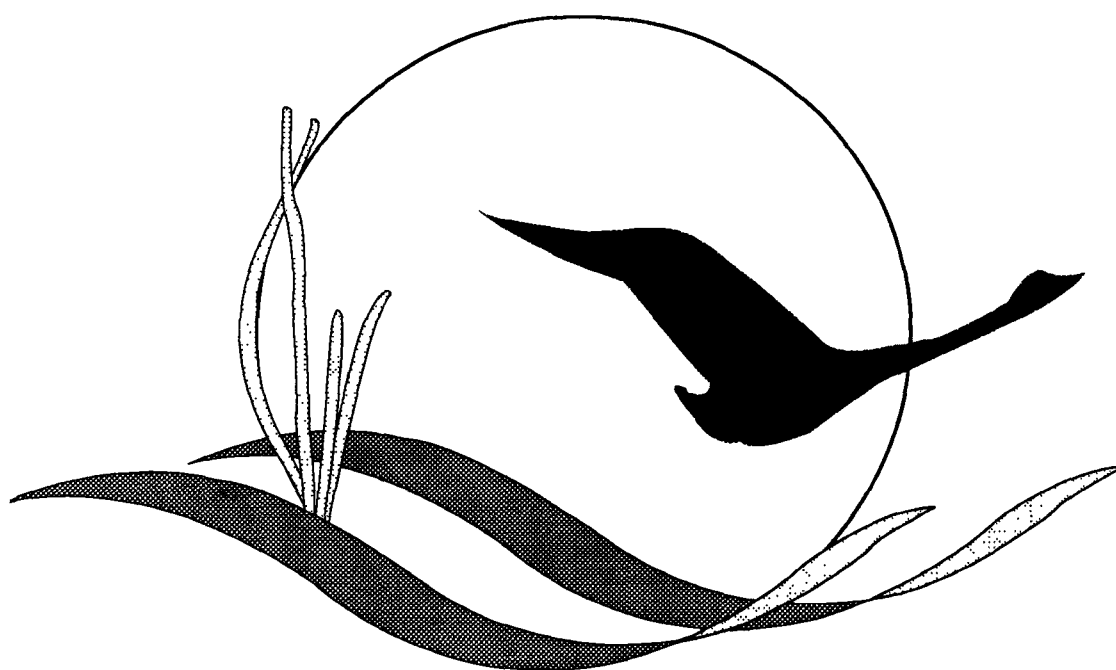


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Chesapeake Bay Benthic Community Restoration Goals



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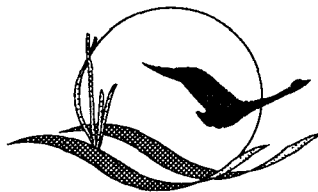
==== **Chesapeake Bay Program** =====



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US EPA Region III
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Philadelphia, PA 19103

Chesapeake Bay Benthic Community Restoration Goals

March 1994



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CHESAPEAKE BAY BENTHIC COMMUNITY RESTORATION GOALS

Prepared for

U.S. Environmental Protection Agency
Chesapeake Bay Program Office
Annapolis, Maryland

and

The Maryland Governor's Council on Chesapeake Bay Research Fund
Chesapeake Bay Research and Monitoring Division
Tidewater Administration
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FOREWORD

This document "Chesapeake Bay Benthic Community Restoration Goals" was prepared by Versar Inc., for Mr. Rich Batiuk of the Chesapeake Bay Program Office, United States Environmental Protection Agency under Contract Number 68-D9-0166 and Dr. Paul Miller of the Chesapeake Bay Research and Monitoring Division, Tidewater Administration, Maryland Department of Natural Resources under Contract Number CB92-006-004 by the Maryland Governor's Council on Chesapeake Bay Research Fund. The purpose of the report is to develop restoration goals for Chesapeake Bay benthic infaunal communities.

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We gratefully acknowledge the contributions of Tim Morris and Nancy Mountford of Cove Corporation for updating the taxonomy and helping to identify and resolve taxonomic conflicts among the many Chesapeake Bay data sets. We also thank B. Richkus, L. Scott, F. Holland, S. Jordan, R. Eskin, and M. Luckenbach for reading and commenting on early drafts of the report, and R. Newport and C. DeLisle for assisting in document production.

EXECUTIVE SUMMARY

Benthic macroinvertebrate assemblages have been an integral part of the Chesapeake Bay monitoring program since its inception due to their ecological importance and their value as biological indicators. The condition of benthic assemblages reflects an integration of temporally variable environmental conditions and the effects of multiple types of environmental stresses. As such, benthic assemblages provide a useful complement to more temporally variable chemical and water quality monitoring measures.

While assessments using benthic monitoring data have been useful for characterizing changes in environmental conditions at individual sites over time, and for relating the condition of sites to pollution loadings and sources, the full potential of these assessments for addressing larger management questions, such as "What is the overall condition of the Bay?" or "How does the condition of various tributaries compare?" has not yet been realized. Regional-scale assessments of ecological status and trends using benthic assemblages are limited by the fact that benthic assemblages are strongly influenced by naturally varying habitat elements, such as salinity, sediment type, and depth. Such natural variability confounds interpretation of differences in the benthic community differences as simple responses to anthropogenic environmental perturbations. An additional limitation is that different sampling methodologies used in various programs often constrain the extent to which the benthic data can be integrated for a unified assessment.

The objective of this project was to develop a practical and conceptually sound framework for assessing benthic environmental conditions in Chesapeake Bay that would address the general constraints and limitations just described. This was accomplished by standardizing benthic data from several different monitoring programs to allow their integration into a single, coherent data base. From that data base a set of measures (Chesapeake Bay Benthic Restoration Goals) was developed to describe characteristics of benthic assemblages expected at sites having little evidence of environmental stress or disturbance. Using these goals, benthic data from any part of the Bay could be compared to determine whether conditions at that site met, were above, or were below expectations defined for reference sites in similar habitats.

The approach used to develop these restoration goals was similar to that used by Karr et al. (1986) to develop an index of biological integrity for freshwater fish. A set of candidate attributes believed to have properties that differentiate high and low quality assemblages were first identified, and reference sites believed to be "minimally impacted" were designated. Properties of the biotic assemblages at these sites were then compared to assemblage properties at all other sites. Properties that differed significantly between these two groups of sites were selected as metrics to be included in the restoration goals. An index was developed to assist managers in identifying the extent to which these restoration goals were being achieved. The Restoration Goals Index (RGI) is calculated as the average score of metrics, after each metric is scored as 5, 3, or 1, depending on whether its value at an

individual site approximated, deviated slightly, or deviated strongly from its value at the best reference sites.

The restoration goals were developed based on available data from seven benthic survey projects: the Maryland and Virginia Chesapeake Bay Benthic Monitoring Programs, U.S. EPA's Environmental Monitoring and Assessment Program (1990), the Maryland and Virginia Biogenics studies, a James River study, and a study in the Wolf Trap area of the Virginia Bay. These seven projects were selected for several reasons: each provided data readily available on electronic media; collectively they provided sample representation in all salinity habitats of Chesapeake Bay; and all used a 0.5 mm sieve in sample processing, which was a critical aspect of the study, since the numbers and types of organisms collected depend on the mesh size used to sieve the sediment.

The attributes incorporated into the restoration goals included metrics from each of the following five categories:

- benthic biodiversity measures
- measures of assemblage abundance and biomass
- life history strategy measures
- measures of activity beneath the sediment surface
- feeding guild measures

Restoration goals were developed independently for eight habitat classes defined by salinity and sediment type to ensure that natural differences in benthic communities related to these habitat factors did not confound interpretation of the indices. The eight habitat classes were determined by cluster analysis of the composite data set.

Restoration goals were developed using data from only the summer period, July 15th through September 30th. This restriction avoided seasonal variation that would confound interpretation of benthic community responses to environmental degradation. The summer sampling period was common to six of the seven benthic survey projects. Using data from a different season would have reduced the data available because the various programs differed substantially in the extent of sampling during other seasons of the year. An index developed for summer was desirable because benthic communities are expected to show the greatest response to pollution stress during the summer.

Three approaches were used to validate the goals and the accompanying index. First, the Restoration Goal Index was computed for all samples taken from each reference site to test whether expectations of RGI values greater than three were met. This test indicated a high degree of correct classification; classification efficiency was more than 95% in five of the

seven habitat classes. The lowest correct classification efficiency for reference sites was 92.3% in the high mesohaline mud habitat class. Second, RGI values were computed for all samples taken from degraded habitats to test whether expectations of RGI values less than three were met. This test used data that had been excluded from development of the RGI; therefore, it was an independent validation test. A high level of classification efficiency was observed in this test; classification efficiency was 85% or better for degraded sites in five of the six habitat classes in which data from degraded sites were available. The one habitat class that did not validate as well was tidal freshwater. For the third validation test, sites that were sampled more than once during the summer of any year were identified, and the RGI was computed for each visit. RGI values at each site were evaluated for differences in status between visits within each year to ascertain the stability of the index. Instability of the index would indicate an unacceptable signal-to-noise ratio in the attributes. The results indicated that the RGI index was relatively stable. The correlation between RGI values for the first and second visits exceeded 80% for all habitats.

The validation results indicate that these preliminary restoration goals are effective for distinguishing between sites of high quality and those of lower quality in six of the seven habitats for which data were available for goal development. The only habitat class for which the restoration goals did not validate well was tidal freshwater. Although restoration goals validated well, additional analysis and development of goals appears to be appropriate before the goals are applied rigorously for environmental management purposes. Steps for further goal development are recommended.

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I. INTRODUCTION

Background

A large number of environmental monitoring efforts have arisen from the need for information about the condition of ecological resources and the responses of those resources to anthropogenic activities. Although chemical measures continue to be a part of most monitoring efforts, interest in biological measures of environmental condition is increasing. Information about biological resources augments chemical monitoring information and can be more useful to environmental resource managers. Most environmental regulations and contaminant control measures are designed to protect biotic resources, since these are the primary concern of environmental resource managers and the public. The condition of biological resources, therefore, provides a more direct measure of the effectiveness of environmental regulations for protecting the environment.

Another reason for interest in biological measures of environmental condition is their ability to integrate temporally variable environmental conditions and multiple environmental stresses. Chemical conditions, especially those describing water quality, are often variable and difficult to characterize. Biological resources integrate this temporal variability and facilitate environmental characterization. The condition of biological resources also represents an integrated response to multiple environmental stresses. In addition to responding to chemical exposure, biological resources also respond to nonchemical stresses such as habitat loss, diversion of water flow, and additions of terrigenous sediments.

Benthic Indicators

Foremost among the biological indicators suggested for assessment of environmental conditions in estuaries are those based upon the abundance, biomass, species composition and richness of bottom-dwelling (benthic) invertebrates. The attributes that make benthic assemblages reliable and sensitive indicators of ecological condition (Bilyard 1987) include

- limited mobility - Members of benthic assemblages generally have limited mobility, and cannot avoid adverse conditions (Gray 1979); therefore, the condition of these communities reflects local environmental conditions.
- habitat - Benthos live in sediments, where exposure to contaminants and low dissolved oxygen concentrations generally is most severe.
- life-span - Benthic macroinvertebrates generally have life spans ranging from months to several years; therefore, population and community level responses to environmental stress or disturbance are reflected in a reasonable period of time (Wass 1967).

- response to multiple stresses - Benthic assemblages are taxonomically diverse and their members encompass multiple feeding modes and trophic levels; thus, they display a wide range of physiological tolerances and respond to multiple types of stress (Pearson and Rosenberg 1978; Rhoads et al. 1978; Boesch and Rosenberg 1981).
- integrated response - Because of their diversity and life-span, benthic assemblages integrate environmental conditions present for weeks or months prior to a sampling event. This ability to integrate local conditions provides information that cannot be obtained from point-in-time physical and chemical measures of water quality.

For these reasons, benthic macroinvertebrate assemblages are considered good indicators of environmental conditions and have been extensively used to describe local ecological status and trends in a wide range of aquatic environments (Dauer et al. 1988, 1989; Holland et al. 1988, 1989).

The utility of benthic invertebrates as biological indicators is also derived from their ecological and economic importance. Ecologically, benthic invertebrates are some of the most important components of estuarine habitats and may represent the largest standing stock of organic carbon (Frithsen 1989). They are important links between primary producers and higher trophic levels (Virnstein 1977; Holland et al. 1980, 1989; Dauer et al. 1982; Baird and Ulanowicz 1989; Diaz and Schaffner 1990). Components of the benthos, such as polychaete worms and shrimp-like crustaceans, contribute significantly to the diets of economically important bottom-feeding juvenile and adult fishes such as spot and croaker (Chao and Musik 1977; Homer and Boynton 1978; Virnstein 1979; Homer et al. 1980).

In addition to their trophic importance, the activities of the benthos significantly affect oxygen, nutrient, and carbon cycles and may control the coupling of benthic and pelagic processes (Kemp and Boynton 1981; Boynton et al. 1982; Officer et al. 1984). The burrowing and sediment reworking activities of polychaetes and bivalves influence the depth to which oxygen penetrates the sediment-water interface, affecting the rate at which nutrients and contaminants are lost from the sediments to the overlying water column (Rhoads and Young 1970; Aller 1980; Blackburn and Henriksen 1983). The feeding activities of the benthos can directly affect planktonic components of the estuarine ecosystem and the concentrations of particles in the water column. Large filter-feeding bivalves effectively remove plankton and other suspended material from the water column and, thus, can improve water clarity (Cloern 1982; Officer et al. 1982; Holland et al. 1989). For example, a filter-feeding model (Holland et al. 1989) indicated that, during each day in the summer, suspension feeding bivalves potentially filter nearly all (84 to 100%) of the water overlying shallow (less than seven meters deep) regions in the Potomac and Patuxent rivers.

Statement of the Problem

Benthos have been included as integral components of Chesapeake Bay monitoring programs for many years. The state of Maryland has monitored benthos regularly since July 1984, collecting an average of 450 samples per year. This program builds upon other monitoring data that date back to the 1970s (Ranasinghe et al. 1993). The Commonwealth of Virginia instituted a similar program in March 1985, which collects about 240 samples per year (Dauer et al. 1989). In addition to these programs, which are specific to the Chesapeake Bay, national programs also collect samples in the Bay. For example, the U.S. Environmental Protection Agency's Environmental Monitoring and Assessment Program (EMAP) has collected approximately 60 samples from the Chesapeake Bay and its tidal tributaries each year since 1990 (Weisberg et al. 1993).

Existing monitoring programs have thoroughly described the benthic communities at various sites within the Chesapeake Bay system. This information has been used to characterize environmental conditions in the Bay and to demonstrate changing conditions (Holland et al. 1989; Dauer 1991). Benthic assessments, however, have yet to reach their full potential to provide information to environmental resource managers about triggers and endpoints for restoration activity.

The interpretation of information produced by monitoring benthic communities is currently limited because there is no clear definition of the characteristics expected for benthic assemblages in nondegraded habitats. Without this definition, it is difficult to quantitatively identify benthic assemblages that indicate degraded environmental habitats. These expectations were recently defined for a few benthic community attributes for the Virginia portion of Chesapeake Bay (Dauer 1993). Most assessments to date, however, have been limited to examining differences in condition at near-field and far-field sites with similar habitat type, or examining changes in condition over time at specific sites. These types of assessments do not lend themselves to addressing general management questions, such as What is the overall status of the Bay across all sites? Are certain large portions of the Bay more degraded than others? or What remediation activities are needed to improve degraded habitats?

The development of expectations for benthic assemblages in relatively nondegraded estuarine areas is an important step toward using measures of benthic condition in estuarine assessments. These expectations

- provide a means to assess measures of benthic abundance, biomass, and species richness quantitatively;
- establish criteria with which to determine the extent of degraded habitats in Chesapeake Bay and identify those bottom habitats most in need of water quality or habitat restoration;

- provide a well defined endpoint for restoration activities; and
- permit intermediate determinations of progress (or the lack thereof) toward attaining goals.

Defining expectations for benthic communities in nondegraded habitats in Chesapeake Bay is a fundamental prerequisite to providing state and federal agencies with the information needed to plan and evaluate the effectiveness of restoration activities.

Historically, efforts to identify characteristics of benthic assemblages associated with environmentally nondegraded and degraded areas have been limited. In part, this was due to the strong influence of habitat on the composition of benthic communities. The complexities of identifying characteristics for each type of habitat (where habitat is defined by salinity, sediment type, and depth) were a stumbling block, and most benthic assessments were limited to comparisons of benthic assemblages within similar habitats. Comparisons across habitats were infrequently attempted. Benthic assemblages are used more frequently in site-specific assessments, where natural variability is minimized, and in studies of trends, where variability is minimized by periodically returning to the same site or area (Pearson 1982; Rosenberg and Möller 1979). One limitation is the paucity of data with which to develop expectations for nondegraded environmental conditions. Few living resource monitoring programs collect adequate data, over large enough array of habitat types, for sufficiently long periods of time for investigators to feel confident about defining "expectations" for living resources.

Recently, there have been several efforts to develop living resource community measures with broader application. For example, Karr et al. (1986) developed the Index of Biotic Integrity (IBI) to characterize the condition of freshwater fish communities in streams. Hilsenhoff (1982) developed an index that reflects the condition of benthic macroinvertebrate assemblages in streams. Word (1978) developed the Infaunal Trophic Index (ITI) based upon the species composition of benthic communities in Southern California coastal areas. Dauer (1993) developed expected values for several benthic infaunal community measures for the Virginia portion of Chesapeake Bay. More recently, a benthic index was developed for the U.S. EPA's Environmental Monitoring and Assessment Program (EMAP) using benthic infaunal measurements from estuaries between Cape Cod and the mouth of the Chesapeake Bay (Weisberg et al. 1993).

Although some of these approaches are promising and resolve the interpretational needs of their specific studies, none are directly applicable to all the benthic data collected for Chesapeake Bay monitoring programs. For instance, the method employed by Dauer (1993) was based on data from the Virginia Benthic Monitoring Program, which samples only a subset of benthic habitat types present in Chesapeake Bay. Applying the EMAP benthic index in its present form requires using standard EMAP sample collection and sample processing protocols; however, several different types of sampling gear and processing protocols were used in the projects for which Chesapeake Bay benthic macroinfaunal data are

available. More importantly, the EMAP index was derived to interpret benthic data for the range of estuarine habitats present in the entire mid-Atlantic region. A greater degree of sensitivity for describing conditions within Chesapeake Bay is probably possible if a similar index is developed using only data from Chesapeake Bay habitats.

Objectives of this Report

This report describes an effort to define the expectations for benthic communities in nondegraded bottom habitats of the Chesapeake Bay. The specific objectives were to

- use existing data to establish expectations (restoration goals) for benthic communities in nondegraded bottom habitats of the Chesapeake Bay;
- develop an index that measures goal attainment; and
- identify areas in which future research may be helpful for refining, and decreasing uncertainty in, the identified restoration goals.

This report describes development of the Chesapeake Bay Benthic Community Restoration Goals, and a Restoration Goal Index (RGI) that can be used to assess whether goals are being met. The approach used to develop the goals and the index, and the results of analytical efforts, are detailed in Chapter II. A discussion of results and recommendations for the future are presented in Chapter III.

