.53'	76° 44.88'	WildCo Box Corer	9-13	>=60	1.0
Patuxent	Patuxent	Tidal	079	38° 45.02'	76° 41.36'	WildCo	<=6	>=50	1.0

River	River	Freshwater				Box Corer			
		Low Mesohaline	077	38° 36.26'	76° 40.52'	WildCo Box Corer	<=5	>=50	1.0
		Low Mesohaline	074	38° 32.83'	76° 40.51'	WildCo Box Corer	<=5	>=50	0.5
		High Mesohaline Mud	071	38° 23.70'	76° 32.95'	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° 12.49'	76° 31.42'	WildCo Box Corer	4-7	>=50	1.0
	Middle Branch	Low Mesohaline	022	39° 15.29'	76° 35.26'	WildCo Box Corer	2-6	>=40	1.0
	Bear Creek	Low Mesohaline	201	39° 14.05'	76° 29.85'	WildCo Box Corer	2-4.5	>=70	1.0
	Curtis Bay	Low Mesohaline	202	39° 13.07'	76° 33.85'	WildCo Box Corer	5-8	>=60	1.0
	Back River	Oligohaline	203	39° 16.50'	76° 26.78'	Young-Grab	1.5-2.5	>=80	1.0
	Severn River	High Mesohaline Mud	204	39° 00.40'	76° 30.30'	Young-Grab	5-7.5	>=50	1.0
Eastern Tributaries	Chester River	Low Mesohaline	068	38° 07.97'	76° 04.74'	WildCo Box Corer	4-8	>=70	1.0
	Choptank	Oligohaline	066	38° 48.08'	75° 55.33'	WildCo Box	<=5	>=60	1.0

	River					Corer			
		High Mesohaline Mud	064	39° 07.97'	76° 04.18'	WildCo Box Corer	7-11	>=70	1.0
	Nanticoke River	Low Mesohaline	062	38° 23.03'	75° 51.02'	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)**
	Elk River	Oligohaline	029	39° 28.77'	75° 56.69'	WildCo Box Corer	3-7	>=40	1.0
		Low Mesohaline	026	39° 16.28'	76° 17.42'	WildCo Box Corer	2-5	>=70	1.0
Upper Bay	Mainstem	High Mesohaline Mud	024	39° 07.32'	76° 21.34'	WildCo Box Corer	5-8	>=80	1.0
		High Mesohaline Sand	015	38° 42.90'	76° 30.84'	Modified Box Corer	<=5	<=10	1.0
		High Mesohaline Sand	001	38° 25.19'	76° 25.02'	Modified Box Corer	<=5	<=20	1.0
Mid Bay	Mainstem	High Mesohaline	006	38° 26.54'	76° 26.60'	Modified Box Corer	<=5	<=20	0.5

		Sand							

cost effective after analysis of the first ten years of data jointly with the Virginia benthic monitoring program (Alden et al. 1997).

2.1.2 Probability-based Sampling

The second sampling element, which was instituted in 1994, was probability-based summer sampling designed to estimate the area of the Maryland Chesapeake Bay and its tributaries that meet the Chesapeake Bay Benthic Community Restoration Goals (Ranasinghe et al. 1994, updated by Weisberg et al. 1997; Alden et al. In press). 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 2000. 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 abiotic.

A similar stratification scheme has been used by the Commonwealth of Virginia since 1996, permitting annual estimates for the extent of area meeting the Benthic

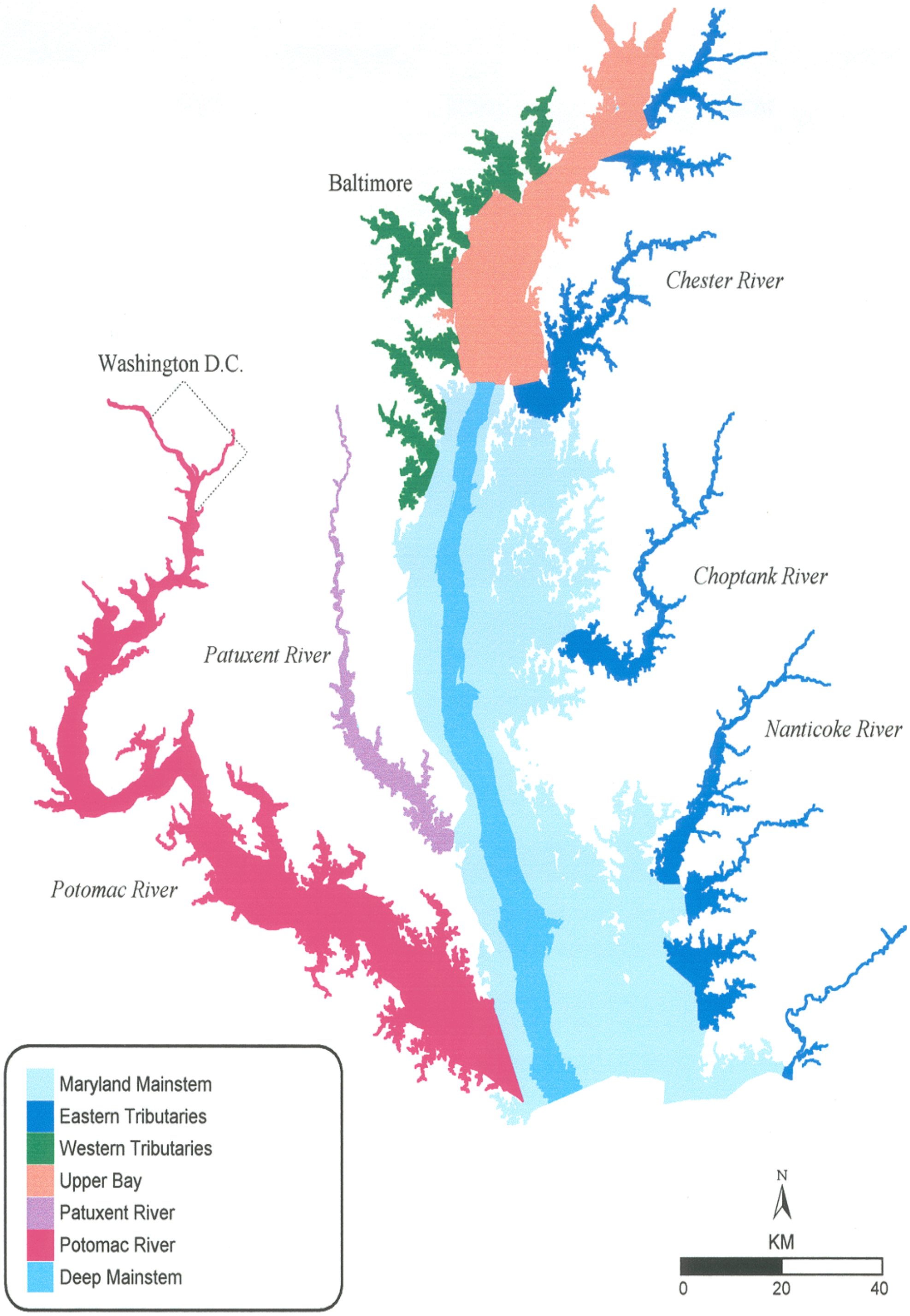

Baltimore
Chester River
Washington D.C.
Choptank River
Patuxent River
Nanticoke River
Potomac River
Maryland Mainstem
Eastern Tributaries
Western Tributaries
Upper Bay
Patuxent River
Potomac River
Deep Mainstem
N
KM
0
20
40

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

Figure 2-5. Maryland probability-based sampling sites for 2000.

