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# BENTHIC BIOLOGICAL MONITORING PROGRAM OF THE ELIZABETH RIVER WATERSHED (2002)

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## 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 fourth year of sampling in 2002. 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 characterized in this report by combining the Benthic Index of Biotic Integrity (B-IBI) developed 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. The 1999 intensive data set is used as a benchmark for comparison with data in collected in succeeding years. Beginning in 2000 a single stratum, the entire Elizabeth River watershed, will be sampled with 25 random samples.

Based upon probability-based sampling the estimate of benthic bottom not meeting the benthic restoration goals was 64 ± 10.1 % in 1999, 72 ± 17.6% in 2000, 52 ± 19.6% in 2001, and 76 ± 16.7 % in 2002. Average B-IBI values for the Elizabeth River watershed were 2.7 in 1999 (area weighted for the five strata (Dauer 2000), 2.6 in 2000 (Dauer 2001), 2.7 in 2001 (Dauer 2002) and 2.4 in 2002 (this report).

In general for the Elizabeth River watershed, species diversity and biomass were below reference condition levels while abundance 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.

## INTRODUCTION

A long-term monitoring program of the macrobenthic communities of the Elizabeth River watershed was initiated 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 watershed as indicated by the structure of the benthic communities. This characterization is based upon application of benthic restoration goals and the Benthic Index of Biotic Integrity (B-IBI) developed for the Chesapeake Bay to the Elizabeth River Watershed (Ranasinghe et al. 1994; Weisberg et al. 1997; Alden et al. 2002). In each year 25 samples are randomly allocated in a probability-based sampling design. A probability-based sampling design allows calculation of confidence intervals around estimates of condition 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 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). The condition of the benthic community of the Elizabeth River watershed was characterized by spatially extensive sampling of the river in 1999 with 175 locations sampled among seven strata (Dauer 2000; Dauer and Llansó 2003). Beginning in 2000 the Elizabeth River watershed was sampled as a single stratum with the benthic community condition characterized at 25 random locations (Dauer 2001, 2002). This study updates the benthic community characterization of the Elizabeth River watershed base upon data collected in 2002.

## 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 responses to stress. 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; Dauer 1993). Recently benthic community condition in the Chesapeake Bay watershed has been related in a quantitative manner 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 13.

### *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. Beginning in 2000 and in subsequent years the Elizabeth River was sampled as a single stratum of 25 random samples. In 2001 Paradise Creek was sampled as a separate stratum.

### *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 2003)

Within each probability-based stratum, 25 random 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. An additional 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 analyses. Salinity, temperature and dissolved oxygen were measured at the bottom and water depth was recorded.

### *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 are randomly selected. 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 3.0. 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 interval for these percentages can be calculated as:

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

where p = percentage attaining goal, q = percentage not attaining goal and N = number of samples. This interval reflects the precision of measuring the level of degradation and indicates that with a 95% certainty the true level of degradation is within this interval. Differences between levels of degradation using a binomial distribution can be tested using the procedure of Schenker and Gentleman (2001).

For each stratum, 50 random points were 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 of inaccessibility by boat, inadequate water depth or inability of the grab to obtain an adequate sample (e.g., on hard bottoms).

### *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 sample were collected for macrobenthic community analysis.

### *Laboratory Analysis*

Each replicate was sieved on a 0.5 mm screen, 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 °C and ashing at 550 °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 $\mu$m) and a silt-clay fraction (< 63 $\mu$m). 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 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; Weisberg et al. 1997; Alden et al. 2002). 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; Dauer et al. 2002).

## 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 conditions, (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 conditions were determined by selecting samples 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 Appendix). 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

### *Elizabeth River Watershed - Probability-Based Sampling*

#### Environmental Parameters

All physical, chemical and sedimentary parameters are summarized in Table 1. Water depths varied from less than 1m to nearly 18 m reflecting shoal and channel depths. All salinity values were in the polyhaline range with values from 22.4 to 28.1 ppt. All bottom dissolved oxygen measurements were above 2.0 ppm except random station 09Z21 in the Southern Branch (Fig. 3 and Table 1). Marobenthic communities are generally not altered by low dissolved oxygen unless values fall below at least 2.0 ppm (Diaz and Rosenberg 1995). Silt-clay content varied from 2.3 to 97.9 % and total volatile solids from 0.4 to 8.9 %.

### Benthic Community Condition

Benthic community parameters including the B-IBI value, abundance, biomass, Shannon diversity and selected metrics are summarized by station in Table 2. The average B-IBI values for the 25 random sites was 2.4. The distribution of the random sites and benthic community condition designations are shown in Figure 3. For the 2002 data 76 ± 16.7 % of the watershed had degraded benthos. Individual metric scores incorporated in the B-IBI are presented in Table 3. 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. 4-9. In these figures the five strata of the Elizabeth River sampled in 1999 are shown. Also shown is the area weighted average for all 125 random samples from the five strata sampled in 1999. The 2000 through 2002 values are based upon the 25 random sampled from each respective year.

## *Elizabeth River Watershed - Fixed-Point Stations*

### Environmental Parameters

All physical, chemical and sedimentary parameters are summarized in Table 5.

### 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. Figure 10 lists the status of the 14 fixed-point stations. Status is determined by the three year (2000-2002) average B-IBI values at each station. Three stations had B-IBI values over 3.0 and were considered to have met the Benthic Restoration Goals of the B-IBI and were located in the Mainstem of the river (EL-C-01, EL-D-01) and the farthest site up the Southern Branch (SB-D-04). Two sites were characterized as severely degraded: EL-F-01 near the confluence of the Mainstem, Eastern Branch and Southern Branch and EB-B-01 in the Eastern Branch. Both sites in the Western Branch and both sites in the Lafayette River were characterized as degraded.

# 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 1999 intensive sampling serves as a benchmark for comparisons in future years. 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 1999 each of the five strata were sampled at 25 random locations for a total of 125 random samples. In succeeding years the entire Elizabeth River watershed was sampled as a single stratum of 25 random samples.

Average B-IBI values for the Elizabeth River watershed were 2.7 in 1999 (area weighted for the five strata (Dauer 2000), 2.6 in 2000 (Dauer 2001), 2.7 in 2001 (Dauer 2002) and 2.4 in 2002 (this report). Based upon probability-based sampling the estimate of benthic bottom not meeting the benthic restoration goals was 76 ± 16.7 % in 2002, 52 ± 19.6% in 2001, 72 ± 17.6% in 2000, and 64 ± 10.1 % in 1999.

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. 4-9). However, there are some positive indications with the increase in the proportion of pollution sensitive species (Fig. 9).

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## 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 randomly within a 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 the1999 study the primary strata were the Mainstem of the river, the Lafayette River, the Eastern Branch, Western Branch and Southern Branch. In succeeding years the entire Elizabeth River watershed was 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

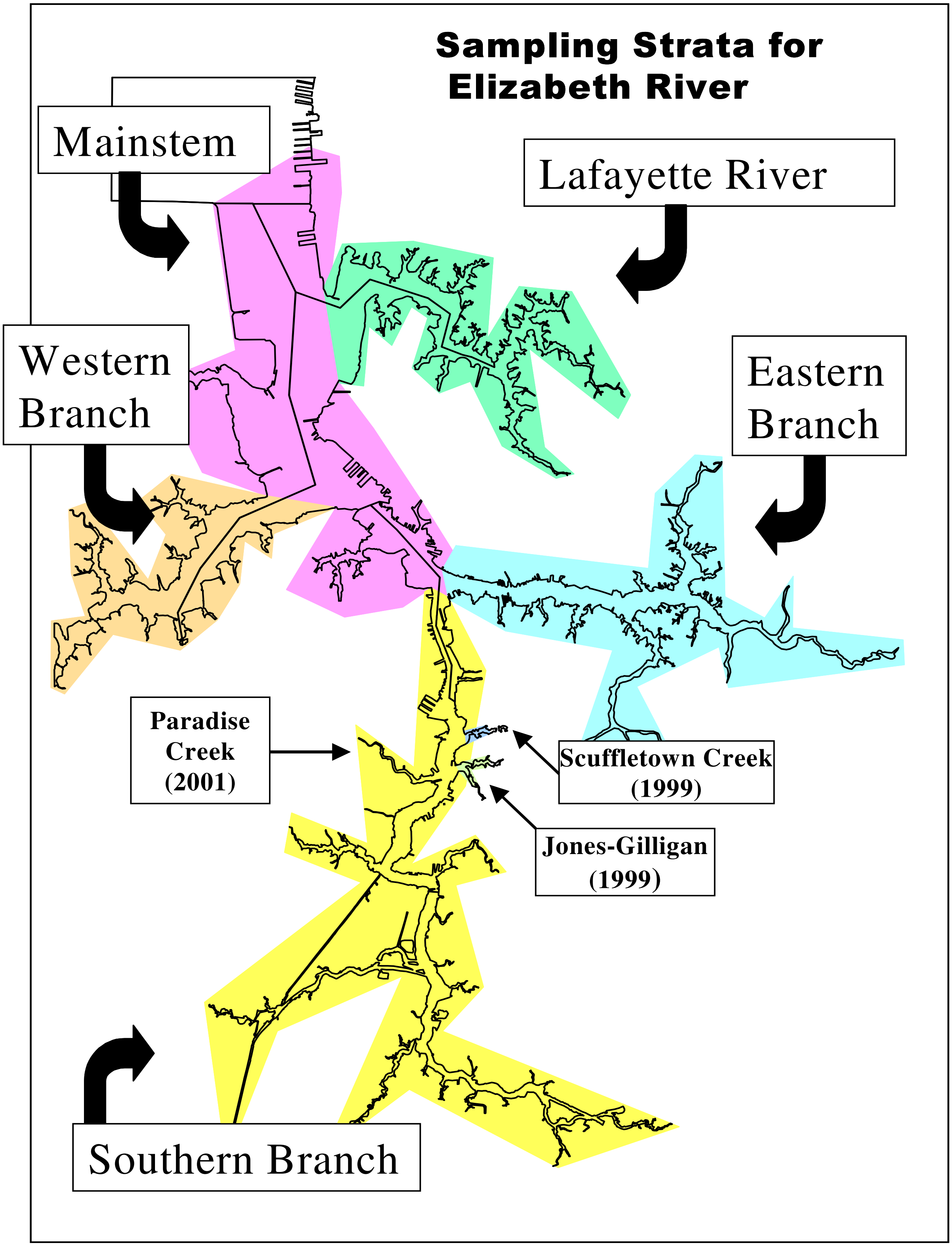


**Figure 1**. Elizabeth River watershed showing the five major segments sampled in 1999. Insert shows Scuffletown Creek and the Jones-Gilligan Creek strata also sampled in 1999 and Paradise Creek stratum sampled in 2001.