II. APPROACH TO SETTING GOALS

Approach

The approach used for developing Chesapeake Bay Benthic Restoration Goals was similar to that used by Karr et al. (1986) to develop an index of biological integrity (IBI) for freshwater fish and includes three complementary activities: selecting community attributes that differ in degraded and undegraded areas (goal attributes); identifying values that differentiate between degraded and undegraded areas for each selected attribute (setting goals); and combining attribute results so that the condition of communities in areas of unknown status can be determined (developing an index). Attributes are selected by identifying a set of reference sites that are believed to be "minimally impacted." Properties of the biotic assemblages at these sites are then compared with the same properties at all other sites, and properties that differ significantly between these two groups of sites are selected. Goals for each of these attributes, or metrics, are established based on the response at reference sites. The index is the average score of metrics after each metric is scored as 5, 3, or 1, depending on whether its value at an individual site approximates, deviates slightly from, or deviates strongly from its value at the best reference sites.

The general IBI approach was adopted here because it results in a quantitative statement of condition that can be used to compare assemblage status over space or time. In addition, the use of multiple attributes provides a more reliable indicator of condition than indices based on single attributes. Incorporation of multiple attributes also provides flexibility in index application, since indices can be developed even if particular data sets are missing information about selected attributes. Flexibility is particularly valuable in working with benthos, since not all types of data are collected by all benthic sampling programs in Chesapeake Bay.

Implementing this approach involved seven steps (Figure 1):

- Modify the data sets to be used for goal development to ensure their compatibility. This step included activities such as ensuring common taxonomic nomenclature and level of identification.
- Define the temporal and spatial strata for which goals will be developed. Benthic macroinvertebrate assemblage composition and abundance vary with season and habitat. These effects must either be corrected for or eliminated by stratification.
- Identify reference and degraded sites for each of these strata. The reference sites are the basis for selecting goal attributes and setting goals; degraded sites are used to validate the goals.

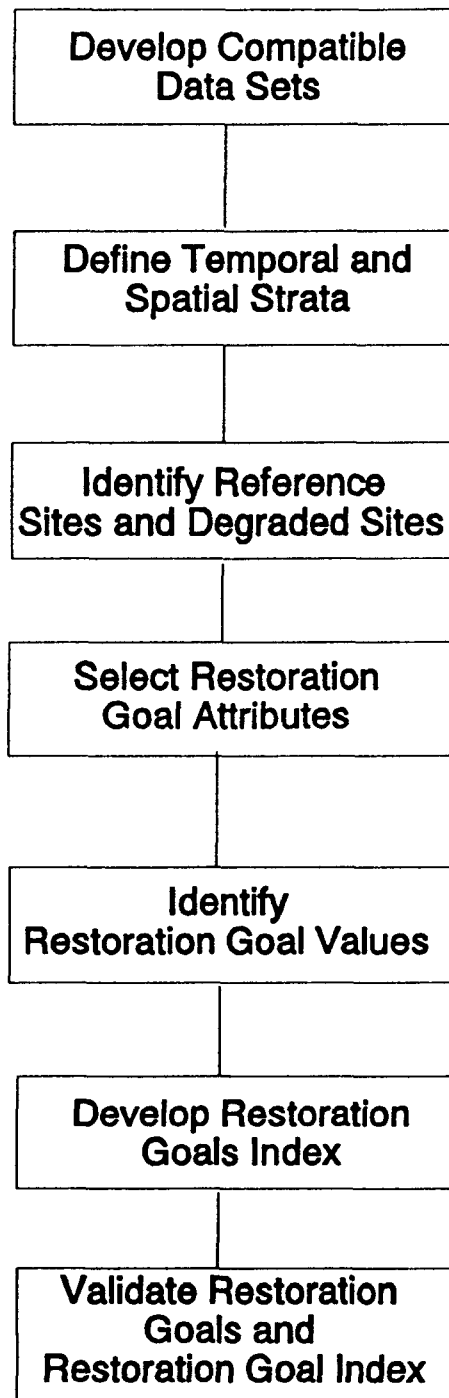


Figure 1. Steps in the development of Chesapeake Bay benthic community restoration goals

- Select benthic assemblage attributes to be included in the restoration goals (restoration goal attributes).
- Determine goal values for each of the restoration goal attributes based on their levels at reference sites.
- Develop a scheme for combining restoration goal attributes into a Restoration Goal Index.
- Validate the restoration goals and Restoration Goal Index based on values for restoration goal attributes at degraded sites.

Each of these steps is described in detail below.

Develop Compatible Data Sets

Data from seven benthic survey projects were used for goal development: the Maryland (Ranasinghe et al. 1992) and Virginia (Dauer et al. 1989) Chesapeake Bay Benthic Monitoring Programs, the U.S. EPA's Environmental Monitoring and Assessment Program (EMAP; Weisberg et al. 1992), the Maryland (Reinharz and O'Connell 1981) and Virginia (Nilsen et al. 1982) biogenics studies, a James River study (Diaz 1989), and a study in the Wolf Trap area of the Virginia Bay (Schaffner, unpublished data). Sampling information for these projects is provided in Table 1.

These seven projects were selected for several reasons: each provided data readily available on electronic media; collectively they provided sample representation in all salinity habitats of Chesapeake Bay; and all used a 0.5-mm sieve in sample processing, which is important because the numbers and types of organisms collected depend on the mesh size used to sieve the sediment. In addition, the selected projects were restricted to those in which the organisms were identified to the lowest possible taxonomic level.

In addition to limiting the data sets to those with common properties, several data transformation procedures were needed to ensure complete data compatibility. This was necessary because sample collection and processing methods varied to some extent among the projects, and corrections were needed to ensure that differences in the data reflected true differences among the sampled benthic communities rather than differences in sampling methodology. Standardization procedures included applying uniform naming conventions across projects, eliminating organisms that were not sampled quantitatively, and standardizing biomass measures.

Taxonomic differences among projects were eliminated by cross-correlating the species lists of the seven projects, identifying differences in nomenclature, and consulting the taxonomic expert for each of the projects to resolve discrepancies. These experts were available for six

Table 1. Data sources and data collection information

Data Source	Time Period	No. of Stations	Sampling Gear	Sampled Area (m ²)	No. of Station Visits	Biomass Data	Depth Distribution Data
Chesapeake Bay Benthic Monitoring Program - Maryland	July 1984 to Sept. 1991	70 Stations 1984-89; 31 Strata 1989-91	Petite Ponar Van Veen Box Corer	0.025 0.1 0.022	3505	Available	
Chesapeake Bay Benthic Monitoring Program - Virginia	March 1985 to Sept. 1991	25	Box Corer	0.0184	487	Available	Available
EMAP	June to Sept. 1990	87	Modified Van Veen	0.044	111	Available	
Biogenics - Maryland	Sept. 1978 to July 1979	38	Box Corer	0.0625	50		Available
Biogenics - Virginia	Sept. 1978 to June 1979	53	Box Corer	0.0625	53		Available
James River	Nov. 1971 to Nov. 1972	40	Ponar	0.05	117		
Wolf Trap	Nov. 1987 to May 1991	2	Box Corer	0.0625	24		
TOTAL		346			4347		

of the seven projects. Development of taxonomic consistency was aided by the fact that many of these experts had previously exchanged samples and had noted and resolved differences in nomenclature. The taxonomic list, after standardization, is provided in Appendix A.

Four groups of organisms that are not truly indicative of bottom habitat conditions and which were found in the species lists of some projects were eliminated from the data. These four groups included algae, vertebrates (larval fish), pelagic invertebrates, and epifauna (Table 2, Appendix B). They are not sampled reliably or accurately by the sampling methods used for benthos. The first two were eliminated because they are also not invertebrate. Organisms considered predominantly epifaunal were excluded for several reasons: the sampling methods did not sample epifauna quantitatively; the exposure of epifauna to pollution insults, particularly chemical contaminants in sediments, is different from the exposure experienced by infauna; and the presence of epifauna is most often associated with the occurrence of shell or structures such as bryozoan colonies, irrespective of habitat condition.

Biomass measures were available for the three largest of the programs, but not in the same format. Biomass measurements were made for all taxa in the Virginia monitoring program, for 22 species in the Maryland program (Ranasinghe et al. 1992) and for 51 taxa and feeding groups in EMAP (Weisberg et al. 1993). In addition, biomass was measured as dry weight for EMAP and as ash-free dry weight for the Maryland and Virginia monitoring programs. To normalize for this difference, EMAP data were converted to ash-free dry weights using conversion factors developed from data used to calculate length-weight regressions for the Maryland Chesapeake Bay Benthic Monitoring Program. The conversion factors and regression results are presented in Table 3. Finally, abundance and biomass measurements were standardized to values per square meter to account for the differences in surface area sampled with the various types of collection gear used in the different projects.

Define Temporal and Spatial Strata

Temporal Stratification

The abundances and diversity of benthic organisms in Chesapeake Bay vary seasonally; most organisms exhibit a large recruitment pulse in the spring, a smaller recruitment pulse in the fall, and reductions in the summer and winter (Holland et al. 1977; Mountford et al. 1977; Holland et al. 1980, Holland 1985; Ranasinghe et al. 1992). Cumulatively, these species-specific changes in abundance and diversity over time result in relatively consistent seasonal variation in community abundance and diversity (Figure 2). This seasonal variation could confound the interpretation of benthic response to environmental degradation if not accounted for in developing benthic restoration goals. This is particularly true given the markedly unequal distribution of sampling effort among seasons in the different projects from which the benthic data were drawn.

Table 2. Groups of organisms eliminated from the data. Additional information is provided in Appendix B.

GROUP	REASON FOR ELIMINATION
Algae	Not invertebrates, Epifaunal
Porifera	Epifaunal
Hydrozoa and Scyphozoa	Epifaunal
Platyhelminthes	Epifaunal or Parasitic
Nematoda	Meiofaunal
Hirudinea	Parasitic
Organisms identified only as "Mollusca"	Too little information
Cephalopoda	Pelagic
Merostomata (<i>Limulus</i>)	Megabenthic, Epifaunal
Cladocera	Meiofaunal, Planktonic
Ostracoda	Meiofaunal
Copepoda	Meiofaunal, many Planktonic
Branchiura	Pelagic, Parasitic
Cirripedia	Epifaunal
Mysidacea	Epifaunal
Isopoda : Cymothoidae	Ectoparasitic on fish
Isopoda : Sphaeromidae	Epifaunal
Amphipoda : Hyperiidæ, Caprellidae	Pelagic
All Zoeae & megalopae	Pelagic, Meiofaunal
Tardigrada	Meiofaunal
Bryozoa	Epifaunal
Entoprocta	Epifaunal
Asteroidea, Echinoidea	Epifaunal
Chaetognatha	Pelagic
Vertebrata	Megafauna, not invertebrate

Table 3. Results of regression analyses used to derive factors for the conversion of EMAP dry weights to ash-free dry weights. The independent variable was the dry weight, and the dependent variable the ash-free dry weight of each individual organism. Intercepts were forced through the origin. The conversion factors were applied to EMAP dry weights by taxonomic group as indicated.

Taxonomic Group with dry weights to be converted	Taxon in Regression	Conversion Factor	N	r²
Nemerteans	Nemerteans	0.83464	57	0.978
Polychaetes and Oligochaetes	Polychaetes	0.62087	244	0.948
Crustaceans	Amphipods and Isopods	0.76622	143	0.990
Bivalves, Gastropods, Insect Larvae, Phoronids, Hemichordates	All taxa	0.73374	444	0.950

To resolve this problem, restoration goals were developed for a single season. Summer was chosen for this purpose because it was a sampling period common to six of the seven projects for which data were available. EMAP, which purposely collected the specific kinds of reference data needed for this project, sampled only during the summer. Considerably less data would have been available to develop restoration goals for other times of the year.

Summer was also selected as the most appropriate period for developing restoration goals because it is the period when assemblage attributes are expected to show the greatest response to pollution stress. Episodic low dissolved oxygen events, identified as a major factor affecting the occurrence of depressed living resources in Chesapeake Bay (Jordan et al. 1992), are most frequent in the summer. In addition, the adverse effects of contaminants are greatest during the summer because of low dilution flows and high temperatures.

Summer was defined as extending from July 15th through September 30th based on mean abundance and diversity data collected in the Maryland Chesapeake Bay Benthic Monitoring Program (Figure 2) and analyses of the frequency of sampling visits. This definition maximized the number of sampling visits available within a window when species abundances

Mean Abundance & Diversity

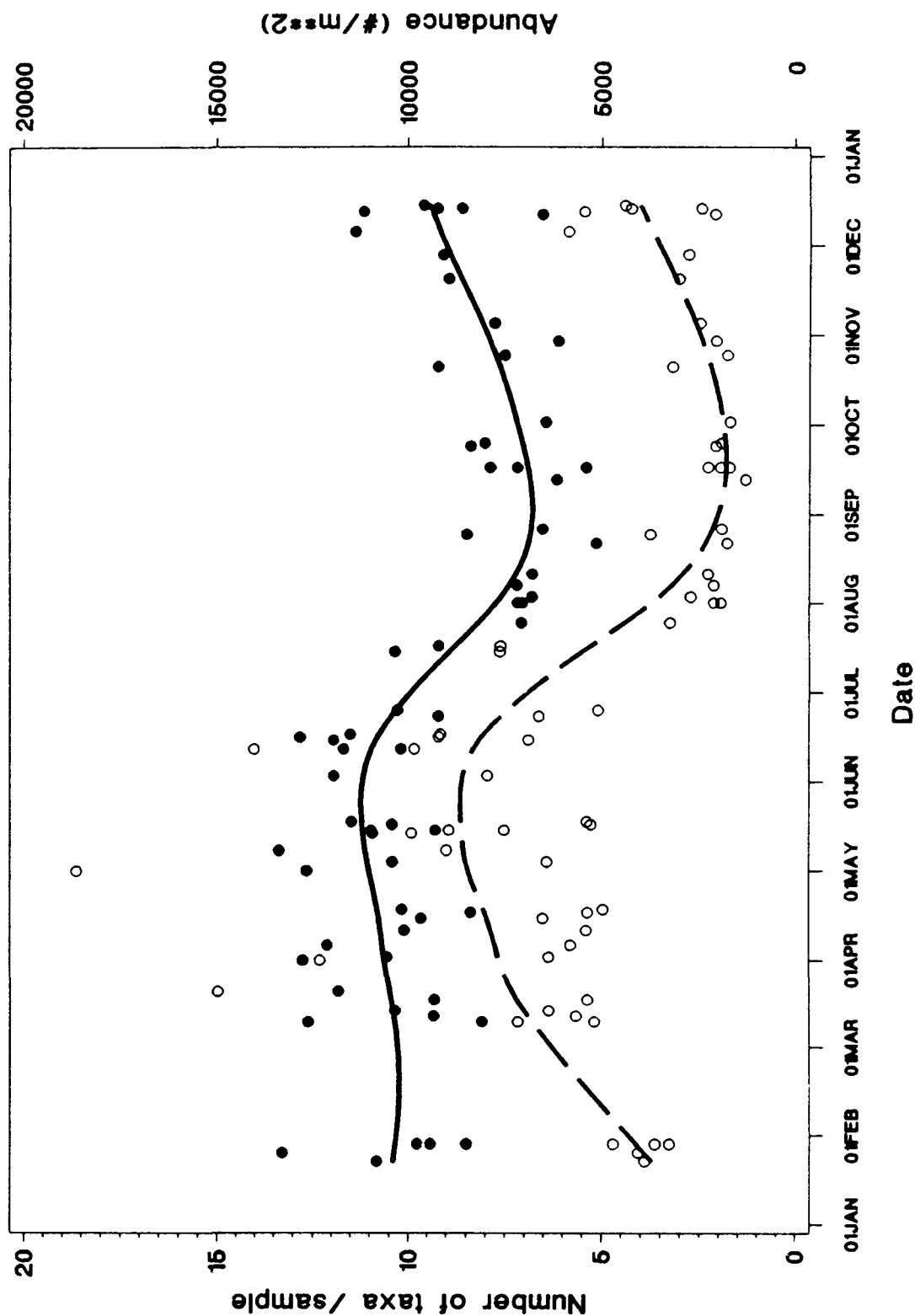


Figure 2. Seasonal patterns in abundance and diversity. Mean cruise sample abundances (open circles) and diversity (filled circles) for Maryland Chesapeake Bay Benthic Monitoring Program cruises from July 1984 to June 1991 are shown in relation to the mid-point of the cruise.

were relatively stable. In addition, visit-to-visit and year-to-year salinity differences at each station were smallest during this period. The total numbers of samples for each project, and for the summer, are provided in Table 4. Sampling location maps for each project are presented in Appendix C.

Table 4. Number of samples and number of summer samples for each of the seven benthic survey projects contributing data

Data Source	Number of Samples	Number of Summer Samples
Chesapeake Bay Benthic Monitoring Program - Maryland	3505	950
Chesapeake Bay Benthic Monitoring Program - Virginia	487	116
EMAP-Near Coastal	111	96
Biogenics - Maryland	50	0
Biogenics - Virginia	53	21
James River	117	28
Wolf Trap	24	4
TOTAL	4347	1215

Spatial Stratification

Even under optimal conditions of water and sediment quality, the composition of benthic communities differs substantially according to bottom salinity and sediment type (Boesch 1973, 1977a; Dauer et al. 1984, 1987; Holland et al. 1989). Benthic communities may also be affected by water depth, because of the nature and magnitude of the hydrodynamic forces influencing bottom habitats. Habitat-specific restoration goals were developed to ensure that natural differences in benthic communities related to such habitat factors did not confound interpretation of the indices being developed.

Habitat strata expected to be relatively homogeneous were delineated using a three-step process. First, cluster analysis was used to identify affinities between sites based on species abundance. Second, each of the sites was assigned to a habitat class defined by salinity, substrate, and depth; these classes were drawn onto the cluster output from step 1. Third,

the initial habitat classes were reduced by eliminating or merging those that did not relate well to the abundance and biomass cluster patterns. Each of these steps is explained in detail below.

Cluster analyses were performed separately on taxon abundances and taxon biomass. Single linkage cluster analysis of stations and strata using \log_{10} -transformed ($\log_{10}(\text{mean} + 1)$) overall mean station abundances per m^2 were applied to all benthic macroinfaunal taxa encountered at each station over all seven projects. The Ecological Analysis Package (Ecoanalysis, Inc. 1988) was used for cluster analysis with the Bray-Curtis similarity coefficient and flexible sorting ($\beta = -0.25$) (Boesch 1977b). The analysis was repeated on \log_{10} -transformed overall mean taxa biomass per m^2 for all stations for which these data were available (Table 1).

Initially, ninety possible habitat classes were derived as a factorial combination of six salinity classes, five substrate classes, and three depth classes. The six salinity classes were defined according to a modified Venice System (Symposium on the classification of brackish waters, 1958): tidal fresh (0.0-0.5 ppt), oligohaline (0.5-5.0 ppt), low mesohaline (5-12 ppt), high mesohaline (12-18 ppt), low polyhaline (18-25 ppt) and high polyhaline (> 25 ppt). Stations were allocated to salinity habitats based on the mean salinity over all summer visits. Each salinity habitat was subdivided into five sediment classes on the basis of silt-clay sized particle content by weight as follows: sand (0-5% silt-clay content), muddy sand (5-25% silt-clay content), mixed sand and mud (25-75% silt-clay content), sandy mud (75-90% silt-clay content), and mud (90-100% silt-clay content). The salinity-sediment habitats were subdivided into depth classes for the tentative habitat classification scheme. Tributary stations were assigned to shallow (0-5 m water depth) and deep (> 5 m water depth) habitats; mainstem Chesapeake Bay stations were assigned to shallow (0-2 m water depth), medium (2-10 m water depth), and deep (> 10 m water depth) habitats.

