CHESAPEAKE BAY WATER QUALITY MONITORING PROGRAM

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

JULY 1984—DECEMBER 1999

VOLUME 1

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FOREWORD

This document, *Chesapeake Bay Water Quality Monitoring Program: Long-Term Benthic Monitoring and Assessment Component, Level I Comprehensive Report (July 1984—December 1999)*, 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 1999 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 likely contribute to the development and spatial variation of hypoxia in the Chesapeake Bay are salinity, temperature, wind stress, tidal circulation, and nutrient inputs (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 may 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. However, 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 asses 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 sixteenth 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, provide a limited examination of how conditions in the current year differ from conditions in previous years of the study, and 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 last year, were refined, statistically validated (Alden et al. 2000), and applied as modified to tidal freshwater and oligohaline sites. In Chapter 4, which describes Bay-wide benthic community condition, estimates of degraded condition are presented for at least four years for all sub-regions of the Bay. The information in this chapter is enhanced in at least two ways. First, the degraded area estimates included, for the second year in a row, the tidal freshwater portion of the Chesapeake Bay. Estimates for the tidal freshwater and oligohaline portions of the Bay were calculated using the improved Tidal Freshwater Benthic Community Restoration Goals (Alden et al. 2000). Second, in each sub-region, analyses of community measures contributing to failure to meet the Restoration Goals were used to diagnose causes of failure.

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

In addition to the improvements in technical content, we 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, and for the first time, a World-Wide-Web site (http://www.esm.versar.com/VCB/Benthos/CBBENhome.htm) was made available to the general public. This web site provides reports, data, and information about the benthic monitoring programs. The 1999 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 five 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 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 1985-1999 fixed site community attribute trend analysis. Appendix B presents B-IBI values for fixed sites in summer 1999, while Appendix C presents the same information for random sites sampled in summer 1999.

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. 2000). The sampling design for each of these elements is described below.

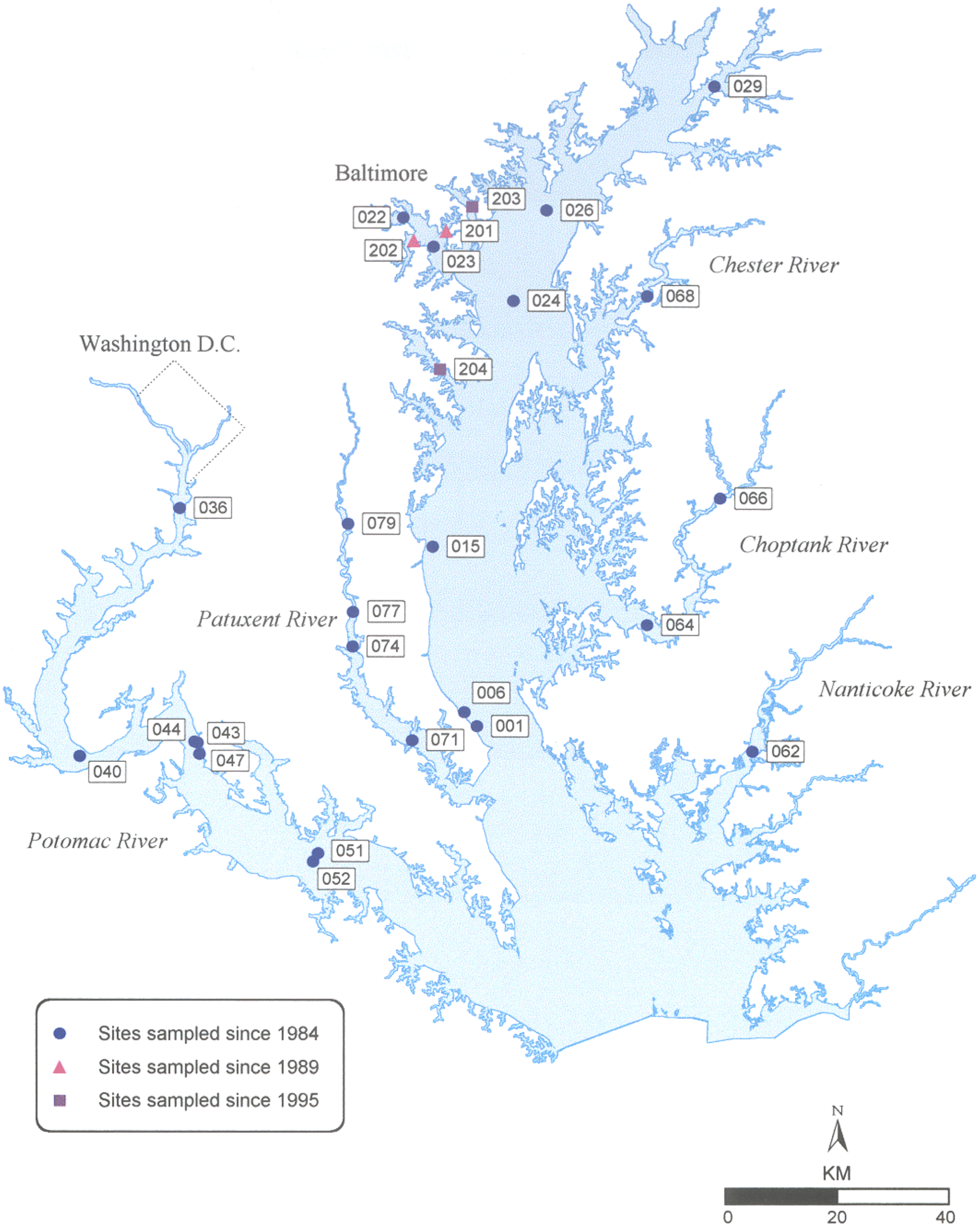
2.1.1 Fixed Site Sampling

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 1999 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 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
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024
068
204
036
066
079
015
077
064
074
006
001
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● Sites sampled since 1984
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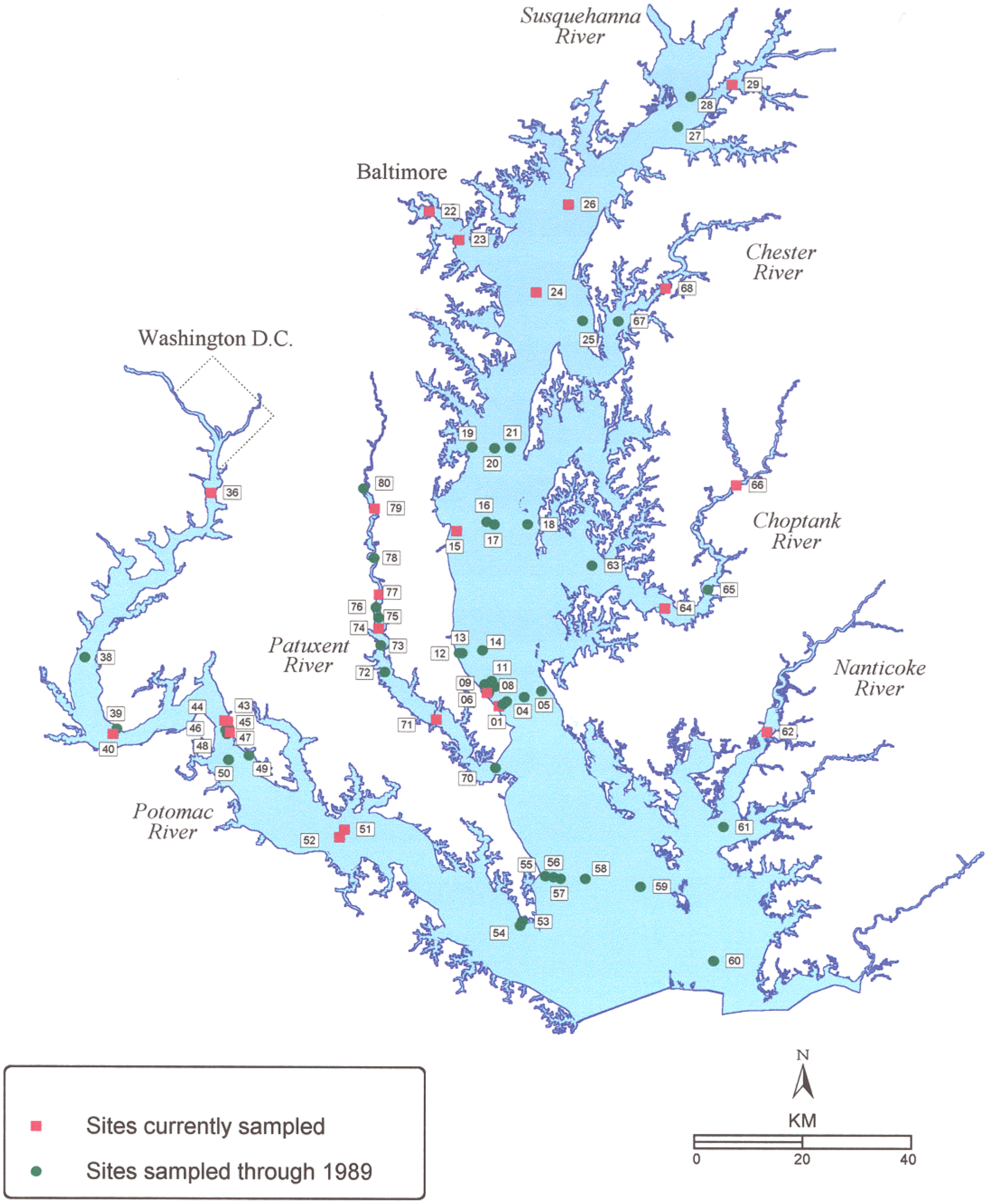