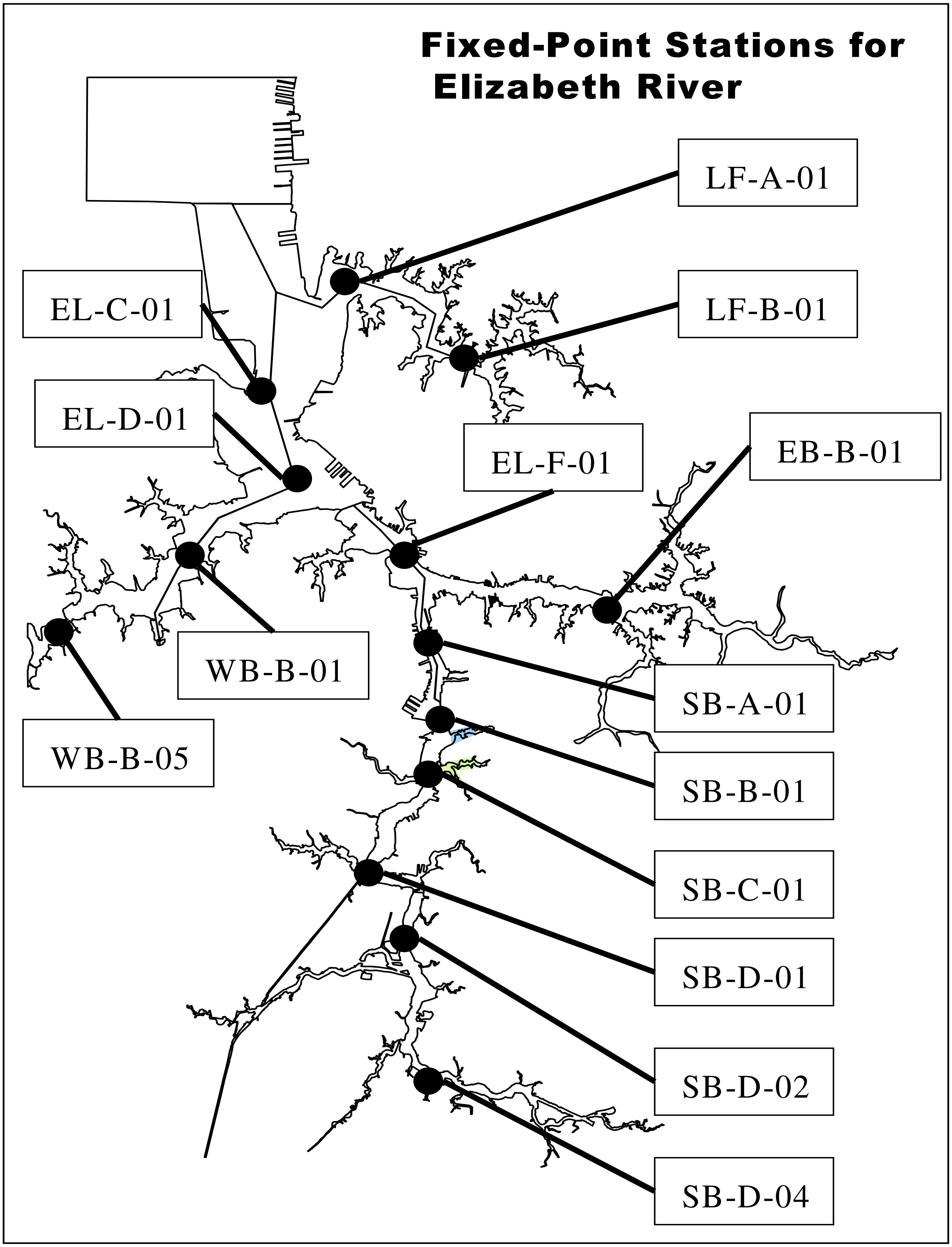


**Figure 2**. Elizabeth River watershed showing the 14 fixed-point stations for long-term trend analyses.

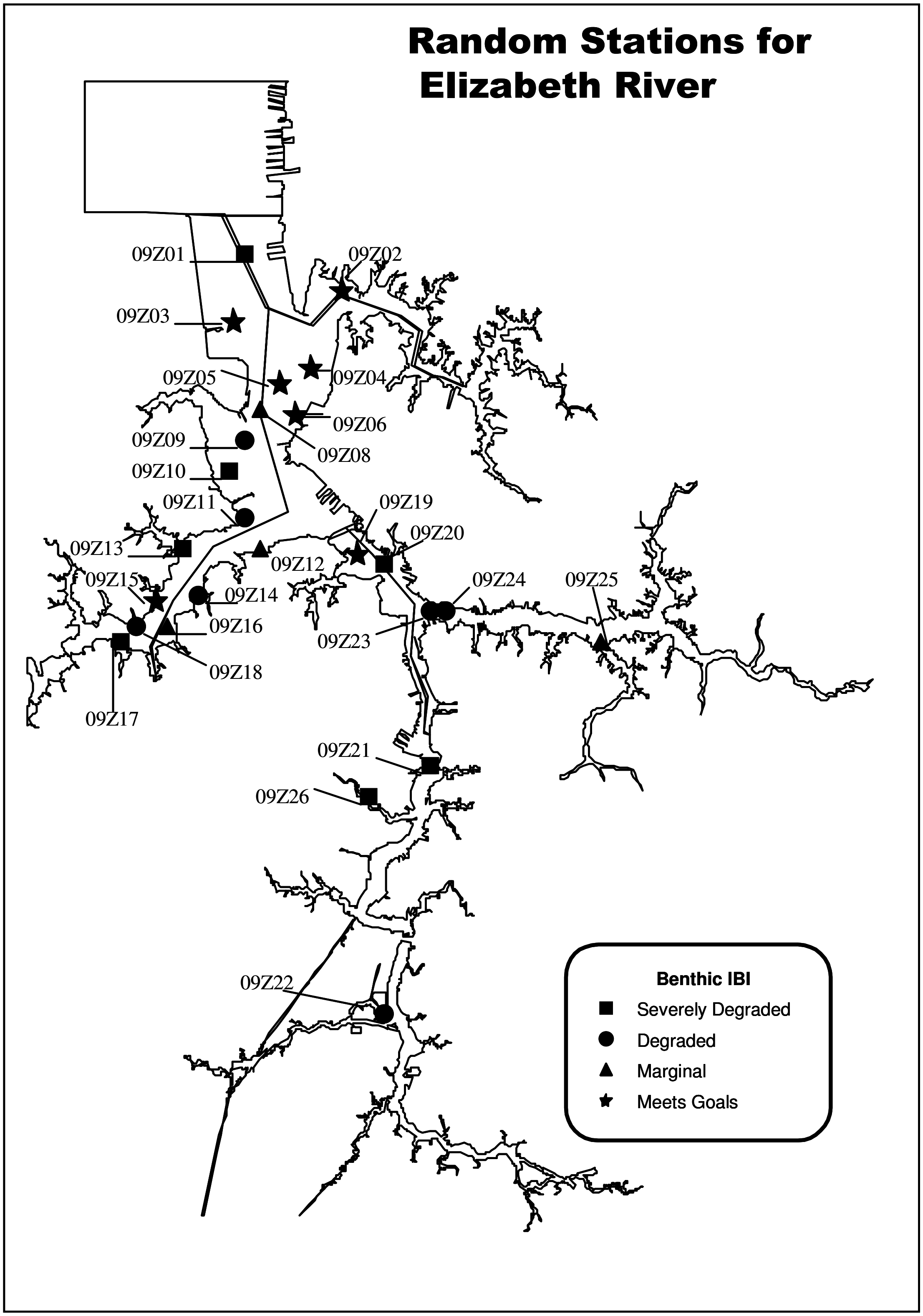


**Figure 3**. Map showing the 25 random locations sampled in 2002 and indicating the station numbers and condition of the benthic communities.

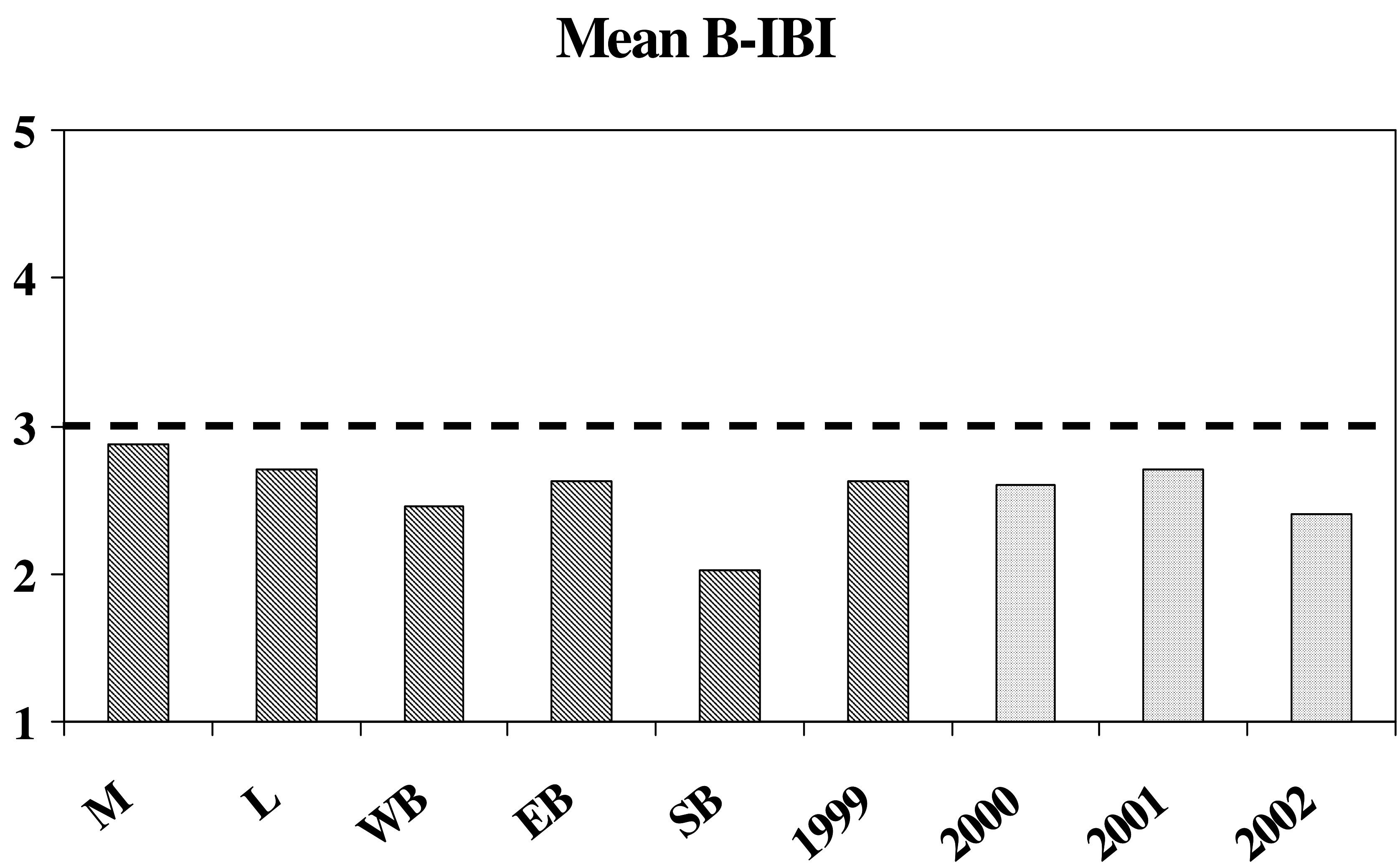


**Figure 4**. Average B-IBI values. Dashed line indicates a B-IBI value of 3.0, the goal for benthic restoration. Shown are the five strata from the 1999 sampling compared with the area weighted value for 1999 (crosshatched bars) and the values for 2000 through 2002 based upon a single stratum for the entire watershed (stippled bars). Abbreviations: M - Mainstem of Elizabeth River, L - Lafayette River, WB - Western Branch, EB - Eastern Branch, SB - Southern Branch.