A comparison of the initial habitat classes to the clustering pattern defined by the benthic assemblages confirmed the dominant influence of salinity on benthic communities in Chesapeake Bay (Dauer et al. 1984, 1987; Holland et al. 1989). A relationship between sediment characteristics and the abundance and biomass clustering was discernible within the three high salinity groups, but only at the broad levels of mud (40% or more silt-clay content) and sand. The effect of depth was not apparent in any of the groupings. Based on these results, the ninety initial habitat classes were reduced to eight habitat classes for which restoration goals would be defined (Table 5). The number of samples available for analysis in each habitat class are presented in Table 6.

Table 5. Habitat classification scheme and definitions

A. CLASSIFICATION SCHEME

HABITAT CLASS
Tidal Freshwater
Oligohaline
Low Mesohaline Sand
Low Mesohaline Mud
High Mesohaline Sand
High Mesohaline Mud
Polyhaline Sand
Polyhaline Mud

B. DEFINITIONS

(i) Bottom Salinity	
Description	Salinity (ppt)
Tidal Fresh	0.0 - 0.5
Oligohaline	0.5 - 5.0
Low Mesohaline	5.0 - 12.0
High Mesohaline	12.0 - 18.0
Polyhaline	> 18.0
(ii) Sediment Grain Size Composition	
Description	Silt & Clay Sized Particle Content by Weight (%)
Sand	0 - 40
Mud	> 40

Table 6. Number of summer samples available for each habitat class

Habitat Class	Number of Summer Samples
Tidal Freshwater	95
Oligohaline	116
Low Mesohaline Sand	65
Low Mesohaline Mud	286
High Mesohaline Sand	237
High Mesohaline Mud	199
Polyhaline Sand	54
Polyhaline Mud	163

Identify Reference Sites and Degraded Sites

Reference sites that represent unimpacted or least impacted conditions were identified to evaluate the validity of benthic community attributes as indicators of habitat status. It was also desirable to identify sites that were clearly degraded, so that data from those sites could be excluded from restoration goal development and used later for validation purposes. Ideally, a number of degraded and reference sites would be identified for each habitat class.

Condition of a site was defined on the basis of bottom water dissolved oxygen concentrations and sediment contamination. These properties were chosen since they represent two of the most important sources of pollutant exposure to benthic invertebrates. In addition, they are readily quantifiable with available data for many of the sites at which benthic data were collected.

The criteria used to define reference and degraded sites are listed in Table 7. Contaminated habitats were identified using threshold contaminant concentrations (ER-M values) above which biological effects are frequently observed (see Long and Morgan 1990 for details and lists of contaminant ER-M values). For many EMAP sites, results of a 10-day acute sediment bioassay using the amphipod *Ampelisca abdita* provided supplementary toxicity information. For dissolved oxygen, the criteria differed slightly depending on the nature of dissolved oxygen data available, as explained in Table 7. Affected EMAP sampling stations

Table 7. Criteria for designating degraded and reference sites. The criteria vary between projects because of the different types of information available. The ER-M value for a chemical is the concentration above which biological effects are observed frequently (Long and Morgan 1990).

A. DEGRADED SITES

Sites meeting any of the following criteria were considered degraded.

Chesapeake Bay Monitoring Program	EMAP
Dissolved Oxygen	
Availability of data for at least five summer site visits, and bottom dissolved oxygen concentrations less than 2 ppm measured on 80% or more of these visits.	Bottom dissolved oxygen concentrations below 0.3 ppm recorded on any occasion, or 10% of the continuous observations less than 1 ppm, or 20% of the observations less than 2 ppm, or bottom dissolved oxygen observations of less than 2 ppm observed for 24 consecutive hours.
Chemical Contaminants	
The measurement of any chemical contaminant concentration exceeding the ER-M value on any visit.	The measurement of any chemical contaminant concentration exceeding the ER-M value on any visit, and test survival significantly different from and less than 75% of control survival for the <i>A. abdita</i> bioassay.

B. NONDEGRADED REFERENCE SITES

Sites were required to meet all of the following criteria to be considered a reference site.

Chesapeake Bay Monitoring Program	EMAP
Dissolved Oxygen	
Availability of data for at least five summer visits to the site with no bottom dissolved oxygen concentration measurements less than 2 ppm, and more than 80% of the measurements greater than 5 ppm.	Summer bottom dissolved oxygen measurements never less than 1 ppm, 90% of the observations greater than 3 ppm, and 75% of the observations greater than 4 ppm.
Chemical Contaminants	
Sediment contaminant data available with no measured concentration exceeding the ER-M value.	Sediment contaminant data available with no measured concentration exceeding the ER-M value, and bioassay test <i>A. abdita</i> survival greater than 75% of, and not significantly different from, control survival.

were identified based on criteria applied to continuously recorded dissolved oxygen data that were available for many of the EMAP benthic sampling sites. In contrast, low dissolved oxygen concentration habitats among Chesapeake Bay Benthic Monitoring Program sites were identified using point-in-time dissolved oxygen measurements made at the time of sample collection, supplemented by point-in-time measurements from the Water Column Physical-Chemical Characterization Components of the Maryland and Virginia Chesapeake Bay Water Quality Monitoring Programs.

Application of these criteria resulted in designing 99 samples as being from relatively undisturbed regional reference sites and 135 samples as being from sites with known habitat degradation (Table 8). Because biomass and depth distribution data were not collected with all samples at all sites, the number of samples for which community data other than abundance were available was fewer than for abundance (Table 8; types of measures are discussed further below). For three of the eight habitat classes, there were more than ten samples in each of the reference and degraded categories. For each of the tidal freshwater and oligohaline classes there were only two samples available from degraded sites; for polyhaline sand there were none. The absence of samples from degraded sites within any habitat class only limits validation efforts; for each habitat class with only one or two samples from degraded sites, there were more than 10 samples considered to have been taken from reference sites; therefore, restoration goals could be developed. Only for the low mesohaline sand habitat class was goal development not possible. For this habitat class, no samples could be classified as being from reference sites, probably reflecting the relatively small spatial extent of this habitat in the Bay.

The number of samples classified was far fewer than the total number of samples in the data base. In part, this was due to the conservative nature of the criteria and the presence of a large "grey zone" in the criteria applied to define exposure to low dissolved oxygen. Several sites could not be classified because exposure information, generally contaminant data, were unavailable. The conservative nature of the classification approach dictated that a site be clearly acceptable with respect to both contaminant and dissolved oxygen exposure.

Select Restoration Goal Attributes

Restoration goal attributes were selected by first identifying a set of candidate attributes that are believed to be properties of benthic assemblages at sites of high environmental quality

Table 8. Numbers of samples collected at sites classified as reference or degraded, by habitat class. The number of sites varies between types of measures (abundance, biomass, depth-distribution) because data for all types of measures were not collected for all seven benthic survey projects.

HABITAT CLASS	Abundance Measures		Biomass Measures		Depth Distribution Measures	
	Reference	Degraded	Reference	Degraded	Reference	Degraded
Tidal Freshwater	15	2	15	2	12	0
Oligohaline	22	2	11	2	6	0
Low Mesohaline Sand	0	0	0	0	0	0
Low Mesohaline Mud	6	29	6	9	6	0
High Mesohaline Sand	11	1	8	1	0	0
High Mesohaline Mud	13	34	13	16	13	4
Polyhaline Sand	19	0	19	0	19	0
Polyhaline Mud	13	67	13	19	13	0
TOTAL	99	135	85	49	69	4

based on the literature and experience of the investigators, and then comparing the value of these candidate attributes at reference sites with their values at all other sites. Attributes that differed between categories of sites were incorporated into the restoration goals.

Identification of Candidate Attributes

A list of 24 candidate attributes potentially indicative of benthic habitat status was developed from among five categories of benthic macroinfaunal community attributes based on the literature, and the knowledge and experience of the authors (Table 9). Attributes in each category were indicative of different aspects of benthic community structure or function. The five attribute categories were

- benthic biodiversity measures
- assemblage abundance and biomass measures
- life history strategy measures
- measures of activity beneath the sediment surface
- feeding guild measures

Brief descriptions of the attribute categories, the candidate attributes in each category, and the rationale for including them, are provided below.

1. Benthic biodiversity measures.

The number of different kinds of benthic organisms supported by the habitat at a particular location is often considered indicative of relative habitat "health." Two benthic macroinfaunal community measures that reflect biodiversity were considered for use as restoration goal attributes:

- the mean number of taxa collected per sample
- the Shannon-Wiener diversity index (Shannon and Weaver, 1949)

Table 9. Candidate attributes investigated in each of the categories.

Benthic biodiversity measures

The mean number of taxa per sample
The Shannon-Wiener diversity index

Assemblage abundance and biomass measures

Total benthic infaunal community abundance per m²
Total benthic infaunal community biomass per m²

Life history strategy measures

The percentage of abundance contributed by equilibrium taxa
The percentage of biomass contributed by equilibrium taxa
The percentage of abundance contributed by opportunistic taxa
The percentage of biomass contributed by opportunistic taxa

Measures of activity beneath the sediment surface

The percentage of benthic biodiversity deeper than 5 cm below the sediment surface
The percentage of benthic biodiversity deeper than 10 cm below the sediment surface
The percentage of benthic abundance deeper than 5 cm below the sediment surface
The percentage of benthic abundance deeper than 10 cm below the sediment surface
The percentage of benthic biomass deeper than 5 cm below the sediment surface
The percentage of benthic biomass deeper than 10 cm below the sediment surface

Feeding guild measures

The percentage of benthic abundance contributed by carnivores and omnivores
The percentage of benthic biomass contributed by carnivores and omnivores
The percentage of benthic abundance contributed by suspension feeders
The percentage of benthic biomass contributed by suspension feeders
The percentage of benthic abundance contributed by deep deposit feeders
The percentage of benthic biomass contributed by deep deposit feeders
The percentage of benthic abundance contributed by interface feeders
The percentage of benthic biomass contributed by interface feeders
The percentage of benthic abundance contributed by suspension and deep deposit feeders
The percentage of benthic biomass contributed by suspension and deep deposit feeders

Other available measures of diversity, such as Sanders' rarefaction index, which measures the number of taxa for a fixed number of individuals (Sanders 1968), were not used because the low numbers of organisms encountered in anoxia-affected environments would preclude consistent application of these measures to data from all samples and sites. Diversity indices, such as Shannon-Wiener, have recently declined in popularity (Green 1979) because they are redundant and more difficult to interpret than the number of taxa encountered. Both measures were treated as candidates, however, because the number of taxa encountered is related in a complex manner to the area sampled (Connor and McCoy 1979) and seven different types of gear differing in sampling area were used to collect samples for the benthic survey projects that contributed data to this study. We were concerned that use of the mean number of taxa per sample might be influenced more by the type of sampling gear than by habitat status. Ewing et al. (1988) showed that when different types of gear are employed at the same location, the Shannon-Wiener diversity index values are less different between sampling devices than are the numbers of taxa encountered, even when standardized by sampling area. To account for all possibilities, both attributes were included as candidates for restoration goal development. Both measures would be expected to have higher values at reference sites, in most cases.

2. Assemblage abundance and biomass measures.

Overall community abundance and overall biomass are measures of the total biological activity at a location. They also indicate the occurrence and availability of food for organisms at higher trophic levels; thus, they provide information about the potential contribution of the benthic community to energy flow in an ecosystem and on the relative size of the benthic community compartment within the ecosystem. Two candidate attributes were identified in this category:

- the total number of organisms present (standardized to numbers per m² surface area)
- the total community biomass (standardized to ash-free dry weight per m² surface area)

In most cases, both measures would be expected to have higher values at reference sites although more exceptions are likely for abundance than for biomass. In addition, eutrophic

sites (which should be considered degraded) may support high abundance and biomass (Pearson and Rosenberg 1978).

3. Life history strategy measures.

Relatively short-lived, tolerant taxa with relatively high reproductive and recruitment potential (opportunistic taxa) often dominate disturbed or stressed habitats (Boesch 1973, 1977a; Pearson and Rosenberg 1978; Rhoads et al. 1978; Dauer 1991, 1993; Dauer et al. 1992). Large, relatively long-lived (equilibrium) taxa often dominate community biomass in undisturbed or unstressed habitats (Warwick 1986; Dauer 1993). Four candidate attributes were identified based on this life history perspective:

- percentage of abundance contributed by equilibrium taxa
- percentage of biomass contributed by equilibrium taxa
- percentage of abundance contributed by opportunistic taxa
- percent of biomass contributed by opportunistic taxa

High percentages of opportunistic taxa would be expected in degraded habitats and low percentages in undegraded habitats. The converse would be expected for equilibrium species. It was expected that the opportunistic measures would be more consistently applicable because equilibrium species tend to be larger and rarer, and even when present, they are more likely to be missed in sampling efforts.

Taxa with adequate available life history information were classified as opportunistic or equilibrium species if their life history characteristics (Boesch 1973; Grassle and Grassle 1974; McCall 1977; Rhoads et al. 1978; Gray 1979; Rhoads and Boyer 1982; Warwick 1986; Dauer 1991, 1993) warranted it. No assignments were made for taxa with inadequate life history information or with intermediate life history characteristics. Sites with no organisms were considered to have 100% opportunistic, and 0% equilibrium membership. The list of opportunistic taxa identified is presented in Table 10, and the list of equilibrium taxa in Table 11.

Table 10. List of opportunistic taxa

Annelida : Polychaeta

Asabellides oculata
Capitella spp.
Glycinde solitaria
Heteromastus filiformis
Hypereteone heteropoda
Leitoscoloplos foliosus
Leitoscoloplos fragilis
Leitoscoloplos robustus
Leitoscoloplos spp.
Mediomastus ambiseta
Neanthes succinea
Paraprionospio pinnata
Polydora cornuta
Spiophanes bombyx
Streblospio benedicti

Mollusca : Bivalvia

Corbicula fluminea
Gemma gemma
Mulinia lateralis
Nucula proxima

Arthropoda : Amphipoda

Ampelisca abdita
Ampelisca spp.
Ampelisca vadorum
Ampelisca verrilli
Ampeliscidae
Byblis serrata
Corophium lacustre
Leptocheirus plumulosus

Arthropoda : Insecta

Chironomus spp.
Cladotanytarsus spp.
Coelotanytus spp.
Glyptotendipes spp.
Polypedilum tripodura
Procladius sublettei
Tanytus spp.

Annelida : Oligochaeta

Aulodrilus limnobius
Aulodrilus paucichaeta
Aulodrilus pigueti
Aulodrilus pluriseta
Bothrioneurum vej dovskyanum
Branchiura sowerbyi
Haber cf. *speciosus*
Ilyodrilus spp.
Ilyodrilus templetoni
Isochaetides curvosetosus
Isochaetides freyi
Limnodrilus cervix
Limnodrilus claparedeanus
Limnodrilus hoffmeisteri
Limnodrilus profundicola
Limnodrilus spp.

Limnodrilus udekemianus
Oligochaeta
Potamotheix spp.
Potamotheix vej dovskyi
Quistadrilus multisetosus
Tubificid imm. with cap. chaetae
Tubificid imm. w/o cap. chaetae
Tubificidae
Tubificoides benedeni
Tubificoides brownae
Tubificoides diazi
Tubificoides gabriellae
Tubificoides heterochaetus
Tubificoides maureri
Tubificoides spp.
Tubificoides wasselli

Table 11. List of equilibrium taxa

Coelenterata : Anthozoa

Ceriantheopsis americanus

Annelida : Polychaeta

Asychis elongata

Chaetopterus variopedatus

Clymenella torquata

Diopatra cuprea

Glycera americana

Macroclymene zonalis

Arthropoda

Alpheus heterochaelis

Biffarius biformis

Callinassa setimanus

Echiurida

Squilla empusa

Thalassema spp.

Echinodermata : Ophiuroidea

Microphiopholis atra

Mollusca : Bivalvia

Anadara ovalis

Anadara transversa

Cyrtopleura costata

Dosinia discus

Ensis directus

Macoma balthica

Mercenaria mercenaria

Mya arenaria

Rangia cuneata

Spisula solidissima

Tagelus divisus

Tagelus plebeius

4. Measures of activity beneath the sediment surface

The large, equilibrium species that often dominate community biomass in undisturbed or unstressed habitats usually live deep within the bottom sediments (Schaffner 1990). In contrast, the smaller, opportunistic, species dominant in disturbed and stressed habitats usually live within one or two centimeters of the sediment-water interface (Warwick 1986; Schaffner et al. 1987; Dauer 1991, 1993). It was considered possible, therefore, that the depth distribution of organisms representing benthic macroinfaunal communities would provide information related to the "health" of bottom habitats. Six measures of the depth of the benthic community within the sediment were considered as candidate attributes:

- the percentage of total species present deeper than 5 cm below the sediment-water interface
- the percentage of total species present deeper than 10 cm below the sediment-water interface

- the percentage of benthic abundance deeper than 5 cm below the sediment-water interface
- the percentage of benthic abundance deeper than 10 cm below the sediment-water interface
- the percentage of benthic biomass deeper than 5 cm below the sediment-water interface
- the percentage of benthic biomass deeper than 10 cm below the sediment-water interface

For all these candidate attributes, higher values would be expected in undegraded habitats than in degraded habitats.

5. Feeding guild measures

Mature stable benthic assemblages typically contain a diverse set of feeding guilds, including carnivores, deposit feeders, and suspension feeders. In contrast, disturbed communities are often dominated by a single feeding group, such as surficial interface feeders. Word's (1978) Infaunal Trophic Index is based on the idea that large, deep-dwelling taxa considered equilibrium species are usually suspension feeders or deep deposit feeders. Based on these ideas, ten feeding guild measures were considered as candidate attributes:

- the percentage of benthic abundance contributed by carnivores and omnivores
- the percentage of benthic biomass contributed by carnivores and omnivores
- the percentage of benthic abundance contributed by deep deposit feeders
- the percentage of benthic biomass contributed by deep deposit feeders
- the percentage of benthic abundance contributed by interface feeders
- the percentage of benthic biomass contributed by interface feeders

- the percentage of benthic abundance contributed by suspension feeders
- the percentage of benthic biomass contributed by suspension feeders
- the percentage of benthic abundance contributed by suspension and deep deposit feeders
- the percentage of benthic biomass contributed by suspension and deep deposit feeders

To create the candidate measures, it was necessary to categorize species into specific trophic groups. Species were classified as being carnivores/omnivores, deep deposit feeders, interface feeders or suspension feeders based upon literature descriptions of feeding behavior (Jorgensen 1966; Bousfield 1975; Fauchald and Jumars 1979; Dauer et al. 1981) as well as the collective judgement of the authors.

