OLD DOMINION UNIVERSITY

Department of Biological Sciences
Old Dominion University, Norfolk, Virginia 23529

BENTHIC BIOLOGICAL MONITORING PROGRAM OF THE ELIZABETH RIVER WATERSHED (2000)

Prepared by

Principal Investigator:

Dr. Daniel M. Dauer

Submitted to:

Mr. B. W. Parolari
Virginia Department of Environmental Quality
Tidewater Regional Office
5636 Southern Blvd
Virginia Beach, VA 23462

July, 2001

EXECUTIVE SUMMARY

A study of the macrobenthic communities of the Elizabeth River watershed was initiated in summer 1999. This report presents the data from the second year of sampling in 2000. The three objectives of the Benthic Biological Monitoring Program of the Elizabeth River watershed are: (1) To characterize the health of the tidal waters of the Elizabeth River watershed as indicated by the structure of the benthic communities. (2) To conduct trend analyses on long-term data at 14 fixed-point stations to relate temporal trends in the benthic communities to changes in water and/or sediment quality. Trend analyses will be updated annually as new data are available. (3) To produce an historical data base that will allow annual evaluations of biotic impacts by comparing trends in status within probability-based strata and trends at fixed-point stations to changes in water and/or sediment quality.

The health of the benthic communities of the Elizabeth River watershed is characterize by combining previously developed benthic restoration goals, the Benthic Index of Biotic Integrity (BIBI) for the Chesapeake Bay and probability-based sampling. A probability-based sampling design allows calculation of confidence intervals around estimates of condition of the benthic communities and allows estimates of the areal extent of degradation of the benthic communities. In summer 1999 a spatially intensive sampling occurred. The Elizabeth River watershed was divided into five sampling strata - the Mainstem of the river, the Lafayette River, the Southern Branch, Western Branch and Eastern Branch. Within each stratum 25 samples were randomly allocated in a probability-based sampling design. In 2000 and in succeeding years a single stratum, the entire Elizabeth River watershed, will be sampled with 25 random samples.

Based upon probabilty-based sampling the estimate of benthic bottom not meeting the benthic restoration goals was 72.0 % in 2000 compared to a value of 64.3 % in 1999. In general for the Elizabeth River watershed, species diversity and biomass were below reference condition levels while abundance values was above reference condition levels. Community composition was unbalanced with levels of pollution indicative species above and levels of pollution sensitive species below reference conditions. Of the 25 random samples 10 received a score of “1" indicating degraded conditions. For 9 of these 10 the score of “1"was due to level of abundance higher than the benthic restoration goal levels. The high level of abundance exceeded the benthic restoration goals and is considered an indication of degradation because abundance levels are too high. The increased densities were due to opportunistic annelids - the polychaete species *Mediomastus ambiseta* and *Streblospio benediciti* and the oligochaete taxa *Tubificoides heterochaetus* and *Tubificoides* spp. Group I. In the 1999 sampling these four taxa accounted for 1,863 individuals m^{-2} and for 5,259 individuals m^{-2} in 2000.

INTRODUCTION

A long-term macrobenthic community monitoring program was initiated in the Elizabeth River in summer 1999. The three objectives of the Benthic Biological Monitoring Program of the Elizabeth River watershed are: 1) to characterize the health of the tidal waters of the Elizabeth River; 2) to conduct trend analyses of changes in water and sediment quality; and 3) to produce an historical database that will allow annual evaluations of biotic communities comparing trends in status within probability-based strata and trends at fixed stations related to water and sediment quality.

Characterization of macrobenthic community health is based on application of benthic restoration goals and the Benthic Index of Biotic Integrity (B-IBI) developed for the Chesapeake Bay as a whole to the Elizabeth River Watershed. Trend analyses for the fixed at 14 fixed stations, will be updated annually as new data are acquired.

The macrobenthic communities of the Elizabeth River have been studied since the 1969 sampling of Boesch (1973) with three stations in the Mainstem of the river. Other important studies were limited to the Southern Branch of the river including seasonal sampling at 10 sites in 1977-1978 (Hawthorne and Dauer 1983), seasonal sampling at the same 10 sites a decade later in 1987-1988 by Hunley (1993), the establishment of two long-term monitoring stations in 1989 as part of the Virginia Chesapeake Bay Benthic Monitoring Program (Dauer et al. 1999) and summarizations of the two Southern Branch long-term monitoring stations (Dauer 1993, Dauer et al. 1993). Dauer (2000) reported the spatially extensive sampling of the river initiating this program.

RATIONALE

Benthic invertebrates are used extensively as indicators of estuarine environmental status and trends because numerous studies have demonstrated that benthos respond predictably to many kinds of natural and anthropogenic stress (Pearson and Rosenberg 1978; Dauer 1993; Tapp et al. 1993; Wilson and Jeffrey 1994). Many characteristics of benthic assemblages make them useful indicators (Bilyard 1987), the most important of which are related to their exposure to stress and the diversity of their response. Exposure to hypoxia is typically greatest in near-bottom waters and anthropogenic contaminants often accumulate in sediments where benthos live. Benthic organisms generally have limited mobility and cannot avoid these adverse conditions. This immobility is advantageous in environmental assessments because, unlike most pelagic fauna, benthic assemblages reflect local environmental conditions (Gray 1979). The structure of benthic assemblages responds to many kinds of stress because these assemblages typically include organisms with a wide range of physiological tolerances, life history strategies, feeding modes, and trophic interactions (Pearson and Rosenberg 1978; Rhoads et al. 1978; Boesch and Rosenberg 1981). Recently benthic community condition in the Chesapeake Bay has been related to water quality, sediment quality, nutrient loads, and land use patterns (Dauer et al. 2000).

METHODS

A glossary of selected terms used in this report is found on page 12.

Strata Sampled

In the summer of 1999, the Elizabeth River watershed was divided into five primary strata - the Mainstem of the river, the Lafayette River, the Southern Branch, Western Branch and Eastern Branch (Fig. 1). In addition two small creeks of the Southern Branch of the river were also sampled as part of a sediment contaminant remediation effort - Scuffletown Creek and Jones-Gilligan Creek. In 2000 a single stratum including the entire Elizabeth River watershed was sampled with 25 random samples.

Probability-based sampling

Sampling design and methodologies for probability-based sampling are based upon procedures developed by EPA's Environmental Monitoring and Assessment Program (EMAP, Weisberg et al. 1993) and allow unbiased comparisons of conditions between strata (Dauer and Llansó Appendix B)

Within each stratum, 25 randomly selected locations were sampled using a 0.04 m^2 Young grab. The minimum acceptable depth of penetration of the grab was 7 cm. At each station one grab sample was taken for macrobenthic community analysis and a second grab sample for sediment particle size analysis and the determination of total volatile solids. A 50 g subsample of the surface sediment was taken for sediment analysis. Salinity, temperature and dissolved oxygen were measured at the bottom and water depth was recorded. Salinity and temperature were measured using a YSI Model 33 S-C-T meter and bottom dissolved oxygen was measured using a YSI model 58 oxygen meter.

Probability-Based Estimation of Degradation

Areal estimates of degradation of benthic community condition within a stratum can be made because all locations in each stratum have equal probability for selection. The estimate of the proportion of a stratum failing the Benthic Restoration Goals developed for Chesapeake Bay (Ranasinghe et al. 1994; updated in Weisberg et al. 1997) is the proportion of the 25 samples with an B-IBI value of less than 3.00. The process produces a binomial distribution: the percentage of the stratum attaining goals versus the percentage not attaining the goals. With a binomial distribution the 95% confidence limits for these percentages can be calculated as:

$$\text{95\% Confidence Limit} \quad = \quad p \pm 1.96\,(\text{SQRT}(pq/N))$$

where p = percentage attaining goal, q = percentage not attaining goal and N = number of samples.

For each stratum, 50 random points were randomly selected using the GIS system of Versar, Inc. Decimal degree reference coordinates were used with a precision of 0.000001 degrees (approximately 1 meter) which is a smaller distance than the accuracy of positioning; therefore, no area of a stratum is excluded from sampling and every point within a stratum has a chance of being sampled. In the field the first 25 acceptable sites are sampled. Sites may be rejected because they are inaccessible by boat, are too shallow, or have a substratum that prevents the minimum acceptable depth of penetration of 7 cm (e.g., shell, gravel or compact sand).

Fixed-Point Station sampling

Fourteen fixed point stations were established for long-term trend analysis (Fig. 2). All field collection procedures were the same as for probability based sampling except that three replicate Young grab samples were collected for macrobenthic community analysis.

Laboratory Analysis

Each replicate was sieved on a 0.5 mm screen, the biota were relaxed in dilute isopropyl alcohol and preserved with a buffered formalin-rose bengal solution. In the laboratory each replicate was sorted and all the individuals identified to the lowest possible taxon and enumerated. Biomass was estimated for each taxon as ash-free dry weight (AFDW) by drying to constant weight at 60 ^{o}C and ashing at 550 ^{o}C for four hours. Biomass was expressed as the difference between the dry and ashed weight.

Particle-size analysis was conducted using the techniques of Folk (1974). Each sediment sample is first separated into a sand fraction (> 63 µm) and a silt-clay fraction (< 63 µm) by wet seiving. The sand fraction was dry sieved and the silt-clay fraction quantified by pipette analysis. For random stations, only the percent sand and percent silt-clay fraction were estimated. For the fixed-point stations particle-size distribution parameters were determined by the graphic and moment measures methods of Folk (1974). Total volatile solids of the sediment was estimated by the loss upon ignition method as described above and presented as percentage of the dry weight of the sediment.

Benthic Index of Biotic Integrity

B-IBI and Benthic Community Status Designations

The B-IBI is a multiple-metric index developed to identify the degree to which a benthic community meets the Chesapeake Bay Program's Benthic Community Restoration Goals (Ranasinghe et al. 1994; updated in Weisberg et al. 1997). The B-IBI provides a means for comparing relative condition of benthic invertebrate communities across habitat types. It also provides a validated mechanism for integrating several benthic community attributes indicative of community health into a single number that measures overall benthic community condition.