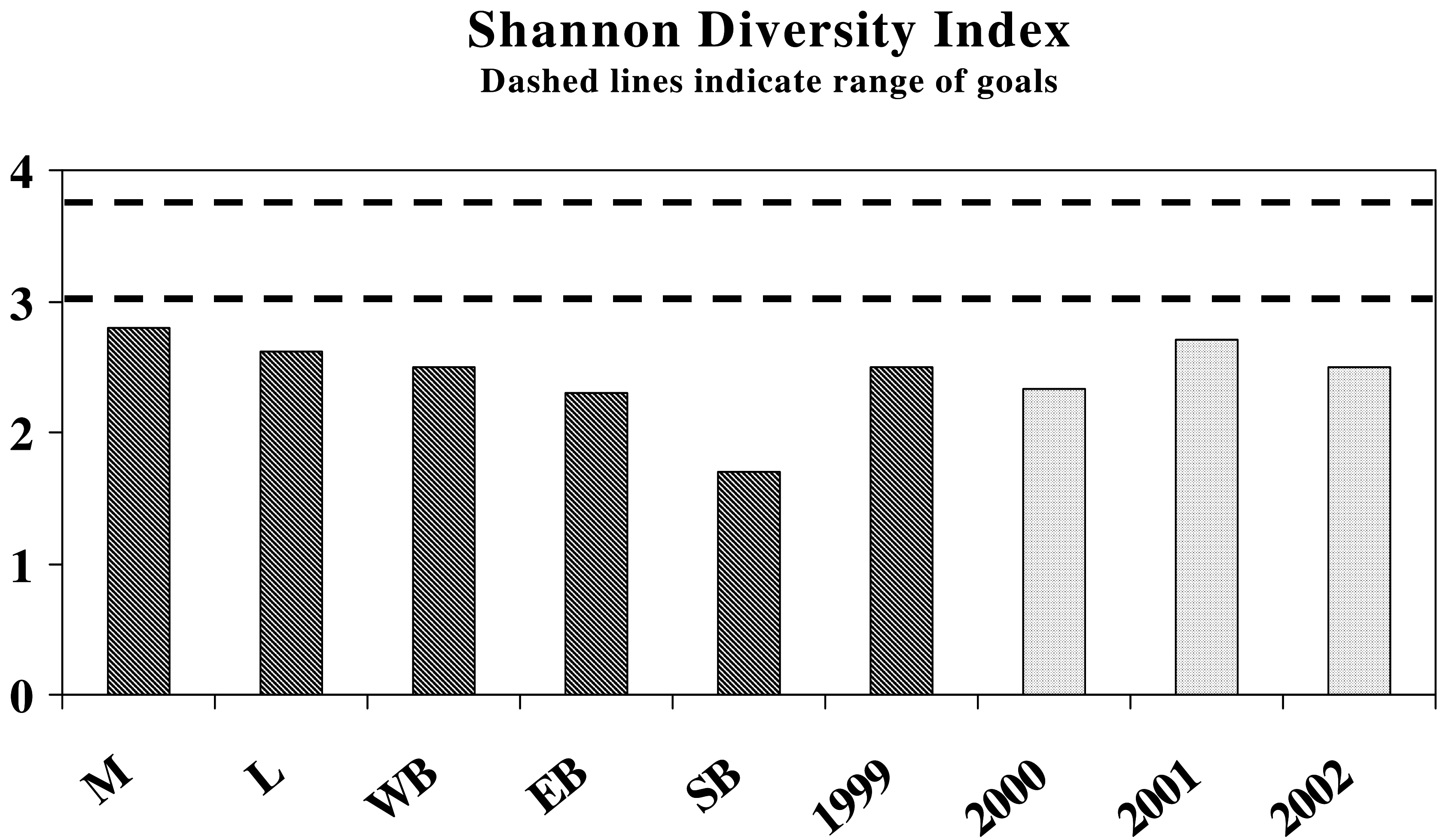


**Figure 5**. Average Shannon diversity index values. Shown are the five strata from the 1999 sampling, the 1999 area weighted average for the entire watershed and the 2000 through 2002 results. See Figure 4 for abbreviations. Dashed lines indicate range of values from benthic restoration goals.

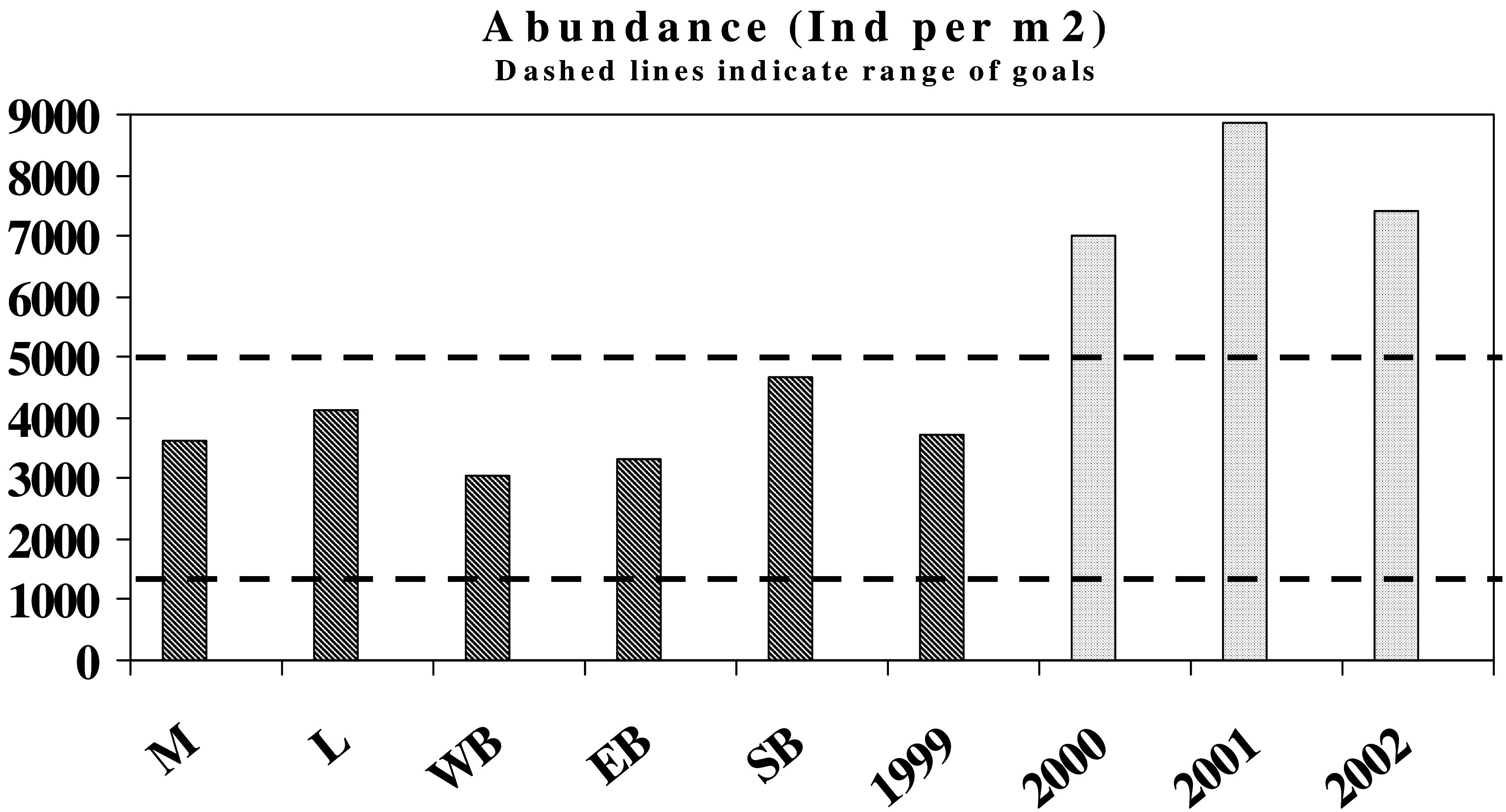


**Figure 6**. Average abundance of individuals per m$^2$. Shown are the five strata from the 1999 sampling, the 1999 area weighted average for the entire watershed and the 2000 through 2002 results. See Figure 4 for abbreviations. Dashed lines indicate range of values from benthic restoration goals.

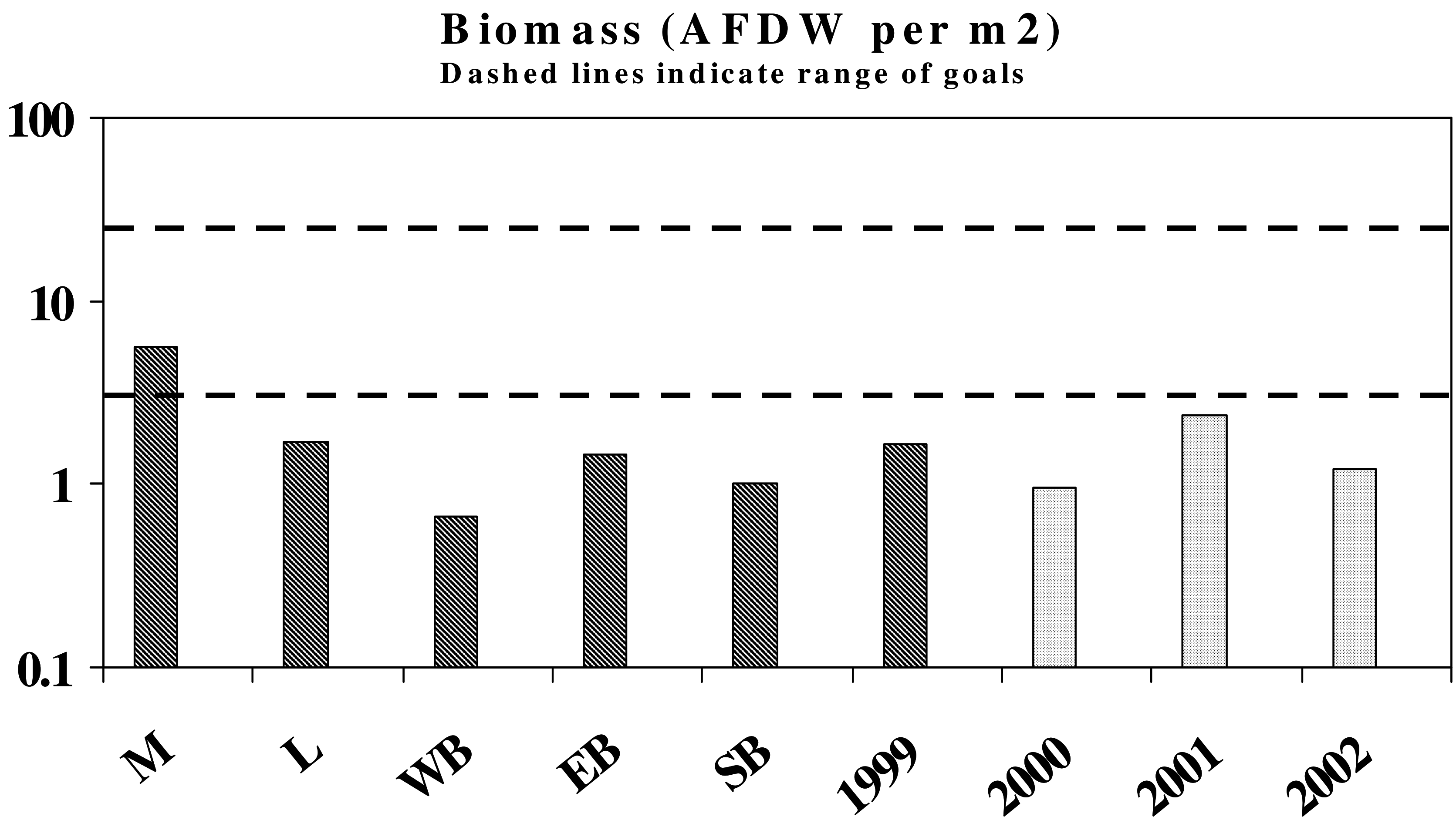


**Figure 7**. Average ash-free dry weight biomass in g per m$^2$. Shown are the five strata from the 1999 sampling, the 1999 area weighted average for the entire watershed and the 2000 through 2002 results. See Figure 4 for abbreviations. Dashed lines indicate range of values from benthic restoration goals.