Figure 2-1. Fixed sites sampled in 1999

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

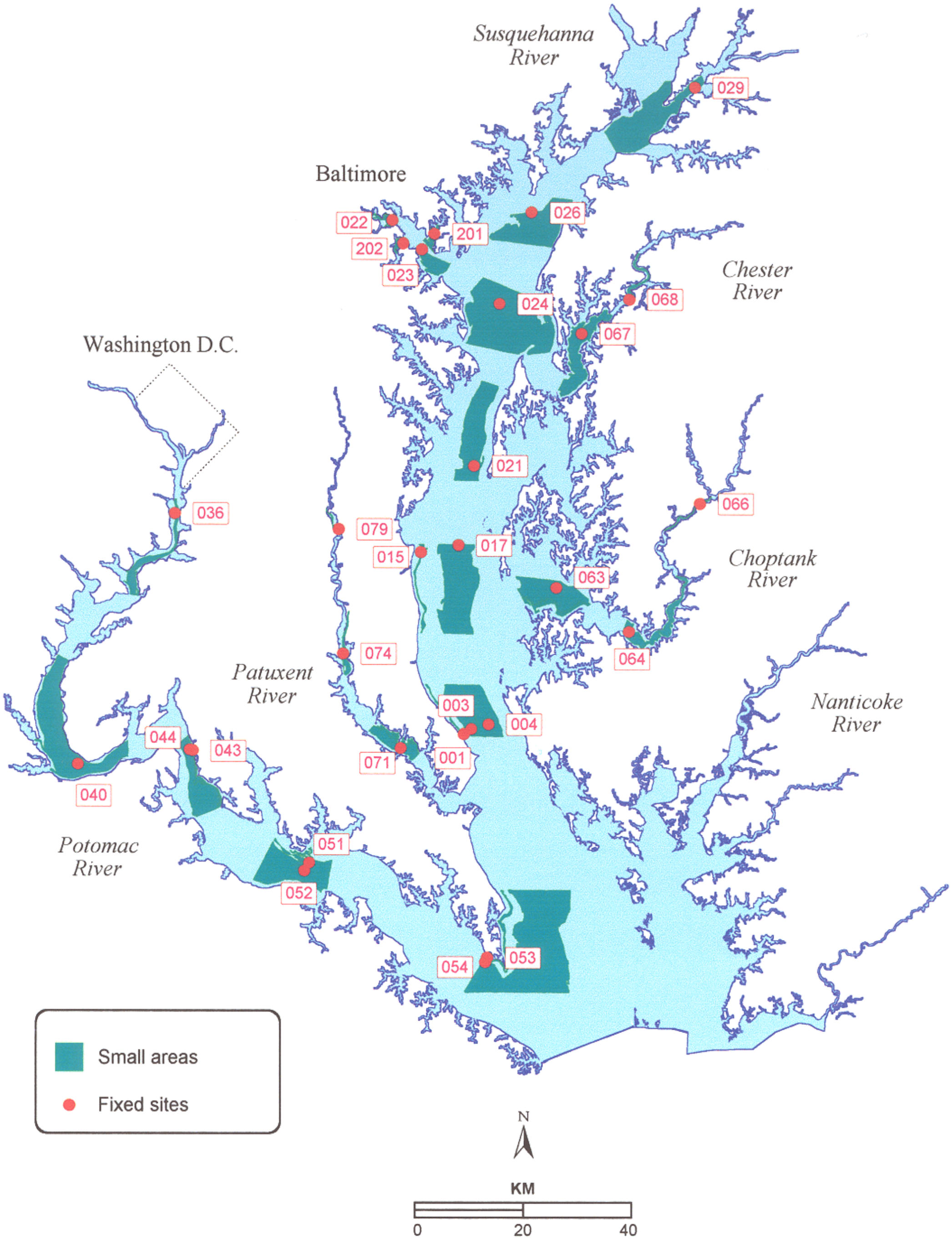


Figure 2-3. Small areas and fixed sites sampled from 1989 to 1994

Table 2-1. Location, habitat (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 River	Patuxent River	Tidal Freshwater	079	38° 45.02'	76° 41.36'	WildCo Box Corer	<=6	>=50	1.0
		Low Mesohaline	077	38° 36.26'	76° 40.52'	WildCo Box Corer	<=5	>=50	1.0
		Low	074	38° 32.83'	76° 40.51'	WildCo	<=5	>=50	0.5

		Mesohaline				Box Corer			
		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	Not set	Not set	1.0
	Severn River	High Mesohaline	204	39° 00.40'	76° 30.30'	Young-Grab	Not set	Not set	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)**
Upper Bay	Elk River	Oligohaline	029	39° 28.77'	75° 56.69'	WildCo Box Corer	3-7	>=40	1.0
	Mainstem	Low Mesohaline	026	39° 16.28'	76° 17.42'	WildCo Box Corer	2-5	>=70	1.0
		High Mesohaline Mud	024	39° 07.32'	76° 21.34'	WildCo Box Corer	5-8	>=80	1.0
Mid Bay	Mainstem	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
		High	006	38°	76°	Modified	<=5	<=20	0.5

		Mesohaline Sand		26.54'	26.60'	Box Corer			

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. 2000). 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	3611	55.5	27

Pocomoke Sounds)			
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 1999. 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

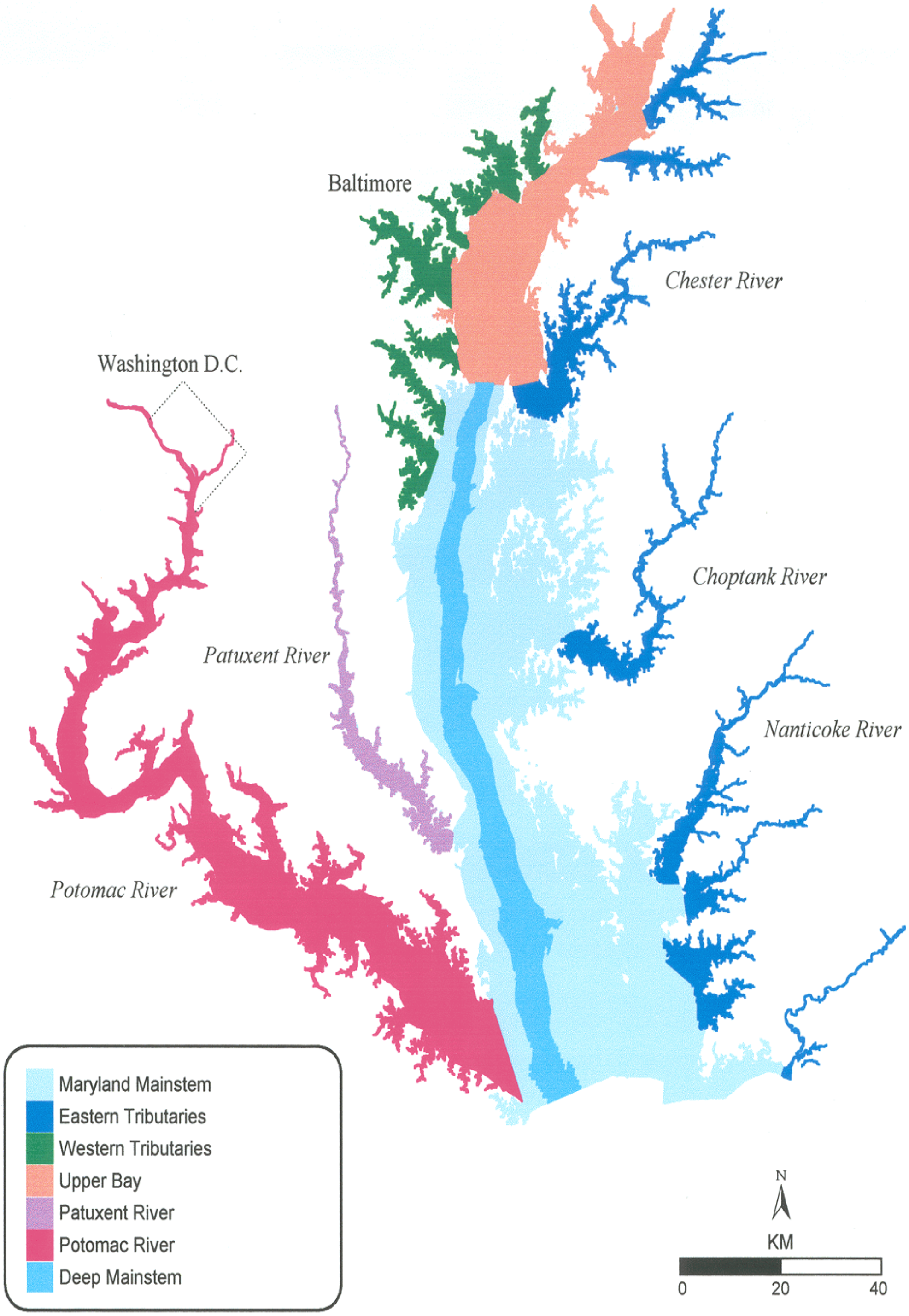


Figure 2-4. Maryland baywide sampling strata in and after 1995

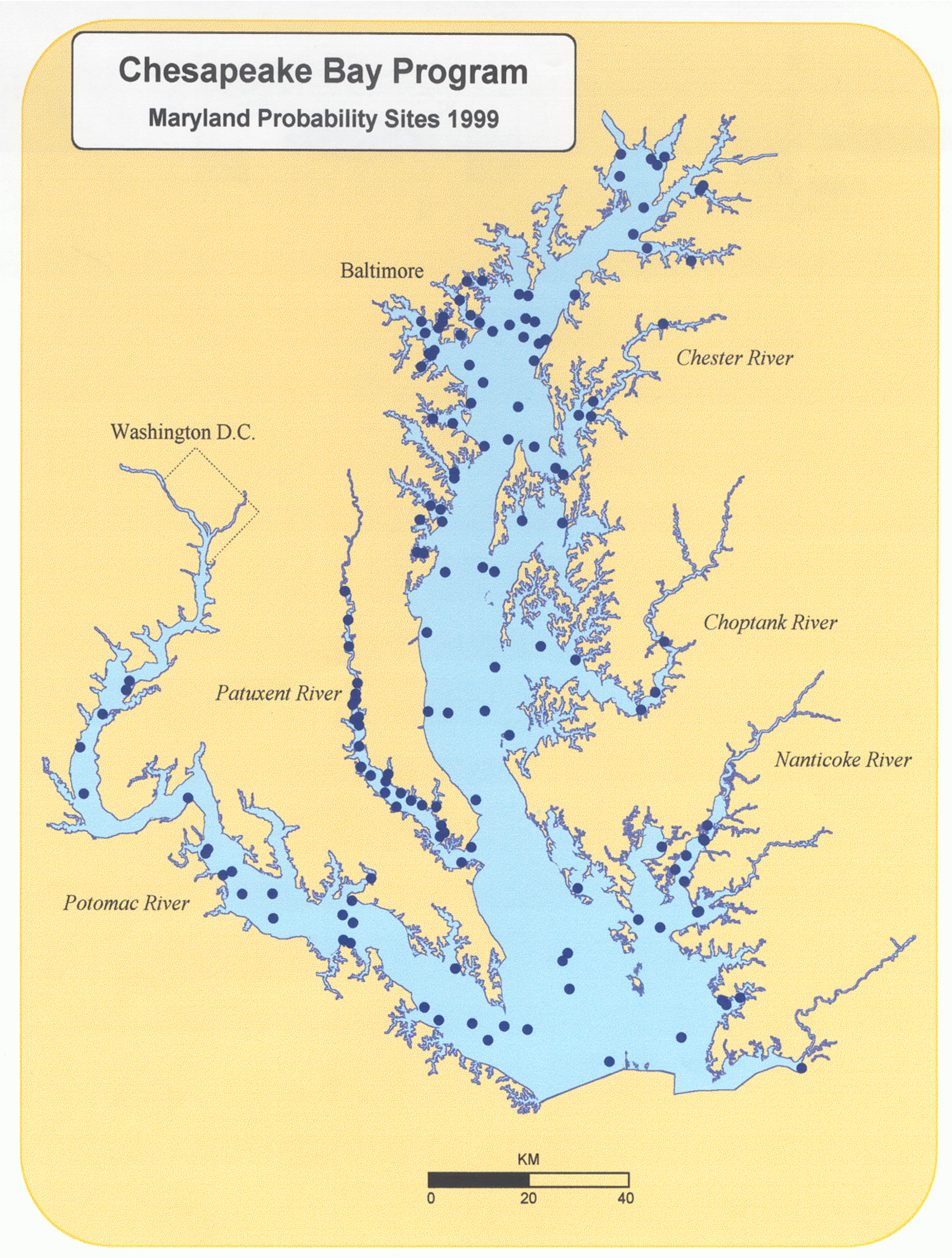


Figure 2-5. Maryland probability-based sampling sites for 1999

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	Mainstem	2,552	45.8	23.4	25
	Eastern Tributaries	534	9.1	4.9	25
	Western Tributaries	292	5.3	2.7	25
	Upper Bay	785	14.1	7.2	25
	Patuxent River	128	2.3	1.2	25
	Potomac River	1,276	22.9	11.7	25
	TOTAL	5,568	99.5	50.9	150
Virginia	Mainstem	4,120	76.8	37.7	25
	Rappahannock River	372	6.9	3.4	25
	York River	187	3.5	1.7	25
	James River	684	12.8	6.3	25
	TOTAL	5,363	100.0	49.1	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 NAD27 coordinate system was used throughout.