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 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
	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	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

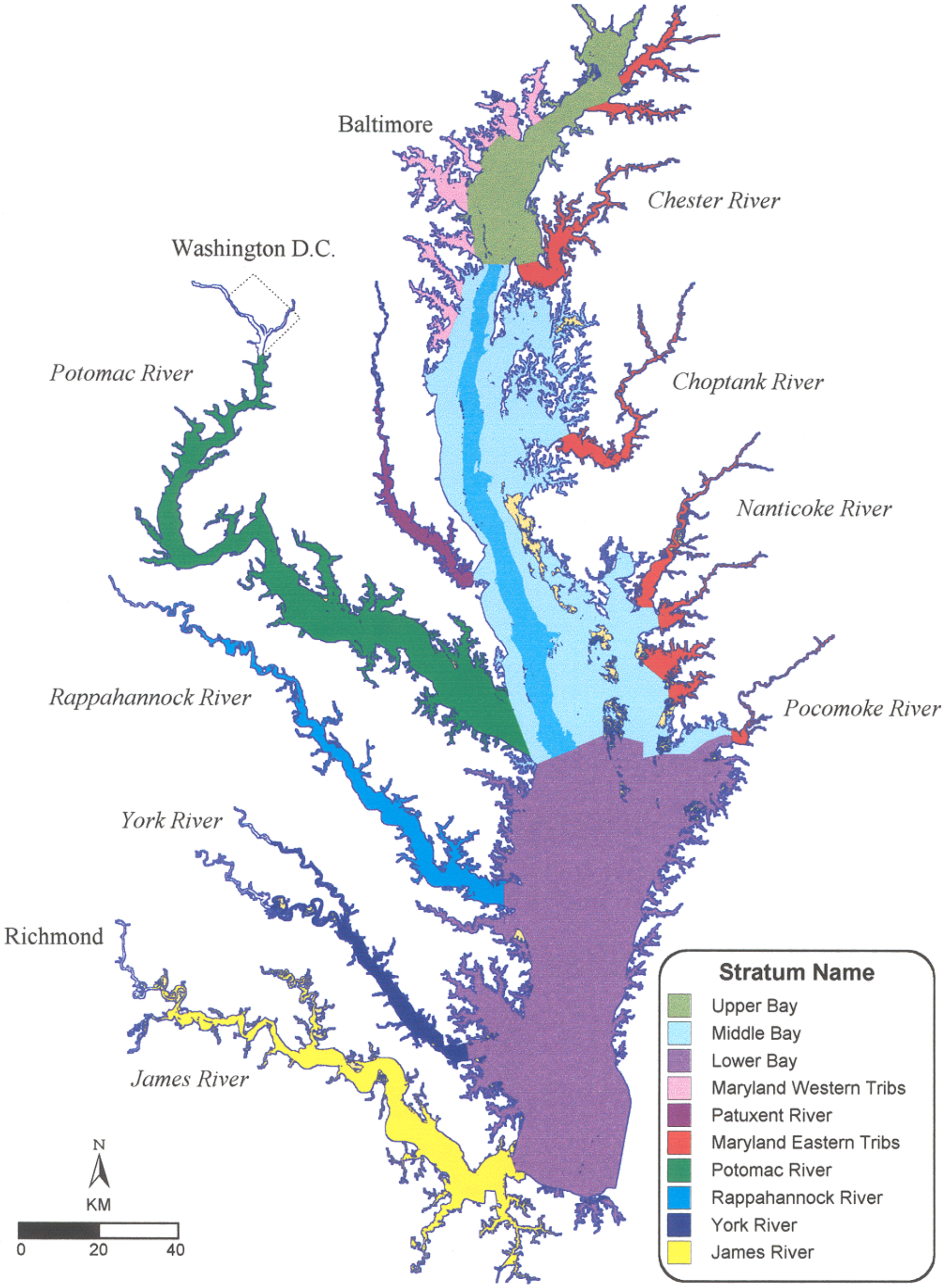


Figure 2-6. Chesapeake Bay-wide stratification scheme.

measured at each fixed site. The profiles consisted of water quality measurements at 1 m intervals from surface to bottom at sites 7 m deep or less, and at 3 m intervals, with additional measurements at 1.5 m intervals in the vicinity of the pycnocline, at sites deeper than 7 m. Surface and bottom measurements were made at all other sampling sites. Table 2-4 lists the measurement methods used.

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 and carbon 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 60°C and ashing in a muffle furnace at 500°C for four hours. For samples collected between July 1985 and August 1993, a regression relationship between ash-free dry weight biomass and size of morphometric characters was defined for 22 species (Ranasinghe et al. 1993). The biomass of the 22 selected species was estimated from these regression relationships. These taxa (Table 2-5) were selected because they accounted for more than 85% of the abundance (Holland et al. 1988). After August 1993, ash-free dry weight biomass was measured directly for each species by drying the organisms to a constant weight at 60°C and ashing in a muffle furnace at 500°C for four hours.

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

Polychaeta

- *Eteone heteropoda*
- *Glycinde solitaria*
- *Heteromastus filiformis*
- *Marenzelleria viridis*
- *Neanthes succinea*
- *Paraprionospio pinnata*
- *Streblospio benedicti*

Mollusca

- *Acteocina canaliculata*
- *Corbicula fluminea*
- *Gemma gemma*
- *Haminoe solitaria*
- *Macoma balthica*
- *Macoma mitchelli*
- *Mulinia lateralis*
- *Mya arenaria*
- *Rangia cuneata*
- *Tagelus plebeius*

Crustacea

Cyathura polita
Gammarus spp.
Leptocheirus plumulosus

Miscellaneous

Carinoma tremaphoros
Micrura leidyi

Silt-clay composition and carbon content were determined for one of the two sediment sub-samples collected at each sampling site. The other sample was archived for quality assurance purposes (Scott et al. 1988). Sand and silt-clay particles were separated by wet-sieving through a 63-µm, stainless steel sieve and weighed using the procedures described in the Versar, Inc., Laboratory Standard Operating Procedures. Carbon 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. 1994, updated by Weisberg et al. 1997; Alden et al. In press). 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 in 1996 (Figure 2-6, Table 2-3).

To estimate the amount of area in the entire Bay that failed to meet the Chesapeake Bay Benthic 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:

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

and

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

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

$$P_{ps}=\overline{y}_{ps}=\sum_{h=1}^{6}W_h\overline{y}_h$$

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

$$\text{var }(P_{ps})=\text{var}(\overline{y}_{ps})=\sum_{h=1}^{6}W_h^2s_h^2/n_h$$

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 analyses are performed on the summer data only in order to apply the B-IBI (Weisberg et al. 1997, Alden et al. In Press). B-IBI calculations and trend analysis methods are described in Section 2.4. This chapter presents trend analysis results for all 27 sites.

The B-IBI is the primary measure used in trend analysis because it integrates several benthic 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.

Sixteen-year (1985-2000) trends are presented for 23 of the 27 trend sites. Twelve-year trends are presented for two sites in Baltimore Harbor (Stations 201 and 202) first sampled in 1989. Six-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 this year using a modified index for these habitats (Alden et al. In Press). Last year, trends for these sites were conducted on B-IBI calculations according to an earlier version of the B-IBI (Llansó et al. 2000). Based on further research by Alden et al. (In Press), the indices for these two salinity habitats were improved and the new B-IBI is applied for the first time to the six fixed sites located in these salinity habitats. Since the B-IBI has changed for these two habitats as a result of the improvements, comparisons to previous years' status and trends should be avoided.

3.1 RESULTS

Statistically significant B-IBI trends (p<0.1) were detected at 9 of the 27 sites (Table 3-1). Benthic community condition declined at four of these sites (significantly decreasing B-IBI trend) and improved at five sites. Currently, 13 stations meet the goals and 14 fail the goals. Initially, 12 stations met the goals and 15 failed the goals (Table 3-1). Six stations with a significant trend have changed status since 1985. Stations 01, 06 (mainstem), and 51 (Potomac River) have improved from initial failure to currently meeting the goal (Table 3-2). Stations 77 (Patuxent River) and 62 (Nanticoke River) have declined in status from initially meeting the goals to currently failing the goals (Table 3-1). Station 71 has declined from a degraded condition to a severely degraded site.

All significant trends through 1999 were still present with the addition of the 2000 data, with two exceptions. Station 64 (Choptank River) had a significantly improving trend through 1999 (Llansó et al. 2000) but with the addition of summer 2000 data, the station no longer has a significant trend (Table 3-1). As for Station 66, changes in the index resulted in no trend being detected. Station 66 is located in the oligohaline portion of the Choptank River. As a result of the index changes, no trend at this station was detected (Table 3-1). 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.

Since the majority of the trends detected through 1999 are still present with the addition of summer 2000 data, this discussion will emphasize changes in attributes and rates (i.e., slopes) from those presented in Llansó et al. (2000), and will include information from basin summaries developed by the Data Analysis Work Group of the Chesapeake Bay Program Monitoring Subcommittee (DAWG).

3.1.1 Declining Trends

Three of the declining sites were located in the Patuxent River (Stations 71, 74, and 77) while the other declining site was in the Nanticoke River (Station 62).

The declining trends in the Patuxent River are of concern since this watershed is completely within Maryland borders and much effort has been devoted to improving conditions within the river. As noted in Llansó et al. (2000), the declining Patuxent River sites vary in benthic condition and degree of change (Table 3-1). Station 77, 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 74, in the mid-mesohaline portion still meets the Restoration Goals, and Station 71 in the deep, lower Patuxent has failed the goals since the program's inception.

Table 3-1. Trends in benthic community condition, 1985-2000. Trends were identified using the van Belle and Hughes (1984) procedure. Current mean B-IBI and condition are based on 1998-2000 values. Initial mean B-IBI and condition are based on 1985-1987 values. NS: not significant; (a): 1989-1991 and (b): 1995-1997 initial condition.