Evaluation of Candidate Attributes

The evaluation of candidate attributes for suitability as indicators of habitat condition was performed by comparing values for candidate attributes between reference sites and all other sites within each habitat category. To be incorporated as a restoration goal, an attribute needed to respond in a manner that was consistent with the hypothesis for its consideration as a candidate. For instance, for species diversity to be incorporated, values at reference sites should be higher on average than at all other sites. This comparison was performed in two ways. First, a t-test was conducted to examine for differences in mean condition. Second, the range of values over all reference sites was compared with the range over all other sites. Figure 3 shows a comparison between values for an attribute that met these criteria and values for one that did not.

Investigator judgement was used to supplement the analytical tests in the selection of attributes, primarily due to the limited amount of reference site data available for a number of the habitat classes. For instance, some parameters such as total biomass were consistently higher at reference sites in all habitat classes, but not significantly so in some others. In this case, the significance of the test was considered less important than the consistency of the response. Investigator judgement was also permitted in an effort to include attributes from

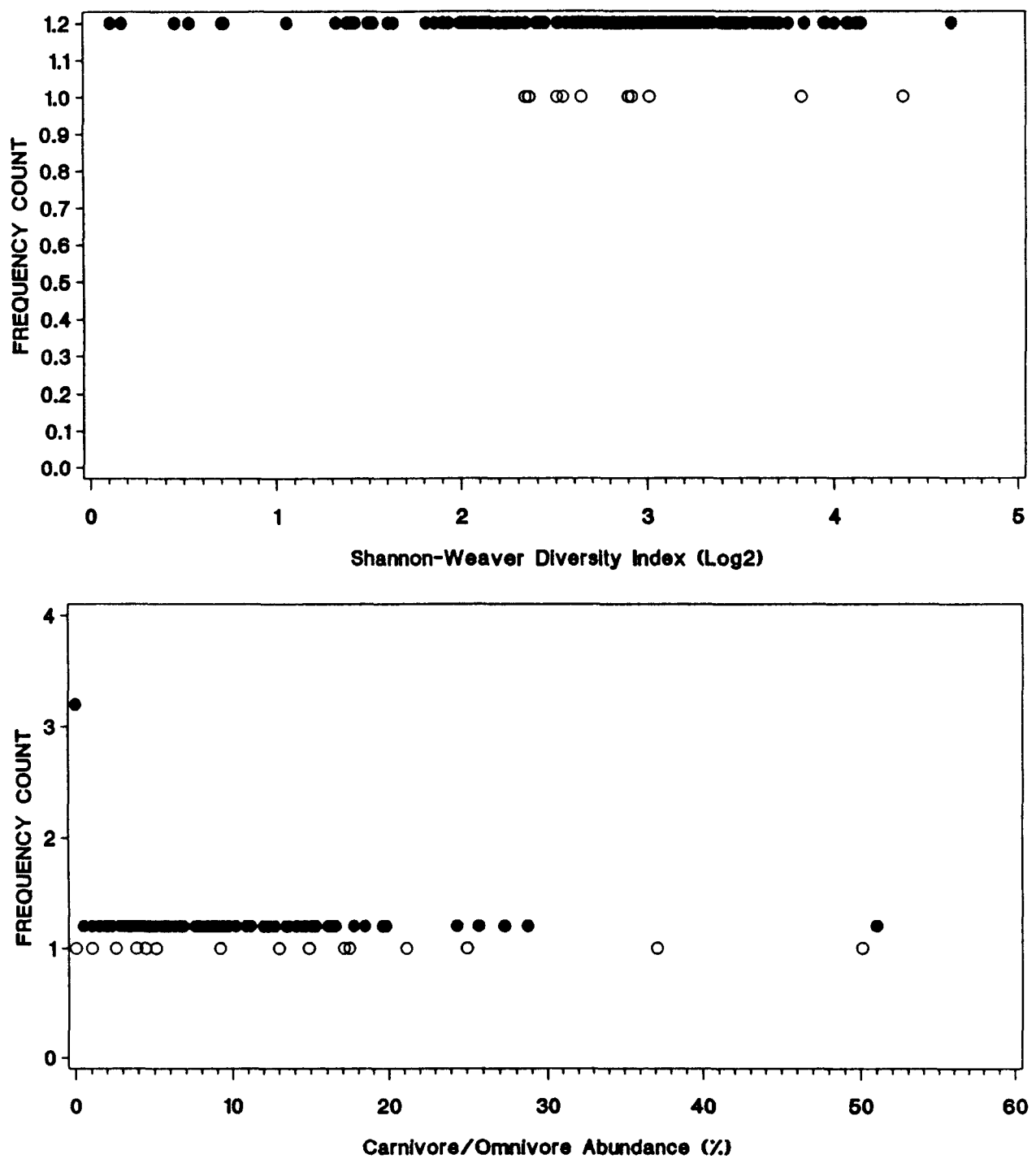


Figure 3. Examples of range comparisons between reference (open circles) and other sites (filled circles). Top: Example for an attribute that was selected. The range for reference samples is much smaller than the range for "other" samples in a manner consistent with ecological theory. Bottom: Example for an attribute that was not selected. There is hardly any difference between reference and "other" sample ranges.

among all five attribute categories, and to avoid over-representation of attributes from a single category.

Ten of the 24 candidates were selected as restoration goal attributes for at least one habitat class. The selected attributes for each habitat class are summarized in Table 12. Restoration goal attributes could not be selected for the low mesohaline sand habitat due to a lack of reference sites in this habitat class.

Identify Restoration Goal Values

Restoration goals for each selected attribute within each habitat class was identified as the fifth percentile value for the reference sites within that class (Table 12). The values at reference sites were used for establishing goals because they represent the response at the least disturbed sites in Chesapeake Bay. Consideration was given to establishing higher values, such as the median response at present day reference sites, as restoration goals given the possibility that all sites in the Bay are impacted relative to historic reference conditions. The lower value was selected, however, because of our inability to define historic reference condition and the concern that historic conditions may no longer be achievable. The fifth percentile value for reference sites was selected to allow for the possibility that we misclassified a small fraction of the reference sites because of incorrect information or because the variables used for classification did not include all of the potential stresses to benthic macroinvertebrates in the Bay.

Develop the Restoration Goal Index

To provide managers with a quantitative tool to assess the extent to which restoration goals were being achieved, an index that combines these attributes into a single value was developed. Development of this Restoration Goals Index (RGI) was patterned after the approach used to develop the Index of Biotic Integrity (IBI) by Karr et al. 1986, in which each metric is scored as 5, 3, or 1, depending on whether its value at a site approximates, deviates slightly from, or deviates greatly from conditions at the best reference sites. For the RGI, the threshold for differentiating between a value of 1 and 3 was defined by the restoration goal for the attribute. The threshold between a value of 3 and 5 was defined as the median value among the reference sites for that habitat class. These threshold values are defined in Table 12.

Table 12. Measures are threshold values used to calculate the RGI for each habitat. The first value in each column is the Restoration Goal.

	Tidal Freshwater	Oligohaline	Low Mesohaline Mud	High Mesohaline		Polyhaline	
				Sand	Mud	Sand	Mud
Shannon-Wiener Diversity Index	0.9, 1.5	0.9, 1.9	2.0, 3.0	2.3, 2.7	2.0, 3.0	2.0, 4.0	2.2, 3.5
Abundance (#/m ²)	200, 1300	300, 2000	-	2500, 6000	500, 1000	500, 3000	1000, 3000
Biomass (g/m ²)	-	0.5, 20.0	5.0, 10.0	1.0, 12.0	0.5, 8.0	1.0, 15.0	1.0, 10.0
% Opportunist Biomass	-	35, 10	30, 10	42, 16	50, 15	30, 10	28, 5
% Opportunist Abundance*	-	-	-	-	-	60, 35*	60, 30*
% Equilibrium Species Biomass	-	30, 45	-	30, 60	-	30, 60	30, 60
% Equilibrium Species Abundance*	-	-	5, 15*	-	-	5, 15*	-
% of Taxa > 5cm below Sediment Surface	-	-	10, 40	10, 40	10, 40	10, 40	10, 40
% of Biomass > 5cm below Sediment Surface	-	-	5, 80	10, 50	10, 50	10, 50	10, 50
% Carnivore and Omnivore Abundance	-	-	-	5, 15	10, 30	5, 30	25, 40

* Abundance attributes are incorporated in the index only if data for the corresponding biomass attribute is unavailable for the sample.

The restoration goal attribute values are combined into a Restoration Goal Index (RGI) by computing the mean attribute score across all attributes for which values are available. This differs from the approach used in the IBI, in which values are summed. Averaging permits greater flexibility to compute the RGI even in instances where one or more attributes are not measured. For example, if biomass was not measured, as is often the case for many benthic survey projects in Chesapeake Bay, the RGI could be computed even if the goal attributes for the habitat class included biomass measures.

Based on this approach, an RGI value of 3 represents the minimum restoration goal. Values less than three indicate unacceptable benthic community status, whereas values of three or more indicate habitats that meet or exceed the restoration goals. The range of the RGI score extends from 1 to 5.

Validating the Restoration Goals Index

Three approaches to index validation were employed. First, the RGI was computed for all samples taken from each reference site to test whether expectations of values of three or more were met. This test included data used for development of the index and, therefore, was not independent. The test was necessary to ensure that selecting the fifth percentile of the attribute values at reference sites, rather than the lowest value, as the first threshold did not cause the RGI to be excessively conservative.

The results of this test indicated a high degree of correct classification (Table 13); classification efficiency was greater than 95% in five of the seven habitat classes. The lowest classification efficiency for reference sites was 92.3% in the high mesohaline mud habitat class.

Second, RGI values were computed for all samples taken from degraded habitats to test whether expectations of RGI values less than three were met. This test used data excluded during development of the RGI and, therefore, was an independent validation test.

A high level of classification efficiency was observed in this second test; classification efficiency was 95% or better for degraded sites in four of the six habitat classes for which data from degraded sites were available (Table 14). The two habitat classes that did not validate as well were tidal freshwater and low mesohaline mud. For tidal freshwater, only two data points, both from the Anacostia River were available for validation. Although it is

tempting to conclude that the failure to validate in tidal freshwater was a result of having so few validation data points, very few attributes showed much difference between reference and nonreference sites in the attribute selection stage, suggesting that factors of importance in tidal freshwater are different than in the other habitats. The limited data available for this habitat category, however, constrains our ability to investigate this issue further.

Table 13. Classification rates for the RGI at reference sites

Habitat Class	Number of Samples	% Correctly Classified
Tidal Freshwater	15	93.3
Oligohaline	22	95.5
Low Mesohaline Mud	6	100.0
High Mesohaline Sand	11	100.0
High Mesohaline Mud	13	92.3
Polyhaline Sand	19	100.0
Polyhaline Mud	13	100.0

Table 14. Classification rates for the RGI at degraded sites

Habitat Class	Number of Samples	% Correctly Classified
Tidal Freshwater	2	0
Oligohaline	2	100.0
Low Mesohaline Mud	29	86.2
High Mesohaline Sand	1	100.0
High Mesohaline Mud	34	97.1
Polyhaline Sand	0	-
Polyhaline Mud	67	95.5

For the third validation test, sites sampled more than once during the summer for any year were identified, and the RGI was computed for each visit. RGI values at each site were evaluated for differences in status designation among visits within each year to ascertain the stability of the index. Instability of the index would indicate an unacceptable signal-to-noise ratio in the attributes. The results indicated that the RGI index was relatively stable. For all seven habitats, the correlation between the first and second visits to these sites exceeded 0.8, and for six of them it exceeded 0.9 (Table 15). In addition, for all but the high mesohaline mud habitat (78.2%), more than 80% of the sites that were sampled twice in the same summer classified the same with respect to goal attainment (Table 15). Most of the sites that classified differently between the two visits were sites where not all the restoration goal attributes were quantified during sampling because biomass or depth distribution data were not available. For all these sites, RGI values were similar for both visits but were close to, and on either side of, the critical value of 3.

Table 15. Classification consistency for sites visited more than once in the same summer.

Habitat Class	Number of Site-Year Combinations with Multiple Summer Samples	Percentage of Sites with Unchanged Annual Status	Correlation between RGI values (r²)
Tidal Freshwater	17	100.0	0.98
Oligohaline	32	93.8	0.97
Low Mesohaline Mud	82	84.2	0.93
High Mesohaline Sand	77	81.8	0.95
High Mesohaline Mud	55	78.2	0.90
Polyhaline Sand	1	100.0	1.00
Polyhaline Mud	36	88.9	0.83

III. DISCUSSION AND RECOMMENDATIONS

The objective of this project was to develop a practical and conceptually sound framework for assessing benthic environmental conditions in Chesapeake Bay. The results suggest that the primary objective of this effort has been met in at least a preliminary manner:

- A set of restoration goals have been identified that can be applied to data from all of the major benthic sampling programs in Chesapeake Bay, despite their differences in sampling techniques. Application of the restoration goals to current and future monitoring efforts has been enhanced by establishing a set of common taxonomic conventions that can be applied across these major programs.
- The calibration and validation results indicate that the restoration goals are effective in distinguishing between sites of high quality and those of lesser quality in six of the seven habitats for which data were available for goal development. For these six habitat classes, correct classification rates for reference samples exceeded 90%; for samples from degraded sites the rates exceeded 85%.

The only habitat class for which the restoration goals did not perform well was tidal freshwater. Although reference sites were identified correctly 93% of the time, the degraded sites did not validate well. There are two possible explanations for the failure of the goals to validate in tidal freshwater. The first is that only two degraded-site data points were available for validation. Both of these were from the Anacostia River, which may not represent typical degraded sites in this habitat class. The validity of this explanation could be assessed if more data from degraded sites within this habitat class were available.

The second possibility is that the tidal freshwater fauna are inherently different from fauna in the other estuarine habitat classes and the attributes incorporated into the goals are not applicable to tidal freshwater benthic communities. Low biomass, shallow-dwelling, opportunistic oligochaetes and chironomids overwhelmingly dominate the tidal freshwater fauna. Estuarine depth distribution and life history parameter degradation effect paradigms that were developed based on work conducted primarily in higher salinity environments may be ineffective for tidal freshwater habitats. The paradigms that are presently used in nontidal freshwater environments (Plafkin et al. 1989) differ substantially from those used in

estuaries. This explanation is consistent with the fact that only two attributes were found to discriminate reference sites from all other sites during goal development. It is also consistent with the findings of EMAP, where development of a benthic indicator was least successful in tidal freshwater environments (Weisberg et al. 1993), and with the high variability observed for these environments in the graphical models of expected values developed for the Virginia portion of Chesapeake Bay (Dauer 1993).

Confidence in the habitat-specific goals was not equally high among the six habitat classes that exhibited acceptable levels of validation. Validation was highest for the high mesohaline mud and the polyhaline mud habitat classes. For these classes, all five attribute categories and as many as nine individual attributes were included in the restoration goals; moreover, for each of these habitat classes there were more than ten degraded sites that could be used for validation. The high level of validation, together with the fact that data for calibration and validation in these two habitat classes were acquired from several different projects, indicates that these particular goals can readily accommodate differences in sampling program methods.

Classification results in the oligohaline, high mesohaline sand, and polyhaline sand habitat classes were encouraging; classification efficiency was greater than 95% samples taken from both degraded and reference sites. For each of these habitat classes, however, fewer than three samples from degraded sites (Table 7) were available for validation. The paucity of sites for validation raises questions concerning the degree to which the available sites represent the full range of degraded conditions in these habitat classes within the Chesapeake Bay. For the high mesohaline sand and polyhaline sand habitat classes, the classification is probably robust because goal attributes from all of the attribute categories were included; however, goal attributes from only three of the five attribute categories were incorporated for the oligohaline habitat, which might limit its general applicability.

Acceptable classification results were obtained for the low mesohaline mud habitat class; however, data available for selection of goal attributes consisted of only six samples from a single river system. Although the attributes and attribute threshold values for this class were generally consistent with those in a number of the other habitat classes, it is not clear to what degree the habitat-specific benthic community characteristics from that single system may or may not represent those from the same habitat class in all other segments of the Bay. Resolution of this issue would require broader sample coverage of this habitat class throughout the Bay.

Most of the potential shortcomings of the restoration goals developed here arise because goal development was carried out using existing data, rather than new data collected specifically for the purpose of restoration goal development. Although the data limitations do not preclude application of these goals, they do suggest that additional refinement is both necessary and appropriate if the goals are to be applied broadly and regularly in Chesapeake Bay environmental management programs. A number of necessary refinement activities are suggested:

1. Obtain additional data from reference and degraded sites to enhance calibration and validation of the restoration goals

The habitat-specific data limitations described above allow relatively specific data needs to be defined. The additional data would contribute to improved confidence in the goals presented in this report:

- Additional reference site data should be obtained for the low mesohaline mud habitat. Only six reference samples were available for analysis and they were all obtained from the same tributary.
- Additional degraded site data are required from the oligohaline, high mesohaline sand, and polyhaline sand habitats. No more than two samples were available for validation in these habitats in this project.
- Data from both reference and degraded sites are needed for the low mesohaline sand and tidal freshwater habitats. No data of either type were available to even begin developing goals for the low mesohaline sand habitat. For the tidal freshwater habitat, goal development was largely unsuccessful, and it is necessary to determine whether this was a function of the calibration/validation data sets, or whether it is a property of the different types of biota inhabiting the habitat.

Beyond these specific needs, there is a general need for more reference site information for validation of the goals for all habitat classes. At present, the validation has been primarily limited to examination of degraded sites. Although the Restoration Goal Index was examined for each of the available reference sites, this activity was somewhat circular given that these same samples were used to calibrate the goals.

In developing the additional reference site information for validation, it is important that such data be gathered from a number of different subsystems within the Bay. Development of the Restoration Goals has been based on the assumption that one can identify expected properties of an assemblage for a particular habitat type, and that the expectation will be the same in all locations in the Bay where that habitat type is found. This assumes that undisturbed sites in mesohaline mud of a tributary like the Chester River have the same expected biomass levels as a mesohaline mud reference site in all other Bay tributaries. Although this assumption is reasonable within the context of establishing broad multi-attribute goals, it certainly needs to be confirmed if the goals are to be applied as management tools. The goals developed so far are particularly vulnerable to this assumption, since most of the reference data tended to be from locations clustered in a small number of tributaries.

The additional data needs identified above can be obtained in several ways. The most obvious is to collect benthic invertebrate and exposure information at sampling locations selected specifically to meet those defined needs. In this project, however, we used data from only the largest, most spatially diverse programs being conducted in the Bay. Numerous site-specific impact assessment efforts have sampled near-field and far-field environments. Although data from many of these studies may be difficult to obtain, they may contain the kind of supporting information needed to classify sites as degraded or reference and to offer a more cost-effective means of meeting the identified data needs. Future restoration goal development efforts may also benefit from the fact that EMAP collects the type of exposure information needed to classify some of its sites as reference or degraded, and it has already collected samples at approximately 120 sites for which data were not available at the time this work was performed.