The B-IBI is scaled from 1 to 5, and sites with values of 3 or more are considered to meet the Restoration Goals. The index is calculated by scoring each of several attributes as either 5, 3, or 1 depending on whether the value of the attribute at a site approximates, deviates slightly from, or deviates strongly from the values found at reference sites in similar habitats, and then averaging these scores across attributes. The criteria for assigning these scores are numeric and dependent on habitat type. Application of the index is limited to a summer index period from July 15th through September 30th.

Benthic community condition was classified into four levels based on the B-IBI. Values less than 2 were classified as **severely degraded**; values from 2.0 to 2.6 were classified as **degraded**; values greater than 2.6 but less than 3.0 were classified as **marginal**; and values of 3.0 or more were classified as **meeting the goal**. Values in the marginal category do not meet the Restoration Goals, but they differ from the goals within the range of measurement error typically recorded between replicate samples. These categories are used in annual characterizations of the condition of the benthos in the Chesapeake Bay (Ranasinghe et al. 1994; Dauer et al. 1998a, 1998b; Ranasinghe et al. 1998).

Further Information concerning the B-IBI

The analytical approach used to develop the B-IBI was similar to the one Karr et al. (1986) used to develop comparable indices for freshwater fish communities. Selection of benthic community metrics and metric scoring thresholds were habitat-dependent but by using categorical scoring comparisons between habitat types were possible. A six-step procedure was used to develop the index: (1) acquiring and standardizing data sets from a number of monitoring programs, (2) temporally and spatially stratifying data sets to identify seasons and habitat types, (3) identifying reference sites, (4) selecting benthic community metrics, (5) selecting metric thresholds for scoring, and (6) validating the index with an independent data set (Weisberg et al. 1997). The B-IBI developed for Chesapeake Bay is based upon subtidal, unvegetated, infaunal macrobenthic communities. Hard-bottom communities, e.g., oyster beds, were not sampled because the sampling gears could not obtain adequate samples to characterize the associated infaunal communities. Infaunal communities associated with submerged aquatic vegetation (SAV) were not avoided, but were rarely sampled due to the limited spatial extent of SAV in Chesapeake Bay.

Only macrobenthic data sets based on processing with a sieve of 0.5 mm mesh aperture and identified to the lowest possible taxonomic level were used. A data set of over 2,000 samples collected from 1984 through 1994 was used to develop, calibrate and validate the index (see Table 1 in Weisberg et al. 1997). Because of inherent temporal sampling limitations in some of the data sets, only data from the period of July 15 through September 30 were used to develop the index. A multivariate cluster analysis of the biological data was performed to define habitat types. Salinity and sediment type were the two important factors defining habitat types and seven habitats were identified - tidal freshwater, oligohaline, low mesohaline, high mesohaline sand, high mesohaline mud, polyhaline sand and polyhaline mud habitats (see Table 5 in Weisberg et al. 1997).

Reference sites were selected as those sites which met all three of the following criteria: no sediment contaminant exceeded Long et al.'s (1995) effects range-median (ER-M) concentration, total organic content of the sediment was less than 2%, and bottom dissolved oxygen concentration was consistently high.

A total of 11 metrics representing measures of species diversity, community abundance and biomass, species composition, depth distribution within the sediment, and trophic composition were used to create the index (see Table 2 in Weisberg et al. 1997). The habitat-specific metrics were scored and combined into a single value of the B-IBI. Thresholds for the selected metrics were based on the distribution of values for the metric at the reference sites. Data used for validation were collected between 1992 and 1994 and were independent of data used to develop the index. The B-IBI classified 93% of the validation sites correctly (Weisberg et al. 1997).

In tables presenting B-IBI results salinity classes are as follows: 1- tidal freshwater, 2 - oligohaline, 3- low mesohaline, 4 - high mesohaline and 5 - polyhaline. The two sediment classes are as follows: 1 - silt clay content < 40% and 2 - silt clay content $\geq$ 40%. All abundance values are individuals per m^{-2}; biomass values are AFDW g per m^{-2}; and pollution indicative, pollution sensitive and cavnivore/omnivore metrics are percent of abundance or biomass as indicated in tables.

RESULTS

Probabilty-Based Sampling

Environmental Parameters

All physical, chemical and sedimentary parameters are summarized in Table 1. Water depths varied from 1-13 m reflecting shoal and channel depths. All salinity values were in the high mesohaline to polyhaline range with values from 15.9 to 23.1 ppt. Bottom dissolved oxygen was generally high except in the Southern Branch. Outside the Southern Branch values ranged from 3.7 to 9.6. The four stations in the Southern Branch varied from 1.1 to 2.8 ppm. Silt-clay content varied from 1.9 to 97.3 % and total volatile solids from 0.3 to 14.8 %.

Benthic Community

Benthic community parameters including the B-IBI value, abundance, biomass, Shannon diversity and selected metrics are summarized by station in Table 2. The average BIBI values for the 25 random sites was 2.6. Individual metric scores incorporated in the B-IBI are presented in

Table 3. A major difference between the random samples of 1999 and those of 2000 was the very high abundances found at 5 sites in 1999 - Z01 and Z04 in the Lafayette River; Z30 at the confluences of the Mainstem, Eastern Branch and Southern Branch; and Z23 and Z25 in the Southern Branch (Table 2 and Figs. 3,4). The high values were due to the polychaete *Streblospio benedicti* (at all five sites), the polychaete *Mediomastus ambiseta* (at Z01, Z30, Z23 and Z25), the oligochaete *Tubificoides heterochaetus* (at Z01 and Z04), the oligochaete taxon *Tubificoides* spp. Group I (at Z04 and Z23) and the polychaete *Laeonereis culveri* (at Z-30). The dominant taxa of the random sites are summarized in Table 4.

The B-IBI value, Shannon's index, abundance, biomass and the proportion of pollution sensitive and pollution indicative species are shown in Figs. 5-10. In these figures the five strata of the Elizabeth River sampled in 1999 are shown. The value for 1999 in each of these figures is the area weighted average for all 125 random samples from the five strata sampled in 1999. The 2000 value is based on the 25 random samples from the single stratum sampled.

Fixed Point Stations

Environmental Parameters

All physical, chemical and sedimentary parameters are summarized in Table 5. Consistent with the pattern of Table 1 the lowest bottom dissolved oxygen values were recorded at stations in the Southern Branch.

Benthic Community

Benthic community parameters including the B-IBI value, abundance, biomass, Shannon diversity and selected metrics are summarized by station in Table 6. These stations will be the basis for future long-term trend analyses.

Discussion

Benthic Communities

In 1999 the condition of the macrobenthic communities of the Elizabeth River watershed was characterized for five strata consisting of the Mainstem of the River, the Lafayette River, the Southern Branch, Western Branch and Eastern Branch (Dauer 2000). The five strata were characterized in terms of benthic community condition into three categories: (1) the best condition in the Mainstem of the river, (2) the worst condition in the Southern Branch, and (3) intermediate condition in the Eastern Branch, Western Branch and Lafayette River. The Mainstem of the river had the highest average B-IBI value of 2.9, the Southern Branch the lowest value of 2.0 and the other branches had values between 2.5 and 2.7 with an overall average of 2.5. In 2000 the random stations had an average B-IBI values of 2.6. The estimated levels of degradation were similar with the 1999 estimate of 64.3% of the bottom failing the benthic restoration goals and a value of 72.0 % for 2000. Consistent with the use of the B-IBI in the Chesapeake Bay Benthic Monitoring Program (Dauer et al. 1998a,b) the overall level of degradation is evaluated as a three year running mean value for the B-IBI and little weight is given to consecutive year changes.

Compared to the Chesapeake Bay Benthic Restoration Goals the macrobenthic communities of the Elizabeth River can be characterized as (1) having lower than expected species diversity and biomass, (2) abundance levels generally higher than reference conditions and (3) species composition with levels of pollution indicative species higher than reference conditions and levels of pollution sensitive species lower than reference conditions (Table 2, Figs. 5-10).

Water Quality

Based upon status and trends for the period 1989 through 2000 , water quality conditions continue to improve while the status of most parameters is poor (Appendix A). However, the status of bottom dissolved oxygen was classified as good in all segments of the Elizabeth River basin except for the Southern Branch for which the status was fair (Fig. A2). Improving trends in surface and bottom total nitrogen and dissolved inorganic nitrogen were detected in nearly all segments of the Elizabeth River. Improving trends in surface and bottom total phosphorus and dissolved inorganic phosphorus were detected in all segments of the Elizabeth River. Improving trends in bottom dissolved oxygen were detected in all segments of the Elizabeth River except for the Eastern Branch and the Elizabeth River mouth. An improving trend in surface chlorophyll *a* was detected in the Western Branch. A degrading trend in water clarity was detected in the Elizabeth River Mainstem.

Acknowledgments

he comments of Mory Roberts of the Virginia Institute of Marine Sciences were very helpful and are gratefully acknowledged.

REFERENCES

Bilyard, G. R. 1987. The value of benthic infauna in marine pollution monitoring studies. *Marine Pollution Bulletin* 18:581-585.

Boesch, D.F. 1973. Classification and community structure of macrobenthos in the Hampton Roads area, Virginia. *Marine Biology* 21: 226-244.

Boesch, D. F. and R. Rosenberg. 1981. Response to stress in marine benthic communities, p. 179-200. In G. W. Barret and R. Rosenberg (eds.), Stress Effects on Natural Ecosystems. John Wiley & Sons, New York.

Dauer, D.M. 1993. Biological criteria, environmental health and estuarine macrobenthic community structure. *Marine Pollution Bulletin* 26: 249-257.

Dauer, D.M. 2000. Benthic Biological Monitoring Program of the Elizabeth River Watershed (1999). Final Report to the Virginia Department of Environmental Quality, Chesapeake Bay Program, 73 pp.

Dauer, D.M., M. F. Lane, H.G. Marshall, K.E. Carpenter. 1998a. Status and trends in water quality and living resources in the Virginia Chesapeake Bay: 1985-1997. Final report to the Virginia Department of Environmental Quality. 84 pages.