Station	Trend Significance	Median Slope (B-IBI units/yr)	Current Condition (1998-2000)	Initial Condition (1985-1987 unless otherwise noted)
Potomac River				
36	$p < 0.01$	0.07	4.22 (Meets Goal)	3.20 (Meets Goal)
40	NS	0.00	3.47 (Meets Goal)	3.21 (Meets Goal)
43	NS	0.00	3.62 (Meets Goal)	3.71 (Meets Goal)
44	NS	0.00	2.33 (Degraded)	2.80 (Marginal)
47	NS	0.00	3.89 (Meets Goal)	3.89 (Meets Goal)
51	$p < 0.001$	0.08	3.41 (Meets Goal)	2.43 (Degraded)
52	NS	0.00	1.30 (Severely Degraded)	1.37 (Severely Degraded)
Patuxent River				
71	$p < 0.01$	-0.06	1.78 (Severely Degraded)	2.59 (Degraded)
74	$p < 0.05$	-0.03	3.36 (Meets Goal)	3.78 (Meets Goal)
77	$p < 0.001$	-0.13	2.56 (Degraded)	3.76 (Meets Goal)
79	NS	0.00	2.48 (Degraded)	2.74 (Marginal)
Choptank River				
64	NS	0.03	2.96 (Marginal)	2.65 (Marginal)
66	NS	0.00	3.11 (Meets Goal)	3.03 (Meets Goal)
Maryland Mainstem				
26	$p < 0.05$	0.00	3.49 (Meets Goal)	3.16 (Meets Goal)
24	NS	0.01	3.15 (Meets Goal)	3.04 (Meets Goal)

15	NS	0.03	2.41 (Degraded)	2.22 (Degraded)
06	$p < 0.05$	0.03	3.00 (Meets Goal)	2.56 (Degraded)
01	$p < 0.05$	0.03	3.41 (Meets Goal)	2.93 (Marginal)
Maryland Western Shore Tributaries				
22	NS	0.00	1.76 (Severely Degraded)	2.08 (Degraded)
23	NS	0.00	1.84 (Severely Degraded)	2.49 (Degraded)
201	NS	0.00	1.22 (Severely Degraded)	1.10 (Severely Degraded) (a)
202	NS	0.00	1.31 (Severely Degraded)	1.40 (Severely Degraded) (a)
203	NS	0.02	2.18 (Degraded)	1.93 (Severely Degraded) (b)
204	NS	0.00	3.70 (Meets Goal)	3.70 (Meets Goal) (b)
Maryland Eastern Shore Tributaries				
29	NS	0.00	2.78 (Marginal)	2.42 (Degraded)
62	$p < 0.05$	-0.03	2.78 (Marginal)	3.42 (Meets Goal)
68	NS	0.00	3.56 (Meets Goal)	3.51 (Meets Goal)

Table 3-2. Summer temporal trends in benthic community attributes 1985-2000. Monotoni
elle and Hughes (1984) procedure. ⇑: Increasing trend; ⇓: Decreasing trend. *: p < 0.1; **: p < 0.05; ***: p < 0.
ion; unshaded trend cells indicate improving conditions; (a): trends based on 1989-2000 data; (b): trends based on 1995-2000
attributes are used in B-IBI calculations when species specific biomass is unavailable; NA: attribute is not included in the repor
t). See Appendix A for further detail.

Station	B-IBI	Abundance	Biomass	Shannon Diversity	Indicative Abundance	Sensitive Abundance
Potomac River						
043					⇑ ***	⇓ *(d)
044				⇑ **		(d)
047			⇑ **			⇓ *(d)
051	⇑ ***		⇓ ***	⇑ ***	⇓ ***	⇑ ***
052					(d)	(d)
Patuxent River						
071	⇓ ***	⇓ **	⇓ ***		⇓ *(d)	⇓ **(d)
074	⇓ **	⇑ ***			⇑ **	⇓ ***(d)
077	⇓ ***		⇓ **		⇑ ***	⇓ **(d)
Choptank River						
064				⇑ **	(d)	(d)
Maryland Mainstem						
01	⇑ **		⇑ *		⇓ **	⇑ **
06	⇑ **				⇓ **	⇑ **
015					⇓ **	
024			⇓ **	⇓ *	(d)	(d)
026	⇑ **					⇑ *(d)
Maryland Western Shore Tributaries						
022					⇑ *	⇑ ***(d)
023		⇓ ***	⇓ *			⇑ ***(d)
201(a)						(d)
202(a)						⇓*(d)
204(b)		⇓ *			(d)	(d)
Maryland Eastern Shore Tributaries						
062	⇓ **		⇓ *	⇓ ***	⇓ ***	(d)
068		⇓ *	⇑ **			⇑ ***(d)

poral trends in benthic community attributes at the oligohaline and tidal freshwater stations 1
van Belle and Hughes (1984) procedure. ⇑: Increasing trend; ⇓: Decreasing trend. *: p < 0.1; **: p < 0.05;
aded trend cells indicate improving conditions; (a): trends based on 1995-2000 data; NA: attribute not calculated. Blanks indic

	Abundance	Tolerance Score	Freshwater Indicative Abundance	Oligohaline Indicative Abundance	Oligohaline Sensitive Abundance	Tanypodini to Chironomidae Ratio	Ab Dee F
				Potomac River			
	⇓ ***	⇓ **	⇓ *	NA	NA	NA	
			NA	⇓ **	⇓ ***		
				Patuxent River			
	⇑ *		⇓ **	NA	NA	NA	
				Choptank River			
	⇑ **		NA		⇓ ***	⇑ ***	
				Maryland Western Shore Tributaries			
			NA				
				Maryland Eastern Shore Tributaries			
		⇓ ***	NA	⇓ ***	⇓ ***		

Station 77 had the most pronounced decline of the three river stations with a slope of -0.13 B-IBI units per year (Table 3-1). The slope has not changed from the one documented in Llansó et al. (2000); however, the current condition of 2.56 is higher than the 2.11 reported last year. With the addition of summer 2000 data, the number of failing samples since 1995 (77.8%) has declined from 86.7% (Table 3-4, Llansó et al. 2000). As previously noted, trends in several community attributes contributed to the declining trend in the overall B-IBI. Total biomass is significantly decreasing (Table 3-2), and 83.3% of the samples are now failing the attribute goal in the period between 1995 and 2000 (Table 3-4). Abundance of pollution-indicative taxa is significantly increasing and abundance of pollution-sensitive species is decreasing (Table 3-2, Appendix A), both signs that the benthic community at this site is degrading. Llansó et al. (2000) reported that total abundance was significantly increasing through 1999 to a level that was scored low as a result of an over abundance. This trend disappeared with the addition of 2000 data (Table 3-2).

The mid-Patuxent Station 74 is located in the thermal impact area of the Chalk Point Power Plant. This station currently meets the Restoration Goals (Table 3-1), but the number of samples failing the Goals has increased over time. The proportion of failing samples from 1995-2000 have improved somewhat with the addition of 2000 data from those reported last year (Table 3-4). The rate of decline in the B-IBI of 0.03 B-IBI units a year is unchanged from the previously reported rate (Table 3-1).

A factor contributing to the declining B-IBI trend is a significantly increasing trend in total abundance (increasing above the upper threshold), an increase in abundance of pollution-indicative species, and a decrease in abundance of pollution-sensitive species (Table 3-2, Appendix A). These attribute trends are unchanged from those reported last year.

Station 71 is located in a deep area of the Patuxent River near Broomes Island that usually has low bottom water dissolved oxygen concentrations in the summer and, as a result, has failed the goals since program inception (Table 3-1). However, the proportion of samples failing the Goals has increased over time from 76% in 1985-1989 to 100% failing since 1990 (Table 3-4). Originally this station was classified as degraded but is now classified as severely degraded with a B-IBI of 1.78 (Table 3-1). Total abundance, total biomass, and abundance of pollution-sensitive species have significantly declining trends, which are indicative of increasing dissolved oxygen stress (Table 3-2).

Table 3-4. Percentages of samples failing the Restoration Goals for each of several attributes and the B-IBI over three time periods at sites with significantly declining benthic community condition. N = total number of samples available upon which the percentages were calculated. Replication varied across years. Blanks indicate measures for which no samples were collected (see Methods).