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

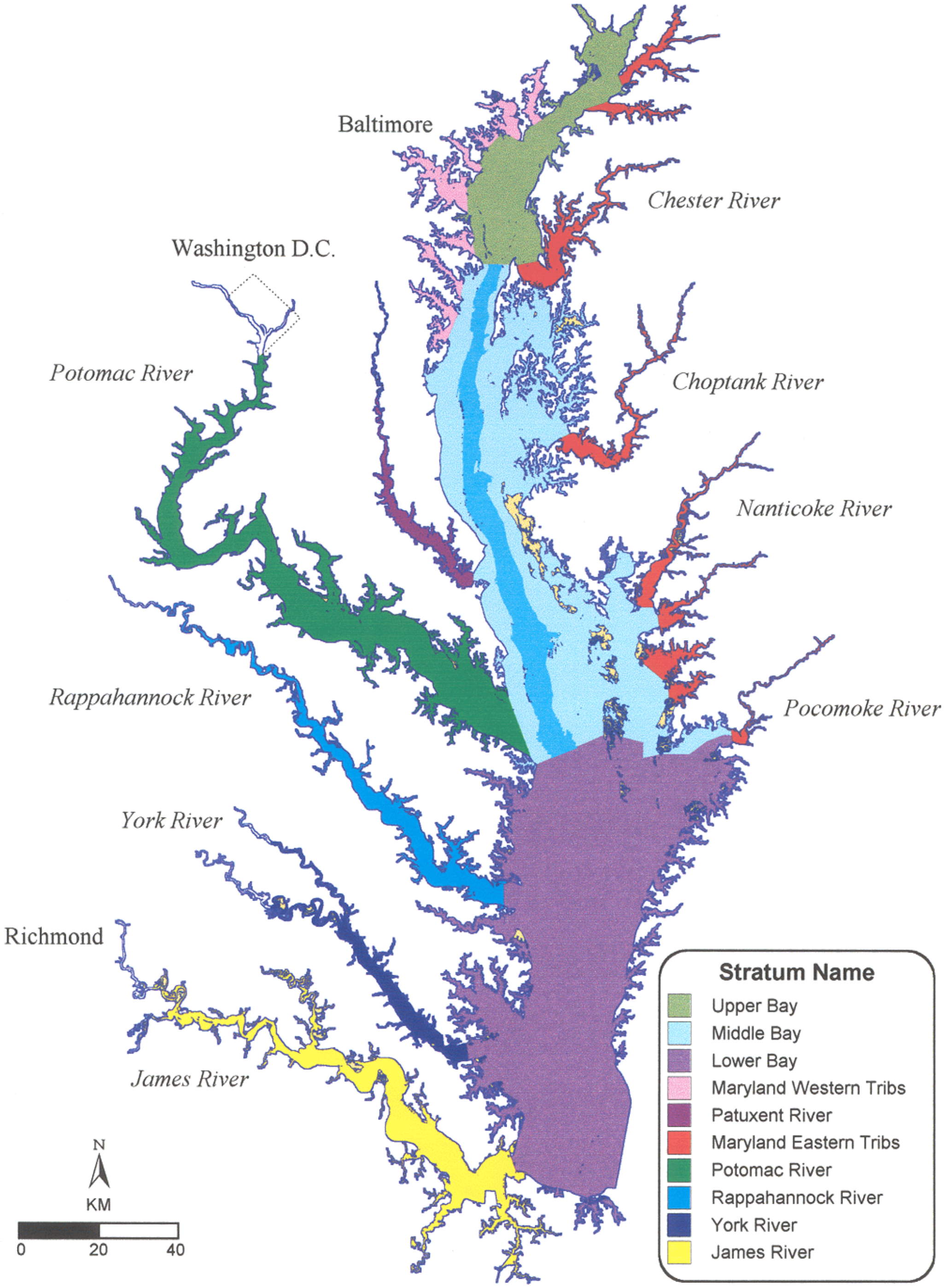


Figure 2-6. Chesapeake Bay-wide stratification scheme
measured at each fixed site. The profiles consisted of water quality measurements at 1 m

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 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 deep-water (more than 4 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	**Mollusca**
Eteone heteropoda	*Acteocina canaliculata*
Glycinde solitaria	*Corbicula fluminea*
Heteromastus filiformis	*Gemma gemma*
Marenzelleria viridis	*Haminoe solitaria*
Neanthes succinea	*Macoma balthica*
Paraprionospio pinnata	*Macoma mitchelli*
Streblospio benedicti	*Mulinia lateralis*
	Mya arenaria
	Rangia cuneata
	Tagelus plebeius

Crustacea	
Cyathura polita *Gammarus* spp. *Leptocheirus plumulosus*	
Miscellaneous	
Carinoma tremaphoros *Micrura leidyi*	

Silt-clay composition and carbon 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. 2000). 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

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

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:

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

For combined strata, the 95% confidence intervals were estimated as the proportion plus or minus twice the standard error. For individual strata (e.g., each of the 10 strata in 1996), the exact confidence interval was determined from tables.

3.0 TRENDS IN FIXED SITE BENTHIC CONDITION

Twenty-seven sites in areas targeted for pollution abatement and other management actions are monitored annually by the LTB program to assess whether benthic community condition is changing. This chapter presents B-IBI trend analysis results for all 27 sites. Our trend analysis methods are described in Section 2.4.

The B-IBI (Weisberg et al. 1997) 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 which 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. While we choose to emphasize trend analysis on the B-IBI because of interpretability in terms of bottom habitat condition, trends for individual attributes that comprise the B-IBI are also presented here. Examining attribute trends is the first step in identifying causes of changes in condition.

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.

Fifteen-year (1985-1999) trends are presented for 23 of the 27 trend sites. Eleven-year trends are presented for two sites in Baltimore Harbor (Stations 201 and 202) first sampled in 1989. Though the sampling period is shorter for two western shore tributaries (Back River, Station 203; and Severn River, Station 204, first sampled in 1995) five years of data are sufficient to determine recent trends at these sites if present. Trend site locations are presented in Figure 2-1.

B-IBI calculations and trend analysis for six stations located in areas with oligohaline or tidal freshwater salinities were updated this year using a new index recently developed for these habitats (Alden et al. 2000). Previously, trends for four oligohaline sites were conducted on B-IBI calculations according to Weisberg et al. (1997). Trends for two freshwater stations were first performed last year on an interim tidal freshwater B-IBI. Based on further research (Alden et al. 2000), indices for these two salinity habitats were improved and applied for the first time to the six fixed stations 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 are not valid for these six fixed stations.

3.1 RESULTS

Statistically significant B-IBI trends ($p<0.1$) were detected at 11 of the 27 sites (Table 3-1). Benthic community condition declined at five of these sites (significantly decreasing B-IBI trend) and improved at six sites. Currently, 13 stations meet the Goals and 14 fail the Goals whereas initially, 16 stations failed the Goals and only 11 met the Goals (Table 3-1). Trends in community attributes that are components of the B-IBI are presented in Table 3-2 (polyhaline and mesohaline stations), Table 3-3 (oligohaline and tidal freshwater stations), and Appendix A.

3.1.1 Declining Trends

All five declining sites were located in Bay tributaries. Three of the five were in the Patuxent River (Stations 71, 74, and 77) while the other two were located in the Choptank (Station 66) and Nanticoke (Station 62) Rivers.

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. The declining Patuxent River sites vary in benthic condition and degree of change (Table 3-1). Station 77 in the upper tidal Patuxent previously met the Restoration Goals but now fails, Station 74 in the mid-Patuxent still meets the Restoration Goals, and Station 71 in the deep, lower Patuxent has failed the goals since program inception.

Upper Patuxent Station 77 had the most pronounced decline. This site initially met the Restoration Goals but currently supports a degraded benthic community (Table 3-1). This station is declining at a rate of about 0.13 B-IBI units per year (Table 3-1). The proportion of samples failing the Goals increased from 18% prior to 1990 to 87% since 1995 (Table 3-4). Trends in several community attributes contributed to the declining trend in the overall B-IBI. Significant trends were observed in total abundance (increasing above upper threshold), total biomass (decreasing), and abundances of pollution-indicative (increasing) and pollution-sensitive (decreasing) species (Table 3-2, Appendix A). Although abundance of pollution-sensitive species is not currently included in the B-IBI for the low mesohaline habitat, this measure can be used (Weisberg et al. 1997) and has been used in previous years in the absence of biomass data.

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 increased from 5% before 1990 to 27% from 1995-99 (Table 3-4). The rate of decline in the B-IBI decreased somewhat with the addition of 1999 data. Through 1998 the rate of decline was 0.05 B-IBI units per year (Ranasinghe et al. 1999) whereas the rate of decline was 0.03 units per year through 1999 (Table 3-1).