Dauer, D.M., M. F. Lane, H.G. Marshall, K.E. Carpenter and R.J. Diaz. 1999. Status and trends in water quality and living resources in the Virginia Chesapeake Bay: 1985-1998. Final report to the Virginia Department of Environmental Quality. 65 pages.

Dauer, D.M. and R. J. Llansó. 2001. Spatial scales and probability based sampling in determining levels of benthic community degradation in the Chesapeake Bay. Submitted to *Environmental Monitoring and Assessment.*

Dauer, D.M, M.W. Luchenback, and A.J. Rodi, Jr. 1993. Abundance biomass comparisons (ABC method): Effects of an estuary gradient, anoxic/hypoxic events and contaminated sediments. *Marine Biology* 116:507-518.

Dauer, D.M., H.G. Marshall, K.E. Carpenter, M. F. Lane, R.W. Alden, III, K.K. Nesius and L.W. Haas. 1998b. Virginia Chesapeake Bay water quality and living resources monitoring programs: Executive Report, 1985-1996. Final report to the Virginia Department of Environmental Quality. 28 pages.

Dauer, D.M., J. A. Ranasinghe, and S. B. Weisberg. 2000. Relationships between benthic community condition, water quality, sediment quality, nutrient loads, and land use patterns in Chesapeake Bay. *Estuaries* 23: 80-96.

Dauer, D.M. and A.J. Rodi, Jr. 1999. Baywide benthic community condition based upon 1998 random probability based sampling. Final report to the Virginia Department of Environmental Quality. 126 pp.

Folk, R.L. 1974. Petrology of sedimentary rocks. Hemphills, Austin, 170 pp.

Gray, J. S. 1979. Pollution-induced changes in populations. *Transactions of the Royal Philosophical Society of London (B*) 286:545-561.

Hawthorne, S.D. and D.M. Dauer. 1983. Macrobenthic communities of the lower Chesapeake Bay. III. Southern Branch of the Elizabeth River. *Internationale Revue der gesamten Hydrobiologie* 68: 193-205.

Hunley, W.S. 1993. Evaluation of long term changes in the macrobenthic community of the Southern Branch of the Elizabeth River, Virginia. Master's Thesis. Old Dominion University. 120 pp.

Karr, J. R., K. D. Fausch, P. L. Angermeier, P. R. Yant, and I. J. Schlosser. 1986. Assessing biological integrity in running waters: A method and its rationale. Special Publication 5. Illinois Natural

History Survey, Champaign, Illinois.

Long, E. R., D. D. McDonald, S. L. Smith, and F. D. Calder. 1995. Incidence of adverse biological effects within ranges of chemical concentrations in marine and estuarine sediments. *Environmental Management* 19:81-95.

Pearson, T. H. and R. Rosenberg. 1978. Macrobenthic succession in relation to organic enrichment and pollution of the marine environment. *Oceanography and Marine Biology Annual Review* 16:229-311.

Ranasinghe, J.A., L.C. Scott and F.S. Kelley. 1998. Chesapeake Bay water quality monitoring program: Long-term benthic monitoring and assessment component, Level 1 Comprehensive Report (July 1984-December 1997). Prepared for the Maryland Department of Natural Resources by Versar, Ins, Columbia, MD.

Ranasinghe, J.A., S.B. Weisberg, D.M. Dauer, L.C. Schaffner, R.J. Diaz and J.B. Frithsen. 1994. Chesapeake Bay benthic community restoration goals. Report for the U.S. Environmental Protection Agency, Chesapeake Bay Office and the Maryland Department of Natural Resources. 49 pp.

Rhoads, D. C., P. L. McCall, and J. Y. Yingst. 1978. Disturbance and production on the estuarine sea floor. *American Scientist* 66:577-586.

Tapp, J. F., N. Shillabeer, and C. M. Ashman. 1993. Continued observation of the benthic fauna of the industrialized Tees estuary, 1979-1990. *Journal of Experimental Marine Biology and Ecology* 172:67-80.

Weisberg, S.B., J.A. Ranasinghe, D.M. Dauer, L.C. Schaffner, R.J. Diaz and J.B. Frithsen. 1997. An estuarine benthic index of biotic integrity (B-IBI) for Chesapeake Bay. *Estuaries* 20: 149-158.

Weisberg, S.B., J.B. Frithsen, A.F. Holland, J.F. Paul, K.J. Scott, J.K. Summers, H.T. Wilson, R. Valente, D. Heimbuch, J. Gerritsen, S.C. Schimmel and R.W. Latimer. 1993. EMAP-Estuaries Virginian Province 1990 Demonstration Project Report. EPA/620/r-93/006. United States Environmental Protection Agency, Office of Research and Development, Environmental Research Laboratory, Narragansett, Rhode Island.

Wilson, J. G. and D. W. Jeffrey. 1994. Benthic biological pollution indices in estuaries, p. 311-327. In J. M. Kramer (ed.), Biomonitoring of Coastal Waters and Estuaries. CRC Press, Boca Raton, Florida.

Glossary of selected terms

Benthos - refers to organisms that dwell on or within the bottom. Includes both hard substratum habitats (e.g. oyster reefs) and sedimentary habitats (sand and mud bottoms).

B-IBI - the benthic index of biotic integrity of Weisberg et al. (1997). The is a multi-metric index that compares the condition of a benthic community to reference conditions.

Fixed Point Stations - stations for long-term trend analysis whose location is unchanged over time.

Habitat - a local environment that has a benthic community distinct for other such habitat types. For the B-IBI of Chesapeake Bay seven habitat types were defined as combinations of salinity and sedimentary types - tidal freshwater, oligohaline, low mesohaline, high mesohaline sand, high mesohaline mud, polyhaline sand and polyhaline mud.

Macrobenthos - a size category of benthic organisms that are retained on a mesh of 0.5 mm.

Metric - a parameter or measurement of benthic community structure (e.g., abundance, biomass, species diversity).

Probability based sampling - all locations within a stratum have an equal chance of being sampled. Allows estimation of the percent of the stratum meeting or failing the benthic restoration goals.

Random Station - a station selected within a stratum in such a way that each point in the stratum has an equal probability of selection. This approach allows areal-based statements to be made about the condition of the stratum. In every succeeding sampling event new random locations are selected.

Reference condition - the structure of benthic communities at reference sites.

Reference sites - sites determined to be minimally impacted by anthropogenic stress. Conditions at theses sites are considered to represent goals for restoration of impacted benthic communities. Reference sites were selected by Weisberg et al. (1997) as those outside highly developed watersheds, distant from any point-source discharge, with no sediment contaminant effect, with no low dissolved oxygen effect and with a low level of organic matter in the sediment.

Restoration Goal - refers to obtaining an average B-IBI value of 3.0 for a benthic community indicating that values for metrics approximate the reference condition.

Stratum - a geographic region of unique ecological condition or managerial interest. In the 1999 sampling event the primary strata were the Mainstem of the river, the Lafayette River, the Eastern Branch, Western Branch and Southern Branch. In 2000 and succeeding years the entire Elizabeth River watershed will be sampled as a single stratum.

Threshold - a value of a metric that determines the B-IBI scoring. For all metrics except abundance and biomass, two thresholds are used - the lower 5^{th} percentile and the 50^{th} percentile (median) of the distribution of values at reference sites. Samples with metric values less than the lower 5^{th} percentile are scored as a 1. Samples with values between the 5^{th} and 50^{th} metrics are scored as 3 and values greater than the 50^{th} percentile are scored as 5. For abundance and biomass, values below the 5^{th} and above the 95^{th} percentile are scored as 1, values between the 5^{th} and 25^{th} and the 75^{th} and 95^{th} percentiles are scored as 3 and values between the 25^{th} and 75^{th} percentiles are scored as 5.