Measure	Samples Failing Restoration Goals (%)		
	1985-1989	1990-1994	1995-2000
Station 71			
N	21	10	18
Total abundance	28.6	80.0	83.3
Total biomass	9.5	60.0	94.4
Shannon-Wiener Index	42.9	60.0	33.3
Biomass of pollution sensitive taxa	--	88.8	94.4
B-IBI	76.2	100	100
Station 74			
N	21	8	18
Total abundance	0	37.5	44.4
Total biomass	61.9	50.0	33.3
Shannon-Wiener Index	4.8	12.5	11.1
Abundance of pollution indicative taxa	9.5	37.5	22.2
B-IBI	4.8	37.5	22.2
Station 77			
N	22	0	18
Total abundance	9.1	--	22.2
Total biomass	31.8	--	83.3
Shannon-Wiener Index	31.8	--	22.2
Abundance of pollution indicative taxa	13.6	--	83.3
B-IBI	18.2	--	77.8
Station 62			
N	21	0	18

Total abundance	9.5	--	16.7
Total biomass	19.1	--	61.1
Shannon-Wiener Index	9.5	--	38.9
Abundance of pollution indicative taxa	0	--	5.6
B-IBI	9.5	--	27.8

As previously noted, the declining trend at Station 71 can most likely be attributed to increasing oxygen stress at the site. The Patuxent Basin Summary produced by DAWG reported that nutrient concentrations in the lower part of the river are decreasing; however, no trend in dissolved oxygen (DO) was detected. This is most likely due to the sampling regime used to measured DO. Bimonthly point-in-time sampling of DO is insufficient to monitor changes occurring over time. The benthic community indicates decreases in abundance and biomass over time; all factors likely linked to decreasing DO. In this portion of the river, DAWG reported a significant increase in chlorophyll *a* concentrations in both surface and bottom layer waters since 1985, which may be a contributing factor to hypokia in the lower Patuxent River.

The decreasing trend in benthic condition at Station 74 may be linked to the reported increase in chlorophyll *a* concentrations, but for a different reason than proposed for Station 71. Station 74 is located in shallow water where low DO has historically not been a problem. The decline in B-IBI at this station is attributed to increases in abundance above reference levels in a pattern symptomatic of intermediate levels of eutrophication. In most cases, failing scores were due to excess, rather than insufficient abundance. Increases in abundance above reference conditions are often associated with organic enrichment (e.g., Pearson and Rosenberg 1978, Weisberg et al. 1997). Additionally, the species associated with organic enrichment typically are those classified as pollution-indicative for the B-IBI.

An oil spill that occurred in Swanson Creek just below Station 74 did not appear to have an impact on the benthic community at this site. The oil spill occurred in April 2000 and sampling conducted in May and September at Station 74 did not reveal an impact (Llansó and Vølstad 2001). Provided additional unpredicted impacts from the Chalk Point Power Plant do not occur, under the current rate of decline at this site, the benthic community should continue to meet the goals for the next 12 years. With additional nutrient reductions in the river, the rate of decline at this site should slow.

As previously stated, the high rate of decline in the B-IBI at Station 77 is problematic. The two major contributors to this trend is a decrease in total biomass and an increase in pollution-indicative species abundance. On the other hand, pollution-sensitive species biomass has significantly increased since 1995 (the period of record for this attribute at this station, Table 3-2). The decrease in total biomass has been attributed to a decrease in the abundance of the bivalve *Macoma balthica* (Llansó et al. 2000). Llansó et al. hypothesized that the decrease in the abundance of *Macoma* 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 *Macoma* in Chesapeake Bay, and spring values decreased below 1 ppt. These changes in salinity occurred during the recruitment period, and may be caused by a 57% flow increase measured at the fall line in the Patuxent River since 1985, as reported by DAWG. Another factor potentially affecting clam densities are changes in the amount and type of predators in this area. At this point, changes in predators are unknown and unquantified but should be investigated further.

The trend detected at Station 62 in the Nanticoke River was newly reported in Llansó et al. (2000) and was only minimally significant at the probability level of 0.1. With the addition of 2000 data the trend is now significant at the probability level of 0.05 (Table 3-1). The slope of -0.03 remained the same as that reported last year. The station initially met the goals but now fails marginally. Attributes contributing to the declining conditions included a decrease in Shannon-Wiener diversity and a decrease in total biomass (Table 3-2). The declining trend in total biomass is new this year. A basin summary of water quality for this river has not yet been completed by DAWG, so comparisons to water quality changes in this river are not possible at this time.

3.1.2 Improving Trends

Three of the sites with improving trends (Stations 01, 06, and 26) were located in the mainstem of the Bay. The other two were located in the Potomac River (Stations 36 and 51). One site, located in the Choptank River (Station 64), had an improving trend through 1999 but disappeared with the addition of 2000 data (Table 3-1). All five sites with improving trends currently meet the Benthic Community Restoration Goals (Table 3-1). Stations 01, 06 and 51 improved from failing conditions to currently meeting the goals, while Stations 26 and 36 initially met the Restoration Goals and still meet the goals.

None of the slopes changed substantially from those reported in Llansó et al. (2000). For the most part, trends in individual attributes at Stations 01, 06, 26, and 51 were similar to those reported last year (Table 3-2).

Station 36, located in the tidal freshwater portion of the Potomac River also had similar attribute trends even with the application of the revised tidal freshwater B-IBI (Alden et al. In Press). Most of the improvements at this site can be attributed to a substantial decrease in the dominant bivalve *Corbicula fluminea*, which has been decreasing from high densities since its peak in the late 1980s. The number of samples with failing abundance metric has decreased from 45.5% in 1985-1989 to 17% in 1995-2000 (Table 3-5). Also, substantial decreases in the abundance of two dominant oligochaetes, *Limnodrilus hoffmeisteri* and immature Tubificidae without capiliform chaetae, led to a significant decrease in pollution-indicative taxa and deep deposit feeders, and an improvement in the tolerance score metric (Table 3-3).

Table 3-5. Percentages of samples failing the Restoration Goals for each of several attributes and the B-IBI over three time periods at sites with significantly improving benthic community condition. N = total number of samples available upon which the percentages were calculated. Replication varied across years. Blanks indicate measures for which no samples were collected (see Methods).

Measure	Samples Failing Restoration Goals (%)		
	1985-1989	1990-1994	1995-2000
Station 01			
N	22	11	18
Total abundance	36.4	0	38.9
Total biomass	54.6	18.2	16.7
Shannon-Wiener Index	36.4	18.2	22.2
Abundance of pollution indicative taxa	22.7	27.3	11.1
Abundance of pollution sensitive taxa	22.7	45.5	11.1
B-IBI	18.2	45.5	16.7
Station 06			
N	22	0	18
Total abundance	72.7	--	55.6
Total biomass	68.2	--	66.7
Shannon-Wiener Index	50.0	--	27.8
Abundance of pollution indicative taxa	40.9	--	0
Abundance of pollution sensitive taxa	22.7	--	0
B-IBI	72.7	--	16.7
Station 26			
N	21	7	18
Total abundance	9.5	0	5.6
Total biomass	85.7	85.7	55.6
Shannon-Wiener Index	23.8	14.3	16.7
Abundance of pollution indicative taxa	0	14.3	22.2
B-IBI	14.3	0	0

Station 36			
N	22	9	18
Total abundance	45.5	11.1	16.7
Abundance of pollution indicative taxa	0	0	0
Tolerance Score	36.4	11.1	5.6
Abundance of deep deposit feeders	0	0	0
B-IBI	40.9	0	5.6
Station 51			
N	22	13	18
Total abundance	4.6	7.7	0
Total biomass	13.7	30.8	16.7
Shannon-Wiener Index	68.2	0	16.7
Abundance of pollution sensitive taxa	72.7	61.5	38.9
Abundance of pollution indicative taxa	50.0	38.5	5.6
B-IBI	77.3	61.5	33.3

The improving benthic condition at Station 36 is most likely related to improvements in nutrient loadings. Areas with high levels of nutrients can lead to high levels of organic matter available in the sediments for the benthos. Under highly eutrophic conditions, the benthic community responds with increased abundance and biomass of a few opportunistic species (Pearson and Rosenberg 1978). At Station 36, total abundance of dominant species such as oligochaetes and *Corbicula fluminea* have been declining over the 16-year time span from high levels indicative of degraded conditions. As nutrient conditions in the river continue to improve over time, the benthic community is expected to continue to respond positively.

The loss of the significantly improving B-IBI trend at Station 64 in the Choptank River is most troubling. The station was clearly improving in benthic condition through 1998, but in 1999 and 2000, 4 of the 6 samples failed to meet the goal, thus eliminating the improving trend. DAWG suggested in their basin summary that the Choptank is presently undergoing changes between a moderately impacted system that may respond rapidly to management and a heavily impacted system requiring extensive management effort. Our benthic data suggest that the system is reverting to the latter condition and is in need of further management efforts to reverse the decline.

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. 1994) which was insufficient to characterize the entire Bay. Probability-based sampling was also used in the Maryland Bay by the U.S. EPA's Environmental Monitoring and Assessment Program (EMAP), but at a sampling density too low to develop precise condition estimates for the Maryland Bay. The 1994-2000 sampling represents the first efforts to develop area-based bottom condition statements for the Maryland Bay.