Table 3-1. Trends in benthic community condition, 1985-1999. Trends were identified using the van Belle and Hughes (1984) procedure. Current mean B-IBI and condition are based on 1997-1999 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 (1997-1999)**	**Initial Condition (1985-1987 unless otherwise noted)**
		Potomac River		
36	$p < 0.05$	0.06	3.98 (Meets Goal)	3.04 (Meets Goal)
40	NS	0.00	3.22 (Meets Goal)	2.93 (Marginal)
43	NS	0.00	3.76 (Meets Goal)	3.71 (Meets Goal)
44	NS	0.00	2.78 (Marginal)	2.80 (Marginal)
47	NS	0.00	3.93 (Meets Goal)	3.89 (Meets Goal)

51	$p < 0.001$	0.08	3.52 (Meets Goal)	2.43 (Degraded)
52	NS	0.00	1.52 (Severely Degraded)	1.37 (Severely Degraded)
Patuxent River				
71	$p < 0.01$	-0.06	1.85 (Severely Degraded)	2.59 (Degraded)
74	$p < 0.05$	-0.03	3.49 (Meets Goal)	3.78 (Meets Goal)
77	$p < 0.001$	-0.13	2.11 (Degraded)	3.76 (Meets Goal)
79	NS	0.00	2.51 (Degraded)	2.58 (Degraded)
Choptank River				
64	$p < 0.05$	0.06	3.52 (Meets Goal)	2.65 (Marginal)
66	$p < 0.01$	-0.04	2.91 (Marginal)	3.33 (Meets Goal)
Maryland Mainstem				
26	$p < 0.05$	0.00	3.49 (Meets Goal)	3.16 (Meets Goal)
24	NS	0.03	3.30 (Meets Goal)	3.04 (Meets Goal)
15	NS	0.02	2.56 (Degraded)	2.22 (Degraded)
06	$p < 0.05$	0.04	3.19 (Meets Goal)	2.56 (Degraded)
01	$p < 0.05$	0.03	3.44 (Meets Goal)	2.93 (Marginal)
Maryland Western Shore Tributaries				
22	NS	0.02	2.69 (Marginal)	2.08 (Degraded)
23	NS	0.00	2.38 (Degraded)	2.49 (Degraded)
201	NS	0.00	1.31 (Severely Degraded)	1.10 (Severely Degraded) (a)
202	NS	0.00	1.31 (Severely Degraded)	1.40 (Severely Degraded) (a)
203	NS	0.00	1.80 (Severely Degraded)	1.89 (Severely Degraded) (b)

204	NS	0.00	3.78 (Meets Goal)	3.70 (Meets Goal) (b)
Maryland Eastern Shore Tributaries				
29	NS	0.00	2.42 (Degraded)	2.62 (Marginal)
62	$p < 0.1$	-0.03	2.82 (Marginal)	3.42 (Meets Goal)
68	NS	0.00	3.42 (Meets Goal)	3.51 (Meets Goal)

er temporal trends in benthic community attributes 1985-99.   Monotonic trends were ident
984) procedure.   ⇑: Increasing trend; ⇓: Decreasing trend.   *: p < 0.1; **: p < 0.05; ***: p < 0.01; shaded trend cells
indicate improving conditions; (a): trends based on 1989-1999 data; (b): trends based on 1995-1999 data; (c): attribute trenc
BI calculations when species specific biomass is unavailable; (e): attribute and trend are not included in the reported B-IBI.
dix A for further detail.

	Abundance	Biomass	Shannon Diversity	Indicative Abundance	Sensitive Abundance	Indicative Biomass (c)	Sensitive Biomass (c)	Abundanc Deep Depo Feeders
				Potomac River				
				⇑ ***				
			⇑ ***			⇓ **(e)		
		⇑ **	⇑ **	⇑ ***				
	⇑ **	⇓ ***	⇑ ***	⇓ ***	⇑ ***			⇓ ***(e)
						⇓ **	⇑ **	
				Patuxent River				
	⇓ **	⇓ ***		⇓ **(d)	⇓ **(d)			
	⇑ ***			⇑ ***	⇓ ***(d)			⇑ *(e)
	⇑ **	⇓ ***		⇑ ***	⇓ **(d)	⇓ *(e)	⇑ *	⇓ **(e)
				Choptank River				
			⇑ **		⇑ **(d)	⇑ **		
				Maryland Mainstem				
		⇑ **		⇓ **		⇓ ***(e)		
	⇑ *				⇑ **			⇓ **(e)
				⇓ **				⇓ ***(e)
								⇓ ***(e)
	⇑ ***				⇑ **(d)			
				Maryland Western Shore Tributaries				
	⇑ *				⇑ ***(d)			⇓ **(e)
	⇓ ***	⇓ *			⇑ **(d)			
						⇑*(e)		
					⇓*(d)	⇑ *(e)		
		⇓ **			⇑*(d)			
				Maryland Eastern Shore Tributaries				
	⇑ *		⇓ ***	⇓ ***				⇑ *(e)
		⇑ **	⇑ **		⇑ ***(d)			

er temporal trends in benthic community attributes at the oligohaline and tidal freshwater st
entified using the van Belle and Hughes (1984) procedure. ⇑: Increasing trend; ⇓: Decreasing trend
ells indicate increasing degradation; unshaded trend cells indicate improving conditions; (a): trends based on 1995-1999 data
nd (not significant). See Appendix A for further detail.

	Abundance	Tolerance Score	Freshwater Indicative Abundance	Oligohaline Indicative Abundance	Oligohaline Sensitive Abundance	Tanypodini to Chironomidae Ratio	Limnodrilus spp. Abundance	Abu D De Fe
Potomac River								
	⇓ **	⇓ **		NA	NA	NA		
	NA	⇑*	NA	⇓**	⇓***		NA	
Patuxent River								
				NA	NA	NA		⇓
Choptank River								
	NA		NA		⇓ **	⇑ ***	NA	
Maryland Western Shore Tributaries								
	NA	⇑ *	NA		⇑**	⇓*	NA	
Maryland Eastern Shore Tributaries								
	NA	⇓ ***	NA	⇓***	⇓ ***		NA	

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 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	1995-1999
Station 71			
N	21	10	15
Total abundance	28.6	80.0	86.7

Total biomass	9.5	60.0	100
Shannon-Wiener Index	42.9	60.0	40.0
Biomass of pollution sensitive taxa	--	88.9	93.3
B-IBI	76.1	100	100
Station 74			
N	21	8	15
Total abundance	0	37.5	40.0
Total biomass	61.9	50.0	33.3
Shannon-Wiener Index	4.8	12.5	13.3
Abundance of pollution indicative taxa	9.5	37.5	26.7
B-IBI	4.8	37.5	26.7
Station 77			
N	22	0	12
Total abundance	9.1	--	20.0
Total biomass	31.8	--	86.7
Shannon-Wiener Index	31.8	--	26.7
Abundance of pollution indicative taxa	13.6	--	86.7
B-IBI	18.2	--	86.7
Station 66			
N	12	8	12
Abundance of pollution indicative taxa	25.0	0	0
Abundance of pollution sensitive taxa	16.7	0	33.3
Tolerance Score	16.7	0	0
Abundance of Omnivore/Carnivore	91.7	25.0	16.7
Tanypodinae/Chironomidae Ratio	0	75.0	75.0
B-IBI	8.3	12.5	16.7
Station 62			
N	21	0	15
Total abundance	9.5	--	20.0
Total biomass	19.1	--	53.3

Shannon-Wiener Index	9.5	--	33.3
Abundance of pollution indicative taxa	0	--	6.7
B-IBI	9.5	--	26.7

Under the current rate of decline and without any change in current conditions (i.e., an impact from the recent oil spill at Chalk Point) this site should continue to meet the Goals for the next 15 years (B-IBI=3.49, Table 3-1). Here, trends in total abundance (increasing above upper threshold), abundance of pollution-indicative species (increasing), and abundance of pollution-sensitive (decreasing) species (Table 3-2, Appendix A) contributed to the declining trend in the B-IBI. Although an increase in benthic production and an increase in the abundance of pollution-indicative species (tolerant of higher temperatures) might be attributable to thermal impacts, power plant operation has a negligible effect on benthic communities in the Chalk Point region (Holland et al. 1989). Trends at Station 74 are more likely to reflect regional water quality problems affecting the Patuxent River watershed.

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). Additionally, the proportion of samples failing the Goals has increased over time. Since 1990, all samples have failed the Goals (Table 3-4). In 1998, this station was classified as “degraded” but Ranasinghe et al. 1999 predicted that at the current rate of decline the station was expected to classify as “severely degraded.” With the addition of 1999 data the station is now classified as severely degraded with a B-IBI of 1.85 (Table 3-1). Declining trends in total abundance, total biomass, and abundance of pollution-sensitive species were observed (Table 3-2, Appendix A). These declines are indicative of increasing dissolved oxygen stress.

Station 66 in the Choptank River is located in the oligohaline portion of the river; therefore, this is the first year that the new oligohaline B-IBI (Alden et al. 2000) has been applied. This station had a declining trend that caused the station to go from initially meeting the goals to currently failing the goals marginally (Table 3-1). The percentage of samples failing the goals since 1995 is still somewhat low (17%) but this is an increase over the 8% failing since before 1990 (Table 3-4). An increasing trend in the Tanypodinae/Chironomidae ratio was likely to contribute to the declining condition at this site (Table 3-3), where higher values are indicative of impaired conditions. Additionally, the abundance of pollution-sensitive species declined over time at this site (Table 3-3). One bright spot for this station is the increasing trend in the abundance of carnivores/omnivores. This attribute has improved from failing conditions in 92% of the samples before 1990 to only 17% failing since 1995 (Table 3-4).

The trend detected at Station 62 in the Nanticoke River is new with the addition of the 1999 data. The trend is only minimally significant at the probability level of 0.1 but is indicative of declining conditions (Table 3-1). The station initially met the Goals but now fails marginally. The percentage of samples failing the goals increased from 10% before 1990 to 27% since 1995 (Table 3-4). Attributes contributing to the declining conditions included abundance (increasing above the upper threshold) and Shannon-Wiener diversity (decreasing) (Table 3-2). Although the biomass attribute is not significantly declining, the number of samples failing to meet this attribute goal has increased from 19% before 1990 to 53% since 1995 (Table 3-4).

The declines in the B-IBI at Stations 62, 66, 74, and 77 can be 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. The fact that increasing trends in the abundance percentage of pollution indicative species and/or decreasing trends in the abundance percentage of pollution sensitive species were observed at stations 66, 74, and 77 (Tables 3-2 and 3-3) supports our eutrophic condition inference.

At Station 77 in the upper-Patuxent, biomass decreased from acceptable to failing levels even as abundance increased from acceptable to failing levels in an apparent contradiction of the “moderate eutrophication” diagnosis. However, the biomass decrease was due to the disappearance of the bivalve *Macoma balthica* from this site. The clam’s decline may be attributable to salinity changes in the river as summer salinity decreased below 7 ppt, the approximate limit of its distribution in Chesapeake Bay, and spring values decreased below 1 ppt. The additional impact of predation by crabs and waterfowl on *M. balthica* cannot be quantified at this time.