2. Obtain samples from reference sites outside of the Chesapeake Bay system

Reference sites for this project were all developed from data within Chesapeake Bay. Thus, the definition of restoration goals is relative to present conditions and may be conservative relative to historic conditions, as all sites in Chesapeake Bay are arguably now in some way anthropogenically influenced. At a minimum, the presently proposed goals provide a benchmark against which to assess future conditions. We suggest, however, that to better understand whether the present restoration goals are conservative, it will be necessary to examine data from less anthropogenically affected reference sites nearby, but outside of Chesapeake Bay. Such data might be found for reference areas along the coastal bays of

Maryland and Virginia, in areas such as Assateague. Alternatively, it may be possible to use historical data for Chesapeake Bay for such comparisons.

3. Conduct specific sampling to quantify eutrophication effects on benthos

At high levels of organic input, benthos respond with a reduction in biomass and abundance as eutrophication leads to hypoxia; at lower or intermediate levels, however, the response is likely to be increased benthic community abundance and biomass, with the observed maxima at some distance, in space and time, from the source (Pearson and Rosenberg 1978, Dauer and Conner 1980; Ferraro et al. 1992). In developing the restoration goals, total biomass and abundance were treated as a monotonic response with higher levels considered indicative of healthier environments. We would prefer to have developed a bimodal scoring system for these attributes, but available information is inadequate to identify specific threshold values above which total abundance or total biomass can be considered "enriched" for any habitat class. A special sampling program instituted at varying distances from the outfalls of wastewater treatment or food processing plants might be an appropriate way to better quantify the effects of increased organic inputs on total benthic abundance and total benthic biomass.

4. Add early warning indicators as candidate attributes

The restoration goals as they are presently developed are structural measures of an assemblage that change only after mortality and/or species replacement has occurred. Benthic assemblages may experience functional alterations (e.g. changes in nutrient cycling or production of biomass) that have important implications for ecosystem function before structural responses become apparent. Further development of the restoration goals should incorporate measures that reflect alterations that occur at lower levels of perturbation. These measures might include physiological measures, which might have to be determined through laboratory studies, or may include the presence of sentinel species or assemblages that are the first members of the communities to show a response to stress. In particular, studies are needed that identify sublethal response by individuals and communities to low dissolved water column oxygen, enrichment conditions, and pollutant stress.

5. Evaluate alternative weighting schemes for the attributes

At present, each of the attributes in the RGI is weighted equally. It is not clear, however, that each of the attributes is equally sensitive or equally reliable as an indicator of condition. Further analyses could be conducted to evaluate the merits of alternative weighting strategies.

6. Define significant deviation from the restoration goal

During this project, we concentrated on identifying attributes, and their average values, that allowed a site to be considered to represent reference conditions. It is inappropriate, however, to conclude that all samples for which the RGI was less than 3 represent degraded sites. Within any sampling program, natural sampling variability confounds interpretation based on any individual sample. The second step in the validation effort, in which index values for multiple samples taken from a single sampling location within a single summer were evaluated, documented that this variability was not excessive; however, no statistical analyses were conducted to establish expected levels of variability and expected ranges of goal values.

These issues will need to be addressed if the RGI is to be applied to generate maps of condition of the Bay. For instance, an area might be classified on the basis of its average RGI score; alternatively, it may be classified on the basis of percentage of samples (e.g., > 75%) exceeding an RGI of 3. Possibly an RGI greater than 3 could be required in order to ensure that only those areas that are meeting goals are classified as such. Choosing among these alternatives is in part philosophical and relates to how protective biological criteria should be (Dauer 1993), but further examination of the variability of the response would provide useful input to that debate.

7. Identify a minimum number of restoration goals attributes

Calculation of the RGI is based on average attribute score, rather than on the sum of the values. Use of the average was incorporated to maintain flexibility, since not all attributes of the RGI are measured by all benthic sampling programs in the Chesapeake Bay and there was a desire to make the index applicable to as many programs as possible. We do not wish to imply, however, that data for a single attribute is sufficient to establish that restoration

goals are being met. Multiple attribute indices have been shown to have less variability and greater responsiveness to a wide array of system perturbations than do single attributes (Karr et al. 1986). Further work is suggested to identify the minimum number of attributes that are required for each habitat class in order for the RGI to be applied.

8. Extend the development of restoration goals to other seasons

The strategy adopted for temporal stratification, restricting restoration goal development to the summer, was selected largely for practicality, based on the nature of the data available for goal development. Summer was also believed to be the most appropriate period for developing goals, given the need for anticipated maximum community response to degraded habitat conditions. Limiting the restoration goals to the summer, however, excludes much of the benthic data available for Chesapeake Bay from the goal development process. The development of more robust goals with higher levels of precision might be possible if all data were employed for the development process. Such analysis would require identification of appropriate procedures for averaging or detrending seasonal changes in community attributes.

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APPENDIX A
LIST OF TAXA

List of Taxa used to determine Chesapeake Bay Benthic Community Restoration Goals. The taxa, their feeding guilds, life history characteristics and the number of stations at which they occurred for each project are listed. MON-MD: Chesapeake Bay Benthic Monitoring Program, Maryland; MON-VA: Chesapeake Bay Benthic Monitoring Program, Virginia; EMAP: Environmental Monitoring and Assessment Program - Near Coastal 1990; BIO-MD: Maryland Biogenics; BIO-VA: Virginia Biogenics; JAMES: James River; WOLF: Wolf Trap.

TAXON	Feeding Guild	Life History	MON-MD	MON-VA	EMAP	BIO-MD	BIO-VA	JAMES	WOLF
Cnidaria : Anthozoa									
Anthozoa									
Ceriantheopsis americanus	Carnivore/Omnivore	Equilibrium	22	11	19			1	
Edwardsia elegans	Carnivore/Omnivore		1	6	4		1		2
Haloclava producta	Carnivore/Omnivore		39				1		2
	Carnivore/Omnivore			2					
Nemertinea									
Nemertinea									
	Carnivore/Omnivore		98	24	36	21	23	16	2
Annelida : Polychaeta									
Aglaophamus circinata	Carnivore/Omnivore						1		
Aglaophamus verrilli	Carnivore/Omnivore			4	2				1
Amastigos caperatus	Deep Deposit		4	1					
Ampharete acutifrons	Interface			1					
Ampharete americana	Interface			1					
Ampharete arctica	Interface			2					
Ampharetidae	Interface		2	8	3		3		
Amphitrite ornata	Interface			1	1		1		
Ancistrosyllis hartmanae	Carnivore/Omnivore			6	9		4		
Ancistrosyllis jonesi	Carnivore/Omnivore		1	9	1		3		1
Ancistrosyllis spp.	Carnivore/Omnivore			1			1		
Apoprionospio pygmaea	Interface			2	2		2		
Arabella iricolor	Carnivore/Omnivore			3			2		
Arabellidae	Carnivore/Omnivore		1	2	4		4		
Aricidea catherinae	Interface			2	3		1		
Aricidea cerrutii	Interface			1					
Aricidea fragilis	Interface			1					
Aricidea spp.	Interface						1		1
Aricidea suecica	Interface						1		
Aricidea wassi	Interface			1	1		1		
Asabellides oculata	Interface	Opportunistic	31	14	3		18		2

TAXON	Feeding Guild	Life History	MON-MD	MON-VA	EMAP	BIO-MD	BIO-VA	JAMES	WOLF
Annelida : Polychaeta (Contd.)									
Asychis elongata	Deep Deposit	Equilibrium	1	11	4		5		2
Asychis spp.	Deep Deposit						2		
Autolytus spp.	Carnivore/Omnivore			3					
Bhawania goodei	Carnivore/Omnivore						4		
Bhawania heteroseta	Carnivore/Omnivore			14	7		10	1	2
Boccardiella ligerica	Interface		22	4	1				
Brania clavata	Carnivore/Omnivore		1	3					
Brania spp.	Carnivore/Omnivore				1				
Brania wellfleetensis	Carnivore/Omnivore			2	4		1		1
Cabira incerta	Carnivore/Omnivore			7	6		5		2
Capitella capitata	Carnivore/Omnivore		20	6					2
Capitella jonesi	Deep Deposit		4	2					1
Capitella spp.	Deep Deposit	Opportunistic		1	2				
Capitellidae	Deep Deposit		25	1	3		7		
Carazziella hobsonae	Interface								2
Caulerfiella sp. B (Blake)	Interface			9	2				
Ceratonereis irritabilis	Carnivore/Omnivore			1					
Chaetopteridae	Suspension						9		
Chaetopterus variopedatus	Suspension	Equilibrium	1	9	1		1		2
Chaetozone setosa	Interface			2					
Chrysopetalidae	Carnivore/Omnivore						1		
Cirratulidae	Interface		8	5	13		3		
Cirriformia grandis	Interface			5	4			1	2
Cirrophorus spp.	Interface			1					
Clymenella spp.	Deep Deposit						1		
Clymenella torquata	Deep Deposit	Equilibrium	6	12	7		14	4	1
Demonax microphthalmus	Suspension				3		1	1	2
Diopatra cuprea	Carnivore/Omnivore	Equilibrium	1	9	6			1	2
Dorvillea rudolphi	Carnivore/Omnivore			3					
Drilonereis filum	Carnivore/Omnivore							3	
Drilonereis longa	Carnivore/Omnivore		3	4	2		4		
Drilonereis magna	Carnivore/Omnivore			4			1		1
Drilonereis spp.	Carnivore/Omnivore			3					
Eteone spp.	Carnivore/Omnivore		1						
Euchone spp.	Suspension		1						

TAXON	Feeding Guild	Life History	MON-MD	MON-VA	EMAP	BIO-MD	BIO-VA	JAMES	WOLF
Annelida : Polychaeta (Contd.)									
Eumida sanguinea	Carnivore/Omnivore		1	1	1				
Exogone dispar	Carnivore/Omnivore			4	2				
Exogone spp.	Carnivore/Omnivore		1						
Exogone verugera	Carnivore/Omnivore			1					
Genetyllis castanea	Carnivore/Omnivore		3	3					
Glycera americana	Carnivore/Omnivore	Equilibrium		13	5		22		2
Glycera capitata	Carnivore/Omnivore			1					
Glycera dibranchiata	Carnivore/Omnivore		37	10	14	9	11		
Glycera robusta	Carnivore/Omnivore						1		
Glycera spp.	Carnivore/Omnivore		1	8	12		6		
Glyceridae	Carnivore/Omnivore				1		3		
Glycinde solitaria	Carnivore/Omnivore	Opportunistic	79	20	27	11	31	10	2
Goniadidae	Carnivore/Omnivore				13		4		
Gyptis vittata	Carnivore/Omnivore			7	1			1	1
Harmothoe sp. A	Carnivore/Omnivore			6			4		
Hesionidae	Carnivore/Omnivore		4	2			2		
Heteromastus filiformis	Deep Deposit	Opportunistic	99	15	33	20	16	13	1
Hobsonia florida	Interface		36	3	3	1			
Hypereteone foliosa	Carnivore/Omnivore		47		2				
Hypereteone heteropoda	Carnivore/Omnivore	Opportunistic	93	18	14	10	21	4	2
Hypereteone spp.	Carnivore/Omnivore				2				
Laonereis culveri	Carnivore/Omnivore		37		1			10	
Leitoscoloplos foliosus	Deep Deposit	Opportunistic					1		
Leitoscoloplos fragilis	Deep Deposit	Opportunistic	56			1	11	4	
Leitoscoloplos robustus	Deep Deposit	Opportunistic	52		21		1		
Leitoscoloplos spp.	Deep Deposit	Opportunistic	68	16	25		2	8	2
Lepidametria commensalis	Carnivore/Omnivore	Opportunistic	10	10	2		2		2
Levinsonia gracilis	Interface			1	1				
Loimia medusa	Interface		29	15	15	2	8		2
Lumbrineridae	Carnivore/Omnivore		1	1					
Lysidice ninetta	Carnivore/Omnivore			1					
Macroclymene zonalis	Deep Deposit	Equilibrium	1	10	3		3		2
Magelona rosea	Suspension						3		
Magelona spp.	Suspension			3	2		1		
Maldanidae	Deep Deposit		5	12	15		4		

TAXON	Feeding Guild	Life History	MON-MD	MON-VA	EMAP	BIO-MD	BIO-VA	JAMES	WOLF
Annelida : Polychaeta (Contd.)									
Malmgreniella sp. A Weston	Carnivore/Omnivore				3				2
Manayunkia aestuarina	Suspension		3		1				
Marenzelleria viridis	Interface		101	14	44	20	5	9	
Marphysa belli	Carnivore/Omnivore						1		
Marphysa sanguinea	Carnivore/Omnivore								1
Mediomastus ambiseta	Deep Deposit	Opportunistic	55	19	31		20		2
Melinna maculata	Interface		3	4	5				1
Melinna spp.	Interface		1						
Microphthalmus aberrans	Carnivore/Omnivore		16		1				
Microphthalmus szcelkowii	Carnivore/Omnivore			1	1				
Microphthalmus spp.	Carnivore/Omnivore		3		1				
Monticellina baptistaeae complex	Interface			6	6				2
Mystides borealis	Carnivore/Omnivore			1					
Neanthes arenaceodentata	Carnivore/Omnivore				1				
Neanthes succinea	Carnivore/Omnivore	Opportunistic	93	23	39	26	29	12	2
Nephtyidae	Carnivore/Omnivore		8	4	8		3		
Nephtys bucera	Carnivore/Omnivore		8	1					
Nephtys incisa	Carnivore/Omnivore			5	5		6		2
Nephtys picta	Carnivore/Omnivore		9	13	11		1		2
Nephtys spp.	Carnivore/Omnivore		6	4	1		2		
Nereididae	Carnivore/Omnivore		3	5	20		1		
Nereiphylla fragilis	Carnivore/Omnivore		5						
Nereis grayi	Carnivore/Omnivore				2				2
Nereis spp.	Carnivore/Omnivore			1					
Notomastus lobatus	Deep Deposit			6					
Notomastus sp. A Ewing	Deep Deposit			4	5				
Notomastus spp.	Deep Deposit			12	1		1		2
Onuphidae	Carnivore/Omnivore				4				
Onuphis eremita	Carnivore/Omnivore				1				
Opheliidae	Deep Deposit		2						
Orbinia ornata	Deep Deposit		2						
Orbinia riseri	Deep Deposit				1				
Orbiniidae	Deep Deposit		4		3		8		
Owenia fusiiformis	Suspension			1	5		2		2
Oweniidae	Suspension			7	2				

TAXON	Feeding Guild	Life History	MON-MD	MON-VA	EMAP	BIO-MD	BIO-VA	JAMES	WOLF
Annelida : Polychaeta (Contd.)									
Paradoneis lyra	Interface		46	1	10				1
Parahesion luteola	Carnivore/Omnivore								1
Paranaitis speciosa	Carnivore/Omnivore		3	6	2		3		1
Paraonidae	Interface						1		
Paraonis fulgens	Interface		30	1	2				
Parapionosyllis longicirrata	Carnivore/Omnivore			1					
Parapionospio pinnata	Interface	Opportunistic	73	20	31	21	35	10	2
Parougia caeca	Carnivore/Omnivore			1					
Pectinaria gouldii	Deep Deposit		55	18	18	5	34	1	2
Pectinaria spp.	Deep Deposit				7				
Phyllodoce arenae	Carnivore/Omnivore		10	11	10		1		2
Phyllodoce mucosa	Carnivore/Omnivore			2			1		
Phyllodoce spp.	Carnivore/Omnivore			2	3				
Phyllodocidae	Carnivore/Omnivore		4		1		3		
Pilargiidae	Carnivore/Omnivore			1	2		2		
Pista cristata	Interface				2				
Pista palmata	Interface			1					
Pista quadrilobata	Interface			1					
Podarke obscura	Carnivore/Omnivore		4	7	1		1		
Podarkeopsis levifuscina	Carnivore/Omnivore		48	18	23		8		2
Polycirrus eximius	Interface			3	1		1		
Polycirrus spp.	Interface				2				
Polydora caulleryi	Interface			3					
Polydora cornuta	Interface	Opportunistic	87	23	14	1	22	7	2
Polydora socialis	Interface			1	2		1		2
Polydora spp.	Interface		5		4				
Polygordius spp.	Deep Deposit			3	2		2		
Polynoidae	Carnivore/Omnivore		5	1	6		1		
Praxillella gracilis	Deep Deposit						2		
Prionospio cirrifera	Interface			9			4		
Prionospio cirrobranchiata	Interface			3			1		
Prionospio perkinsi	Interface			8	6				2
Prionospio spp.	Interface								
Prionospio steenstrupi	Interface		1				2		
Proceraea spp.	Carnivore/Omnivore			1			1		

TAXON	Feeding Guild	Life History	MON-MD	MON-VA	EMAP	BIO-MD	BIO-VA	JAMES	WOLF
Annelida : Polychaeta (Contd..)									
Pseudeurythoe paucibranchiata	Carnivore/Omnivore		27	18	20	4	41	5	2
Sabellidae	Suspension				2				
Sabellides octocirrata	Interface			1					
Scalibregma inflatum	Deep Deposit				1				
Scolecipis bousfieldi	Interface			5	4				
Scolecipis spp.	Interface			2	1				2
Scolecipis squamata	Interface						1		
Scolecipis texana	Interface		26	1	3				
Scoletoma acicularum	Carnivore/Omnivore			1					
Scoletoma tenuis	Carnivore/Omnivore				1				
Scoloplos acmeceps	Deep Deposit						2		
Scoloplos rubra	Deep Deposit		5	6	3	2	5		2
Sigambra bassi	Carnivore/Omnivore			4					
Sigambra spp.	Carnivore/Omnivore				1		1		
Sigambra tentaculata	Carnivore/Omnivore		26	18	11		19		2
Sphaerosyllis taylori	Carnivore/Omnivore				1				
Spio filicornis	Interface		4				1		
Spio pettiboneae	Interface			3					
Spio setosa	Interface		1	4	1		3		
Spio spp.	Interface		18				1		2
Spiochaetopterus costarum	Interface		16	13	22		1	8	2
Spionidae	Interface		8	3	1		5		
Spiophanes bombyx	Interface	Opportunistic	23	13	12		4		
Spiophanes spp.	Interface						1		
Spiophanes wigleyi	Interface						1		2
Sthenelais boa	Carnivore/Omnivore			1	1				1
Streblospio benedicti	Interface	Opportunistic	99	22	39	27	27	8	2
Syllidae	Carnivore/Omnivore			2			1		
Syllis cornuta	Carnivore/Omnivore						1		
Terebellidae	Interface		1	3	10		2		
Tharyx sp. A Morris	Interface		29	13	14	2	19		1
Travisia carnea	Deep Deposit						1		
Travisia sp. A Morris	Deep Deposit				1				
Websteriopsis tridentata	Carnivore/Omnivore			1			1		