Estimates of tidal bottom area meeting the Benthic 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 2000 Maryland and Virginia tidal waters probability-based sampling and adds a seventh 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.

Estimates presented in this report include tidal freshwater samples, and both tidal freshwater and oligohaline samples were analyzed using new and statistically optimized restoration goals (Alden et al. In press).

4.2 RESULTS

Of the 150 Maryland samples collected with the probability-based design in 2000, 65 met and 85 failed the Chesapeake Bay Benthic Community Restoration Goals (Figure 4-1). Of the 250 probability samples collected in the entire Chesapeake Bay in 2000, 124 met and 126 failed the Restoration Goals. The Virginia sampling results are presented in Figure 4-2.

An improvement in the Maryland Bay condition was observed from 1994 to 1997 followed by a decline in 1998, and again an improvement in 1999 and 2000 (Figure 4-3). The changes in condition were within the uncertainty margins of the estimates, although 1996 showed the greatest improvement in the seven-year time series. Results from the individual sites were weighted based on the area of the stratum represented by the site in the stratified sampling design to estimate the tidal Maryland area failing the Restoration Goals. In 2000, 61% (±5% SE) of the Maryland Bay was estimated to fail the Restoration Goals, compared with 63% (±5% SE) in 1999, 69% (±4%) in 1998, 57% (±5%) in 1997, 56% (±5%) in 1996, 59% (±5%) in 1995, and 64% (±6%) in 1994. Expressed as area, 3,828±183 km^2 of the tidal Maryland Chesapeake Bay remained to be restored in 2000.

In previous years, the Potomac River and the mid-Bay mainstem were in the poorest condition among the six Maryland strata. In 2000, however, benthic condition in the Patuxent River and the upper western tributaries declined substantially, and these two strata were now among those with the largest percent of degradation (Figure 4-4). The upper Bay and the eastern tributaries were in best condition. Over the seven-year time series (1994-2000), more than half of the Potomac River (714-1,173 km^2) failed the

Restoration Goals each year (Figure 4-5) and 48-93% of that area (510-793 km^2, Table 4-1) was severely degraded. The mid-Bay Maryland mainstem had the largest amount of degraded area (>2,000 km^2, including the deep trough) and 63-80% of that area (1,391-1,799 km^2, Table 4-1) was severely degraded. In contrast, more than half the area in the eastern shore tributaries met the Restoration Goals in most years and a very small portion of the eastern tributary bottom area (4-12%) was severely degraded in the last five years.

Figure 4-1. Results of probability-based benthic sampling of the Maryland Chesapeake Bay and its tidal tributaries in 2000. 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 2000. Each sample was evaluated in context of the Chespeake Bay Benthic Community Restoration Goals.

Maryland Chesapeake Bay

Area Failing Restoration Goal

Chesapeake Bay 2000

Area Failing Restoration Goal

Chesapeake Bay

Stratum Area Failing Restoration Goal

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 ten 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.

Region	Year	Severely Degraded*	Degraded	Marginal	Total Failing	% Failing
Chesapeake Bay	1996	3,010	1,174	1,098	5,282	46
	1997	2,884	1,757	1,199	5,841	50
	1998	3,709	1,810	1,203	6,722	58
	1999	3,121	1,648	681	5,450	47
	2000	2,684	1,379	1,563	5,626	48
Maryland Tidal Waters	1994	2,746	1,172	278	4,196	64
	1995	2,603	563	488	3,654	59
	1996	2,626	720	155	3,501	56
	1997	2,348	697	483	3,529	57
	1998	2,663	1,016	601	4,281	69
	1999	2,423	1,137	374	3,935	63
	2000	2,455	1,013	359	3,828	61
Virginia Tidal Waters	1996	384	454	943	1,781	33
	1997	535	1,060	716	2,312	43
	1998	1,045	794	601	2,441	46
	1999	698	510	306	1,515	28
	2000	229	366	1,203	1,798	34
Potomac River	1994	793	330	0	1,123	61
	1995	510	153	51	714	56
	1996	714	51	0	765	60
	1997	561	204	102	867	68
	1998	561	510	102	1,173	92
	1999	663	153	102	918	72

	2000	612	255	0	867	68
Patuxent River	1995	46	10	5	61	48
	1996	41	20	0	61	48
	1997	20	5	10	36	28
	1998	31	26	5	61	48
	1999	20	10	10	41	32
	2000	51	26	10	87	68
Maryland Upper Western Tributaries	1995	58	47	23	129	44
	1996	129	35	0	164	56
	1997	105	23	12	140	48
	1998	94	23	12	129	44
	1999	117	47	12	175	60
	2000	140	70	0	210	72

Table 4-1. (Continued)

Region	Year	Severely Degraded	Degraded	Marginal	Total Failing	% Failing
Maryland Eastern Tributaries	1995	150	86	0	236	44
	1996	21	150	21	192	36
	1997	43	64	21	128	24
	1998	21	64	43	128	24
	1999	43	150	86	279	52
	2000	64	128	43	235	44
Maryland Upper Bay Mainstem	1995	345	63	0	408	52
	1996	126	157	31	314	40
	1997	126	94	31	251	32
	1998	157	188	31	376	48
	1999	188	63	63	314	40

	2000	94	126	0	220	28
Maryland Mid Bay Mainstem	1995	1,493	204	408	2,105	65
	1996	1,595	306	102	2,003	62
	1997	1,493	306	306	2,105	65
	1998	1,799	204	408	2,411	75
	1999	1,391	715	102	2,208	68
	2000	1,493	408	306	2,207	68
Virginia Mainstem	1996	165	330	824	1,319	32
	1997	165	824	659	1,648	40
	1998	824	330	494	1,648	40
	1999	494	165	165	824	20
	2000	0	165	1,154	1,319	32
Rappahannock River	1996	119	60	0	179	48
	1997	134	74	15	223	60
	1998	60	119	45	224	60
	1999	74	104	45	223	60
	2000	164	89	15	268	72
York River	1996	45	37	37	129	64
	1997	45	52	15	112	60
	1998	52	45	7	104	56
	1999	75	22	15	112	60
	2000	37	30	7	74	40
James River	1996	55	27	82	164	24
	1997	191	109	27	327	48
	1998	109	301	55	465	68
	1999	55	219	82	356	52
	2000	27	82	27	136	20

The area of Chesapeake Bay estimated to fail the Restoration Goals did not change appreciably from 1999, but a decrease in the severely degraded condition was noticeable in 1999 and 2000. (Figure 4-6). Weighting results from the 250 probability sites in Maryland and Virginia, 48% (±5%) or 5,626±259 km^2 of the tidal Chesapeake Bay was estimated to fail the Restoration Goals in 2000. Comparable values for 1999 were 47% (±4%) or 5,450±234 km^2, 58% (±5%) or 6,722 ±309 km^2 for 1998, 50% (±5%) or 5,841±279 km^2 for 1997, and 46% (±5%) or 5,282 ±247 km^2 for 1996.

Baywide, the upper western tributaries and the Rappahannock River were in the worst condition in 2000 (Figure 4-4), both with 72% percent of the bottom area failing the Restoration Goals. The area of severely degraded bottom in the Rappahannock River increased substantially from 20% in 1999 to 44%, or 164 km^2, in 2000 (Table 4-1). Improvements in benthic condition were observed in the York and James Rivers (Figure 4-4). Over the 1996-1999 period, 56-64% of the tidal bottom area of the York River failed the Restoration Goals. The estimate for 2000 decreased to 40%. In the James River, 48-68% of the tidal bottom area failed the Restoration Goals over the 1997-1999 period. The estimate for 2000 decreased to a pre-1997 level of about 20%. Baywide, the James River was in best condition in 2000 (Figure 4-4). Over the study period, the lower (Virginia) Bay mainstem was in best condition overall. The increase in the percentage of failure observed in the lower Bay mainstem in 2000 was entirely in the marginal category and within the error of the estimate.

In five of the ten strata more than 70% of the sites failing the goals were depauperate, failing the abundance goal, the biomass goal, or both because of insufficient numbers or mass of organisms (Table 4-2). Except for the lower (Virginia) Bay, these strata also had a high percentage (>50) 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, biomass, or both. The lower Bay also had a large percentage of depauperate sites, but this percentage was based on a comparatively small number of sites failing the Restoration Goals. Failing sites in the

York and James Rivers exhibited 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.