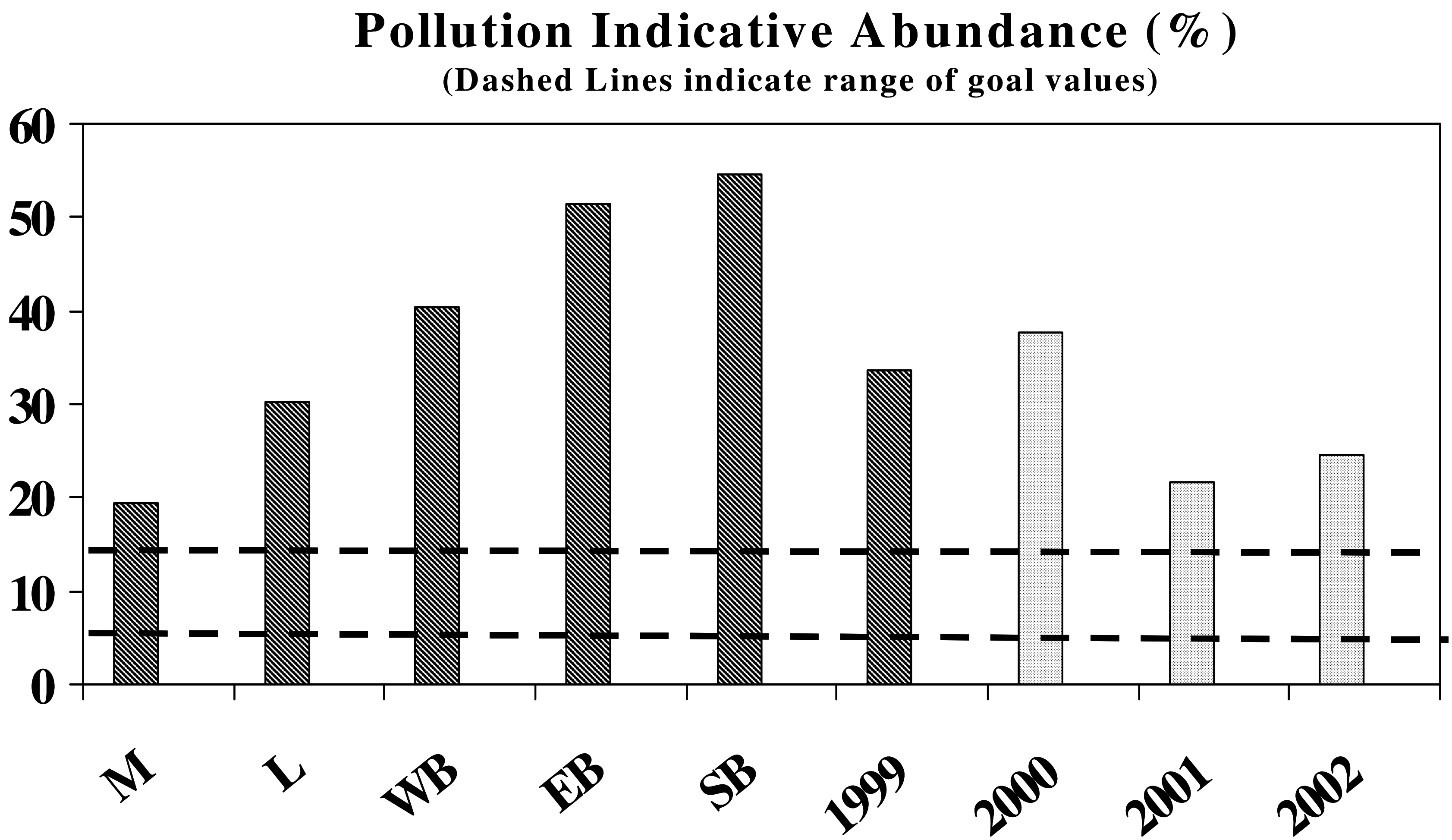


**Figure 8**. Average percentage of pollution indicative species abundance. Shown are the five strata from the 1999 sampling, the 1999 area weighted average for the entire watershed and the 2000 through 2002 results. See Figure 4 for abbreviations. Dashed lines indicate range of values from benthic restoration goals.

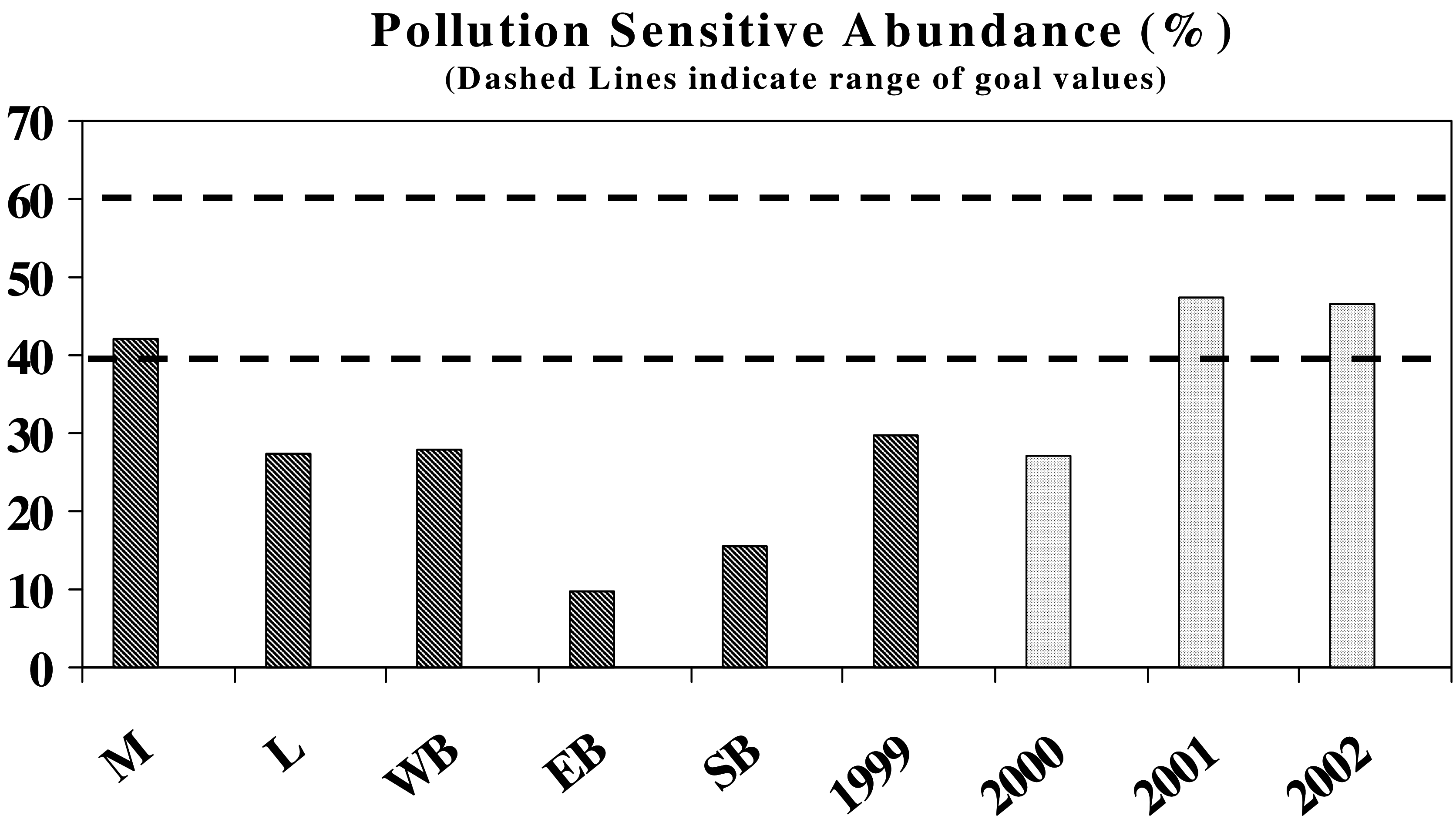


**Figure 9**. Average percentage of pollution sensitive species abundance. Shown are the five strata from the 1999 sampling, the 1999 area weighted average for the entire watershed and the 2000 through 2002 results. See Figure 4 for abbreviations. Dashed lines indicate range of values from benthic restoration goals.

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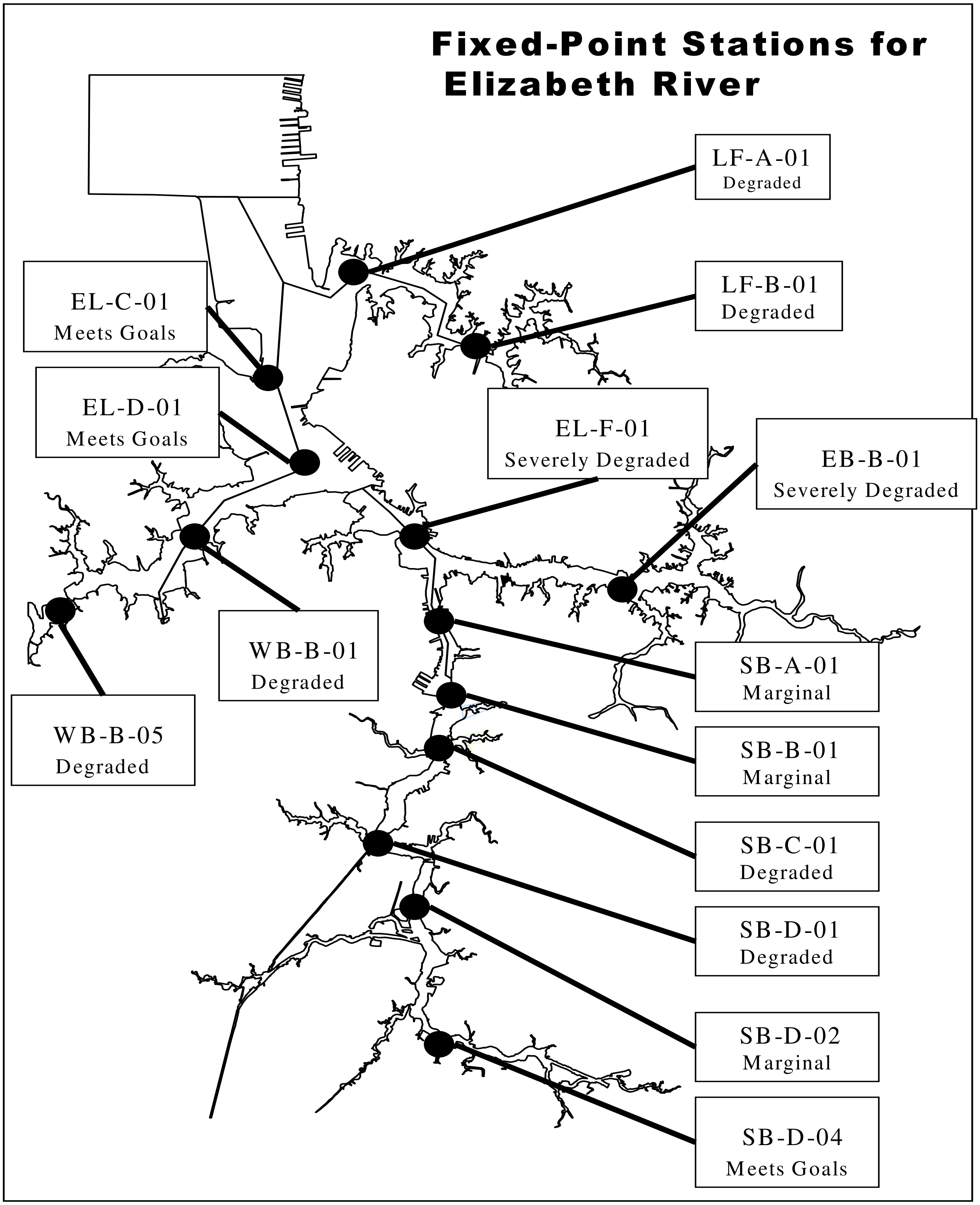



**Figure 10**. Fixed-point stations showing the benthic community status of each station. Status is based upon the average value of the B-IBI for the three year period 2000-2003. Values less than 2 were classified as **severely degraded**; values from 2.0 to 2.6 as **degraded**; values greater than 2.6 but less than 3.0 as **marginal**; and values of 3.0 or more as **meeting the goal**.