TAXON	Feeding Guild	Life History	MON-MD	MON-VA	EMAP	BIO-MD	BIO-VA	JAMES	WOLF
Annelida : Oligochaeta									
Arcteonais lomondi	Deep Deposit	Opportunistic	1		1				
Aulodrilus limnobius	Deep Deposit	Opportunistic	5		9				
Aulodrilus paucichaeta	Deep Deposit	Opportunistic	5		1				
Aulodrilus pigueti	Deep Deposit	Opportunistic	8	1	9			6	
Aulodrilus pluriseti	Deep Deposit	Opportunistic	1		1				
Bothrioneurum vejovskyanum	Deep Deposit	Opportunistic	9						
Branchiura sowerbyi	Deep Deposit	Opportunistic	9	1	4			8	
Bratislavia bilongata	Deep Deposit		1						
Bratislavia unidentata	Deep Deposit		3		1				
Dero digitata	Deep Deposit		3		8			5	
Dero flabelliger	Deep Deposit		1						
Dero spp.	Deep Deposit		4		1				
Enchytraeidae	Deep Deposit		2	1					
Haber cf. speciosus	Deep Deposit	Opportunistic			5				
Ilyodrilus spp.	Deep Deposit	Opportunistic	1						
Ilyodrilus templetoni	Deep Deposit	Opportunistic	6	1	13			23	
Isochaetides curvosestosus	Deep Deposit	Opportunistic	1						
Isochaetides freyi	Deep Deposit	Opportunistic	4	2	5				
Limnodrilus cervix	Deep Deposit	Opportunistic	6	1	4			26	
Limnodrilus claparedeanus	Deep Deposit	Opportunistic	6						
Limnodrilus hoffmeisteri	Deep Deposit	Opportunistic	18	4	26				
Limnodrilus profundicola	Deep Deposit	Opportunistic		3					
Limnodrilus spp.	Deep Deposit	Opportunistic	16	6				28	
Limnodrilus udekemianus	Deep Deposit	Opportunistic	9	1	4			9	
Lumbriculidae	Deep Deposit		3						
Nais barbata	Deep Deposit								
Nais behningi	Deep Deposit							1	
Nais communis	Deep Deposit							2	
Nais pardalis	Deep Deposit								
Nais spp.	Deep Deposit		1	1					
Nais variabilis	Deep Deposit		5	2					
Oligochaeta	Deep Deposit	Opportunistic	71	4	49		16		2
Oligochaeta sp. X (no setae)	Deep Deposit			1					
Ophidonais serpentina	Deep Deposit		3						
Paranais frici	Deep Deposit		7						

TAXON	Feeding Guild	Life History	MON-MD	MON-VA	EMAP	BIO-MD	BIO-VA	JAMES	WOLF
Annelida : Oligochaeta (Contd.)									
Paranais littoralis	Deep Deposit		5						
Paranais spp.	Deep Deposit		9						
Piguetiella michiganensis	Deep Deposit				1				
Potamothrix spp.	Deep Deposit	Opportunistic	1	1					
Potamothrix vejovskyi	Deep Deposit	Opportunistic		1					
Pristinella jenkinsae	Deep Deposit			1					
Pristinella osborni	Deep Deposit			1					
Pristinella sima	Deep Deposit			4					
Pristinella spp.	Deep Deposit		1						
Quistadrilus multisetosus	Deep Deposit	Opportunistic	7	2	9			12	
Slavina appendiculata	Deep Deposit		4						
Specaria josinae	Deep Deposit		3		1				
Stephensoniana tandyi	Deep Deposit				1				
Stephensoniana trivandana	Deep Deposit				1				
Stylaria lacustris	Deep Deposit		1					2	
Tubificid imm. w/o cap. chaetae	Deep Deposit	Opportunistic	56		27				
Tubificid imm. with cap. chaetae	Deep Deposit	Opportunistic	13		15				
Tubificidae	Deep Deposit	Opportunistic						4	
Tubificoides benedeni	Deep Deposit	Opportunistic		5					
Tubificoides brownae	Deep Deposit	Opportunistic	35						
Tubificoides gabriellae	Deep Deposit	Opportunistic						6	
Tubificoides heterochaetus	Deep Deposit	Opportunistic	46	11	7			13	
Tubificoides maureri	Deep Deposit	Opportunistic	28						
Tubificoides spp.	Deep Deposit	Opportunistic	97	23					
Tubificoides wasselli	Deep Deposit	Opportunistic	5	12					
Wapsa mobilis	Deep Deposit	Opportunistic		1					
Mollusca : Gastropoda									
Acteocina canaliculata	Carnivore/Omnivore		65	15	25	3	28	4	2
Acteocina spp.	Carnivore/Omnivore		1						
Acteon punctostriatus	Carnivore/Omnivore		61	12	20		9		2
Ancylidae	Carnivore/Omnivore		1						
Boonea bisuturalis	Carnivore/Omnivore			1				6	
Busycon carica	Carnivore/Omnivore						2		
Busycon spp.	Carnivore/Omnivore			1					

TAXON	Life History	MON-MD	MON-VA	EMAP	BIO-MD	BIO-VA	JAMES	WOLF
Mollusca : Gastropoda (Contd.)								
Caecum pulchellum						1		
Cerithiopsis greeni			1					
Cylichna alba						2		
Ferrissia spp.		1					2	
Gyraulus spp.		1						
Haminoea solitaria		31	4	3				
Helisoma spp.		1						
Hydrobia spp.							1	
Hydrobia truncata		13						
Kurtziella atrostyla				1				
Kurtziella cerina						1		
Littoridinops tenuipes		43		5				
Littorina spp.		1						
Natica pusilla			3	1		1		2
Naticidae		1						
Odostomia engonia		28						2
Physa spp.		1						
Physidae		4						
Planorbidae		1						
Pleurocera spp.		2						
Pleuroceridae		1						
Polinices duplicatus			2					
Pyrgocithara plicosa			1					
Sayella chesapeakea		46						
Sayella fusca							1	
Turbonilla interrupta		3	9			10		2
Turbonilla stricta						1		2
Turridae			1					
Valvata spp.							2	

TAXON	Feeding Guild	Life History	MON-MD	MON-VA	EMAP	BIO-MD	BIO-VA	JAMES	WOLF
Mollusca : Bivalvia									
<i>Aligena elevata</i>	Suspension		5	7	1		6	1	
<i>Anadara ovalis</i>	Suspension	Equilibrium	2	3	1		1		
<i>Anadara spp.</i>	Suspension		1						
<i>Anadara transversa</i>	Suspension	Equilibrium	2	10	5		13	1	2
<i>Anodonta</i>	Suspension		2						
<i>Bivalvia</i>	Deep Deposit		37	17	8		2	8	
<i>Cerastoderma pinnulatum</i>	Suspension								1
<i>Corbicula fluminea</i>	Suspension	Opportunistic	7	3	15	1		22	
<i>Cyrtopleura costata</i>	Suspension	Equilibrium		6					
<i>Dosinia discus</i>	Suspension	Equilibrium		5					
<i>Eliptio complanata</i>	Suspension				1				
<i>Ensis directus</i>	Suspension	Equilibrium	34	13	13		17		2
<i>Gemma gemma</i>	Suspension	Opportunistic	45	3	5		1	1	1
<i>Lampsilis</i>	Suspension		1						
<i>Lyonsia hyalina</i>	Interface		39	11	10	3	16		2
<i>Macoma balthica</i>	Interface	Equilibrium	94	14	21	23	8	13	2
<i>Macoma mitchelli</i>	Interface		94	8	14	18	2	10	
<i>Macoma spp.</i>	Interface			1					
<i>Macoma tenta</i>	Interface			15	9			7	2
<i>Mercenaria mercenaria</i>	Suspension	Equilibrium	3	4	5		2	1	1
<i>Mulinia lateralis</i>	Suspension	Opportunistic	88	19	26	16	31	6	2
<i>Musculium</i>	Suspension		7		13				
<i>Musculium transversum</i>	Suspension		3		3				
<i>Mya arenaria</i>	Suspension	Equilibrium	87	9	2	3	13	7	
<i>Nucula proxima</i>	Deep Deposit	Opportunistic		6	6		4		1
<i>Nuculana messanensis</i>	Deep Deposit			3					
<i>Pandora gouldiana</i>	Suspension				1				
<i>Pandora spp.</i>	Suspension				1				
<i>Parvilucina multilineata</i>	Suspension		17	7	12	1	1		2
<i>Periploma margaritacea</i>	Suspension				1				
<i>Periploma spp.</i>	Suspension								2
<i>Petricola pholadiformis</i>	Suspension		5						
<i>Pholadidae</i>	Suspension				1				
<i>Pisidium</i>	Suspension		5	1					
<i>Pisidium spp.</i>	Suspension		9	2	5	1			

TAXON	Feeding Guild	Life History	MON-MD	MON-VA	EMAP	BIO-MD	BIO-VA	JAMES	WOLF
Mollusca : Bivalvia (Contd.)									
Pitar morrhua	Suspension	Equilibrium	59	8	22	2	1	26	1
Rangia cuneata	Suspension			1					
Semele purpurascens	Suspension		1						
Siliqua costata	Deep Deposit				1				
Solemya velum	Suspension			2					
Sphaerium spp.	Suspension			1					
Spisula solidissima	Suspension			3	2				1
Tagelus divisus	Suspension		31	2	1				2
Tagelus plebeius	Suspension		1		1				
Tagelus spp.	Interface		25	12	17	16			2
Tellina agilis	Interface		38		18	1			
Tellinidae	Suspension								1
Thracia spp.	Suspension		1		2			5	
Unionidae	Deep Deposit			7	4	11			2
Yoldia limatula	Deep Deposit			1					
Yoldia spp.									
Arthropoda : Stomatopoda									
Squilla empusa	Carnivore/Omnivore	Equilibrium	1	2					1
Arthropoda : Cumacea									
Almyracuma proximoculi	Interface		3					1	
Cyclaspis varians	Interface		42	3	2	2			
Leucon americanus	Interface		31	13	11		14	5	1
Oxyurostylis smithi	Interface		31	9	6		7	1	2
Pseudoleptocuma minor	Interface		9						
Arthropoda : Tanaidacea									
Hargeria rapax	Interface		13						

TAXON	Feeding Guild	Life History	MON-MD	MON-VA	EMAP	BIO-MD	BIO-VA	JAMES	WOLF
Arthropoda : Isopoda									
Amakusanthura magnifica	Carnivore/Omnivore				1				
Anthuridae	Carnivore/Omnivore						1		
Asellidae	Carnivore/Omnivore		1						
Asellus spp.	Carnivore/Omnivore		2						
Caecidotea spp.	Carnivore/Omnivore		2						
Chiridotea almyra	Carnivore/Omnivore		31		11			2	
Chiridotea caeca	Carnivore/Omnivore		27	2		4	1		
Chiridotea nigrescens	Carnivore/Omnivore			5					
Chiridotea spp.	Carnivore/Omnivore			1					
Cyathura burbancki	Carnivore/Omnivore							1	
Cyathura polita	Carnivore/Omnivore		72	9	31	9	1	18	
Cyathura spp.	Carnivore/Omnivore			1					
Isopoda	Carnivore/Omnivore		1						
Ptilanthura tenuis	Carnivore/Omnivore		9	2	4		1		1
Arthropoda : Amphipoda									
Acanthohaustorius millisi	Interface		9		2				
Ampelisca abdita	Suspension	Opportunistic	28	14	8	4	29	2	2
Ampelisca spp.	Suspension	Opportunistic	1	8	21				
Ampelisca vadorum	Suspension	Opportunistic	1	9	1	2	5	1	
Ampelisca verrilli	Suspension	Opportunistic	2	7	8		7		2
Ampeliscidae	Suspension	Opportunistic					1		
Amphipoda	Interface		5						
Aoridae	Interface			1					
Corophiidae	Interface		1						
Gammaridae	Interface							1	
Gammarus daiberi	Interface		47	8	15			14	
Gammarus fasciatus	Interface		7		2			14	
Gammarus palustris	Interface		1	11					
Gammarus spp.	Interface		79	5	18			5	
Gammarus tigrinus	Interface		16	2					
Haustoriidae	Interface				1				
Lepidactylus dytiscus	Interface		28		1			4	
Leptocheirus plumulosus	Interface	Opportunistic	98	10	29	20	1	12	
Listriella barnardi	Interface		4	7	6				2

TAXON	Feeding Guild	Life History	MON-MD	MON-VA	EMAP	BIO-MD	BIO-VA	JAMES	WOLF
Arthropoda : Amphipoda (Contd.)									
Listriella clymenellae	Interface		2	12	8		12	1	
Listriella smithi	Interface			2					
Listriella spp.	Interface		2	4	2		1		
Monoculodes intermedius	Interface			3					
Monoculodes sp. 1 Watling	Interface		93	6	6		3	2	
Mucrogammarus mucronatus	Interface		57	3	1	2	8		
Rhepoxynius hudsoni	Interface			2	3		2		
Synchelidium americanum	Interface			1					
Unciola irrorata	Interface			3			3	3	
Unciola serrata	Interface		2	8	2		4		
Unciola spp.	Interface		1	2	1				
Arthropoda : Decapoda									
Alpheus heterochaelis	Carnivore/Omnivore	Equilibrium		1	1				1
Automate evermanni	Carnivore/Omnivore								
Biffarius biformis	Carnivore/Omnivore	Equilibrium		3					
Callianassa setimanus	Carnivore/Omnivore			3			2		
Euceramus praelongus	Carnivore/Omnivore		1	6	5				1
Pinnixa chaetoptera	Carnivore/Omnivore		8	10			3		
Pinnixa cristata	Carnivore/Omnivore			2					
Pinnixa retinens	Carnivore/Omnivore			7			4		1
Pinnixa sayana	Carnivore/Omnivore			4					1
Pinnixa spp.	Carnivore/Omnivore		3	9	6				
Pinnotheres ostreum	Carnivore/Omnivore			2					
Pinnotheres spp.	Carnivore/Omnivore						1		
Pinnotheridae	Carnivore/Omnivore						2		
Polyonyx gibbesi	Carnivore/Omnivore			1					2
Thalassinidea	Carnivore/Omnivore			1	1				
Upogebia affinis	Carnivore/Omnivore		1	6	4		2	1	
Arthropoda : Insecta									
Insecta	Carnivore/Omnivore		1					3	
Arthropoda : Collembola									
Collembola	Carnivore/Omnivore		2						

TAXON	Feeding Guild	Life History	MON-MD	MON-VA	EMAP	BIO-MD	BIO-VA	JAMES	WOLF
Arthropoda : Ephemeroptera									
Caenis spp.	Carnivore/Omnivore		2						
Ephemeridae	Carnivore/Omnivore		1						
Ephemeroptera	Carnivore/Omnivore		1	1				1	
Ephoron spp.	Carnivore/Omnivore		1						
Hexagenia mingo	Carnivore/Omnivore							8	
Hexagenia spp.	Carnivore/Omnivore		1	2					
Paraleptophlebia spp.	Carnivore/Omnivore		1						
Potamanthus spp.	Carnivore/Omnivore		2						
Stenonema annexum	Carnivore/Omnivore							1	
Tricorythodes spp.	Carnivore/Omnivore		1						
Arthropoda : Odonata									
Aeshna spp.	Carnivore/Omnivore		1						
Anisoptera	Carnivore/Omnivore		1						
Dromogomphus spp.	Carnivore/Omnivore		1						
Gomphidae	Carnivore/Omnivore		1						
Gomphus spp.	Carnivore/Omnivore		1						
Ischnura spp.	Carnivore/Omnivore		1						
Odonata	Carnivore/Omnivore							1	
Arthropoda : Plecoptera									
Allocapnia spp.	Carnivore/Omnivore		1						
Arthropoda : Coleoptera									
Chrysomelidae	Carnivore/Omnivore		1						
Dubiraphia spp.	Carnivore/Omnivore		3						
Elmidae	Carnivore/Omnivore		4						
Microcylloepus spp.	Carnivore/Omnivore		1						
Stenelmis spp.	Carnivore/Omnivore		3						

TAXON	Life History	MON-MD	MON-VA	EMAP	BIO-MD	BIO-VA	JAMES	WOLF
Arthropoda : Trichoptera								
Ceraclea spp.	Carnivore/Omnivore	1						
Cheumatopsyche	Carnivore/Omnivore	1						
Hydropsychidae	Carnivore/Omnivore	1						
Hydroptila spp.	Carnivore/Omnivore	1						
Leptoceridae	Carnivore/Omnivore	1						
Oecetis inconspicua	Carnivore/Omnivore		1					
Polycentropus spp.	Carnivore/Omnivore	1						
Trichoptera	Carnivore/Omnivore	5	3				3	
Arthropoda : Diptera								
Bezzia spp.	Carnivore/Omnivore	1		1				
Ceratopogonidae	Carnivore/Omnivore	6	1					
Chaoboridae	Carnivore/Omnivore	1						
Chaoborus albatrus	Carnivore/Omnivore		1					
Chaoborus punctipennis	Carnivore/Omnivore		6	13			14	
Chaoborus pupae	Carnivore/Omnivore	3						
Chaoborus spp.	Carnivore/Omnivore	21					10	
Cryptotendipes spp.	Carnivore/Omnivore	3						
Demicryptochironomus spp.	Carnivore/Omnivore			1				
Diptera	Carnivore/Omnivore	2		2			1	
Djalmabatista pulcher	Carnivore/Omnivore		1					
Dolichopodidae	Carnivore/Omnivore	1						
Erioptera spp.	Carnivore/Omnivore	1						
Harnischia	Carnivore/Omnivore	17	2	9				
Hemerodromia spp.	Carnivore/Omnivore	1						
Microchironomus	Carnivore/Omnivore	2						
Micropsectra spp.	Carnivore/Omnivore	1						
Palpomyia spp.	Carnivore/Omnivore		2	3				
Paracladopelma spp.	Carnivore/Omnivore	2						
Phaenopsectra spp.	Carnivore/Omnivore	4						
Sphaeromias spp.	Carnivore/Omnivore			1				
Stempellina spp.	Carnivore/Omnivore	3						
Tipulidae	Carnivore/Omnivore	1						
Tribelos spp.	Carnivore/Omnivore	3						

TAXON	Feeding Guild	Life History	MON-MD	MON-VA	EMAP	BIO-MD	BIO-VA	JAMES	WOLF
Arthropoda : Chironomidae									
<i>Ablabesmyia aurifensis</i>	Carnivore/Omnivore		1						
<i>Ablabesmyia parajanta</i>	Carnivore/Omnivore		1	5					
<i>Ablabesmyia</i> spp.	Carnivore/Omnivore		1						
Chironomidae	Carnivore/Omnivore		72	3	17	5			
Chironomini	Carnivore/Omnivore		5	1	1				
<i>Chironomus attenuatus</i>	Carnivore/Omnivore			1					
<i>Chironomus decorus</i>	Carnivore/Omnivore			1					
<i>Chironomus</i> spp.	Carnivore/Omnivore	Opportunistic	47	1	16				
<i>Cladotanytarsus</i> spp.	Carnivore/Omnivore	Opportunistic	3		4			6	
<i>Clinotanypus pinguis</i>	Carnivore/Omnivore		1	6					
<i>Clinotanypus</i> spp.	Carnivore/Omnivore		1			4			
<i>Coelotanypus</i> spp.	Carnivore/Omnivore		38	2	26	1		26	
<i>Cricotopus bicornutus</i>	Carnivore/Omnivore	Opportunistic	1						
<i>Cricotopus</i> spp.	Carnivore/Omnivore		5	3					
<i>Cryptochironomus fulvus</i>	Carnivore/Omnivore			6	3			18	
<i>Cryptochironomus nr fulvus</i>	Carnivore/Omnivore								
<i>Cryptochironomus parafulvus</i>	Carnivore/Omnivore			2					
<i>Cryptochironomus</i> spp.	Carnivore/Omnivore		26		17	2		4	
<i>Dicrotendipes nervosus</i>	Carnivore/Omnivore			2	1				
<i>Dicrotendipes</i> spp.	Carnivore/Omnivore		6						
Einfeldia	Carnivore/Omnivore		2						
<i>Endochironomus</i> spp.	Carnivore/Omnivore		2						
<i>Eukiefferiella devonica</i> complex	Carnivore/Omnivore		1						
<i>Eukiefferiella</i> spp.	Carnivore/Omnivore		1						
<i>Glyptotendipes</i> spp.	Carnivore/Omnivore	Opportunistic	2	2	1				
<i>Hydrobaenus</i> spp.	Carnivore/Omnivore		6						
<i>Lauterborniella</i>	Carnivore/Omnivore		2						
<i>Limnophyes</i> spp.	Carnivore/Omnivore		4						
<i>Microtendipes</i> spp.	Carnivore/Omnivore		1						
<i>Nanocladius balticus</i>	Carnivore/Omnivore		1						
Orthoclaadiinae	Carnivore/Omnivore		1						
<i>Parachironomus</i> spp.	Carnivore/Omnivore		1						
<i>Paralauterborniella</i> spp.	Carnivore/Omnivore		3						
<i>Parametriochnemus</i> spp.	Carnivore/Omnivore		1						
<i>Paratendipes</i> spp.	Carnivore/Omnivore		2	1					