Chesapeake Bay

Area Failing Restoration Goal

Table 4-2. Sites severely degraded (B-IBI ≤ 2) and failing the Restoration Goals (scored at 1.0) for insufficient abundance, insufficient biomass, or both as a percentage of sites failing the Goals (B-IBI < 3), 1996 to 2000. Strata are 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 a Percentage of Sites Failing the Goals	Number of Sites	As a Percentage of Sites Failing the Goals
Western Tributaries	50	71.4	49	70.0
Potomac River	61	67.8	70	77.8
Mid Bay	43	58.1	54	73.0
Patuxent River	32	57.1	44	78.6
Rappahannock River	37	49.3	43	57.3
York River	34	48.6	29	41.4
Upper Bay	22	46.8	27	57.4
James River	16	30.2	22	41.5
Lower Bay	10	24.4	29	70.7
Eastern Tributaries	9	20.0	24	53.3

In the Upper Bay, York River, and James River, over 25% of the sites failing the Restoration Goals failed due to excess abundance, excess biomass, or both (Table 4-3). Excess abundance and excess biomass are phenomena associated with eutrophic conditions. Percentages in Table 4-2 and 4-3 include oligohaline sites, as abundance is used this year to score oligohline sites. These results are therefore enhanced over those reported in previous years.

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 2000. Strata are in decreasing percentage order.

Stratum	Number of Sites	As a Percentage of Sites Failing the Goals
Upper Bay	14	29.8
York River	20	28.6
James River	14	26.4
Eastern Tributaries	11	24.4
Rappahannock River	17	22.7
Western Tributaries	13	18.6
Mid Bay	12	16.2
Potomac River	14	15.6
Patuxent River	8	14.3
Lower Bay	3	7.3

4.3 DISCUSSION

Estimates of benthic community condition for the Chesapeake Bay and the Maryland Bay are similar to those reported for 1999 (Llansó et al. 2000). About half of the Chesapeake Bay and sixty percent of the Maryland Bay failed the Chesapeake Bay Benthic Community Restoration Goals. Again, much of this area had B-IBI values greater than two, indicating mild degradation that should respond quickly to moderate improvements in water quality. Fifty-two percent of the degraded Chesapeake Bay bottom in 2000 (2,942 km^2) and about a third (36%) of the degraded Maryland Bay bottom (1,372 km^2) were marginally to moderately impaired. Of the additional 2,455 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. A study conducted in coordination with the Chesapeake Bay Program assessed how much of the degraded benthos is located in areas of periodic hypoxia that the Chesapeake Bay modeling efforts predict are likely to improve in response to nutrient reduction efforts. The results of this study are presented in Chapter 5.0.

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 clumping of the random sites in perennially degraded areas such as those typically affected by summer hypoxia. Estimates for the Maryland upper western tributaries and the Patuxent River increased substantially in 2000 relative to previous years. This increase in benthic community degradation may be related to higher than normal flows throughout spring and summer 2000. High spring flows have been theorized to cause earlier and spatially more extensive stratification within the Bay, leading to more extensive hypoxia (Tuttle et al. 1987). Spatial patterns of degradation between years, although small, were also in the direction expected from abnormally strong spring freshets in 1994 and 1998 and the drier summers experienced in 1996 and 1997.

The James and the York Rivers exhibited decreases in the estimated degraded area in 2000. These two systems 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. 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 stratum also had a high percentage of sites with excess abundance. While organic enrichment of the sediment 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 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. In Press). These events are likely to exert a significant stress on the benthic community, masking potential effects from other sources.

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 strong eutrophic conditions in the absence of low dissolved oxygen stress (e.g., Pearson and Rosenberg 1975). As noted in previous years, our results confirm suspicions that dissolved oxygen stress is the more serious and widespread problem affecting benthic communities in the Chesapeake Bay. The results also confirm that dissolved oxygen stress is the most common problem for benthic communities in the Potomac River. No obvious trend in baywide benthic community status is discernible with the five years of data examined. Other stresses to the Bay benthos include toxic contamination, 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).

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. (1994) and updated by Weisberg et al. (1997); however, a few uncertainties about the statistical properties of the B-IBI were left to be resolved. Last year, a series of statistical and simulation studies were conducted to evaluate and optimize the Benthic Index of Biotic Integrity (Alden et al. In press). In addition, new metric and threshold combinations for the tidal freshwater and oligohaline habitats were produced and further refined this year. Details of the new Tidal Freshwater Goals are presented in Alden et al. (In press), and will be posted in the Maryland long-term Benthic Monitoring Program website. The results of Alden et al. indicate that the B-IBI is sensitive, stable, robust, and statistically sound. The thresholds published in Weisberg et al. (1997) for mesohaline and polyhaline habitats performed as well in classifying stations as any of the alternative values that were examined. Performance of the B-IBI, as measured by correct classification of sites and statistical discriminatory power, increased with the salinity of the habitats, with tidal freshwater and oligohaline habitats having the lowest level of discrimination and correct classification efficiencies. Nonetheless, the statistical models in Alden et al. (In press) predicted overall correct classification of sites in the 69-100% range. Also, these studies revealed good classification performance even if not all community attributes are measured. An application of the findings and recommendations of Alden et al. is presented in Chapter 6.0.

B-IBI improvements conducted to date were applied to current and previous data without any dramatic changes in previous results. The improved metric/threshold combinations for the tidal freshwater and oligohaline habitats (Alden et al. In press) were applied to the 2000 data and retroactively to previous years, recalculating previously presented results after applying the modified index. Tidal freshwater areas constitute about 7% of the Bay and 4-10% of the Maryland Bay, depending on river flow. They are important for Bay management because of their location close to human activity and the limited potential for dilution due to their small size.

As baywide application of the Benthic Community Restoration Goals enters its sixth 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 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 is underway and will further augment the usefulness of the B-IBI to management.

Although a continuing evolution of the goals may lead to changes in estimates of the area of the Bay meeting 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 SETTING AN AREA GOAL FOR HEALTHY BENTHIC COMMUNITIES IN CHESAPEAKE BAY

6.0 APPLICATION OF THE BENTHIC INDEX OF BIOTIC INTEGRITY TO ENVIRONMENTAL MONITORING IN CHESAPEAKE BAY

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APPENDIX A

FIXED SITE COMMUNITY ATTRIBUTE
1985-2000 TREND ANALYSIS RESULTS

Appendix Table A-1. Summary temporal trends in benthic community attributes 1985-2000.
trend. Monotonic trends were identified using the van Belle and Hughes (1984) proced
p < 0.1; **: p < 0.05; ***: p < 0.01; shaded trend cells indicate increasing degradation; unshaded trend cells indicate impro
data; (b): trends based on 1995-2000 data; (c): attribute trend based on 1990-2000 data; (d): attributes are used in B-IBI
unavailable; (e): attribute and trend are not included in the reported B-IBI.

Station	B-IBI	Abundance	Biomass	Shannon Diversity	Indicative Abundance	Sensitive Abundance
Potomac River						
043	0.00	-40.00	-0.73	0.00	0.44***	-0.99*(d)
044	0.00	-14.03	-0.03	0.04**	0.00	0.00(d)
047	0.00	-8.00	1.96**	0.03	0.18	-0.95*(d)
051	0.08***	30.00	-0.24***	0.03***	-1.58***	0.55***
052	0.00	0.00	0.00	0.00	0.00(d)	0.00(d)
Patuxent River						
071	-0.06***	-47.39**	-0.12***	-0.00	-1.65*(d)	-0.42**(d)
074	-0.03**	288.28***	-0.80	-0.00	0.50**	-1.62***(d)
077	-0.13***	56.20	-0.35**	-0.02	3.52***	-1.01**(d)
Choptank River						
064	0.03	22.73	0.02	0.05**	0.18(d)	0.53(d)
Maryland Mainstem						
001	0.03**	0.00	0.06*	0.00	-0.56**	0.89**
006	0.03**	20.00	-0.03	0.01	-0.56**	1.29**
015	0.03	17.78	-0.05	0.01	-1.23**	0.18
024	0.01	-30.15	-0.33**	-0.02 *	-0.42(d)	0.35(d)
026	0.00**	29.70	0.69	0.02	0.32	1.18*(d)
Maryland Western Shore Tributaries						
022	0.02	58.53	-0.00	0.01	1.66*	0.34***(d)
023	0.00	-120.00***	-0.06*	0.01	0.32	0.29***(d)
201(a)	0.00	-9.09	-0.00	0.04	0.00	0.00(d)
202(a)	0.00	0.00	0.00	0.00	0.00	0.00*(d)
204(b)	0.00	-287.88*	-0.36	-0.00	0.65(d)	1.08(d)
Maryland Eastern Shore Tributaries						
062	-0.03**	58.46	-0.07*	-0.05***	-0.26***	-0.23(d)
068	0.00	-90.91*	0.71**	0.02	-0.09	2.53***(d)

Appendix Table A-2.Summer temporal trends in benthic community attributes at the oligoha stations 1985-2000. Shown is the median slope of the trend. Monotonic trends were i Belle and Hughes (1984) procedures. ⇑: Increasing trend; ⇓: Decreasing trend. *: p < 0.1; **: p < 0.05; indicate increasing degradation; unshaded trend cells indicate improving conditions; (a): trends based on 1995-2000 data;