Tables

Table 1. Random Stations of the Elizabeth River sampled in 2002. Summary of physical-chemical parameters.

| Station | Date collected | Latitude | Longitude | Water depth (m) | Temperature ($^0$C) | Salinity (ppt) | Dissolved oxygen (ppm) | Silt-clay content (%) | Volatile organics (%) |
|---|---|---|---|---|---|---|---|---|---|
| 09Z01 | 8/5/2002 | 36.9166 | 76.3401 | 15.5 | 26.2 | 28.1 | 2.1 | 97.3 | 6.7 |
| 09Z02 | 8/5/2002 | 36.9082 | 76.3141 | 3.5 | 29.6 | 23.9 | 3.5 | 52.3 | 3.4 |
| 09Z03 | 8/5/2002 | 36.9011 | 76.3481 | 3.0 | 30.7 | 24.1 | 6.7 | 47.8 | 2.5 |
| 09Z04 | 8/5/2002 | 36.8901 | 76.3228 | 2.2 | 29.7 | 23.8 | 5.8 | 14.8 | 1.1 |
| 09Z05 | 8/5/2002 | 36.8892 | 76.3268 | 3.2 | 29.5 | 24.0 | 5.0 | 38.9 | 2.4 |
| 09Z06 | 8/5/2002 | 36.8830 | 76.3241 | 1.3 | 31.4 | 23.8 | 10.0 | 3.3 | 0.6 |
| 09Z08 | 8/5/2002 | 36.8806 | 76.3344 | 18.0 | 26.1 | 28.1 | 2.1 | 90.4 | 6.5 |
| 09Z09 | 8/5/2002 | 36.8791 | 76.3384 | 12.0 | 27.8 | 25.7 | 3.3 | 85.6 | 5.1 |
| 09Z10 | 8/1/2002 | 36.8679 | 76.3429 | 1.5 | 32.1 | 23.5 | 7.3 | 2.5 | 0.5 |
| 09Z11 | 8/1/2002 | 36.8619 | 76.3405 | 1.3 | 31.4 | 23.5 | 5.5 | 8.3 | 0.4 |
| 09Z12 | 8/1/2002 | 36.8550 | 76.3365 | 1.5 | 30.9 | 23.5 | 7.3 | 2.3 | 0.4 |
| 09Z13 | 8/1/2002 | 36.8533 | 76.3566 | 4.0 | 29.9 | 23.6 | 5.6 | 95.4 | 5.6 |
| 09Z14 | 8/1/2002 | 36.8464 | 76.3524 | 1.0 | 32.0 | 23.2 | 7.6 | 6.1 | 0.7 |
| 09Z15 | 8/1/2002 | 36.8479 | 76.3668 | 1.0 | 32.7 | 23.1 | 9.6 | 97.0 | 7.0 |
| 09Z16 | 8/1/2002 | 36.8356 | 76.3621 | 1.0 | 32.9 | 22.7 | 10.1 | 12.7 | 1.0 |
| 09Z17 | 8/1/2002 | 36.8331 | 76.3741 | 1.0 | 32.8 | 22.4 | 8.1 | 93.7 | 5.9 |
| 09Z18 | 8/1/2002 | 36.8390 | 76.3737 | 1.0 | 32.4 | 22.4 | 6.3 | 7.9 | 0.7 |
| 09Z19 | 8/26/2002 | 36.8504 | 76.3095 | 3.0 | 28.5 | 24.9 | 4.7 | 50.5 | 3.1 |
| 09Z20 | 8/26/2002 | 36.8507 | 76.2998 | 8.0 | 28.7 | 24.8 | 4.2 | 91.4 | 6.9 |
| 09Z21 | 8/15/2002 | 36.8097 | 76.2898 | 9.0 | 28.6 | 24.2 | 1.8 | 94.5 | 8.1 |
| 09Z22 | 8/15/2002 | 36.7575 | 76.3039 | 2.5 | 32.1 | 22.4 | 2.2 | 2.9 | 0.6 |
| 09Z23 | 9/19/2002 | 36.8415 | 76.2895 | 10.0 | 25.4 | 23.3 | 4.8 | 97.9 | 7.8 |
| 09Z24 | 8/26/2002 | 36.8418 | 76.2887 | 10.0 | 28.6 | 24.9 | 4.2 | 95.3 | 7.3 |
| 09Z25 | 8/26/2002 | 36.8332 | 76.2433 | 0.7 | 28.9 | 23.0 | 5.3 | 9.8 | 0.9 |
| 09Z26 | 8/15/2002 | 36.8004 | 76.3042 | 1.5 | 30.1 | 24.1 | 2.5 | 87.7 | 8.9 |

Table 2. Random Stations of the Elizabeth Rive sampled in 2002. 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 | B-IBI | Abundance | Biomass | Shannon Index | Pollution Indicative Abundance | Pollution Sensitive Biomass | Pollution Indicative Biomass | Pollution Sensitive Biomass | Carnivore Omnivore Abundance | Deep Deposit Feeder Abundance |
|---|---|---|---|---|---|---|---|---|---|---|
| 09Z01 | 1.7 | 1,225 | 0.476 | 2.8 | 50.0 | 33.3 | 66.7 | 14.3 | 13.0 | 46.3 |
| 09Z02 | 3.3 | 2,699 | 1.383 | 3.4 | 21.0 | 53.8 | 11.5 | 44.3 | 6.7 | 49.6 |
| 09Z03 | 3.3 | 2,767 | 0.885 | 3.2 | 18.0 | 68.0 | 10.3 | 38.5 | 32.0 | 42.6 |
| 09Z04 | 3.7 | 2,699 | 2.109 | 3.9 | 9.2 | 41.2 | 6.5 | 23.7 | 26.1 | 29.4 |
| 09Z05 | 4.0 | 2,064 | 1.678 | 4.1 | 19.8 | 52.7 | 5.4 | 59.5 | 23.1 | 28.6 |
| 09Z06 | 3.0 | 1,973 | 1.066 | 3.5 | 17.2 | 42.5 | 36.2 | 25.5 | 20.7 | 29.9 |
| 09Z08 | 2.7 | 2,064 | 0.522 | 3.2 | 34.1 | 34.1 | 26.1 | 21.7 | 33.0 | 34.1 |
| 09Z09 | 2.3 | 2,654 | 0.544 | 2.8 | 35.9 | 49.6 | 25.0 | 16.7 | 13.7 | 45.3 |
| 09Z10 | 1.7 | 1,610 | 0.612 | 2.5 | 28.2 | 22.5 | 59.3 | 14.8 | 2.8 | 23.9 |
| 09Z11 | 2.0 | 2,449 | 0.272 | 1.1 | 11.1 | 10.2 | 16.7 | 16.7 | 1.9 | 88.0 |
| 09Z12 | 2.7 | 1,610 | 0.567 | 2.9 | 35.2 | 45.1 | 40.0 | 24.0 | 12.7 | 38.0 |
| 09Z13 | 1.7 | 3,674 | 0.544 | 1.5 | 17.9 | 73.5 | 33.3 | 16.7 | 6.8 | 77.2 |
| 09Z14 | 2.3 | 5,307 | 0.862 | 2.3 | 20.5 | 18.8 | 5.3 | 13.2 | 3.0 | 31.6 |
| 09Z15 | 3.0 | 7,167 | 1.383 | 1.4 | 13.0 | 77.5 | 1.6 | 86.9 | 4.7 | 80.1 |
| 09Z16 | 2.7 | 8,119 | 2.223 | 2.0 | 7.3 | 23.5 | 4.1 | 5.1 | 3.6 | 38.5 |
| 09Z17 | 1.7 | 16,194 | 1.293 | 1.1 | 16.1 | 79.6 | 29.8 | 56.1 | 2.7 | 82.1 |
| 09Z18 | 2.3 | 8,528 | 1.656 | 2.5 | 22.6 | 29.3 | 15.1 | 6.8 | 5.1 | 50.0 |
| 09Z19 | 3.0 | 4,173 | 1.882 | 3.3 | 15.8 | 70.7 | 8.4 | 78.3 | 13.6 | 44.6 |
| 09Z20 | 1.7 | 11,658 | 1.678 | 2.2 | 22.2 | 63.0 | 40.5 | 43.2 | 10.1 | 66.1 |
| 09Z21 | 1.7 | 18,212 | 1.542 | 1.8 | 15.6 | 73.1 | 35.3 | 52.9 | 8.6 | 75.1 |
| 09Z22 | 2.0 | 816 | 0.204 | 2.2 | 38.9 | 44.4 | 44.4 | 22.2 | 44.4 | 41.7 |
| 09Z23 | 2.0 | 3,221 | 0.635 | 2.5 | 54.2 | 28.2 | 60.7 | 10.7 | 8.5 | 37.3 |
| 09Z24 | 2.3 | 5,194 | 0.680 | 2.4 | 30.1 | 58.5 | 46.7 | 33.3 | 14.8 | 54.1 |
| 09Z25 | 2.7 | 13,721 | 4.423 | 2.8 | 31.2 | 7.1 | 11.3 | 7.7 | 28.4 | 41.8 |
| 09Z26 | 1.7 | 55,816 | 2.495 | 1.2 | 29.2 | 67.8 | 44.5 | 48.2 | 0.5 | 70.5 |
| | | | | | | | | | | |
| Mean | 2.4 | 7,425 | 1.265 | 2.5 | 24.6 | 46.7 | 27.4 | 31.2 | 13.6 | 49.9 |
| Std error | 0.1 | 2,235 | 0.18447 | 0.2 | 2.4 | 4.3 | 3.9 | 4.5 | 2.3 | 3.8 |

| Table 3. Random Stations of the Elizabeth River sampled in 2002. Summary of benthic community parameters scores of the B-IBI. | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Station | B-IBI | 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 |
| 09Z01 | 1.7 | 5 | 2 | 3 | 3 | 1 | . | . | 1 | 1 | 1 | . |
| 09Z02 | 3.3 | 5 | 2 | 5 | 5 | 3 | . | . | 3 | 3 | 1 | . |
| 09Z03 | 3.3 | 5 | 2 | 3 | 5 | 3 | . | . | 3 | 3 | 3 | . |
| 09Z04 | 3.7 | 5 | 1 | 5 | 3 | 3 | . | 3 | 3 | . | . | 5 |
| 09Z05 | 4.0 | 5 | 1 | 5 | 3 | 3 | . | 5 | 3 | . | . | 5 |
| 09Z06 | 3.0 | 5 | 1 | 3 | 3 | 3 | . | 3 | 1 | . | . | 5 |
| 09Z08 | 2.7 | 5 | 2 | 3 | 5 | 3 | . | . | 1 | 1 | 3 | . |
| 09Z09 | 2.3 | 5 | 2 | 3 | 5 | 3 | . | . | 1 | 1 | 1 | . |
| 09Z10 | 1.7 | 5 | 1 | 1 | 3 | 1 | . | 1 | 1 | . | . | 3 |
| 09Z11 | 2.0 | 5 | 1 | 1 | 3 | 1 | . | 1 | 1 | . | . | 5 |
| 09Z12 | 2.7 | 5 | 1 | 3 | 3 | 1 | . | 3 | 1 | . | . | 5 |
| 09Z13 | 1.7 | 5 | 2 | 1 | 3 | 3 | . | . | 1 | 1 | 1 | . |
| 09Z14 | 2.3 | 5 | 1 | 1 | 3 | 1 | . | 1 | 3 | . | . | 5 |
| 09Z15 | 3.0 | 5 | 2 | 1 | 3 | 3 | . | . | 5 | 5 | 1 | . |
| 09Z16 | 2.7 | 5 | 1 | 1 | 1 | 3 | . | 1 | 5 | . | . | 5 |
| 09Z17 | 1.7 | 5 | 2 | 1 | 1 | 3 | . | . | 1 | 3 | 1 | . |
| 09Z18 | 2.3 | 5 | 1 | 1 | 1 | 3 | . | 3 | 1 | . | . | 5 |
| 09Z19 | 3.0 | 5 | 2 | 3 | 3 | 3 | . | . | 3 | 5 | 1 | . |
| 09Z20 | 1.7 | 5 | 2 | 1 | 1 | 3 | . | . | 1 | 3 | 1 | . |
| 09Z21 | 1.7 | 5 | 2 | 1 | 1 | 3 | . | . | 1 | 3 | 1 | . |
| 09Z22 | 2.0 | 5 | 1 | 1 | 1 | 1 | . | 3 | 1 | . | . | 5 |
| 09Z23 | 2.0 | 5 | 2 | 3 | 3 | 3 | . | . | 1 | 1 | 1 | . |
| 09Z24 | 2.3 | 5 | 2 | 3 | 3 | 3 | . | . | 1 | 3 | 1 | . |
| 09Z25 | 2.7 | 5 | 1 | 3 | 1 | 3 | . | 1 | 3 | . | . | 5 |
| 09Z26 | 1.7 | 5 | 2 | 1 | 1 | 3 | . | . | 1 | 3 | 1 | . |