3.1.2 Improving Trends

Three of the six sites with improving trends (Stations 01, 06, and 26) were located in the mainstem of the Bay (Table 3-1). Of the remaining three, two were located in the Potomac River (Stations 36 and 51) and one was located in the Choptank River (Station 64). The six stations were located in habitats of diverse salinity and sediment type (Table 2-1). All six sites currently meet the Benthic Community Restoration Goals (Table 3-1). Stations 06 and 51 improved from failing conditions to currently meeting the Goals, while

Stations 01and 64 improved from marginal to currently meeting the Goals. Stations 26 and 36 initially met the Restoration Goals and still meet the Goals.

Stations 01 and 26 had a significantly improving trend through 1998 at the probability level of 0.1 (Ranasinghe et al. 1999). With the addition of 1999 data, the trend became stronger at Station 01 but was still weak at Station 26 (Table 3-1) and contributed little to interpretations. Additionally, an improving trend at Station 22 in the Patapsco River through 1998 disappeared with the addition of the 1999 data.

Stations 01 and 06 in the mid Maryland Bay near Calvert Cliffs improved by 0.03 and 0.04 B-IBI units a year since 1985 (Table 3-1). The percentage of samples failing the Restoration Goals decreased dramatically at Station 06 from 73% before 1990 to 13% since 1995 (Table 3-5). The percentage of samples failing to meet the individual attribute goals for biomass, Shannon-Wiener, and abundances of pollution-indicative and sensitive taxa decreased overtime at both stations (Table 3-5). Improving trends in abundance, biomass, and biomass of pollution-indicative species (declining) contributed most to the increases in the B-IBI at Station 01 (Table 3-2). Improving trends in abundance and abundance of pollution-sensitive taxa contributed to the improvement at Station 06 (Table 3-2).

Station 26 in the low mesohaline mainstem near Pooles Island has always met the goals (Table 3-1) and since 1990 no sample has failed the goals (Table 3-5). Improving trends in total abundance and the abundance of pollution-sensitive taxa (Table 3-2), as well as a decrease in the percentage of biomass samples failing to meet the goal (Table 3-5) contributed to the improving trends at this station.

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 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	1995-1999
Station 01			
N	22	11	15
Total abundance	36.4	0	33.3
Total biomass	54.6	18.2	13.3
Shannon-Wiener Index	36.4	18.2	13.3
Abundance of pollution indicative taxa	22.7	27.3	13.3
Abundance of pollution sensitive taxa	22.7	45.5	13.3
B-IBI	18.2	45.5	13.3
Station 06			
N	22	0	15
Total abundance	72.7	--	46.7
Total biomass	68.2	--	60.0
Shannon-Wiener Index	50.0	--	26.7
Abundance of pollution indicative taxa	40.9	--	0
Abundance of pollution sensitive taxa	22.7	--	0
B-IBI	72.7	--	13.3

Table 3-5. (Continued)

	Samples Failing Restoration Goals (%)		

Measure	1985-1989	1990-1994	1995-1998
Station 26			
N	21	7	15
Total abundance	9.5	0	0
Total biomass	85.7	85.7	53.3
Shannon-Wiener Index	23.8	14.3	20.0
Abundance of pollution indicative taxa	0	14.3	20.0
B-IBI	14.3	0	0
Station 36			
N	22	9	15
Total abundance	45.5	11.1	20.0
Abundance of pollution indicative taxa	4.5	0	0
Tolerance Score	54.6	44.4	13.3
Abundance of deep deposit feeders	0	0	0
Abundance of Limnodrilus spp.	0	0	0
B-IBI	36.4	22.2	20.0
Station 51			
N	22	13	12
Total abundance	4.6	7.7	0
Total biomass	13.7	30.8	16.7
Shannon-Wiener Index	66.7	50.0	20.0
Abundance of pollution sensitive taxa	72.7	61.5	41.7
Abundance of pollution indicative taxa	50.0	38.5	0
B-IBI	77.3	61.5	41.7
Station 64			

N	18	10	12
Total abundance	38.9	20.0	16.7
Total biomass	5.6	0	8.3
Shannon-Wiener Index	72.2	50.0	25.0
Abundance of pollution indicative taxa	61.1	0	0
B-IBI	72.2	20.0	0

Station 36 is located in the tidal freshwater habitat of the upper Potomac River. This is the first year that the new freshwater B-IBI (Alden et al. 2000) has been applied to this station. A significantly improving trend was detected at this station which initially met the goals barely but now meets the goals with a B-IBI of 3.98 (Table 3-1). The substantial improvement can be attributed to significantly increasing improvement in total abundance (declining from excess abundance), tolerance score (declining to improving condition) and abundance of deep deposit feeders (declining to improving condition, Table 3-3). The tolerance score improved from 55% of the samples failing to meet the attribute goal before 1990 to only 13% failing to meet the attribute goal since 1995 (Table 3-5). The majority of the abundance decrease is attributable to the introduced bivalve *Corbicula fluminea*, which has been decreasing in abundance since its peak in the late 1980s. Also, pollution-indicative oligochaetes have been decreasing over time. Declines in oligochaete taxa also led to an improving tolerance score for this station.

Station 51 in the shallow polyhaline Potomac River improved from degraded conditions at a rate of 0.08 B-IBI units a year to currently meeting the Restoration Goals (Table 3-1). The proportion of samples failing the goals decreased from 77% prior to 1990 to 42% since 1995 (Table 3-5). Improving trends in total abundance, Shannon-Wiener diversity, and pollution-indicative and pollution-sensitive taxa abundance contributed to the improving B-IBI trend (Table 3-2).

Station 64 in the Choptank River improved from a marginal condition at a rate of 0.06 B-IBI units a year to currently meeting the Restoration Goals (Table 3-1). The proportion of samples failing the Goals decreased from 72% before 1990 to none failing the Goals after 1994 (Table 3-5). Increasing trends in the Shannon-Wiener Diversity Index and pollution-sensitive taxa abundance contributed to the improving B-IBI trend (Table 3-2).

The improving benthic condition at the freshwater station in the Potomac River (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 15-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.

Improving benthic condition at all of the five higher salinity sites is related to changes in abundance. Stations 06, 26, and 51 had a significant increase in total abundance over the 15-year time span. Correspondingly, the abundance of pollution-sensitive taxa increased at Stations 06, 26, 51, and 64 during the same time period.

Station locations and observed B-IBI attribute changes at these higher salinity sites are consistent with decreases in the extent, intensity, duration, or frequency of low dissolved oxygen episodes. Increases from low to acceptable levels in a variety of benthic attributes such as abundance, diversity, and pollution-sensitive and indicative species abundances are probably indicative of reduced oxygen stress. All of these sites (with the exception of Station 26) are located in shallower waters near areas that are known to develop hypoxia in the summer. Currently, the dissolved oxygen (DO) record obtained at these sites is insufficient to support or refute our hypothesis. Point in time measurement data do not adequately reflect oxygen stress and advection of low DO waters from surrounding depths. The benthos may be a more sensitive indicator of oxygen stress because they are continuously exposed to hypoxic events whenever they occur, whereas instrument measurements are often inadequate to characterize oxygen conditions over long-term periods.

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 Bay-wide 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 emphasizes quantifying change at selected locations, the probability sampling approach emphasizes quantifying 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 1994-1999 sampling represents the first efforts to develop area-based Maryland Bay-wide bottom condition statements.

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 1999 Maryland and Virginia tidal Chesapeake Bay-wide probability-based sampling and adds a sixth year of results to LTB’s tidal 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. 2000).

4.2 RESULTS

Of the 150 Maryland samples collected with the probability-based design in 1999, 71 met and 79 failed the Chesapeake Bay Benthic Community Restoration Goals (Figure 4-1). Of the 250 probability samples collected in the entire Chesapeake Bay in 1999, 119 met and 131 failed the Restoration Goals. The Virginia sampling results are presented in Figure 4-2.

An improvement in Maryland Bay-wide condition was observed from 1994 to 1997 followed by a decline in 1998 and 1999 (Figure 4-3). The changes in condition were within the uncertainty margins of the estimates. 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 1999, 63% (±5% SE) of the Maryland Bay was estimated to fail the Restoration Goals, compared with 69% (± 4%) in 1998, 57% (±5%) in 1997, 58% (±5%) in 1996, 60% (±5%) in 1995, and 65% (±6%) in 1994. Expressed as area, 3,935± 188 km^2 of the tidal Maryland Chesapeake Bay remained to be restored in 1999. Previous years estimations were 4,312±188, 3,537± 169, 3,603±175, 3,726±183, and 4,262±268 km^2 in 1998, 1997, 1996, 1995, and 1994, respectively.

Like in previous years, the Potomac River and the mid-Bay mainstem were in the poorest condition of the six Maryland strata, while the Patuxent River and the upper Bay were in the best condition (Figure 4-4). From 1994-1999, at least 60% of the Potomac

River (765-1,173 km^2) failed the Restoration Goals each year (Figure 4-5) and well over half of that area (just less than half the Potomac River bottom) was severely degraded (Table 4-1). The mid-Bay Maryland mainstem had the largest amount of degraded area (>2,000 km^2, including the deep trough) and about three-quarters of that area was severely degraded, although the amount of severely degraded area declined to 63% in 1999. In contrast, more than half the area in the eastern shore tributaries met the Restoration Goals almost every year and less than 10% of the eastern tributary bottom area has been severely degraded in the last four years.

Although the Bay-wide estimate of area failing the Restoration Goals decreased in 1999, the decrease was within the margin of uncertainty of the estimate (Figure 4-6). An estimate of 48% (±8%) or 5,527±443 km^2 of the tidal Chesapeake Bay failing the Restoration Goals in 1999 was calculated by weighting results from the 250 probability sites in Maryland and Virginia for 1999. Comparable values for 1998 were 58% (±9%) or 6,753 ±604 km^2, 51% (±9%) or 5,891±540 km^2 for 1997, and 48% (±9%) or 5,520 ±492 km^2 for 1996.