Station	B-IBI	Abundance	Tolerance Score	Freshwater Indicative Abundance	Oligohaline Indicative Abundance	Oligohaline Sensitive Abundance	Tanypodir Chironomi Ratio
Potomac River							
036	0.07***	-178.84***	-0.05**	-1.55*	NA	NA	NA
040	0.00	-33.73	0.01	NA	-1.51**	-3.32***	0.00
Patuxent River							
079	0.00	149.71*	-0.01	-2.00**	NA	NA	NA
Choptank River							
066	0.00	85.62**	0.12	NA	-0.52	-3.02***	5.56***
Maryland Western Shore Tributaries							
203(a)	0.02	-11.36	0.00	NA	0.00	0.00	0.00
Maryland Eastern Shore Tributaries							
029	0.00	-32.36	-0.16***	NA	-3.74***	-0.22***	0.00

APPENDIX B

FIXED SITE B-IBI VALUES, SUMMER 1999

Appendix Table B-1. Fixed site B-IBI values, Summer 2000

Station	Sampling Date	Latitude (NAD83 Decimal Degrees)	Longitude (NAD83 Decimal Degrees)	B-IBI	Status
01	7-Sep-00	38.41983	76.41700	3.11	Meets Goal
06	7-Sep-00	38.44233	76.44333	2.89	Marginal
15	7-Sep-00	38.71500	76.51400	2.78	Marginal
22	31-Aug-00	39.25483	76.58767	1.00	Severely Degraded
23	31-Aug-00	39.20817	76.52367	2.33	Degraded
24	31-Aug-00	39.12200	76.35567	3.11	Meets Goal
26	1-Sep-00	39.27133	76.29033	3.27	Meets Goal
29	1-Sep-00	39.47950	75.94483	3.53	Meets Goal
36	25-Sep-00	38.76967	77.03783	4.33	Meets Goal
40	25-Sep-00	38.35733	77.23083	3.11	Meets Goal
43	29-Aug-00	38.38400	76.98933	3.40	Meets Goal
44	29-Aug-00	38.38550	76.99600	1.40	Severely Degraded
47	29-Aug-00	38.36500	76.98500	3.80	Meets Goal
51	29-Aug-00	38.20533	76.73833	2.78	Marginal
52	29-Aug-00	38.19217	76.74800	1.00	Severely Degraded
62	26-Sep-00	38.38383	75.85033	3.13	Meets Goal
64	30-Aug-00	38.59033	76.06967	2.56	Degraded
66	30-Aug-00	38.80133	75.92217	3.00	Meets Goal
68	5-Sep-00	39.13283	76.07900	4.07	Meets Goal
71	6-Sep-00	38.39500	76.54917	2.11	Degraded
74	5-Sep-00	38.54883	76.67650	3.67	Meets Goal
77	6-Sep-00	38.60433	76.67533	3.13	Meets Goal
79	25-Sep-00	38.75033	76.68933	1.22	Severely Degraded
201	31-Aug-00	39.23417	76.49750	1.00	Severely Degraded
202	31-Aug-00	39.21783	76.56417	1.27	Severely Degraded
203	31-Aug-00	39.27500	76.44450	2.56	Degraded

204	7-Sep-00	39.00667	76.50500	3.67	Meets Goal

APPENDIX C

RANDOM SITE B-IBI VALUES, SUMMER 1999

Appendix Table C-1. Random site B-IBI values, Summer 2000.

Station	Sampling Date	Latitude (NAD83 Decimal Degrees)	Longitude (NAD83 Decimal Degrees)	B-IBI	Status
MET-07401	28-Aug-00	38.06089	75.80770	2.00	Severely Degraded
MET-07402	28-Aug-00	38.09563	75.86869	3.33	Meets Goal
MET-07403	28-Aug-00	38.12413	75.91129	2.67	Marginal
MET-07404	28-Aug-00	38.12550	75.87257	2.33	Degraded
MET-07405	28-Aug-00	38.22018	75.83007	3.40	Meets Goal
MET-07406	28-Aug-00	38.24224	75.87798	3.00	Meets Goal
MET-07407	26-Sep-00	38.37420	75.86746	4.20	Meets Goal
MET-07408	26-Sep-00	38.46751	75.81638	4.60	Meets Goal
MET-07409	30-Aug-00	38.57390	76.04174	3.40	Meets Goal
MET-07410	30-Aug-00	38.62485	76.16729	2.20	Degraded
MET-07411	30-Aug-00	38.63500	75.98280	3.40	Meets Goal
MET-07412	30-Aug-00	38.64164	75.97554	2.20	Degraded
MET-07413	30-Aug-00	38.72031	76.00885	2.67	Marginal
MET-07415	5-Sep-00	39.04260	76.20826	2.60	Degraded
MET-07417	5-Sep-00	39.06896	76.08751	2.20	Degraded
MET-07419	5-Sep-00	39.08614	76.19661	2.60	Degraded
MET-07420	5-Sep-00	39.11717	76.10150	3.40	Meets Goal
MET-07421	5-Sep-00	39.11952	76.10886	3.80	Meets Goal
MET-07422	5-Sep-00	39.11971	76.18344	4.60	Meets Goal
MET-07423	5-Sep-00	39.12811	76.16770	4.60	Meets Goal
MET-07424	5-Sep-00	39.18452	76.05155	3.80	Meets Goal
MET-07425	1-Sep-00	39.50955	75.90577	3.40	Meets Goal
MET-07426	28-Aug-00	38.26742	75.78880	4.20	Meets Goal
MET-07427	5-Sep-00	38.99302	76.19151	1.80	Severely Degraded
MET-07428	5-Sep-00	39.08262	76.10355	1.00	Severely Degraded
MMS-07501	28-Aug-00	37.94013	75.79226	1.67	Severely Degraded
MMS-07502	28-Aug-00	37.95671	75.68555	1.67	Severely Degraded
MMS-07503	28-Aug-00	37.97641	75.86743	2.33	Degraded
MMS-07504	28-Aug-00	38.02000	76.13716	3.00	Meets Goal
MMS-07505	28-Aug-00	38.03240	76.09874	3.33	Meets Goal
MMS-07506	28-Aug-00	38.04156	75.93474	4.00	Meets Goal
MMS-07507	28-Aug-00	38.04202	75.98200	3.00	Meets Goal
MMS-07508	28-Aug-00	38.05327	75.91469	4.00	Meets Goal
MMS-07509	29-Aug-00	38.09523	76.08970	2.67	Marginal

MMS-07510	28-Aug-00	38.16432	76.00804	2.67	Marginal
MMS-07511	29-Aug-00	38.17777	76.16713	3.33	Meets Goal
MMS-07512	29-Aug-00	38.20721	76.33565	1.00	Severely Degraded
MMS-07513	29-Aug-00	38.22657	76.37544	2.00	Severely Degraded
MMS-07514	29-Aug-00	38.23317	76.35422	1.00	Severely Degraded
MMS-07515	28-Aug-00	38.28905	76.27266	2.67	Marginal
MMS-07516	28-Aug-00	38.30249	76.20476	3.33	Meets Goal
MMS-07517	28-Sep-00	38.32730	75.97640	1.80	Severely Degraded
MMS-07518	28-Sep-00	38.35617	75.97945	4.20	Meets Goal

Appendix Table C-1. (Continued)