Table 4. Random Stations of the Elizabeth River sampled in 2002. Dominant taxa by abundance. Abundance is average for the 25 random samples expressed as individuals per $m^2$. Taxon code: A = amphipod, An=Anemone B = bivalve, G = gastropod, I = isopod, O = oligochaete, P = polychaete, R = rhynchocoel

| | Taxon | Abundance per $m^2$ |
|---|---|---|
| 1 | Mediomastus ambiseta (P) | 3,778 |
| 2 | Streblospio benedicti (P) | 1,216 |
| 3 | Caulleriella killariensis (P) | 386 |
| 4 | Paraprionospio pinnata (P) | 368 |
| 5 | Caprella penantis (A) | 278 |
| 6 | Tubificoides spp. Group I (O) | 220 |
| 7 | Heteromastus filiformis (P) | 189 |
| 8 | Capitella capitata (P) | 160 |
| 9 | Laeonereis culveri (P) | 138 |
| 10 | Leitoscoloplos spp. (P) | 125 |
| 11 | Paracaprella tenuis (A) | 104 |
| 12 | Acteocina canaliculata (G) | 86 |
| 13 | Nemertea spp. (R) | 85 |
| 14 | Glycinde solitaria (P) | 63 |
| 15 | Spiochaetopterus costarum (P) | 61 |

| Table 5. Fixed Stations of the Elizabeth River sampled in 2002. Summary of physical-chemical parameters. | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Station | Date collected | Latitude | Longitude | Water Depth (m) | Temperature ($^{0}C$) | Salinity (ppt) | Dissolved oxygen (ppm) | Silt-clay Content (%) | Volatile Organics (%) |
| EBB1 | 8/20/01 | 36.8378 | 76.2422 | 1.2 | 28.8 | 18.6 | 8.0 | 71.6 | 8.5 |
| ELC1 | 8/21/01 | 36.8796 | 76.3476 | 3.1 | 29.6 | 22.4 | 5.1 | 27.6 | 1.2 |
| ELD1 | 8/21/01 | 36.8614 | 76.3357 | 2.1 | 28.3 | 22.5 | 4.8 | 4.2 | 0.4 |
| ELF1 | 8/21/01 | 36.8486 | 76.2967 | 11.9 | 25.0 | 22.4 | 4.0 | 95.9 | 7.8 |
| LFA1 | 8/13/01 | 36.9092 | 76.3138 | 1.8 | 28.2 | 21.5 | 6.9 | 79.5 | 3.8 |
| LFB1 | 8/13/01 | 36.8896 | 76.2830 | 3.5 | 28.8 | 20.8 | 3.8 | 98.9 | 7.8 |
| SBA1 | 8/20/01 | 36.8255 | 76.2907 | 10.4 | 24.2 | 22.3 | 3.1 | 90.2 | 7.9 |
| SBB1 | 8/20/01 | 36.8117 | 76.2886 | 3.7 | 29.8 | 22.1 | 3.6 | 38.6 | 5.6 |
| SBC1 | 8/20/01 | 36.7994 | 76.2944 | 10.7 | 24.3 | 22.2 | 2.9 | 92.7 | 0.4 |
| SBD1 | 8/20/01 | 36.7796 | 76.3106 | 9.1 | 24.2 | 21.5 | 3.6 | 87.9 | 10.0 |
| SBD2 | 8/20/01 | 36.7668 | 76.2969 | 0.9 | 34.0 | 21.2 | 3.1 | 42.1 | 6.5 |
| SBD4 | 8/20/01 | 36.7402 | 76.2990 | 1.5 | 29.8 | 20.5 | 2.7 | 17.3 | 2.3 |
| WBB1 | 8/14/01 | 36.8462 | 76.3576 | 1.5 | 30.6 | 21.4 | 3.9 | 92.7 | 5.6 |
| WBB5 | 8/14/01 | 36.8293 | 76.3932 | 0.5 | 31.2 | 19.6 | 4.7 | 68.5 | 5.3 |

| Table 6. Fixed Point Stations of the Elizabeth River sampled in 2002. 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 | B-IBI | Abundance | Biomass | Shannon Index | Pollution Indicative Abundance | Pollution Sensitive Abundance | Pollution Indicative Biomass | Pollution Sensitive Biomass | Carnivore Omnivore Abundance | Deep Deposit Feeder Abundance |
| EBB1 | 1.9 | 12,973 | 1.3684 | 1.34 | 30.5 | 66.7 | 19.3 | 62.7 | 3.2 | 67.0 |
| ELC1 | 3.6 | 3,462 | 1.2625 | 2.62 | 15.0 | 65.3 | 10.9 | 37.2 | 11.3 | 67.8 |
| ELD1 | 3.6 | 6,305 | 1.6027 | 3.24 | 10.2 | 60.5 | 10.2 | 47.9 | 6.5 | 60.3 |
| ELF1 | 2.1 | 2,948 | 0.9223 | 2.79 | 36.3 | 42.2 | 59.4 | 23.2 | 9.7 | 47.9 |
| LFA1 | 2.2 | 2,979 | 1.3079 | 2.46 | 33.8 | 61.5 | 43.3 | 20.9 | 7.0 | 49.3 |
| LFB1 | 2.1 | 4,944 | 0.6048 | 1.57 | 43.4 | 48.6 | 30.4 | 56.7 | 3.2 | 54.5 |
| SBA1 | 1.4 | 10,168 | 1.3532 | 2.16 | 67.2 | 1.3 | 35.2 | 5.8 | 4.3 | 24.1 |
| SBB1 | 2.7 | 12,860 | 1.2928 | 1.56 | 18.3 | 74.5 | 49.5 | 25.4 | 2.4 | 84.0 |
| SBC1 | 1.5 | 12,686 | 2.2604 | 2.01 | 34.0 | 57.9 | 55.9 | 22.3 | 2.3 | 61.8 |
| SBD1 | 1.6 | 8,513 | 1.3457 | 2.45 | 20.8 | 49.4 | 56.5 | 16.9 | 6.1 | 57.7 |
| SBD2 | 1.9 | 8,565 | 0.3704 | 1.12 | 9.4 | 87.4 | 23.3 | 51.8 | 11.2 | 79.2 |
| SBD4 | 3.0 | 3,969 | 0.5216 | 2.00 | 10.8 | 73.2 | 23.4 | 37.9 | 12.6 | 67.6 |
| WBB1 | 1.7 | 7,764 | 0.9299 | 1.06 | 15.3 | 80.3 | 15.9 | 30.8 | 1.5 | 81.8 |
| WBB5 | 2.2 | 8,596 | 1.1642 | 0.99 | 9.3 | 86.3 | 10.0 | 55.8 | 3.6 | 86.0 |

Appendix A

Metrics and thresholds for calculating the Benthic Index Biotic Integrity

Table A1. Thresholds used to score each metric of the Chesapeake Bay B-IBI. Updated for the tidal freshwater and oligohaline habitats, and corrected from Weisberg et al. (1997) for the high mesohaline mud and polyhaline sand habitats.

| | Scoring Criteria | | |
|---|---|---|---|
| | **5** | **3** | **1** |
| **Tidal Freshwater** | | | |
| Abundance (#/m$^2$) | ≥1050-4000 | 800-1050 or ≥4000-5500 | <800 or ≥5500 |
| Abundance of pollution-indicative taxa (%) | ≤39 | 39-87 | >87 |
| Abundance of deep-deposit feeders (%) | ≤70 | 70-95 | >95 |
| Tolerance Score | ≤8 | 8-9.35 | >9.35 |
| **Oligohaline** | | | |
| Abundance (#/m$^2$) | ≥450-3350 | 180-450 or ≥3350-4050 | <180 or ≥4050 |
| Abundance of pollution-indicative taxa (%) | ≤27 | 27-95 | >95 |
| Abundance of pollution-sensitive taxa (%) | ≥26 | 0.2-26 | <0.2 |
| Abundance of carnivores and omnivores (%) | ≥35 | 15-35 | <15 |
| Tolerance Score | ≤6 | 6-9.05 | >9.05 |
| Tanypodini to Chironomidae abundance ratio (%) | ≤17 | 17-64 | >64 |
| **Low Mesohaline** | | | |
| Shannon-Wiener | ≥2.5 | 1.7-2.5 | <1.7 |
| Abundance (#/m$^2$) | ≥1500-2500 | 500-1500 or ≥2500-6000 | <500 or ≥6000 |
| Biomass (g/m$^2$) | ≥5-10 | 1-5 or ≥10-30 | <1 or ≥30 |
| Abundance of pollution-indicative taxa (%) | ≤10 | 10-20 | >20 |
| Biomass of pollution-sensitive taxa (%) | ≥80 | 40-80 | <40 |
| Biomass deeper than 5 cm (%) | ≥80 | 10-80 | <10 |

Table A1. Continued.

| | Scoring Criteria | | |
|---|---|---|---|
| | 5 | 3 | 1 |
| **High Mesohaline Sand** | | | |
| Shannon-Wiener | ≥3.2 | 2.5-3.2 | <2.5 |
| Abundance (#/$m^2$) | ≥1500-3000 | 1000-1500 or ≥3000-5000 | <1000 or ≥5000 |
| Biomass (g/$m^2$) | ≥3-15 | 1-3 or ≥15-50 | <1 or ≥50 |
| Abundance of pollution-indicative taxa (%) | ≤10 | 10-25 | >25 |
| Abundance of pollution-sensitive taxa (%) | ≥40 | 10-40 | <10 |
| Abundance of carnivores and omnivores (%) | ≥35 | 20-35 | <20 |
| **High Mesohaline Mud** | | | |
| Shannon-Wiener | ≥3.0 | 2.0-3.0 | <2.0 |
| Abundance (#/$m^2$) | ≥1500-2500 | 1000-1500 or ≥2500-5000 | <1000 or ≥5000 |
| Biomass (g/$m^2$) | ≥2-10 | 0.5-2 or ≥10-50 | <0.5 or ≥50 |
| Biomass of pollution-indicative taxa (%) | ≤5 | 5-30 | >30 |
| Biomass of pollution-sensitive taxa (%) | ≥60 | 30-60 | <30 |
| Abundance of carnivores and omnivores (%) | ≥25 | 10-25 | <10 |
| Biomass deeper than 5 cm (%) | ≥60 | 10-60 | <10 |
| **Polyhaline Sand** | | | |
| Shannon-Wiener | ≥3.5 | 2.7-3.5 | <2.7 |
| Abundance (#/$m^2$) | ≥3000-5000 | 1500-3000 or ≥5000-8000 | <1500 or ≥8000 |
| Biomass (g/$m^2$) | ≥5-20 | 1-5 or ≥20-50 | <1 or ≥50 |
| Biomass of pollution-indicative taxa (%) | ≤5 | 5-15 | >15 |
| Abundance of pollution-sensitive taxa (%) | ≥50 | 25-50 | <25 |
| Abundance of deep-deposit feeders (%) | ≥25 | 10-25 | <10 |

Table 1. Continued.

| | Scoring Criteria | | |
|---|---|---|---|
| | **5** | **3** | **1** |
| Polyhaline Mud | | | |
| Shannon-Wiener | ≥3.3 | 2.4-3.3 | <2.4 |
| Abundance (#/$m^2$) | ≥1500-3000 | 1000-1500 or ≥3000-8000 | <1000 or ≥8000 |
| Biomass (g/$m^2$) | ≥3-10 | 0.5-3 or ≥10-30 | <0.5 or ≥30 |
| Biomass of pollution-indicative taxa (%) | ≤5 | 5-20 | >20 |
| Biomass of pollution-sensitive taxa (%) | ≥60 | 30-60 | <30 |
| Abundance of carnivores and omnivores | ≥40 | 25-40 | <25 |
| Number of taxa >5 cm below the sediment-water interface (%) | ≥40 | 10-40 | <10 |

Appendix B

Summary of water quality status and trends for the Elizabeth River

**Preface:**

In this appendix water quality status and trends for the Elizabeth River are summarized. These data are collected by the Virginia Water Quality Monitoring Program as part of the Chesapeake Bay Restoration Program. Details of collection and laboratory methodology can be found in Dauer et al. 2003 which can be downloaded in pdf format from the Old Dominion University Chesapeake Bay Program website <www.chesapeakebay.odu.edu> under "Reports." The James River Report includes the Elizabeth River, the Chickahominy River and the Appomattox River. The York River Report includes the tidal Pamunkey River and Mattaponi River. The Rappahannock River Report includes the Corrotoman River. Also available at this website are appendices that include (1) tables of status for all parameters measured at all stations sampled by each program, (2) tables of all parameters and metrics for which there was a significant trend, and (3) scatter plots of all parameters over time. There are five appendices: water quality, phytoplankton, primary productivity, zooplankton and benthos.