Figures

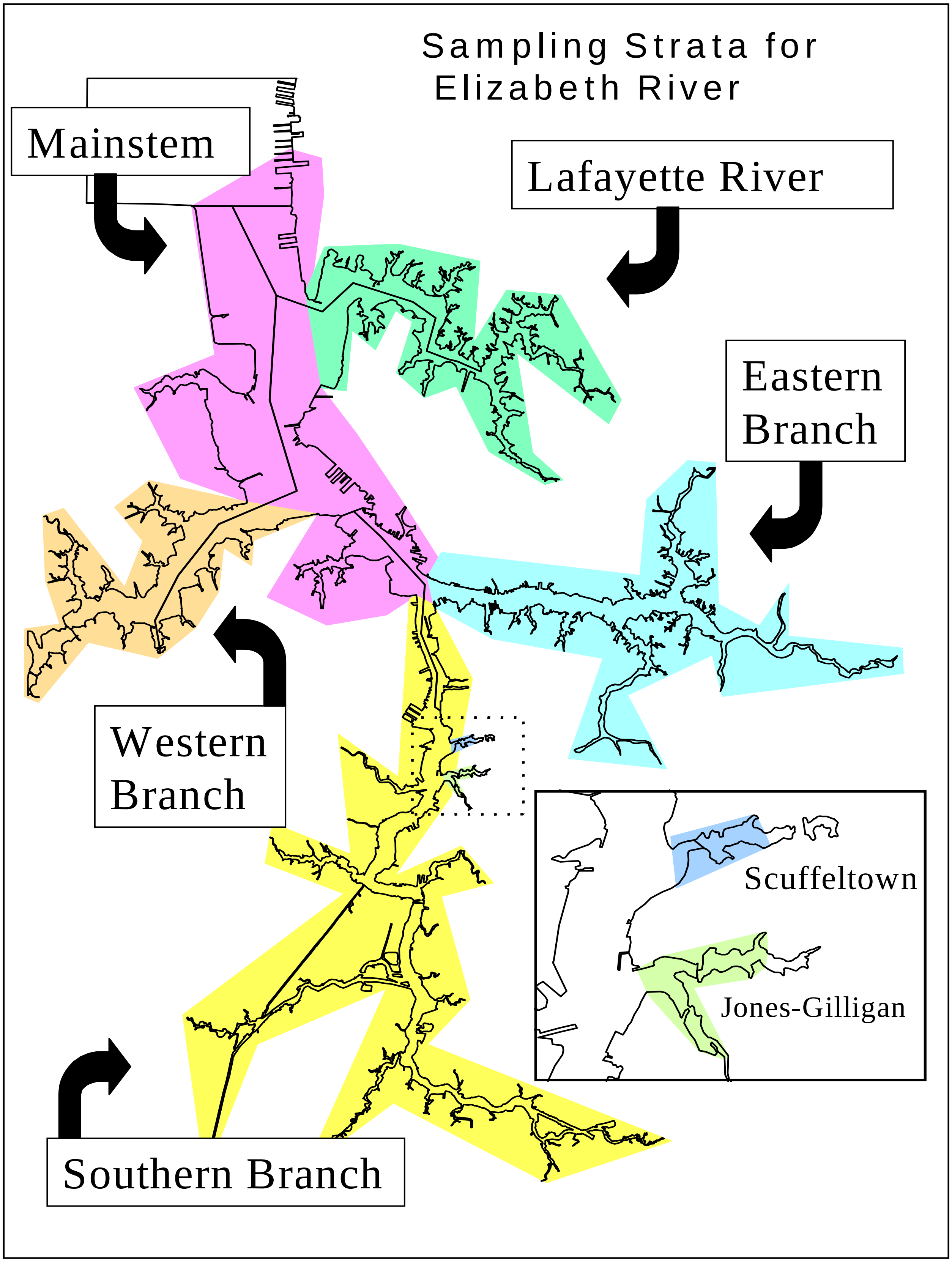

Figure 1. Elizabeth River watershed showing the five major segments sampled in 1999. Insert shows Scuffletown Creek and the Jones-Gilligan Creek strata also sampled in 1999.

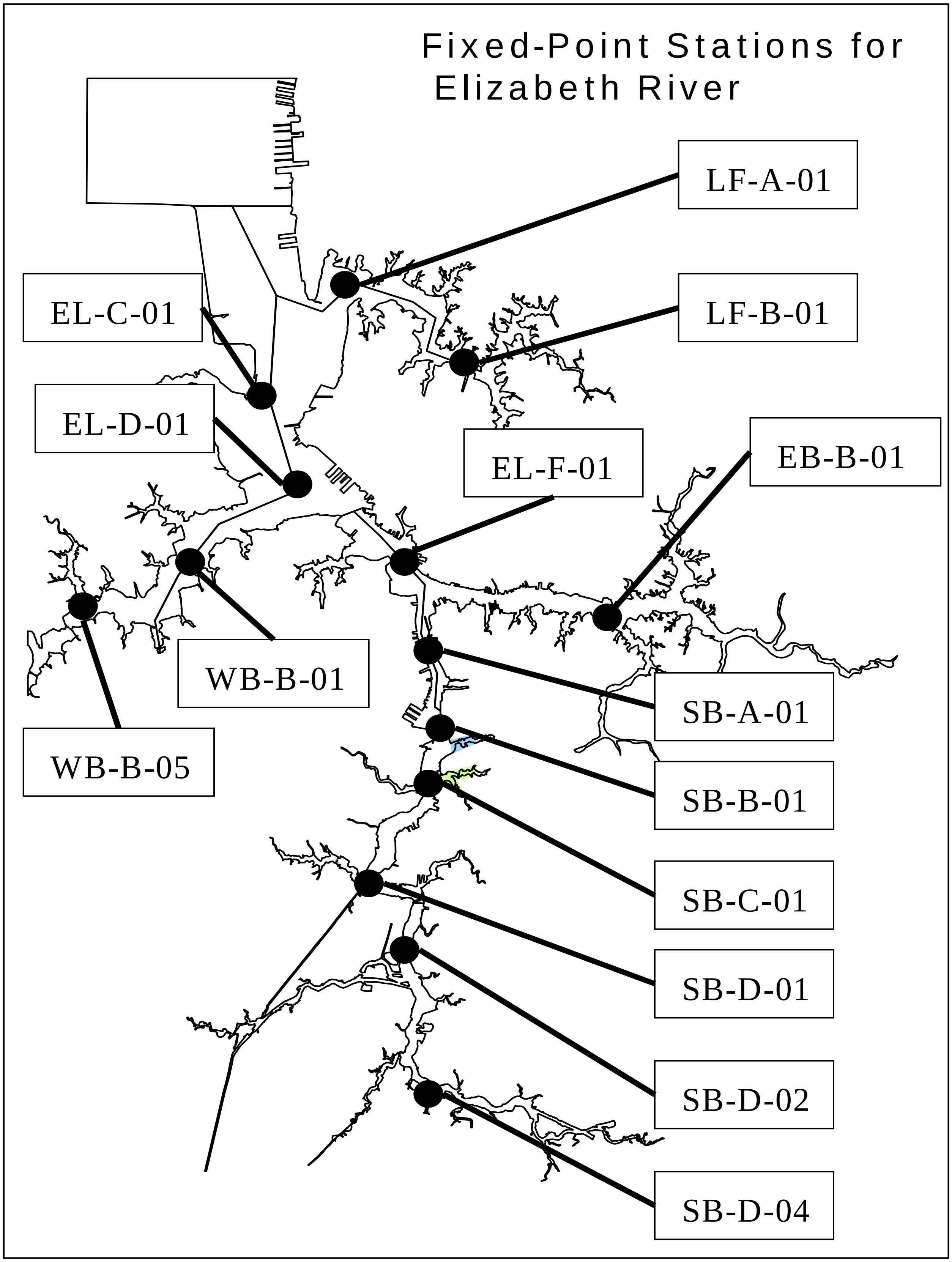

Figure 2. Elizabeth River watershed showing the 14 fixed-point stations for long-term trend analyses.

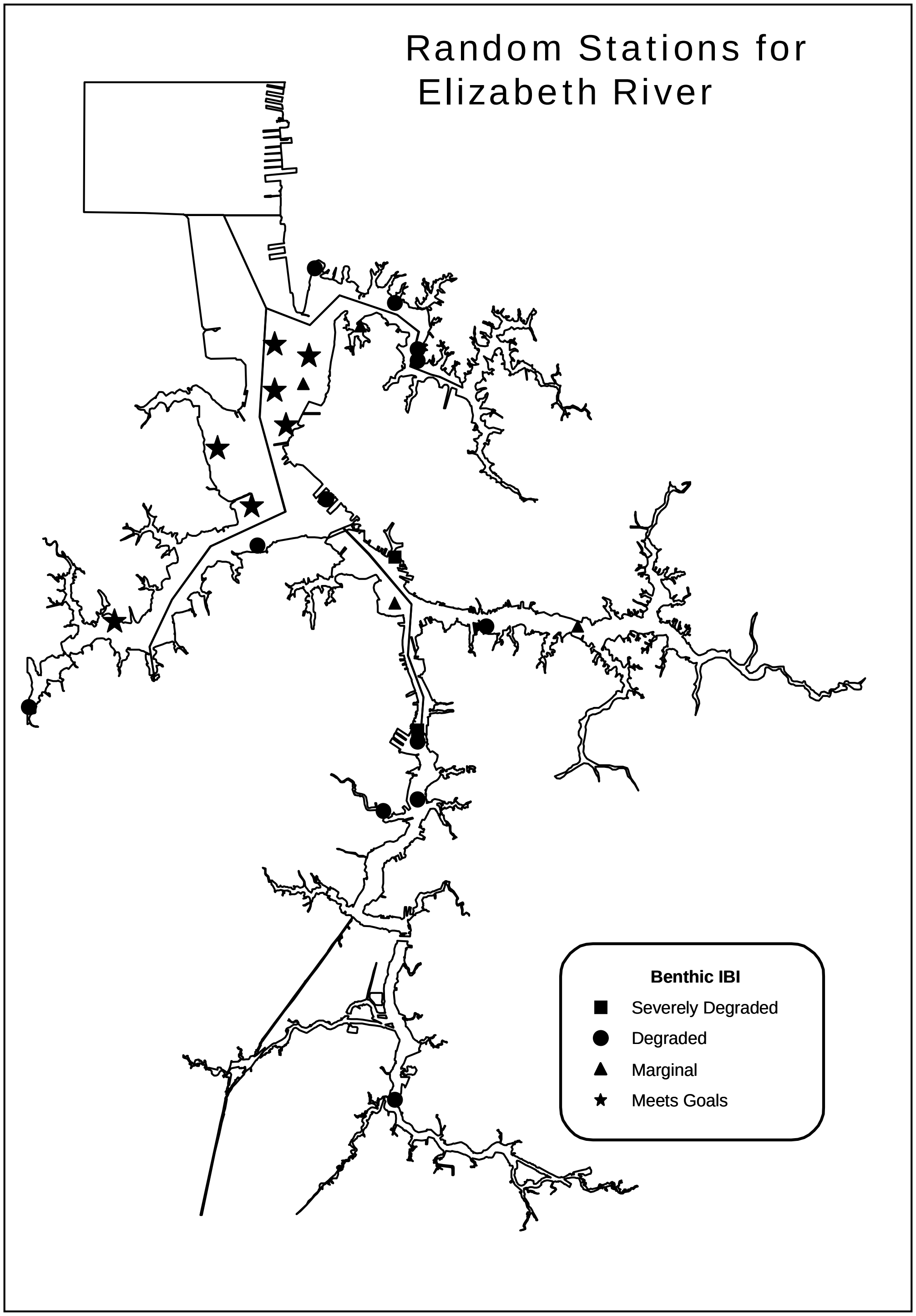

Figure 3. Map showing the 25 random stations sampled in 2000 and indicating the condition of the benthic communities.