TAXON	Feeding Guild	Life History	MON-MD	MON-VA	EMAP	BIO-MD	BIO-VA	JAMES	WOLF
Arthropoda : Chironomidae (Contd.)									
<i>Pelopia stellata</i>	Carnivore/Omnivore							1	
<i>Pentaneura nr decolorata</i>	Carnivore/Omnivore							9	
<i>Pentaneura</i> spp.	Carnivore/Omnivore							3	
<i>Polypedium convictum</i>	Carnivore/Omnivore			3					
<i>Polypedium fallax</i>	Carnivore/Omnivore			1					
<i>Polypedium</i> spp.	Carnivore/Omnivore			1				12	
<i>Polypedium tripodura</i>	Carnivore/Omnivore		18		10				
<i>Procladius</i> spp.	Carnivore/Omnivore		25		3	2		19	
<i>Procladius sublettei</i>	Carnivore/Omnivore			5	18				
<i>Pseudochironomus fulviventris</i>	Carnivore/Omnivore			1					
<i>Pseudochironomus</i> spp.	Carnivore/Omnivore								
<i>Rheotanytarsus</i> spp.	Carnivore/Omnivore				2				
<i>Smittia</i> spp.	Carnivore/Omnivore		1						
<i>Stenochironomus nr taeniapennis</i>	Carnivore/Omnivore							2	
<i>Stictochironomus devinctus</i>	Carnivore/Omnivore							4	
<i>Stictochironomus nr devinctus</i>	Carnivore/Omnivore							1	
<i>Stictochironomus</i> spp.	Carnivore/Omnivore							1	
<i>Tanypus</i>	Carnivore/Omnivore		2		3				
<i>Tanypus nr stellatus</i>	Carnivore/Omnivore		4	1	3				
<i>Tanytarsini</i>	Carnivore/Omnivore							2	
<i>Tanytarsus</i> spp.	Carnivore/Omnivore		1	2					
<i>Tendipes nervosus</i>	Carnivore/Omnivore		8		4			4	
<i>Tendipes riparius</i>	Carnivore/Omnivore							3	
<i>Thienemannimyia</i> spp.	Carnivore/Omnivore		1					6	
<i>Xenochironomus festivus</i>	Carnivore/Omnivore			1					
<i>Xenochironomus</i> spp.	Carnivore/Omnivore			2					
<i>Zavrelliella</i> spp.	Carnivore/Omnivore		1						
Sipuncula									
<i>Phascolion strombi</i>	Deep Deposit			1					
<i>Sipuncula</i>	Deep Deposit		3	5					
Echlurida									
<i>Thalassema</i> spp.	Deep Deposit	Equilibrium		2					

TAXON	Feeding Guild	Life History	MON-MD	MON-VA	EMAP	BIO-MD	BIO-VA	JAMES	WOLF
Phoronida									
Phoronis spp.	Suspension		26	13	19	1	19	4	2
Echinodermata : Ophiuroidea									
Microphiopholis atra	Deep Deposit	Equilibrium		10	3		5	1	2
Ophiuroidea	Deep Deposit		1	2	11				
Echinodermata : Holothuroidea									
Holothuroidea	Deep Deposit			2					
Leptosynapta tenuis	Deep Deposit		20	5	8				1
Pentamera pulcherrima	Deep Deposit			1					
Thyonella pervicax	Deep Deposit			1					
Hemichordata									
Balanoglossus aurantiacus	Deep Deposit			10					
Hemichordata	Deep Deposit			4					
Saccoglossus kowalevskii	Deep Deposit		20	8	11			1	2

APPENDIX B
TAXA DELETED FROM ORIGINAL DATA

Taxa not meeting benthic macroinfaunal criteria.

Porifera

Microciona prolifera
Porifera

Cnidaria

Cnidaria

Cnidaria : Hydrozoa

Bougainvillia rugosa
Cordylophora lacustris
Garveia cerulea
Hydra spp.
Hydractinia echinata
Hydrozoa
Moerisia lyonsi
Obelia spp.
Sertularia argentea

Cnidaria : Scyphozoa

Chrysaora polyps
Scyphozoan polyps

Cnidaria : Anthozoa

Diadumene leucolena

Platyhelminthes : Turbellaria

Dugesia tigrina
Euplana gracilis
Hydrolimax grisea
Stylochus ellipticus
Turbellaria

Platyhelminthes : Trematoda

Trematoda

Nematoda

Nematoda

Annelida : Polychaeta

Harmothoe extenuata
Harmothoe spp.
Hydroides
Hydroides protulicola
Lepidonotus sublevis
Lepidonotus variabilis
Polychaeta
Polydora websteri
Protodrilus spp.
Sabellaria vulgaris

Annelida : Polychaeta (Continued)

Serpulidae
Syllides spp.
Syllides verrilli

Annelida : Oligochaeta

Naididae
Nais pseudobtusa

Annelida : Hirudinea

Alboglossiphonia heteroclita
Batrachobdella spp.
Batracobdella phalera
Glossiphoniidae
Helobdella elongata
Helobdella fusca
Helobdella spp.
Helobdella stagnalis
Helobdella triserialis
Hirudinea
Illinobdella moorei
Piscicola spp.
Piscicolidae
Rhynchobdellida

Mollusca

Mollusca

Mollusca : Gastropoda

Amnicola limosa
Anachis avara
Anachis lafresnayi
Anachis obesa
Astyris lunata
Balcis intermedia
Boonea impressa
Cincinnatia winkleyi
Columbella spp.
Cratena kaoruae
Cratena pilata
Cratena spp.
Crepidula fornicata
Crepidula plana
Crepidula spp.
Cylichnella bidentata
Doridella obscura
Epitonium multistriatum
Epitonium rupicola
Epitonium spp.

Mollusca : Gastropoda (Continued)

Eupleura caudata
Fargoa bushiana
Gastropoda
Hydrobiidae
Ilyanassa obsoleta
Nassarius spp.
Nassarius trivittatus
Nassarius vibex
Nudibranchia
Odostomia spp.
Physella spp.
Pyramidellidae
Skeneopsis planorbis
Turbonilla spp.
Urosalpinx cinerea
Vitrinellidae

Mollusca : Bivalvia

Amygdalum papyrium
Anomia simplex
Anomia spp.
Crassostrea virginica
Geukensia demissa
Ischadium recurvum
Mysella planulata
Mysella spp.
Mytilidae
Mytilopsis leucophaeata
Mytilus edulis

Mollusca : Cephalopoda

Lolliguncula brevis

Arthropoda : Merostomata

Limulus polyphemus

Arthropoda : Hydracarina

Hydracarina

Arthropoda : Pycnogonida

Pycnogonida

Arthropoda : Cephalocarida

Cephalocarida
Hutchinsoniella macracantha

Arthropoda : Cladocera

Alona affinis
Cladocera

Arthropoda : Ostracoda

Ostracoda
Sarsiella spp.

Arthropoda : Copepoda

Calanidae
Calanoida
Caligoida

Arthropoda : Branchiura

Argulus spp.

Arthropoda : Cirripedia

Balanus
Balanus amphitrite niveus
Balanus balanoides
Balanus eburneus
Balanus improvisus
Cirripedia

Arthropoda : Mysidacea

Heteromysis formosa
Mysidae
Mysidopsis
Mysidopsis almyra
Mysidopsis bigelowi
Neomysis americana

Arthropoda : Isopoda

Aegathoa medialis
Cassidinidea ovalis
Cymothoidae
Edotea triloba
Erichsonella attenuata
Erichsonella filiformis
Erichsonella spp.
Paracereis caudata

Arthropoda : Amphipoda

Ampithoe longimana
Ampithoe valida
Ampithoidae
Batea catharinensis
Caprella andreae
Caprella equilibra
Caprella penantis
Caprella spp.
Caprellidae
Cerapus tubularis
Corophium acherusicum
Corophium acutum
Corophium insidiosum

Arthropoda : Amphipoda (Continued)

Corophium lacustre
Corophium simile
Corophium spp.
Corophium tuberculatum
Corophium volutator
Cymadusa compta
Dulichella appendiculata
Elasmopus laevis
Erichthonius brasiliensis
Gitanopsis spp.
Melita nitida
Melita spp.
Microprotopus raneyi
Paracaprella tenuis
Parametopella cypris
Parapleustes aestuarius
Parathemisto compressa
Photis dentata
Photis pollex
Photis pugnator
Photis spp.
Pleustidae
Pleusymtes glaber
Pleusymtes spp.
Stenothoe minuta
Stenothoe spp.

Arthropoda : Decapoda

Brachyuran megalopa
Brachyuran zoea
Callinectes sapidus
Caridean zoea
Crangon septemspinosa
Decapoda
Eurypanopeus depressus
Hexapanopeus angustifrons
Libinia dubia
Libinia spp.
Majidae
Neopanope sayi
Ogyrides alphaerostris
Paguridae
Pagurus longicarpus
Pagurus spp.
Palaemonetes pugio
Palaemonetes sp. zoea
Palaemonetes spp.
Palaemonetes vulgaris
Panopeus herbstii
Processa vicina
Rhithropanopeus harrisi

Arthropoda : Decapoda (Continued)

Rhithropanopeus harrisi zoea
Xanthidae

Arthropoda : Trichoptera

Oecetis spp.

Tardigrada

Haplomacrobatus spp.

Bryozoa

Aeeverillia armata
Alcyonidium spp.
Anguinella palmata
Cristatella spp.
Electra crustulenta
Membranipora membranacea
Membranipora spp.

Entoprocta

Urnatella gracilis

Echinodermata

Echinodermata

Echinodermata : Echinoidea

Echinoidea

Chordata : Ascidiacea

Ascidiacea
Botryllus schlosseri
Cnemidocarpa mollis
Molgula lutulenta
Molgula manhattensis