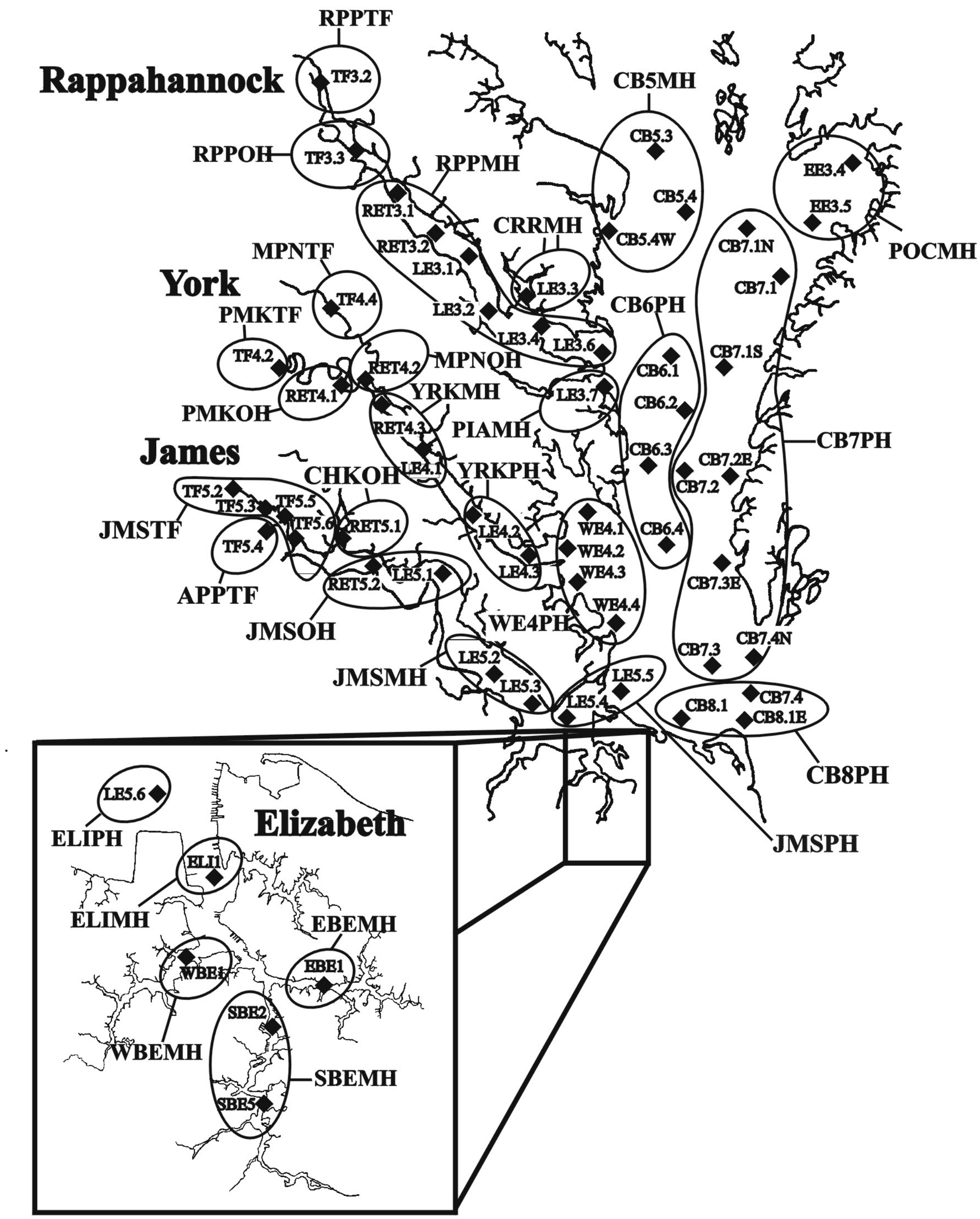
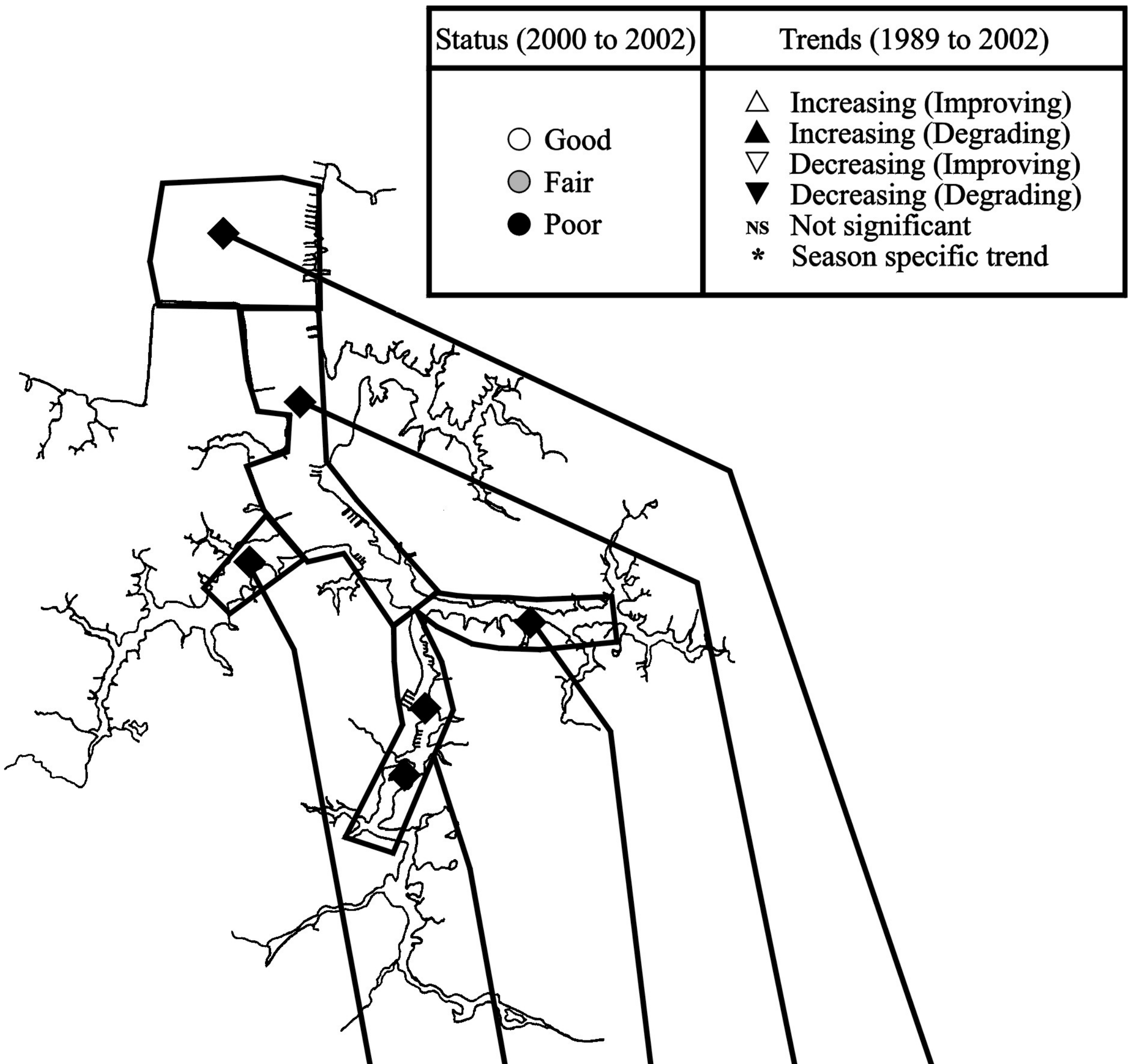
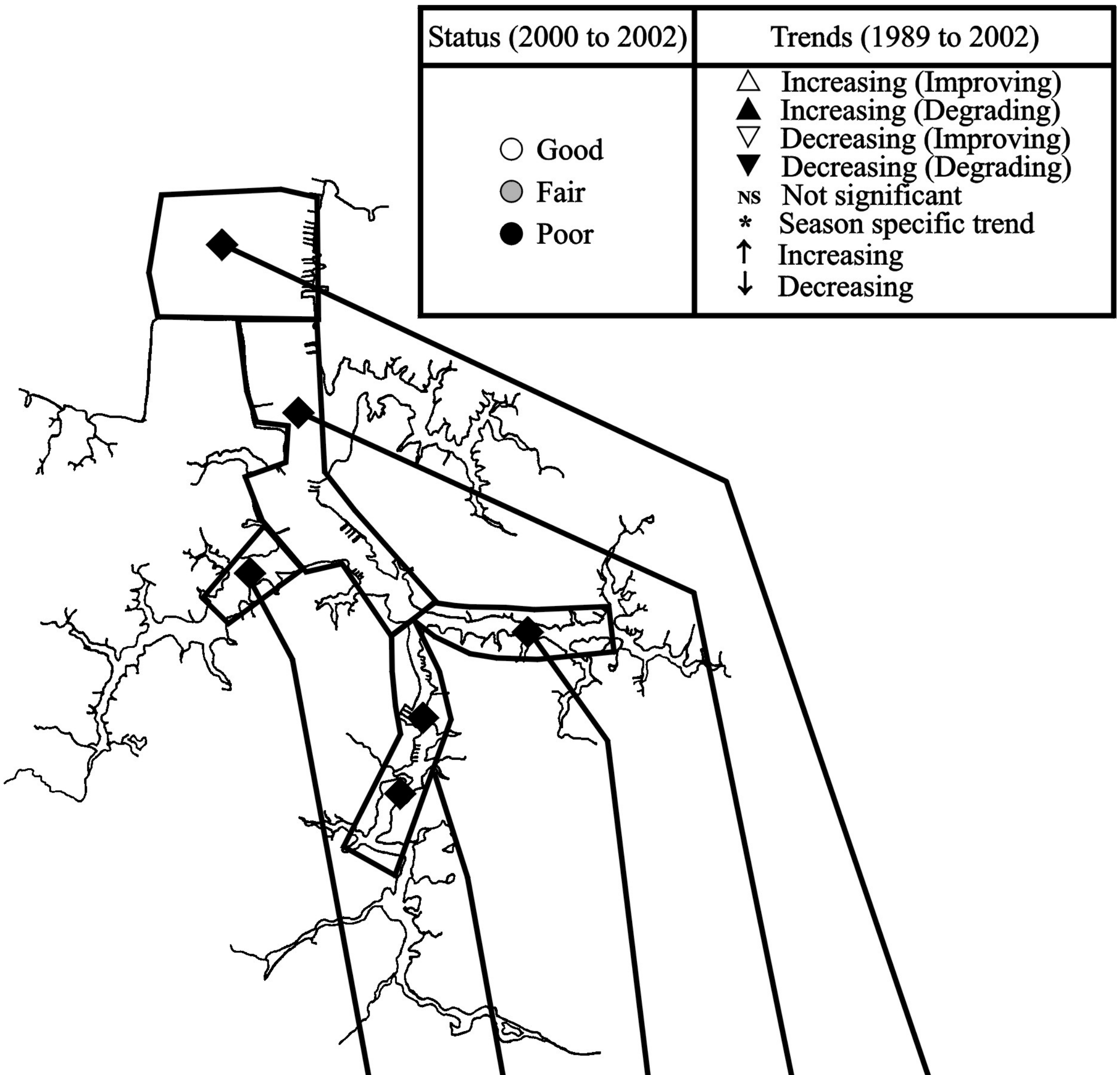