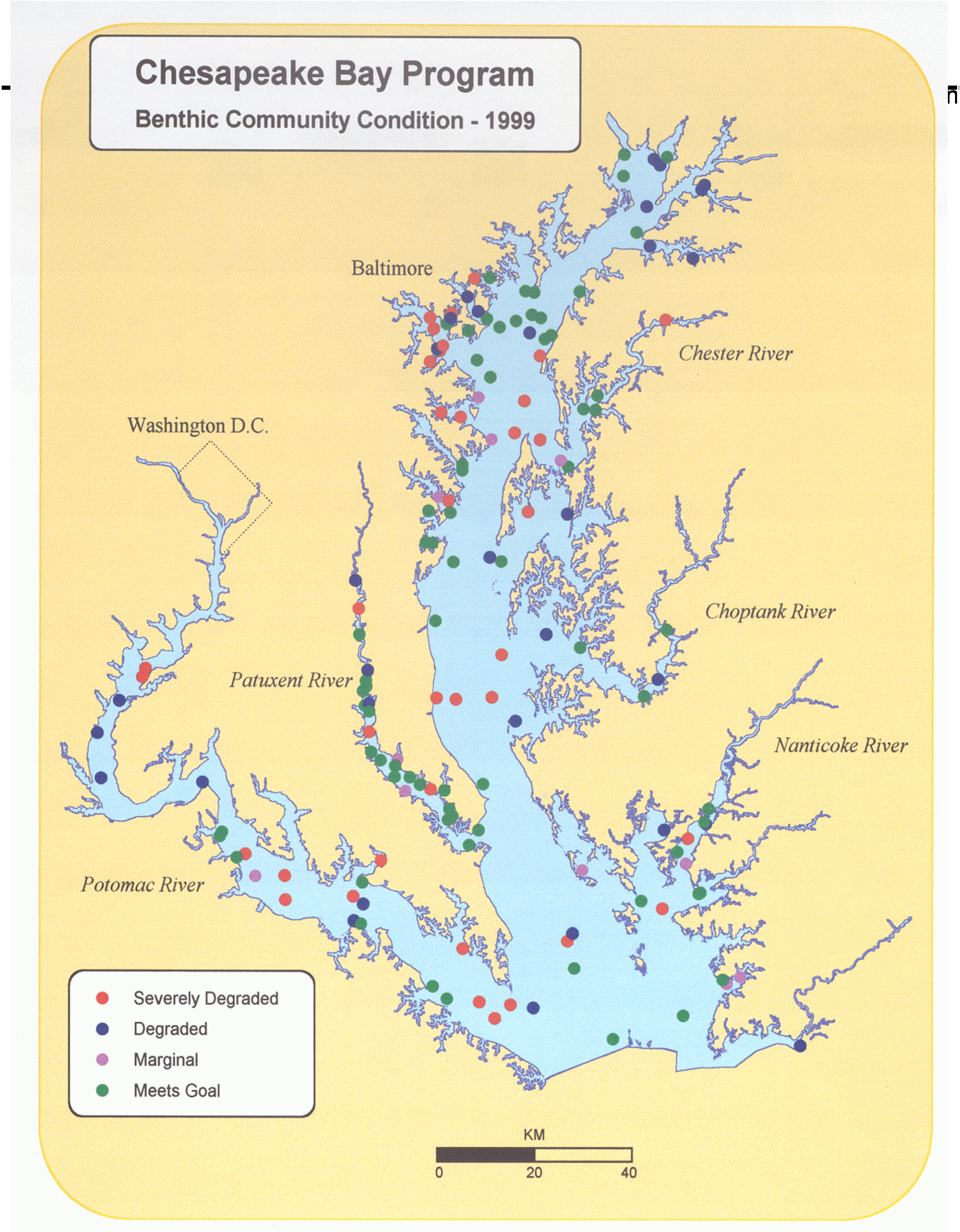


Figure 4-1. Results of probability-based benthic sampling of the Maryland Chesapeake Bay and its tidal tributaries in 1999. Each sample was evaluated in context of the Chesapeake Bay Benthic Community Restoration Goalss.

Chesapeake Bay 1999

Area Failing Restoration Goal

Condition:

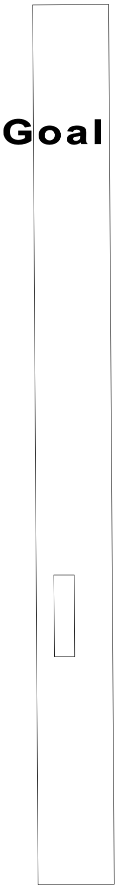
Deep Trough Degraded

Severe Degr.

Marginal

Chesapeake Bay

Stratum Area Failing Restoration Goal



Condition: **Deep Trough Degraded** **Severe Degr.** **Marginal**

Chesapeake Bay

Area Failing Restoration Goal

Condition:

Deep Trough Degraded

Severe Degr.

Marginal

Baywide, the mid-Bay Maryland mainstem and the Potomac River were in the worst condition in 1999 (Figure 4-4, Table 4-1), with 68% and 72% percent of the bottom area failing the Restoration Goals, respectively. Among the Virginian tributaries, the York and the Rappahannock Rivers were in worst condition, each with 64% of the area failing the Restoration Goals in 1999. However, the area of severely degraded bottom was comparatively small in these estuaries. Over the 1994-1999 study period, the mid-Bay Maryland mainstem, the Potomac River, the York River, and the Rappahannock River were overall in worst condition (Figure 4-5). The Patuxent River and the upper and lower (Virginia) Bay mainstems were in the best condition in 1999 (Figure 4-4), although the lower (Virginia) Bay mainstem and the Maryland eastern tributaries were in the best condition overall, averaging less than 40% degraded area over the study period (Figure 4-5, Table 4-1).

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.

Region	Year	Severely Degraded	Degraded	Marginal
Chesapeake Bay	1996	2939	1569	1012
	1997	2796	1959	1137
	1998	3755	1892	1106
	1999	2951	1946	630
Maryland	1994	2746	1238	278
	1995	2603	647	476
	1996	2556	924	123
	1997	2288	829	420

	1998	2601	1164	547
	1999	2253	1358	323
Virginia	1996	384	645	889
	1997	508	1130	716
	1998	1155	727	559
	1999	698	587	306
Potomac River	1994	793	396	0
	1995	510	204	51
	1996	612	255	0
	1997	510	357	51
	1998	561	510	102
	1999	561	306	51
Patuxent River	1995	46	10	5
	1996	41	20	0
	1997	20	5	10
	1998	31	26	5
	1999	15	15	10

Table 4-1. Continued

Region	Year	Severely Degraded	Degraded	Marginal
Maryland Upper Western Tributaries	1995	58	58	12
	1996	129	35	0
	1997	117	23	0
	1998	94	23	0
	1999	117	47	12
	1995	150	107	0

Maryland Eastern Tributaries	1996	21	150	21
	1997	21	43	21
	1998	21	150	0
	1999	43	150	86
Upper Bay Mainstem (Maryland)	1995	345	63	0
	1996	157	157	0
	1997	126	94	31
	1998	94	251	31
	1999	126	126	63
Mid-Bay Mainstem (Maryland)	1995	1493	204	408
	1996	1595	306	102
	1997	1493	306	306
	1998	1799	204	408
	1999	1391	715	102
Lower Bay Mainstem (Virginia)	1996	165	330	824
	1997	165	824	659
	1998	824	330	494
	1999	494	165	165
Rappahannock River	1996	119	60	0
	1997	134	89	15
	1998	60	134	30
	1999	74	119	45
York River	1996	45	37	37
	1997	45	52	15
	1998	52	45	7

	1999	75	30	15
James River	1996	55	219	27
	1997	164	164	27
	1998	219	219	27
	1999	55	273	82

In four 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 of failing sites classified as severely degraded (Table 4-2). The Potomac River had the largest percentage of depauperate sites (85%), 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.

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 1999 (N = 100). 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	39	76.5	34	75.6
Mid Bay	35	59.3	41	69.5
Potomac River	44	57.9	56	84.8
Patuxent River	21	53.8	28	73.7
York River	29	47.5	27	45.0
Rappahannock River	26	44.1	30	54.5
Upper Bay	16	40.0	22	68.8
James River	18	32.1	19	47.5
Lower Bay	10	30.3	24	72.7
Eastern Tributaries	5	14.7	16	59.3

* Oligohaline sites excluded because abundance and biomass are not used to score oligohaline sites.

In the James River and the Maryland Eastern Tributaries, 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.

Table 4-3. Sites failing the Restoration Goals (scored 1.0) for excess abundance, excess biomass, or both as a percentage of sites failing the Goals (B-IBI < 3), 1996 to 1999 (N = 100). Strata are in decreasing percentage order.

Stratum	**Number of Sites**	**As a Percentage of Sites Failing the Goals***
James River	13	32.5
Eastern Tributaries	7	25.9
Rappahannock River	14	25.5
Upper Bay	8	25.0
York River	14	23.3
Patuxent River	8	21.1
Western Tributaries	9	20.0
Mid Bay	10	16.9
Potomac River	6	9.1
Lower Bay	1	3.0

* Oligohaline sites excluded because abundance and biomass are not used to score oligohaline sites.

4.3 DISCUSSION

As found for previous years, about half of the Chesapeake Bay and sixty percent of the Maryland Bay failed the Chesapeake Bay Benthic Community Restoration Goals. Much of this area, however, had B-IBI values greater than two, indicating only mild degradation that should respond quickly to moderate improvements in water quality. Nearly half (44-52%) the degraded Chesapeake Bay bottom (2,998-3,064 km^2 1996-1999) and about a third (29-43%) of the degraded Maryland Bay bottom (1,047-1,711 km^2 1994-1999) were only slightly impaired. Of the additional 2,500 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. On-going LTB efforts involving coordination with the Chesapeake Bay Program will assess which of the remaining 1,700-1,900 km^2 of severely degraded benthos were located in areas of periodic hypoxia, and which are located in areas that the Chesapeake Bay modeling efforts predict are likely to improve in response to nutrient reduction efforts.

The estimates of degraded area for regions measured in multiple years were generally similar between years, with most estimates included within the confidence interval of other years (Figure 4-5). Some exceptions, such as estimates for the Potomac River in 1998, can be explained by clumping of the random sites in perennially degraded areas such as those typically affected by summer low dissolved oxygen. Spatial patterns of degradation were also similar between years (Figures 4-1 and 4-2, Ranasinghe et al. 1996, 1997, 1998, 1999). While between-year differences were small, they were in the direction expected from the abnormally strong 1994 and 1998 spring freshets and the cooler, milder summers experienced in 1996 and 1997. 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). The larger amount of area failing the Benthic Community Restoration Goals in the major Chesapeake Bay tributaries for 1994 and 1998 was most likely linked to low dissolved oxygen conditions. Conversely, smaller temperature gradients existing when summer surface water temperatures are lower weaken stratification and reduce hypoxia, and may account for the smaller amount of area failing the Restoration Goals in 1996 and 1997.

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). However, all of the York River sites in 1999 failed the goals because of insufficient abundance or biomass. 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 benthic communities, masking any effect from anthropogenic nutrient inputs to the system. Also, hypoxia is not a problem for most of the river.

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). Therefore, our results confirm suspicions that dissolved oxygen stress is the more serious and widespread problem affecting benthic communities in the Bay. The results also confirm that dissolved oxygen stress is the most common problem for benthic communities in the Potomac 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. The multi-year review examined program objectives, analysis techniques, and power of the programs to detect trends. One objective that emerged from the program review process was a goal of producing a Bay-wide area estimate of degraded benthic communities with known and acceptable uncertainty. That goal has now been accomplished in four consecutive years.

Bay-wide 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. Recently, a series of statistical and simulation studies were conducted to evaluate and optimize the Benthic Index of Biotic Integrity (Alden et al. 2000). In addition, new metric and threshold combinations produced last year for the tidal freshwater and oligohaline habitats were evaluated and optimized during these studies. The results of Alden et al. (2000) 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. (2000) 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.