Chordata : Cephalochordata

Branchiostoma caribaeum

Chordata : Vertebrata

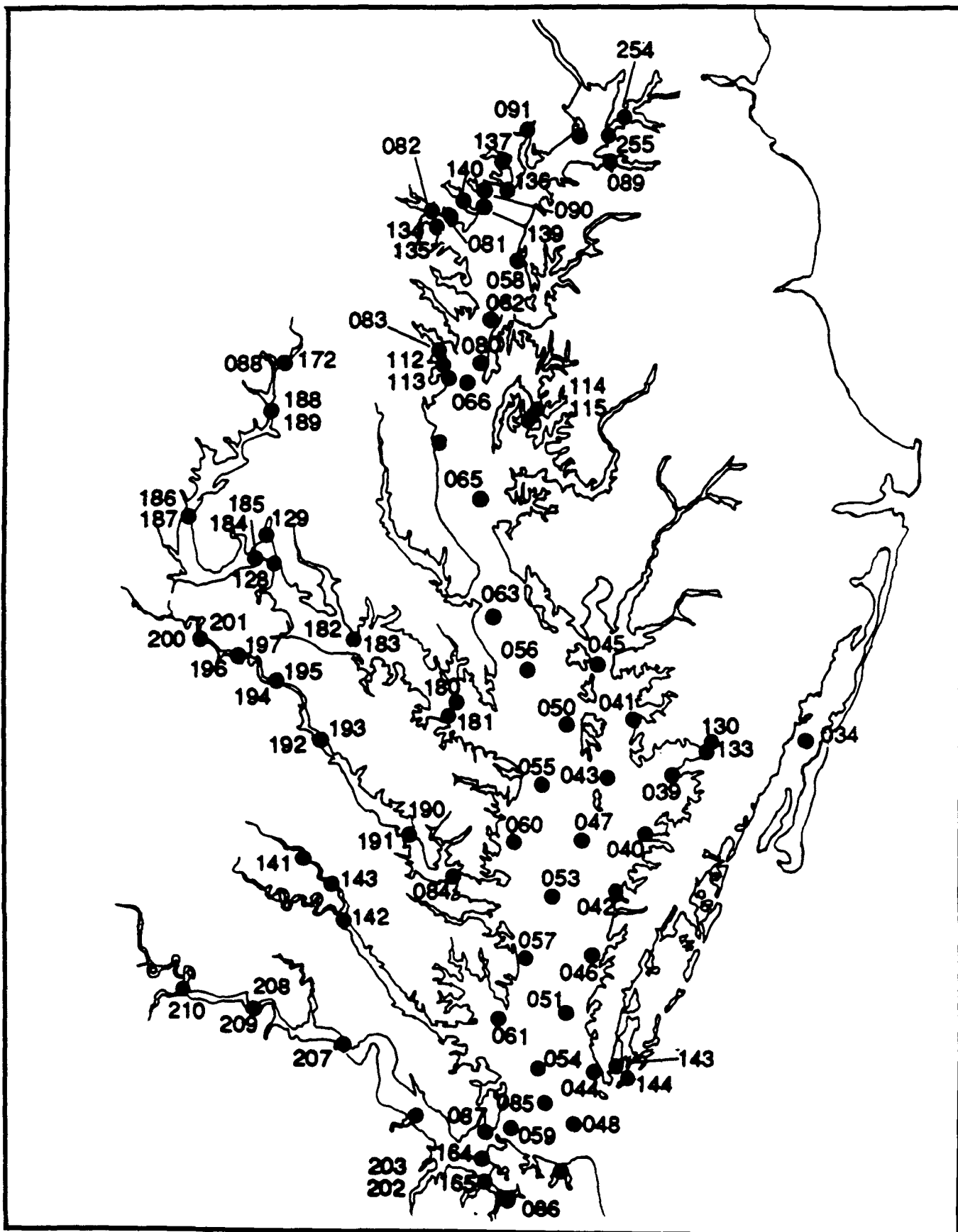
Alosa mediocris
Teleostei

Miscellanea

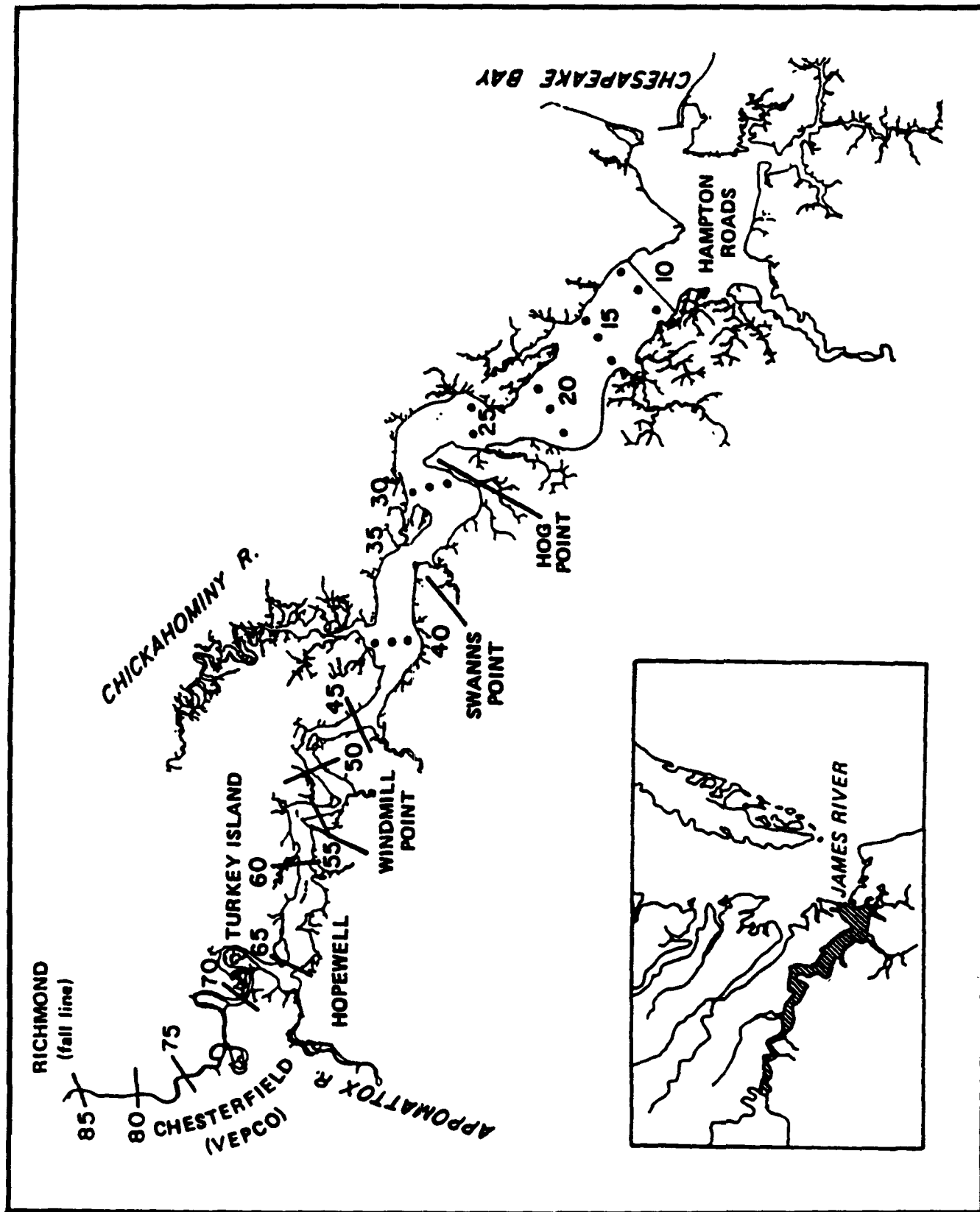
Algae

APPENDIX C

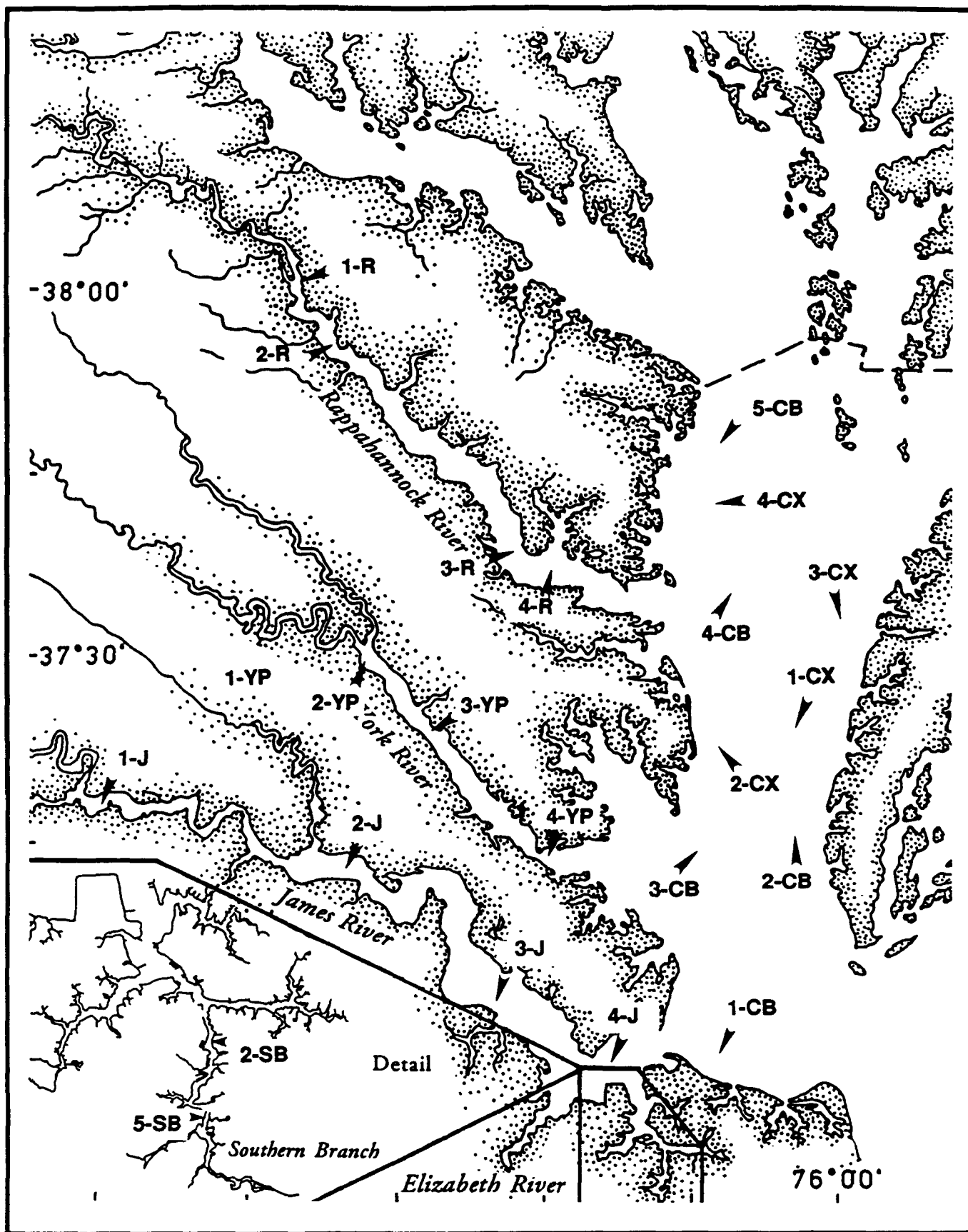
STATION LOCATIONS



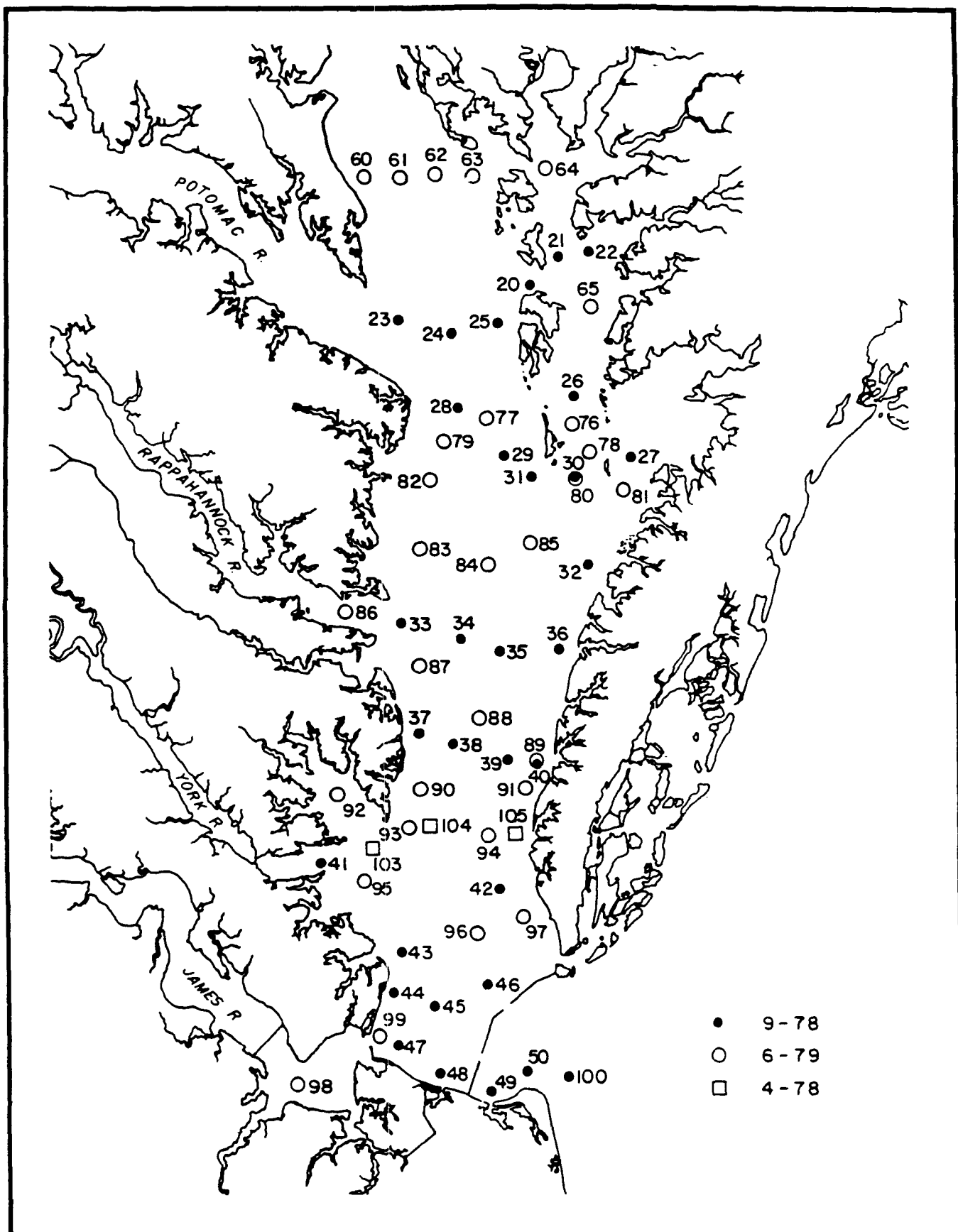
Station locations for the Environmental Monitoring and Assessment Program-Near Coastal 1990 (Goals Station Prefix EMAP)



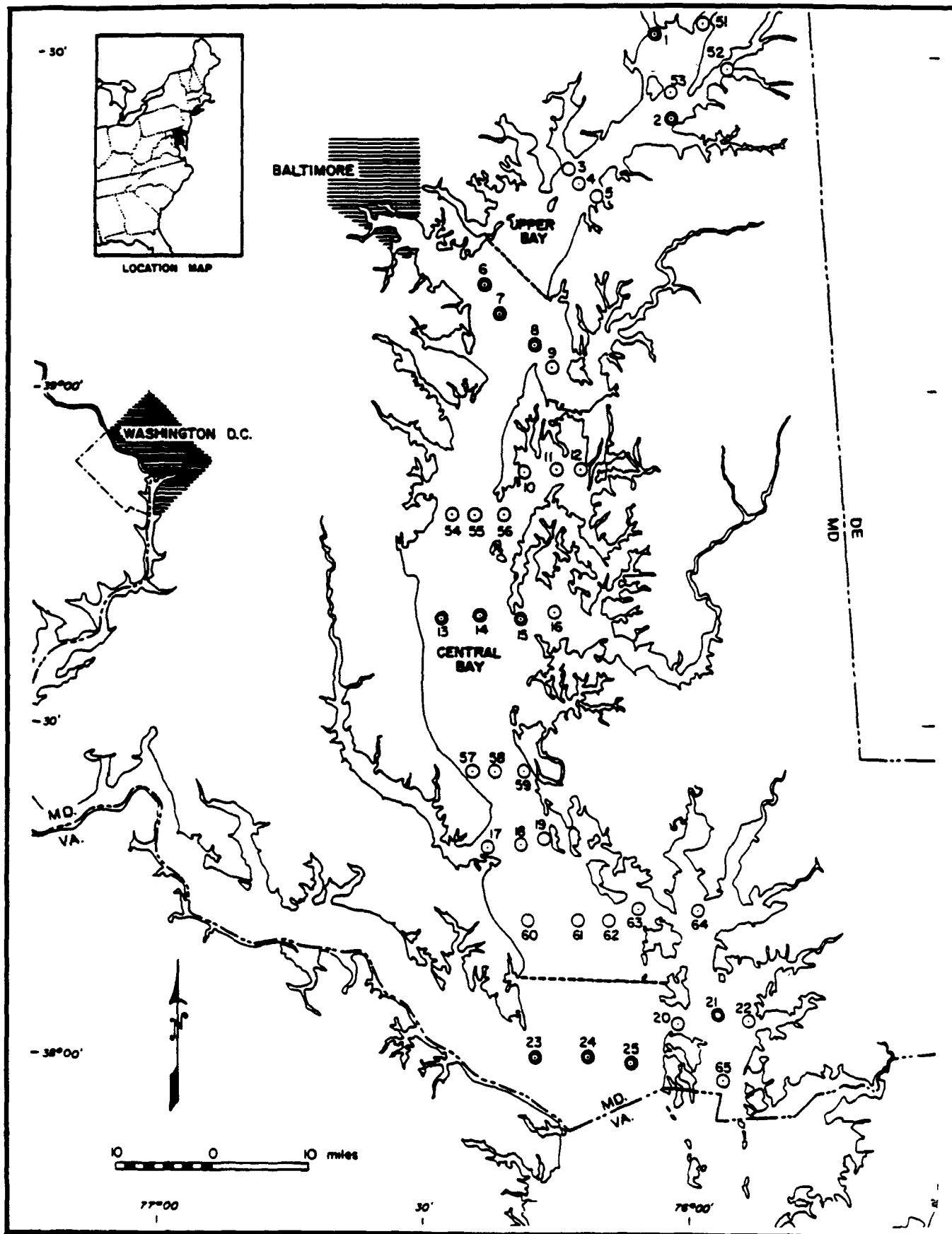
Station locations for the James River Project (Goals Station Prefix JAME)



Station locations for the Virginia Chesapeake Bay Benthic Monitoring Program (Goals Station Prefix MONV)







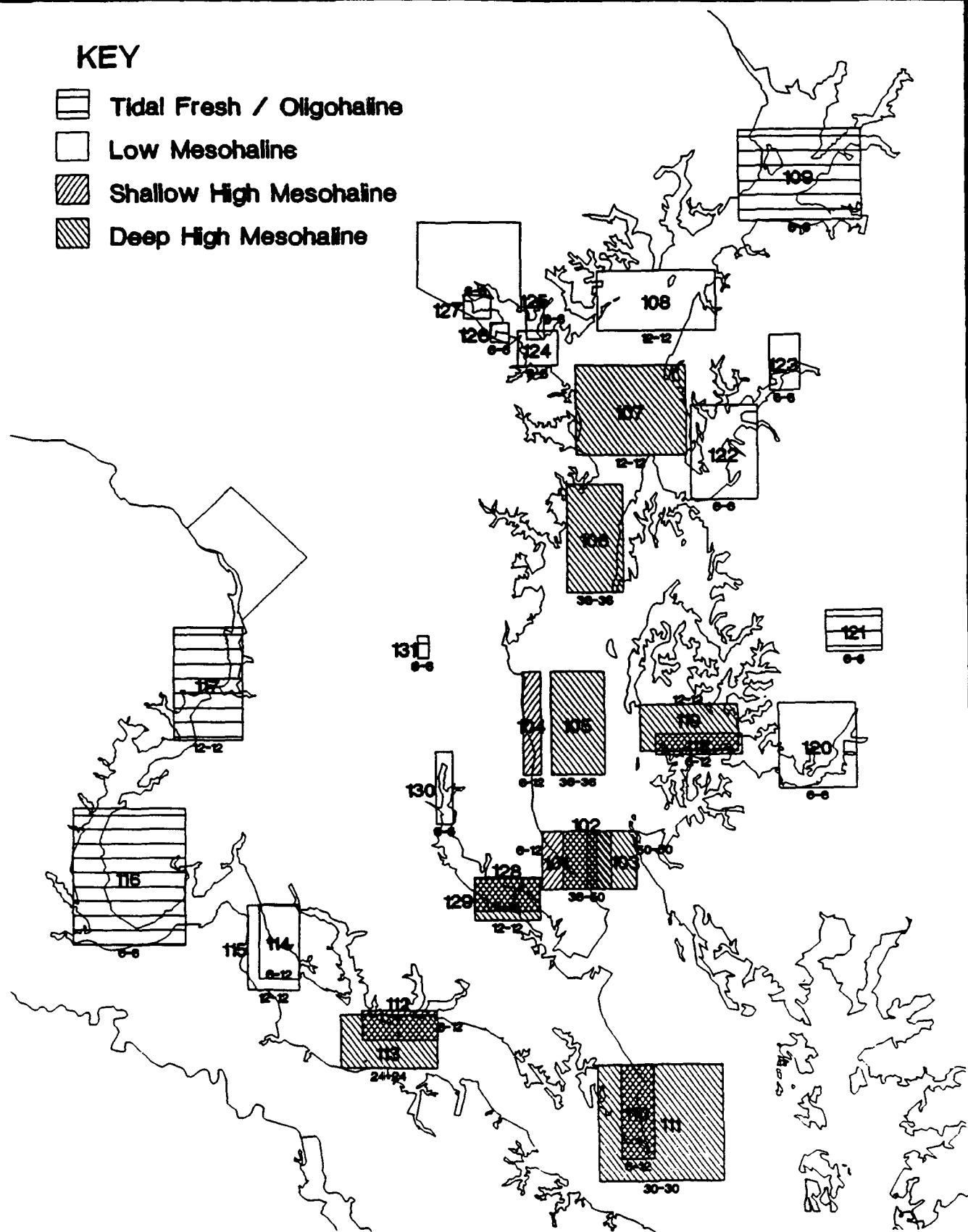
Station locations for the Virginia Biogenics Project (Goals Station Prefix BIOV)



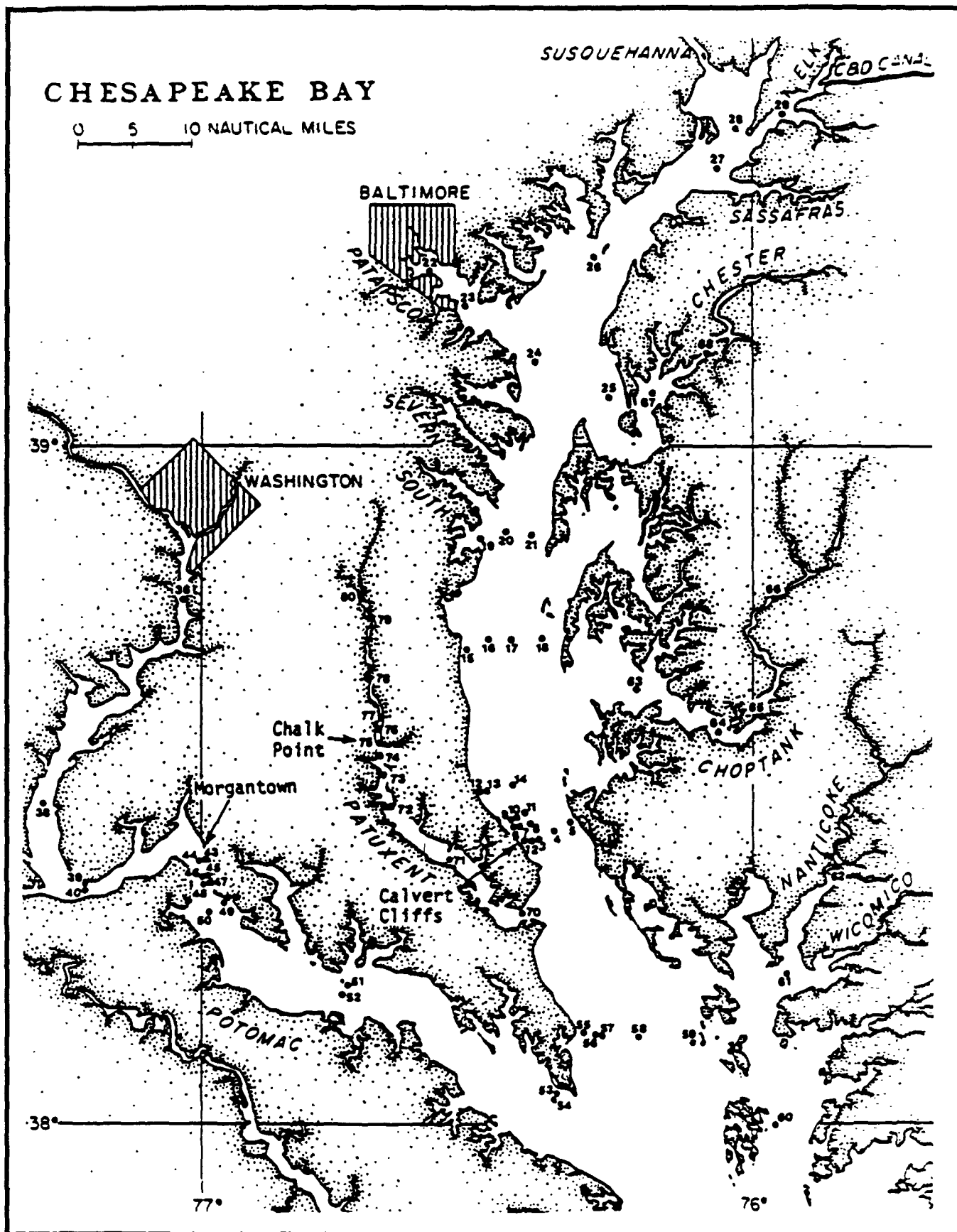
Station locations for the Maryland Biogenics Project (Goals Station Prefix BIOM)

KEY

-  Tidal Fresh / Oligohaline
-  Low Mesohaline
-  Shallow High Mesohaline
-  Deep High Mesohaline



Stratum locations for the Maryland Chesapeake Bay Benthic Monitoring Program 1989-1991 (Stations MONM-101 to MONM-131)



Fixed station locations for the Maryland Chesapeake Bay Benthic Monitoring Program 1984-1989 (Stations MONM-001 to MONM-080)