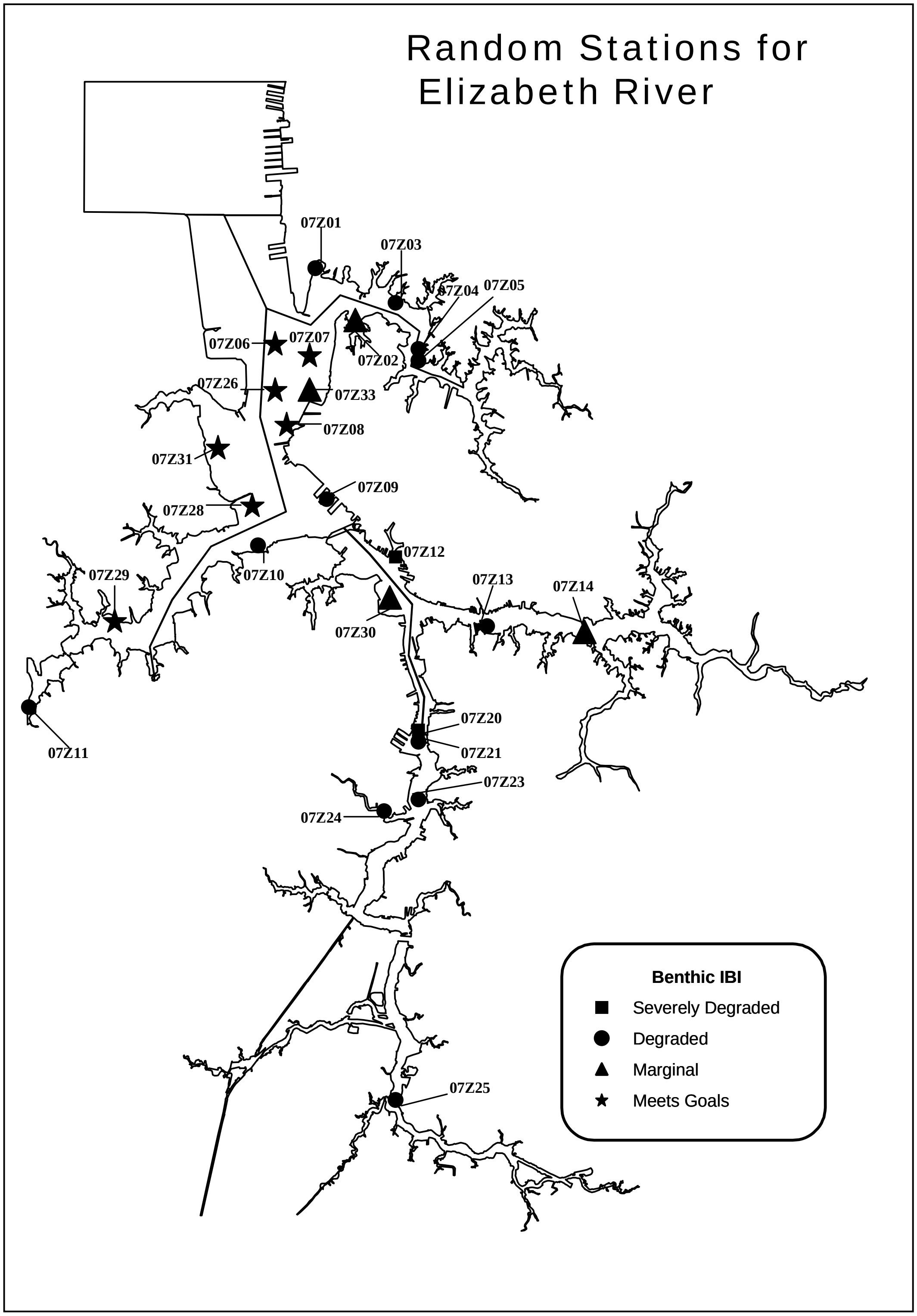

Figure 4. Map showing the 25 random locations sampled in 2000 and indicating both the condition of the benthic communities and the station number.

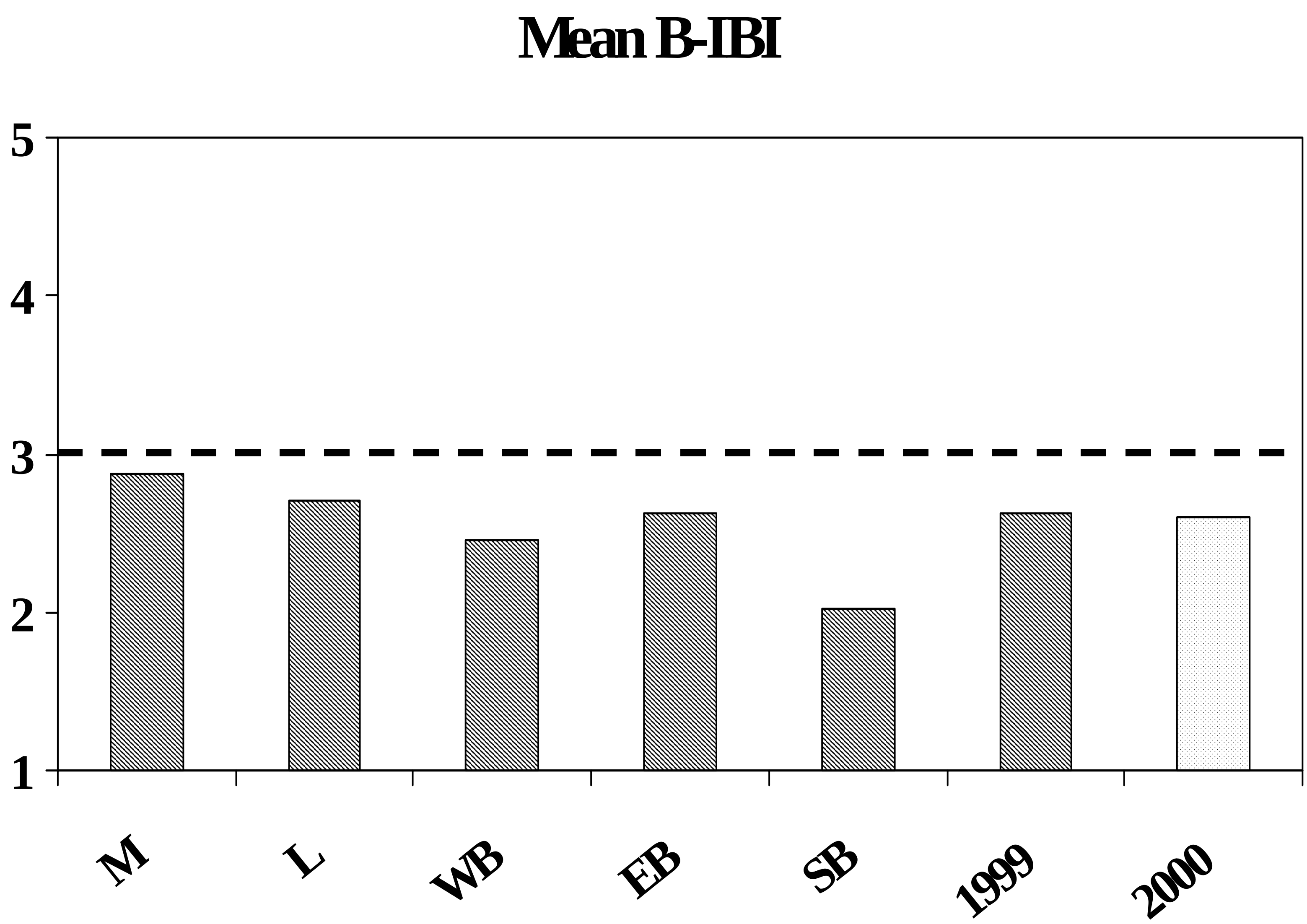

Figure 5. Average B-IBI values. Dashed line indicates a B-IBI value of 3.0 the goal for benthic restoration. Shown are the five strata from the 1999 sampling, the 1999 area weighted average for the entire watershed and the 2000 results. Abbreviations: Bay - Mainstem of Chesapeake Bay, M - Mainstem of Elizabeth River, L - Lafayette River, WB - Western Branch, EB - Eastern Branch, SB - Southern Branch.