Station	Sampling Date	Latitude (NAD83 Decimal Degrees)	Longitude (NAD83 Decimal Degrees)	B-IBI	Status
MMS-07519	28-Sep-00	38.36660	75.99271	4.20	Meets Goal
MMS-07520	30-Aug-00	38.55787	76.29772	2.33	Degraded
MMS-07521	30-Aug-00	38.58012	76.33201	2.00	Severely Degraded
MMS-07522	30-Aug-00	38.60899	76.36238	2.33	Degraded
MMS-07523	7-Sep-00	38.69245	76.46987	1.67	Severely Degraded
MMS-07524	5-Sep-00	38.93495	76.28878	3.67	Meets Goal
MMS-07525	7-Sep-00	38.97355	76.44305	2.20	Degraded
MWT-07301	7-Sep-00	38.86540	76.52419	2.20	Degraded
MWT-07303	7-Sep-00	38.95984	76.46077	3.00	Meets Goal
MWT-07304	7-Sep-00	38.96584	76.47970	3.40	Meets Goal
MWT-07305	31-Aug-00	39.07377	76.47635	1.00	Severely Degraded
MWT-07306	31-Aug-00	39.08358	76.43592	1.80	Severely Degraded
MWT-07307	31-Aug-00	39.15854	76.53081	1.40	Severely Degraded
MWT-07308	31-Aug-00	39.17319	76.45307	1.80	Severely Degraded
MWT-07309	31-Aug-00	39.18654	76.45968	1.00	Severely Degraded
MWT-07310	31-Aug-00	39.18688	76.57303	1.80	Severely Degraded
MWT-07311	31-Aug-00	39.19703	76.48334	2.20	Degraded
MWT-07312	31-Aug-00	39.20385	76.50053	1.00	Severely Degraded
MWT-07313	31-Aug-00	39.22402	76.54162	1.80	Severely Degraded
MWT-07314	31-Aug-00	39.22770	76.55187	1.00	Severely Degraded
MWT-07315	31-Aug-00	39.22851	76.53969	1.00	Severely Degraded
MWT-07316	31-Aug-00	39.23288	76.52670	1.00	Severely Degraded
MWT-07317	31-Aug-00	39.23478	76.52566	2.60	Degraded
MWT-07318	31-Aug-00	39.24316	76.56647	1.00	Severely Degraded
MWT-07319	31-Aug-00	39.30374	76.40773	3.33	Meets Goal
MWT-07321	21-Sep-00	39.33665	76.36853	3.40	Meets Goal
MWT-07322	21-Sep-00	39.38128	76.30628	2.33	Degraded
MWT-07323	21-Sep-00	39.40541	76.25480	3.33	Meets Goal
MWT-07324	21-Sep-00	39.42755	76.24332	3.67	Meets Goal
MWT-07325	21-Sep-00	39.44091	76.24365	3.00	Meets Goal
MWT-07326	21-Sep-00	39.36963	76.33877	2.33	Degraded
MWT-07327	21-Sep-00	39.34490	76.36257	2.60	Degraded
PMR-07101	29-Aug-00	37.93747	76.30982	3.67	Meets Goal

PMR-07102	29-Aug-00	38.00510	76.36060	1.00	Severely Degraded
PMR-07103	29-Aug-00	38.01096	76.34746	1.00	Severely Degraded
PMR-07104	29-Aug-00	38.05695	76.52450	3.00	Meets Goal
PMR-07105	29-Aug-00	38.07183	76.51769	1.00	Severely Degraded
PMR-07106	29-Aug-00	38.12288	76.51984	1.00	Severely Degraded
PMR-07107	29-Aug-00	38.13055	76.50180	2.33	Degraded
PMR-07108	29-Aug-00	38.14881	76.72866	2.60	Degraded
PMR-07109	29-Aug-00	38.15613	76.44613	1.00	Severely Degraded
PMR-07110	29-Aug-00	38.17654	76.72280	1.00	Severely Degraded
PMR-07111	29-Aug-00	38.18048	76.61290	2.33	Degraded
PMR-07112	29-Aug-00	38.18228	76.65113	1.00	Severely Degraded

Appendix Table C-1. (Continued)

Station	Sampling Date	Latitude (NAD83 Decimal Degrees)	Longitude (NAD83 Decimal Degrees)	B-IBI	Status
PMR-07113	29-Aug-00	38.19806	76.69616	1.00	Severely Degraded
PMR-07114	29-Aug-00	38.20032	76.63118	1.00	Severely Degraded
PMR-07115	29-Aug-00	38.21091	76.88372	1.80	Severely Degraded
PMR-07116	29-Aug-00	38.21508	76.80021	2.20	Degraded
PMR-07117	29-Aug-00	38.21632	76.77274	1.80	Severely Degraded
PMR-07118	29-Aug-00	38.21982	76.61385	3.00	Meets Goal
PMR-07119	29-Aug-00	38.32069	77.01035	1.80	Severely Degraded
PMR-07120	25-Sep-00	38.39204	77.12933	3.40	Meets Goal
PMR-07121	25-Sep-00	38.42236	77.07175	3.80	Meets Goal
PMR-07122	25-Sep-00	38.47635	77.30362	5.00	Meets Goal
PMR-07123	25-Sep-00	38.54522	77.26122	2.50	Degraded
PMR-07124	25-Sep-00	38.56990	77.26002	3.50	Meets Goal
PMR-07125	25-Sep-00	38.70538	77.08298	3.00	Meets Goal
PXR-07201	5-Sep-00	38.30512	76.43507	2.00	Severely Degraded
PXR-07202	5-Sep-00	38.31973	76.42543	1.67	Severely Degraded
PXR-07203	5-Sep-00	38.33031	76.45976	1.00	Severely Degraded
PXR-07204	5-Sep-00	38.33228	76.43748	1.00	Severely Degraded
PXR-07205	5-Sep-00	38.36562	76.49377	2.67	Marginal
PXR-07206	5-Sep-00	38.37135	76.48896	3.33	Meets Goal
PXR-07207	5-Sep-00	38.37621	76.49284	3.67	Meets Goal
PXR-07208	5-Sep-00	38.39143	76.54462	1.00	Severely Degraded
PXR-07209	5-Sep-00	38.39753	76.57303	1.00	Severely Degraded
PXR-07210	5-Sep-00	38.41069	76.55950	2.33	Degraded
PXR-07211	5-Sep-00	38.41193	76.59666	1.80	Severely Degraded
PXR-07212	5-Sep-00	38.41213	76.60124	2.20	Degraded
PXR-07213	5-Sep-00	38.41342	76.58030	2.67	Marginal
PXR-07214	5-Sep-00	38.42365	76.61434	1.00	Severely Degraded
PXR-07215	5-Sep-00	38.43650	76.61052	2.33	Degraded
PXR-07216	5-Sep-00	38.45534	76.59798	2.20	Degraded
PXR-07217	5-Sep-00	38.45612	76.63287	1.67	Severely Degraded
PXR-07218	5-Sep-00	38.45684	76.59808	1.40	Severely Degraded
PXR-07219	5-Sep-00	38.47475	76.64722	3.00	Meets Goal

PXR-07220	5-Sep-00	38.48957	76.66194	2.33	Degraded
PXR-07221	5-Sep-00	38.49865	76.67701	3.00	Meets Goal
PXR-07222	5-Sep-00	38.51775	76.67188	4.20	Meets Goal
PXR-07223	5-Sep-00	38.53122	76.66362	3.80	Meets Goal
PXR-07224	5-Sep-00	38.53861	76.68169	4.60	Meets Goal
PXR-07225	5-Sep-00	38.56664	76.68159	4.20	Meets Goal
UPB-07602	31-Aug-00	39.07883	76.36486	2.20	Degraded
UPB-07603	31-Aug-00	39.12138	76.25512	2.00	Severely Degraded
UPB-07604	31-Aug-00	39.12355	76.38589	3.40	Meets Goal
UPB-07605	31-Aug-00	39.13802	76.35344	2.20	Degraded
UPB-07606	31-Aug-00	39.14000	76.39811	3.80	Meets Goal

Appendix Table C-1. (Continued)

Station	Sampling Date	Latitude (NAD83 Decimal Degrees)	Longitude (NAD83 Decimal Degrees)	B-IBI	Status
UPB-07607	31-Aug-00	39.15825	76.42799	3.80	Meets Goal
UPB-07608	31-Aug-00	39.15998	76.41559	2.20	Degraded
UPB-07609	1-Sep-00	39.20327	76.25334	1.00	Severely Degraded
UPB-07610	1-Sep-00	39.20649	76.27340	4.20	Meets Goal
UPB-07611	31-Aug-00	39.21323	76.35692	4.20	Meets Goal
UPB-07612	1-Sep-00	39.21534	76.27797	3.40	Meets Goal
UPB-07613	1-Sep-00	39.21620	76.29568	3.40	Meets Goal
UPB-07614	31-Aug-00	39.21682	76.40691	4.20	Meets Goal
UPB-07615	31-Aug-00	39.22369	76.32956	4.20	Meets Goal
UPB-07616	1-Sep-00	39.22993	76.26740	4.20	Meets Goal
UPB-07617	1-Sep-00	39.25214	76.30082	3.80	Meets Goal
UPB-07618	1-Sep-00	39.27725	76.28220	3.00	Meets Goal
UPB-07619	1-Sep-00	39.28152	76.29242	3.40	Meets Goal
UPB-07620	1-Sep-00	39.33372	76.21707	3.67	Meets Goal
UPB-07621	1-Sep-00	39.40956	76.11749	3.40	Meets Goal
UPB-07622	1-Sep-00	39.43690	76.03305	3.80	Meets Goal
UPB-07623	1-Sep-00	39.47555	76.05362	3.00	Meets Goal
UPB-07624	1-Sep-00	39.53871	75.96998	2.33	Degraded
UPB-07625	1-Sep-00	39.58875	75.95387	3.50	Meets Goal
UPB-07626	1-Sep-00	39.49133	76.11252	2.00	Severely Degraded