B-IBI improvements 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 (Table 6 in Alden et al. 2000) were applied to the 1999 data and retroactively to previous years, recalculating previously presented results after applying the new thresholds. 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 bay-wide application of the Benthic Community Restoration Goals enters its fifth 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. Independent assessments should provide the evidence that sites classified as failing or meeting the Restoration Goals are in fact degraded or non-degraded. On-going oxygen mapping efforts to quantify the relationships between dissolved oxygen and benthic condition and establish areal goals for healthy benthic communities in response to nutrient reduction efforts is a step in that direction.

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 revised Goals can be recalculated in future years as the thresholds are improved so that trends in the area meeting the Goals can be compared in a consistent and rigorous fashion.

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APPENDIX A

FIXED SITE COMMUNITY ATTRIBUTE 1985-1999 TREND ANALYSIS RESULTS

e A-1. Summer temporal trends in benthic community attributes 1985-99. Shown is the median slope
trends were identified using the van Belle and Hughes (1984) procedure. ⇑: Increasing trend; ⇓: Decreasing trenc
0.01; shaded trend cells indicate increasing degradation; unshaded trend cells indicate improving conditions; (a): trends based on 1989-1999 d
-1999 data; (c): attribute trend based on 1990-1999 data; (d): attributes are used in B-IBI calculations when species specific biomass is unavail
ot included in the reported B-IBI.

	Abundance	Biomass	Shannon Diversity	Indicative Abundance	Sensitive Abundance	Indicative Biomass (c)	Sensitive Biomass (c)	Abundance Deep Deposit Feeders
Potomac River								
	-60.00	0.00	0.01	0.55***	-0.78(d)	0.00(e)	0.56	-0.26(e)
	-10.71	-0.02	0.05***	-0.25	0.71(d)	-0.14**(e)	-0.03	-0.74(e)
	-16.00	3.85**	0.04**	0.36***	-0.73(d)	-0.01(e)	-0.41	-0.41(e)
*	61.68**	-0.25***	0.03***	-1.72***	0.74***	0.00(e)	-1.82(e)	-2.25***(e)
	0.23	0.00	0.00	0.00(d)	0.00(d)	0.00**	0.00**	0.00(e)
Patuxent River								
*	-49.55**	-0.14***	-0.01	-2.31**(d)	-0.42**(d)	1.98	0.00	0.00(e)
*	280.00***	-0.79	-0.02	0.67***	-1.65***(d)	0.01(e)	-0.03	1.31*(e)
*	83.64**	-0.46***	-0.03	4.45***	-1.30**(d)	-4.97*(e)	6.53*	-2.17**(e)
Choptank River								
	45.89	0.23	0.04**	-0.01(d)	1.04**(d)	0.13**	-0.70	-0.11(e)
Maryland Mainstem								
	37.14	0.10**	0.01	-0.55**	0.70	-0.26***(e)	0.52(e)	-0.16(e)
	40.00*	-0.02	0.01	-0.43	1.33**	-0.01(e)	6.00(e)	-0.67**(e)
	24.62	-0.05	0.00	-1.26**	0.10	-0.08(e)	-1.99(e)	-1.36***(e)
	2.27	-0.22	-0.02	-0.20(d)	0.04(d)	0.01	0.07	-1.63***(e)
	67.47***	0.63	0.01	0.21	1.97**(d)	0.00(e)	-0.01	-0.01(e)
Maryland Western Shore Tributaries								
	74.53*	0.01	0.00	1.33	0.44***(d)	0.05(e)	0.00	-1.17**(e)
	-120.00***	-0.07*	0.01	0.00	0.17**(d)	0.12(e)	-4.54	-0.23(e)
	12.99	0.00	0.01	0.00	0.00(d)	6.67*(e)	0.00	0.00(e)
	60.61	0.00	0.00	0.00	0.00*(d)	4.76*(e)	0.00	0.00(e)
	-329.54	-0.73**	0.04	2.51(d)	3.13*(d)	0.02	-1.64	0.98(e)
Maryland Eastern Shore Tributaries								
	133.33*	-0.03	-0.05***	-0.26***	-0.23(d)	0.00(e)	-7.48	1.65*(e)
	-99.39	0.71**	0.04**	0.21	3.02***(d)	0.00(e)	0.04	-0.62(e)

Appendix Table A-2. Summer temporal trends in benthic community attributes at the oligohaline and ti stations 1985-99. Shown is the median slope of the trend. Monotonic trends were identified us Belle and Hughes (1984) procedures. ⇑: Increasing trend; ⇓: Decreasing trend. *: p < 0.1; **: p < 0.05; ***: p < 0.01 indicate increasing degradation; unshaded trend cells indicate improving conditions; (a): trends based on 1995-1999 data; NA: attrib

Station	B-IBI	Abundance	Tolerance Score	Freshwater Indicative Abundance	Oligohaline Indicative Abundance	Oligohaline Sensitive Abundance	Tanypodini to Chironomidae Ratio	Limnodrilus spp. Abundance	Abur Deep Fee
Potomac River									
036	0.06**	-172.87**	-0.05**	0.66	NA	NA	NA	-1.32	-1
040	0.00	NA	0.03*	NA	-2.14**	-3.17***	0.00	NA	N
Patuxent River									
079	0.00	162.08	-0.01	0.12	NA	NA	NA	-1.25	-1.
Choptank River									
066	-0.04***	NA	0.14	NA	-0.81	-2.98**	5.56***	NA	N
Maryland Western Shore Tributaries									
203(a)	0.00	NA	0.04*	NA	0.00	0.00**	0.00*	NA	N
Maryland Eastern Shore Tributaries									
029	0.00	NA	-0.14***	NA	-3.39***	-0.81***	0.00	NA	N

APPENDIX B

FIXED SITE B-IBI VALUES, SUMMER 1999

Appendix Table B-1. Fixed site B-IBI values, Summer 1999

Station	Sampling Date	Latitude (NAD83 Decimal Degrees)	Longitude (NAD83 Decimal Degrees)	B-IBI	Status
01	10-Sep-99	38.41907	76.41853	4.00	Meets Goal
06	10-Sep-99	38.44233	76.44333	3.33	Meets Goal
15	10-Sep-99	38.71507	76.51433	2.33	Degraded
22	8-Sep-99	39.25483	76.58767	1.80	Severely Degraded
23	8-Sep-99	39.20825	76.52377	1.80	Severely Degraded
24	8-Sep-99	39.12200	76.35567	2.66	Marginal
26	9-Sep-99	39.27128	76.29020	3.80	Meets Goal
29	10-Sep-99	39.47950	75.94483	3.00	Meets Goal
36	13-Sep-99	38.76968	77.03645	3.80	Meets Goal
40	13-Sep-99	38.35767	77.23157	3.00	Meets Goal
43	21-Sep-99	38.38402	76.98880	3.40	Meets Goal
44	21-Sep-99	38.38550	76.99600	3.40	Meets Goal
47	21-Sep-99	38.36447	76.98422	4.20	Meets Goal
51	21-Sep-99	38.20533	76.73833	4.33	Meets Goal
52	21-Sep-99	38.19173	76.74765	1.33	Severely Degraded
62	20-Sep-99	38.38383	75.85033	2.60	Degraded
64	7-Sep-99	38.59078	76.06982	3.33	Meets Goal
66	23-Sep-99	38.80038	75.92330	2.60	Degraded
68	15-Sep-99	39.13270	76.07867	3.40	Meets Goal
71	31-Aug-99	38.39500	76.54917	1.33	Severely Degraded
74	31-Aug-99	38.54737	76.67532	3.40	Meets Goal
77	30-Aug-99	38.60433	76.67533	3.00	Meets Goal
79	30-Aug-99	38.74928	76.68943	2.20	Degraded
201	8-Sep-99	39.23417	76.49750	1.40	Severely Degraded
202	8-Sep-99	39.21773	76.56422	1.40	Severely Degraded
203	9-Sep-99	39.27500	76.44450	1.80	Severely Degraded
204	10-Sep-99	39.00683	76.50527	3.67	Meets Goal

APPENDIX C

RANDOM SITE B-IBI VALUES, SUMMER 1999

Appendix Table C-1. Random site B-IBI values, Summer 1999

Station	Sampling Date	Latitude (NAD83 Decimal Degrees)	Longitude (NAD83 Decimal Degrees)	B-IBI	Status
MET-06401	23Sep99	37.95125	75.64808	2.60	Degraded
MET-06402	23Sep99	38.06052	75.82043	2.67	Marginal
MET-06403	23Sep99	38.06798	75.83007	3.67	Meets Goal
MET-06404	23Sep99	38.07297	75.78920	2.67	Marginal
MET-06405	20Sep99	38.22057	75.88799	4.00	Meets Goal
MET-06406	20Sep99	38.22272	75.88472	4.00	Meets Goal
MET-06407	20Sep99	38.27458	75.91837	2.67	Marginal
MET-06408	20Sep99	38.29455	75.93907	4.00	Meets Goal
MET-06409	20Sep99	38.31896	75.91425	2.00	Severely Degraded
MET-06410	20Sep99	38.34629	75.87349	2.60	Degraded
MET-06411	20Sep99	38.34824	75.87604	3.80	Meets Goal
MET-06412	20Sep99	38.37244	75.86756	4.20	Meets Goal
MET-06413	07Sep99	38.57214	76.02202	3.33	Meets Goal
MET-06414	07Sep99	38.60279	75.98974	2.33	Degraded
MET-06415	07Sep99	38.69142	75.97033	4.20	Meets Goal
MET-06416	07Sep99	38.97916	76.20816	4.00	Meets Goal
MET-06417	07Sep99	38.99009	76.22634	2.67	Marginal
MET-06418	07Sep99	39.08165	76.14584	4.67	Meets Goal
MET-06419	07Sep99	39.08321	76.17414	3.33	Meets Goal
MET-06420	07Sep99	39.10741	76.14145	3.00	Meets Goal
MET-06421	15Sep99	39.24443	75.98268	1.40	Severely Degraded
MET-06422	09Sep99	39.35436	75.91997	2.20	Degraded
MET-06423	09Sep99	39.37524	76.02264	2.20	Degraded
MET-06424	09Sep99	39.47793	75.90138	2.20	Degraded
MET-06425	09Sep99	39.48593	75.89443	2.20	Degraded
MMS-06501	20Sep99	37.95937	76.08420	3.67	Meets Goal
MMS-06502	20Sep99	38.00296	75.92177	4.00	Meets Goal
MMS-06503	20Sep99	38.01304	76.27109	2.33	Degraded
MMS-06505	20Sep99	38.08480	76.17745	3.67	Meets Goal
MMS-06506	20Sep99	38.13314	76.19327	1.67	Severely Degraded