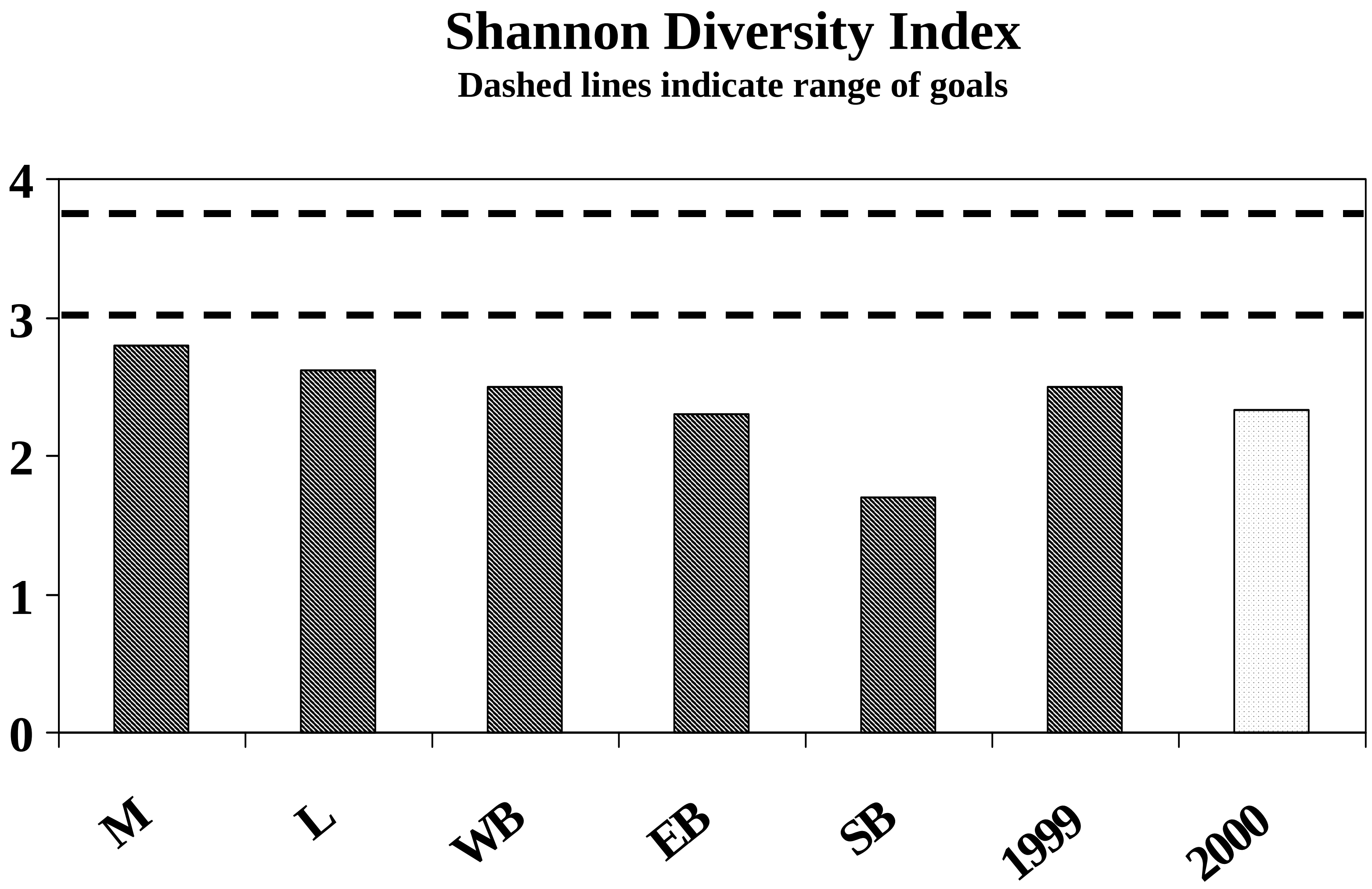

Figure 6. Average Shannon diversity index values. Dashed lines indicate the range of habitat specific benthic restoration goals from Weisberg et al. (1997). Shown are the five strata from the 1999 sampling, the 1999 area weighted average for the entire watershed and the 2000 results. See Figure 5 for abbreviations.

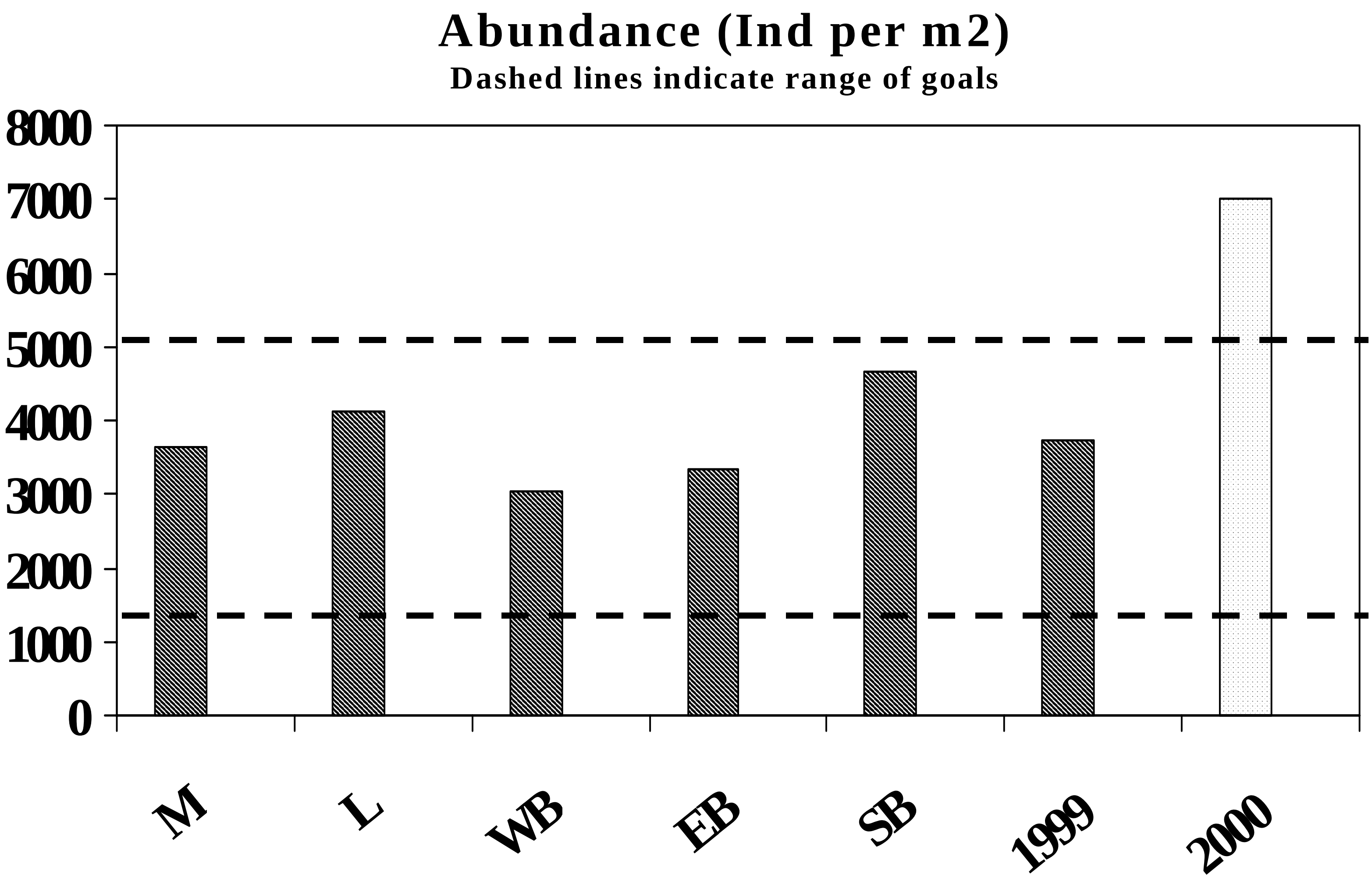

Figure 7. Average abundance of individuals per m^2. Shown are the five strata from the 1999 sampling, the 1999 area weighted average for the entire watershed and the 2000 results. See Figure 5 for abbreviations.

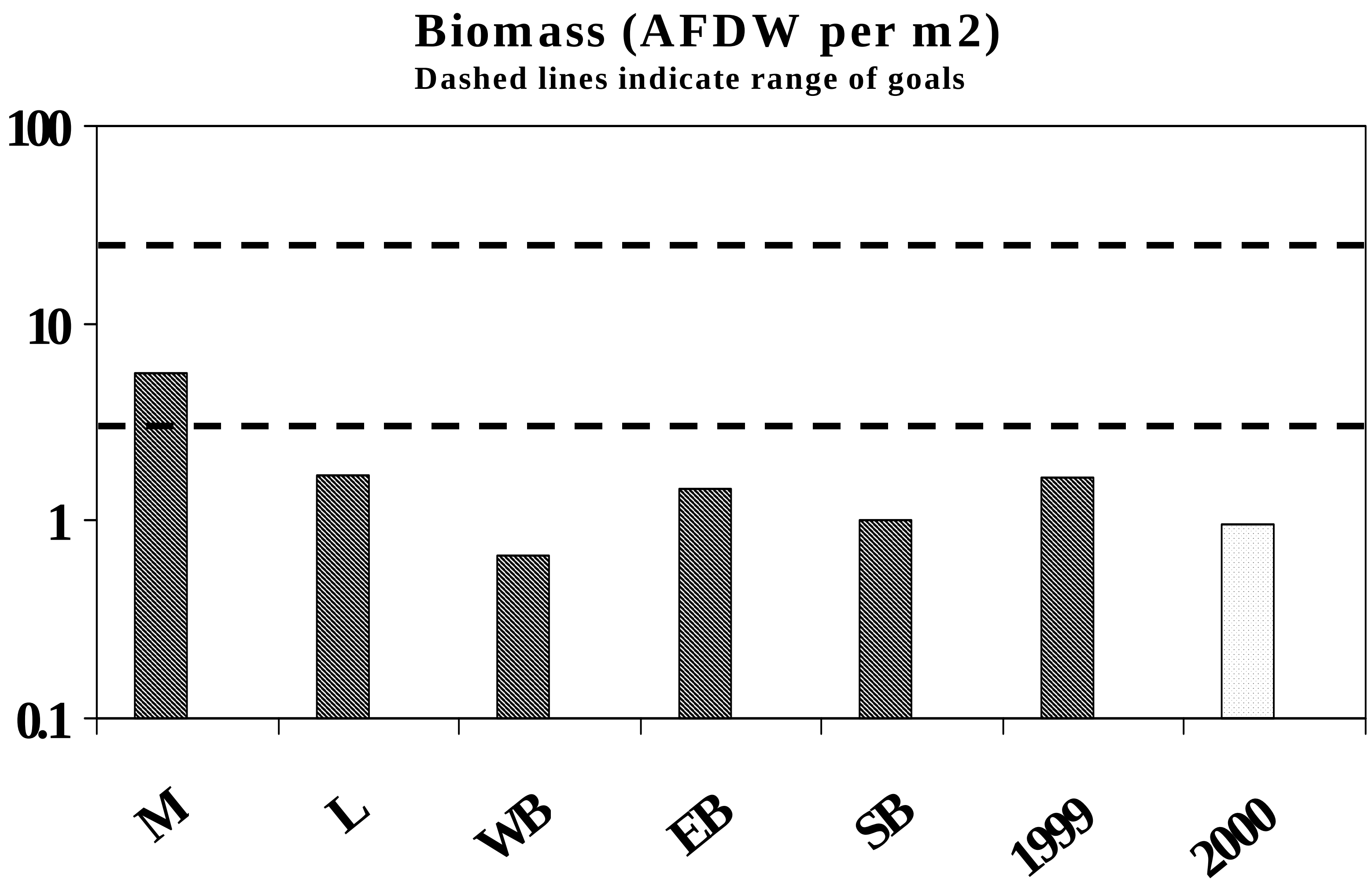

Figure 8. Average AFDW biomass in g per m^2. Shown are the five strata from the 1999 sampling, the 1999 area weighted average for the entire watershed and the 2000 results. See Figure 5 for abbreviations.

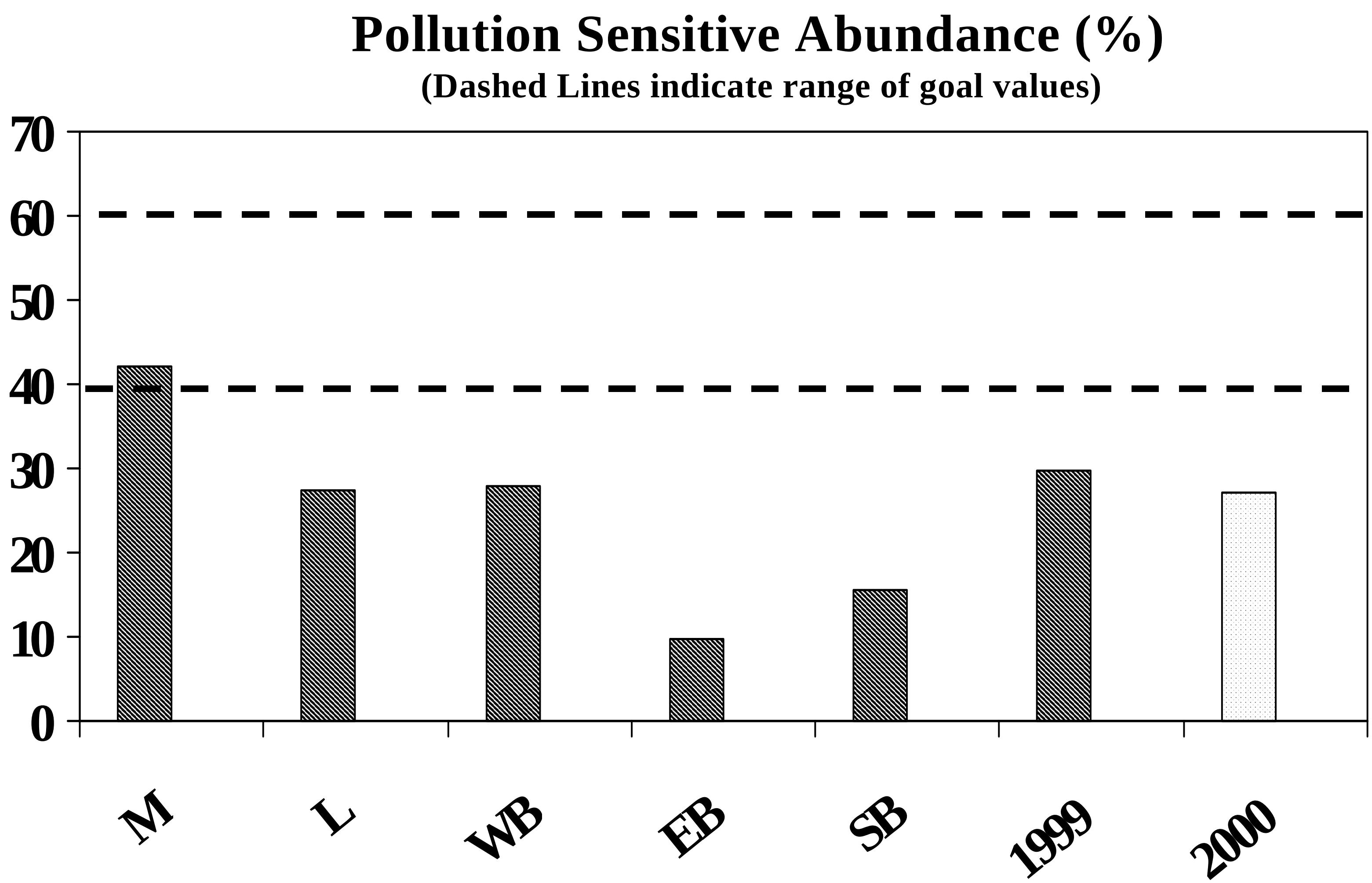

Figure 9. Average percentage of pollution sensitive species abundance. Shown are the five strata from the 1999 sampling, the 1999 area weighted average for the entire watershed and the 2000 results. See Figure 5 for abbreviations.

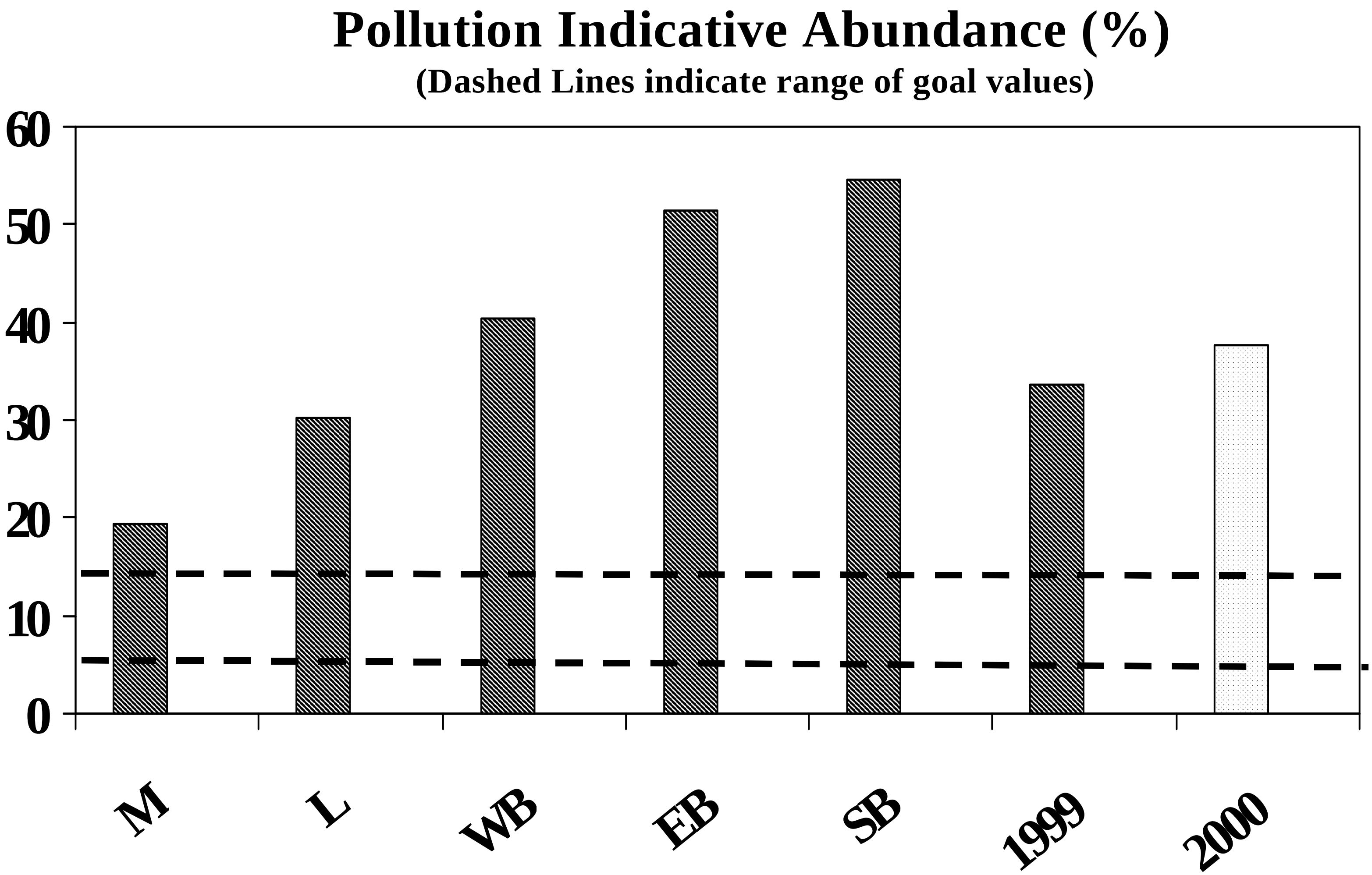

Figure 10. Average percentage of pollution indicative species abundance. Shown are the five strata from the 1999 sampling, the 1999 area weighted average for the entire watershed and the 2000 results. See Figure 5 for abbreviations.

Tables

Table 1. Random Stations of the Elizabeth River. Summary of physical parameters.

Station	Date collected	Latitude	Longitude	Water Depth (m)	Salinity (ppt)	Dissolved oxygen (ppm)	Silt-clay Content (%)	Volatile Organics (%)
07Z01	8/9/00	36.9126	-76.3195	1	17.7	7.9	52.1	2.9
07Z02	8/9/00	36.8995	-76.3082	1	17.9	9.6	76.2	5.3
07Z03	8/9/00	36.9051	-76.2977	5	17.8	5.4	97.3	7.5
07Z04	8/9/00	36.8958	-76.2906	1	16.1	7.0	95.3	7.1
07Z05	8/9/00	36.8937	-76.2910	1	16.4	7.9	91.8	6.8
07Z06	8/17/00	36.8960	-76.3309	4	20.0	6.3	35.7	2.5
07Z07	8/17/00	36.8947	-76.3219	2	19.9	6.6	18.8	1.1
07Z08	8/17/00	36.8811	-76.3257	1	19.9	6.4	1.9	0.3
07Z09	8/14/00	36.8661	-76.3185	10	20.1	3.7	94.3	9.2
07Z10	8/14/00	36.8558	-76.3371	1	18.5	8.8	2.8	0.5
07Z11	8/17/00	36.8231	-76.3980	2	15.4	6.0	95.6	8.2
07Z12	8/14/00	36.8514	-76.2991	4	19.2	4.1	55.9	7.7
07Z13	9/26/00	36.8374	-76.2727	3	17.5	3.9	86.2	9.3
07Z14	9/26/00	36.8365	-76.2481	2	16.7	3.9	83.1	9.1
07Z20	8/14/00	36.8144	-76.2907	13	23.1	1.1	74.2	7.7
07Z21	8/14/00	36.8141	-76.2907	13	22.6	1.2	79.8	8.5
07Z23	8/14/00	36.8012	-76.2936	6	18.5	2.7	55.8	7.2
07Z24	8/14/00	36.7991	-76.3015	1	15.9	2.8	96.4	14.8
07Z25	8/14/00	36.7421	-76.2990	4	17.7	1.6	19.0	3.2
07Z26	8/17/00	36.8871	-76.3306	4	20.1	5.8	24.9	3.3
07Z28	8/14/00	36.8654	-76.3374	1	19.5	7.3	5.6	0.8
07Z29	8/17/00	36.8414	-76.3772	1	18.0	5.7	87.7	5.3
07Z30	8/14/00	36.8404	-76.3002	1	16.6	6.5	4.2	0.7
07Z31	8/17/00	36.8750	-76.3494	1	19.3	7.9	2.0	0.5
07Z33	8/17/00	36.8886	-76.3222	2	19.7	7.1	26.5	0.4

Table 2. Random Stations of the Elizabeth River. Summary of benthic community parameters. Abundance reported as ind./m^2, Biomass reported as grams/m^2, all other abundance and biomass metrics are percentages.