Appendix Table C-1. Random site B-IBI values, Summer 1999

Station	Sampling Date	Latitude (NAD83 Decimal Degrees)	Longitude (NAD83 Decimal Degrees)	B-IBI	Status
MMS-06507	20Sep99	38.14693	76.18226	2.33	Degraded
MMS-06508	20Sep99	38.19388	75.97228	2.00	Severely Degraded
MMS-06509	20Sep99	38.20686	76.02239	3.67	Meets Goal
MMS-06510	20Sep99	38.25972	76.16084	2.67	Marginal
MMS-06511	10Sep99	38.32858	76.40561	3.33	Meets Goal
MMS-06512	23Sep99	38.33425	75.97037	2.20	Degraded
MMS-06513	10Sep99	38.41076	76.39706	3.00	Meets Goal
MMS-06514	07Sep99	38.52448	76.32307	2.33	Degraded
MMS-06515	10Sep99	38.56111	76.46378	1.67	Severely Degraded
MMS-06516	10Sep99	38.56320	76.50928	1.67	Severely Degraded
MMS-06517	07Sep99	38.56598	76.37957	1.00	Severely Degraded
MMS-06518	07Sep99	38.64191	76.35805	2.00	Severely Degraded
MMS-06519	07Sep99	38.65744	76.17361	3.00	Meets Goal
MMS-06520	07Sep99	38.67993	76.25360	2.33	Degraded
MMS-06521	10Sep99	38.80582	76.47636	3.00	Meets Goal
MMS-06522	07Sep99	38.80883	76.36297	3.00	Meets Goal
MMS-06523	07Sep99	38.81544	76.39009	2.33	Degraded
MMS-06524	07Sep99	38.89508	76.20889	2.33	Degraded
MMS-06525	07Sep99	38.89809	76.30136	2.00	Severely Degraded
MMS-06526	10Sep99	38.70056	76.51547	4.00	Meets Goal
MWT-06301	10Sep99	38.83869	76.52627	4.00	Meets Goal
MWT-06302	10Sep99	38.83978	76.54172	3.00	Meets Goal
MWT-06303	10Sep99	38.89402	76.48490	3.33	Meets Goal
MWT-06304	10Sep99	38.89613	76.53647	3.00	Meets Goal
MWT-06305	10Sep99	38.91473	76.48929	1.67	Severely Degraded
MWT-06306	10Sep99	38.92120	76.51248	2.67	Marginal
MWT-06307	10Sep99	38.96958	76.45892	3.00	Meets Goal
MWT-06308	10Sep99	38.97974	76.45911	3.00	Meets Goal
MWT-06309	08Sep99	39.06464	76.46431	1.67	Severely Degraded
MWT-06310	08Sep99	39.07220	76.51064	1.67	Severely Degraded

Appendix Table C-1. Random site B-IBI values, Summer 1999

Station	Sampling Date	Latitude (NAD83 Decimal Degrees)	Longitude (NAD83 Decimal Degrees)	B-IBI	Status
MWT-06311	08Sep99	39.16194	76.54006	1.40	Severely Degraded
MWT-06312	08Sep99	39.18218	76.51673	1.33	Severely Degraded
MWT-06313	08Sep99	39.18552	76.52249	2.33	Degraded
MWT-06314	08Sep99	39.19124	76.51055	1.33	Severely Degraded
MWT-06315	08Sep99	39.21836	76.45033	4.60	Meets Goal
MWT-06316	08Sep99	39.22088	76.53227	1.67	Severely Degraded
MWT-06317	08Sep99	39.22995	76.50186	3.40	Meets Goal
MWT-06318	08Sep99	39.24003	76.49198	2.60	Degraded
MWT-06319	09Sep99	39.24044	76.40678	3.40	Meets Goal
MWT-06320	08Sep99	39.24105	76.54120	1.00	Severely Degraded
MWT-06321	08Sep99	39.24943	76.49109	1.40	Severely Degraded
MWT-06322	09Sep99	39.25311	76.42822	2.20	Degraded
MWT-06323	09Sep99	39.27880	76.45363	2.20	Degraded
MWT-06324	09Sep99	39.31185	76.43791	1.80	Severely Degraded
MWT-06325	09Sep99	39.31383	76.40192	3.00	Meets Goal
PMR-06101	20Sep99	37.99327	76.36072	1.33	Severely Degraded
PMR-06102	20Sep99	38.01784	76.32464	1.33	Severely Degraded
PMR-06103	20Sep99	38.02235	76.39763	2.00	Severely Degraded
PMR-06104	20Sep99	38.02697	76.47349	3.00	Meets Goal
PMR-06105	20Sep99	38.04849	76.50670	3.33	Meets Goal
PMR-06106	20Sep99	38.11680	76.43777	2.00	Severely Degraded
PMR-06107	21Sep99	38.15805	76.67741	3.00	Meets Goal
PMR-06108	21Sep99	38.16301	76.69437	2.33	Degraded
PMR-06109	21Sep99	38.19322	76.67323	2.33	Degraded
PMR-06110	21Sep99	38.19761	76.85469	1.33	Severely Degraded
PMR-06111	21Sep99	38.20663	76.69664	1.33	Severely Degraded
PMR-06112	21Sep99	38.23120	76.67645	3.33	Meets Goal
PMR-06113	21Sep99	38.23875	76.92684	2.67	Marginal
PMR-06114	21Sep99	38.24056	76.85756	1.67	Severely Degraded
PMR-06115	21Sep99	38.27076	76.97128	4.20	Meets Goal

Appendix Table C-1. Random site B-IBI values, Summer 1999

Station	Sampling Date	Latitude (NAD83 Decimal Degrees)	Longitude (NAD83 Decimal Degrees)	B-IBI	Status
PMR-06116	21Sep99	38.27099	76.63285	1.33	Severely Degraded
PMR-06117	21Sep99	38.27719	76.95109	1.33	Severely Degraded
PMR-06118	21Sep99	38.31540	77.00712	3.00	Meets Goal
PMR-06120	13Sep99	38.40373	77.05503	2.20	Degraded
PMR-06121	13Sep99	38.40583	77.29363	2.20	Degraded
PMR-06122	13Sep99	38.48650	77.30468	2.20	Degraded
PMR-06123	13Sep99	38.54500	77.25527	2.20	Degraded
PMR-06124	13Sep99	38.58816	77.20268	1.80	Severely Degraded
PMR-06125	13Sep99	38.60335	77.19617	1.80	Severely Degraded
PMR-06126	21Sep99	38.30762	77.01226	3.80	Meets Goal
PXR-06201	10Sep99	38.30146	76.42711	3.00	Meets Goal
PXR-06202	31Aug99	38.35282	76.46766	3.00	Meets Goal
PXR-06203	31Aug99	38.36542	76.47523	3.33	Meets Goal
PXR-06204	31Aug99	38.39649	76.57833	2.67	Marginal
PXR-06205	31Aug99	38.39814	76.48695	3.00	Meets Goal
PXR-06207	31Aug99	38.40031	76.51967	2.00	Severely Degraded
PXR-06208	31Aug99	38.40764	76.54475	3.00	Meets Goal
PXR-06209	31Aug99	38.42060	76.60535	3.00	Meets Goal
PXR-06210	31Aug99	38.42060	76.56862	3.00	Meets Goal
PXR-06211	31Aug99	38.44027	76.60348	3.33	Meets Goal
PXR-06212	31Aug99	38.45002	76.63834	3.00	Meets Goal
PXR-06213	31Aug99	38.45302	76.59890	2.67	Marginal
PXR-06214	31Aug99	38.46432	76.66092	3.33	Meets Goal
PXR-06215	31Aug99	38.50036	76.66691	2.00	Severely Degraded
PXR-06216	31Aug99	38.53680	76.66727	3.33	Meets Goal
PXR-06217	31Aug99	38.54619	76.67754	3.33	Meets Goal
PXR-06218	31Aug99	38.55073	76.66875	2.33	Degraded
PXR-06219	30Aug99	38.57242	76.68330	4.20	Meets Goal
PXR-06220	30Aug99	38.58052	76.67523	4.20	Meets Goal
PXR-06221	30Aug99	38.59105	76.67688	3.80	Meets Goal

Appendix Table C-1. Random site B-IBI values, Summer 1999

Station	Sampling Date	Latitude (NAD83 Decimal Degrees)	Longitude (NAD83 Decimal Degrees)	B-IBI	Status
PXR-06222	30Aug99	38.60979	76.67346	2.20	Degraded
PXR-06223	30Aug99	38.67293	76.69423	3.80	Meets Goal
PXR-06224	30Aug99	38.71923	76.69683	1.40	Severely Degraded
PXR-06225	30Aug99	38.76966	76.70568	2.20	Degraded
PXR-06226	31Aug99	38.34642	76.47767	3.00	Meets Goal
UPB-06601	08Sep99	39.02617	76.39120	2.67	Marginal
UPB-06602	08Sep99	39.03843	76.33676	1.33	Severely Degraded
UPB-06603	08Sep99	39.09540	76.31436	1.33	Severely Degraded
UPB-06604	08Sep99	39.10054	76.42314	2.67	Marginal
UPB-06605	08Sep99	39.13684	76.39589	4.00	Meets Goal
UPB-06608	08Sep99	39.16672	76.42862	3.33	Meets Goal
UPB-06609	09Sep99	39.17680	76.27905	2.00	Severely Degraded
UPB-06610	09Sep99	39.20649	76.26894	3.33	Meets Goal
UPB-06611	09Sep99	39.21305	76.25392	4.33	Meets Goal
UPB-06612	09Sep99	39.21707	76.30488	2.33	Degraded
UPB-06613	09Sep99	39.22635	76.37629	4.60	Meets Goal
UPB-06614	09Sep99	39.23779	76.33750	3.80	Meets Goal
UPB-06615	09Sep99	39.24404	76.27928	3.33	Meets Goal
UPB-06616	09Sep99	39.24936	76.30093	3.40	Meets Goal
UPB-06617	09Sep99	39.28913	76.29551	3.80	Meets Goal
UPB-06618	09Sep99	39.29142	76.31613	3.80	Meets Goal
UPB-06619	09Sep99	39.29203	76.18747	3.00	Meets Goal
UPB-06620	09Sep99	39.39904	76.05436	3.80	Meets Goal
UPB-06621	09Sep99	39.44599	76.03099	2.60	Degraded
UPB-06622	14Sep99	39.49970	76.08807	3.40	Meets Goal
UPB-06623	14Sep99	39.52018	76.00145	2.60	Degraded
UPB-06624	14Sep99	39.53080	76.01552	2.60	Degraded
UPB-06625	14Sep99	39.53432	75.98478	3.00	Meets Goal
UPB-06626	08Sep99	39.02662	76.27585	1.33	Severely Degraded
UPB-06627	14Sep99	39.53807	76.08602	3.00	Meets Goal