Station	BIBI	Abundance	Biomass	Shannon Index	Pollution Indicative Abundance	Pollution Sensitive Abundance	Pollution Indicative Biomass	Pollution Sensitive Biomass	Carnivore Omnivore Abundance
07Z01	2.0	14016	1.066	2.19	38.0	34.0	12.8	10.6	0.6
07Z02	2.7	5080	1.179	2.23	35.3	6.3	3.8	42.3	7.1
07Z03	2.3	1520	0.862	2.11	65.7	16.4	81.6	13.2	6.0
07Z04	2.3	15128	1.701	2.14	29.8	3.6	6.7	33.3	3.9
07Z05	2.3	6713	0.522	2.52	31.8	20.3	17.4	30.4	5.1
07Z06	4.0	5330	2.313	4.13	5.1	31.9	2.0	54.9	25.5
07Z07	3.7	5375	1.383	2.75	11.4	62.9	11.5	49.2	8.0
07Z08	3.0	2903	0.522	2.28	31.3	47.7	4.3	17.4	21.1
07Z09	2.0	1996	0.295	2.16	20.5	28.4	15.4	7.7	2.3
07Z10	2.3	1361	0.318	2.39	50.0	26.7	14.3	21.4	8.3
07Z11	2.0	7870	0.907	2.52	20.2	4.0	7.5	20.0	6.9
07Z12	1.3	6963	0.476	2.08	34.5	45.6	28.6	23.8	2.0
07Z13	2.0	5534	0.635	2.13	18.9	49.6	10.7	17.9	3.3
07Z14	2.7	3153	1.610	2.72	15.8	37.4	2.8	21.1	4.3
07Z20	1.7	3810	0.658	1.84	19.6	58.9	37.9	13.8	0.0
07Z21	2.3	2654	0.544	2.15	21.4	47.0	12.5	16.7	0.0
07Z23	2.0	37422	1.270	1.41	15.2	72.8	16.1	58.9	3.3
07Z24	2.0	3493	0.204	1.94	30.5	46.1	22.2	44.4	3.2
07Z25	2.0	16375	0.567	1.15	20.2	77.4	16.0	56.0	3.6
07Z26	4.7	4014	2.586	3.79	4.5	54.2	4.4	48.2	22.0
07Z28	3.0	3674	0.839	2.48	32.7	47.5	8.1	10.8	9.9
07Z29	3.3	1882	0.748	2.32	36.1	25.3	3.0	87.9	18.1
07Z30	2.7	15037	1.565	1.94	11.2	11.2	5.8	7.2	62.7
07Z31	3.0	1656	0.658	2.65	37.0	28.8	3.4	10.3	17.8
07Z33	2.7	2223	0.567	2.30	37.8	56.1	8.0	60.0	16.3
Mean	2.6	7007	0.960	2.33	27.0	37.6	14.3	31.1	10.4
Std. Error	0.2	1561	0.123	0.12	2.8	374.1	3.3	4.3	2.6

Table 3. Random Stations of the Elizabeth River. Summary of benthic community parameters scores of the B-IBI.

Station	BIBI	Salinity Class	Sediment Class	Shannon Index	Abundance	Biomass	Pollution Indicative Abundance	Pollution Sensitive Abundance	Pollution Indicative Biomass	Pollution Sensitive Biomass	Carnivore Omnivore Abundance	Deep Deposit Feeders
07Z01	2.000	4	2	3	1	3			3	1	1	
07Z02	2.667	4	2	3	1	3			5	3	1	
07Z03	2.333	4	2	3	5	3			1	1	1	
07Z04	2.333	4	2	3	1	3			3	3	1	
07Z05	2.333	4	2	3	1	3			3	3	1	
07Z06	4.000	5	1	5	3	3		3	5			5
07Z07	3.667	5	1	3	3	3		5	3			5
07Z08	3.000	5	1	1	3	1		3	5			5
07Z09	2.000	5	2	1	5	1			3	1	1	
07Z10	2.333	5	1	1	1	1		3	3			5
07Z11	2.000	4	2	3	1	3			3	1	1	
07Z12	1.333	5	2	1	3	1			1	1	1	
07Z13	2.000	4	2	3	1	3			3	1	1	
07Z14	2.667	4	2	3	3	3			5	1	1	
07Z20	1.667	5	2	1	3	3			1	1	1	
07Z21	2.333	5	2	1	5	3			3	1	1	
07Z23	2.000	5	2	1	1	3			3	3	1	
07Z24	2.000	4	2	1	3	1			3	3	1	
07Z25	2.000	4	1	1	1	1	3	5			1	
07Z26	4.667	5	1	5	5	3		5	5			5
07Z28	3.000	5	1	1	5	1		3	3			5
07Z29	3.333	5	2	1	5	3			5	5	1	
07Z30	2.667	4	1	1	1	3	3	3			5	
07Z31	3.000	5	1	1	3	1		3	5			5
07Z33	2.667	5	1	1	3	1		5	3			3

Table 4. Random Stations of the Elizabeth River. Dominant taxa by abundance. Taxon code: A = amphipod, B = bivalve, G = gastropod, I = isopod, O = oligochaete, P = polychaete, Ph = phoronid.

	Taxon	Abundance per m^2
1	Mediomastus ambiseta (P)	2685
2	Streblospio benedicti (P)	1495
3	Tubificoides spp. Group I (O)	563
4	Tubificoides heterochaetus (O)	516
5	Laeonereis culveri (P)	368
6	Heteromastus filiformis (P)	177
7	Leptocheirus plumulosus (A)	122
8	Glycinde solitaria (P)	109
9	Capitella capitata (P)	99
10	Leitoscoloplos spp. (P)	98
11	Caulleriella killariensis (P)	93
12	Cyathura polita (I)	85
13	Nereis succinea (P)	56
14	Paraprionospio pinnata (P)	53
15	Phoronis psammophila (Ph)	47

Table 5. Fixed Point Stations of the Elizabeth River. Summary of physical parameters.

Station	DATE collected	Latitude	Longitude	Water Depth (m)	Salinity (ppt)	Dissolved oxygen (ppm)	Silt-clay Content (%)	Volatile Organics (%)
EBB1	8/14/00	36.83777	-76.24222	2	16.7	4.1	69.3	9.3
ELC1	8/9/00	36.87960	-76.34755	2	19.5	6.3	31.2	1.8
ELD1	8/14/00	36.86141	-76.33573	1	19.7	7.0	3.7	0.5
ELF1	8/14/00	36.84861	-76.29666	10	19.4	4.0	83.0	6.1
LFA1	9/16/00	36.90918	-76.31378	3	17.4	7.3	62.0	5.0
LFB1	8/17/00	36.88958	-76.28303	3	17.0	5.8	99.2	8.7
SBA1	8/14/00	36.82549	-76.29070	10	21.0	2.0	58.7	8.3
SBB1	8/14/00	36.81166	-76.28861	3	17.6	3.6	37.9	4.9
SBC1	8/14/00	36.79934	-76.29439	11	21.8	1.3	98.2	10.6
SBD1	8/14/00	36.77961	-76.31058	9	21.4	1.3	73.2	8.7
SBD2	8/17/00	36.76674	-76.29694	1	14.1	3.7	3.5	1.4
SBD4	8/17/00	36.74020	-76.29909	1	13.0	3.1	4.7	1.9
WBB1	8/14/00	36.84622	-76.35760	2	19.0	6.4	94.4	7.4
WBB5	8/9/00	36.82926	-76.39315	1	16.4	6.0	71.9	6.4

Table 6. Fixed Point Stations of the Elizabeth River. Summary of benthic community parameters. All values are station means (n=3). Abundance reported as ind./m^2, Biomass reported as grams/m^2, all other abundance and biomass metrics are percentages.

Station	BIBI	Abundance	Biomass	Shannon Index	Pollution Indicative Abundance	Pollution Sensitive Abundance	Pollution Indicative Biomass	Pollution Sensitive Biomass	Carnivore Omnivore Abundance
EBB1	3.222	3954	1.164	2.998	20.1	15.1	3.9	38.3	15.5
ELC1	3.111	2192	0.793	3.206	11.1	56.5	8.4	45.7	27.4
ELD1	3.333	2601	0.590	2.552	15.7	61.3	6.8	31.7	13.7
ELF1	1.667	6902	0.590	2.105	28.9	22.7	21.5	19.0	1.3
LFA1	1.889	2654	0.605	2.285	40.5	50.4	44.9	18.3	7.9
LFB1	2.111	4400	0.627	2.343	21.5	9.6	31.3	26.1	3.0
SBA1	2.667	5398	0.915	2.612	29.9	21.9	13.8	45.5	4.8
SBB1	2.000	665	0.272	2.525	11.0	50.1	13.7	18.5	11.3
SBC1	1.778	2283	0.401	2.044	19.4	57.0	13.5	28.6	4.1
SBD1	2.000	1950	0.885	1.765	14.9	65.6	11.5	53.7	7.8
SBD2	2.222	4982	0.990	2.523	37.0	46.7	9.6	35.1	14.0
SBD4	2.111	4687	0.620	2.230	26.0	49.9	8.8	19.3	11.6
WBB1	2.333	2177	0.862	2.261	30.1	55.0	22.9	12.4	7.3
WBB5	3.667	2638	1.089	2.943	13.9	28.1	4.3	50.7	30.9