**Figure B1.** Map showing the locations of the water quality monitoring stations in the Virginia tributaries and the Lower Chesapeake Bay Mainstem (Dauer et al 2003). Insert shows location of Elizabeth River monitoring stations. Also shown are ellipses that delineate the Chesapeake Bay Program segmentation scheme.




| Parameter | Western Branch | Southern Branch | Eastern Branch | Elizabeth River Mainstem | Elizabeth River Mouth |
|---|---|---|---|---|---|
| STN | ○ ▽ | ● ▽ | ◍ ▽ | ○ ▽ | ● NS |
| BTN | ○ ▽ | ● NS | ◍ ▽ | ○ NS | ● NS |
| SDIN | ○ ▽ | ● ▽ | ● ▽ | ◍ ▽ | ● NS |
| BDIN | ○ ▽ | ● ▽ | ◍ ▽ | ○ ▽ | ● NS |
| STP | ● ▽ | ● ▽ | ◍ ▽ | ● ▽ | ● ▲ NS |
| BTP | ● ▽ | ● ▽ | ◍ ▽ | ● ▽ | ● NS |
| SDIP | ● ▽ | ● ▽ | ● ▽ | ● ▽ | ● ▲ |
| BDIP | ● ▽ | ● ▽ | ● ▽ | ● ▽ | ● ▲ |

**Figure B2.** Map of the Elizabeth River basin showing summaries of the status and trend analyses for each segment. Abbreviations: TN - total nitrogen; DIN - dissolved inorganic nitrogen; TP - total phosphorus; DIP - dissolved inorganic phosphorus. The prefixed S and B refer to surface and bottom measurements.




| Parameter | Western Branch | Southern Branch | Eastern Branch | Elizabeth River Mainstem | Elizabeth River Mouth |
|---|---|---|---|---|---|
| SCHLA | ● ▽ | ○ NS | ○ NS | ● NS | ◍ NS |
| STSS | ● NS | ○ ▽ | ◍ ▽ | ◍ NS | ◍ NS |
| BTSS | ● NS | ○ ▽ | ○ ▽ | ◍ NS | ○ NS |
| SECCHI | ● △ | ○ △ | ◍ △ | ◍ NS | ● NS |
| BDO | ◍ △ | ◍ △ | ○ △ | ○ △ | ○ △ |
| SWTEMP | ↑ | ↑ | ↑ | ↑ | ↑ |
| BWTEMP | ↑ | ↑ | ↑ | ↑ | NS |
| SSALIN | ↑ | ↑ | ↑ | ↑ | ↑ |
| BSALIN | NS | NS | ↑ | NS | ↑ |

**Figure B3.** Map of the Elizabeth River basin showing summaries of the status and trend analyses for each segment. Abbreviations: SCHLA - surface chlorophyl *a*; TSS - total suspended solids, SECCHI - secchi depth, DO - dissolved oxygen; WTEMP - water temperature, SALIN - salinity. The prefixed S and B refer to surface and bottom measurements.

Table B-1. Status in water quality environmental indicators in the Elizabeth River. Status designations determined by the Chesapeake Bay Program for the three year period 2000 through 2002. For information about field collection, laboratory analyses and status determination see Dauer et al. 2003. Secchi depth in meters, chlorophyll *a* in µg/l, all others in mg/l. S is surface and B is bottom layer. WBEMH - Western Branch, SBEMH - Southern Branch, EBEMH - Eastern Branch, ELIMH - Mainstem of Elizabeth River, ELIPH - Elizabeth River Mouth.

| Segment | Layer | Parameter | Season | Value | Status |
|---|---|---|---|---|---|
| WBEMH | S | Total nitrogen | Annual | 0.6388 | Fair |
| WBEMH | B | Total nitrogen | Annual | 0.6293 | Good |
| WBEMH | S | Dissolved Inorganic nitrogen | Annual | 0.0911 | Good |
| WBEMH | B | Dissolved Inorganic nitrogen | Annual | 0.1101 | Fair |
| WBEMH | S | Total phosphorus | Annual | 0.0627 | Poor |
| WBEMH | B | Total phosphorus | Annual | 0.063 | Poor |
| WBEMH | S | Dissolved inorganic phosphorus | Annual | 0.0104 | Fair |
| WBEMH | B | Dissolved inorganic phosphorus | Annual | 0.0134 | Poor |
| WBEMH | S | Chlorophyll *a* | Annual | 11.392 | Poor |
| WBEMH | S | Total suspended solids | Annual | 21.775 | Poor |
| WBEMH | B | Total suspended solids | Annual | 27.15 | Poor |
| WBEMH | S | Secchi depth | Annual | 0.7 | Poor |
| WBEMH | B | Dissolved oxygen | Summer1 | 5.7655 | Good |
| SBEMH | S | Total nitrogen | Annual | 0.9652 | Poor |
| SBEMH | B | Total nitrogen | Annual | 0.8734 | Poor |
| SBEMH | S | Dissolved Inorganic nitrogen | Annual | 0.4316 | Poor |
| SBEMH | B | Dissolved Inorganic nitrogen | Annual | 0.373 | Poor |
| SBEMH | S | Total phosphorus | Annual | 0.0572 | Poor |
| SBEMH | B | Total phosphorus | Annual | 0.0616 | Fair |
| SBEMH | S | Dissolved inorganic phosphorus | Annual | 0.0268 | Poor |
| SBEMH | B | Dissolved inorganic phosphorus | Annual | 0.0274 | Poor |
| SBEMH | S | Chlorophyll *a* | Annual | 4.8416 | Good |
| SBEMH | S | Total suspended solids | Annual | 9.35 | Good |
| SBEMH | B | Total suspended solids | Annual | 11.2113 | Good |
| SBEMH | S | Secchi depth | Annual | 1.175 | Good |
| SBEMH | B | Dissolved oxygen | Summer1 | 4.5165 | Fair |
| EBEMH | S | Total nitrogen | Annual | 0.723 | Poor |
| EBEMH | B | Total nitrogen | Annual | 0.6736 | Fair |
| EBEMH | B | Dissolved Inorganic nitrogen | Annual | 0.2119 | Poor |
| EBEMH | S | Dissolved Inorganic nitrogen | Annual | 0.271 | Poor |
| EBEMH | B | Total phosphorus | Annual | 0.0521 | Fair |
| EBEMH | S | Total phosphorus | Annual | 0.0526 | Poor |
| EBEMH | B | Dissolved inorganic phosphorus | Annual | 0.0223 | Poor |
| EBEMH | S | Dissolved inorganic phosphorus | Annual | 0.0204 | Poor |
| EBEMH | S | Chlorophyll *a* | Annual | 6.3546 | Good |
| EBEMH | B | Total suspended solids | Annual | 15.175 | Good |
| EBEMH | S | Total suspended solids | Annual | 11.08 | Fair |
| EBEMH | S | Secchi depth | Annual | 1.1 | Fair |
| EBEMH | B | Dissolved oxygen | Summer1 | 4.93 | Fair |

Table B-1. Continued.

| Segment | Layer | Parameter | Season | Value | Score | Status |
|---|---|---|---|---|---|---|
| ELIMH | S | Total nitrogen | Annual | 0.6498 | 48.5 | Fair |
| ELIMH | B | Total nitrogen | Annual | 0.5719 | 26.5 | Good |
| ELIMH | S | Dissolved Inorganic nitrogen | Annual | 0.1348 | 58.9 | Fair |
| ELIMH | B | Dissolved Inorganic nitrogen | Annual | 0.1318 | 57.5 | Fair |
| ELIMH | S | Total phosphorus | Annual | 0.0533 | 63.4 | Fair |
| ELIMH | B | Total phosphorus | Annual | 0.059 | 58.8 | Fair |
| ELIMH | S | Dissolved inorganic phosphorus | Annual | 0.0133 | 69.1 | Poor |
| ELIMH | B | Dissolved inorganic phosphorus | Annual | 0.0225 | 84.6 | Poor |
| ELIMH | S | Chlorophyll *a* | Annual | 10.0392 | 60.0 | Poor |
| ELIMH | S | Total suspended solids | Annual | 13.1625 | 55.1 | Fair |
| ELIMH | B | Total suspended solids | Annual | 17.36 | 44.1 | Fair |
| ELIMH | S | Secchi depth | Annual | 1 | 49.9 | Fair |
| ELIMH | B | Dissolved oxygen | Summer1 | 5.725 | - | Good |
| ELIPH | S | Total nitrogen | Annual | 0.5375 | 37.9 | Good |
| ELIPH | B | Total nitrogen | Annual | 0.51 | 38.1 | Good |
| ELIPH | S | Dissolved Inorganic nitrogen | Annual | 0.1283 | 54.6 | Fair |
| ELIPH | B | Dissolved Inorganic nitrogen | Annual | 0.104 | 46.6 | Fair |
| ELIPH | S | Total phosphorus | Annual | 0.054 | 46.7 | Fair |
| ELIPH | B | Total phosphorus | Annual | 0.066 | 56.0 | Fair |
| ELIPH | S | Dissolved inorganic phosphorus | Annual | 0.02 | 57.9 | Fair |
| ELIPH | B | Dissolved inorganic phosphorus | Annual | 0.023 | 64.3 | Poor |
| ELIPH | S | Chlorophyll *a* | Annual | 8.945 | 57.9 | Fair |
| ELIPH | S | Total suspended solids | Annual | 9 | 44.8 | Fair |
| ELIPH | B | Total suspended solids | Annual | 15.5 | 36.0 | Good |
| ELIPH | S | Secchi depth | Annual | 1.05 | 31.7 | Poor |
| ELIPH | B | Dissolved oxygen | Summer1 | 5.805 | - | Good |

Table B-2. Significant ($p \leq 0.05$) water quality trends in the Elizabeth River for the period of 1989 through 2002. Abbreviations: See legends of Figures 2 and 3. The prefixed S and B refer to surface and bottom measurements. Baseline is the median value for the period 1989-1991. Secchi depth in meters, salinity in parts per thousand, temperature in degrees Celsius, chlorophyll *a* in µg/l, all others in mg/l.

| Segment | Season | Layer | Parameter | Baseline | % Change | p Value | Direction |
|---|---|---|---|---|---|---|---|
| WBEMH | ANNUAL | S | TN | 0.7760 | -27.06 | 0.0000 | **Improving** |
| WBEMH | ANNUAL | B | TN | 0.7845 | -19.89 | 0.0007 | **Improving** |
| WBEMH | ANNUAL | S | DIN | 0.1948 | -30.03 | 0.0040 | **Improving** |
| WBEMH | ANNUAL | B | DIN | 0.2677 | -35.30 | 0.0054 | **Improving** |
| WBEMH | ANNUAL | B | TP | 0.0835 | -30.54 | 0.0001 | **Improving** |
| WBEMH | ANNUAL | S | TP | 0.0795 | -37.74 | 0.0000 | **Improving** |
| WBEMH | ANNUAL | B | PO4F | 0.0345 | -34.78 | 0.0000 | **Improving** |
| WBEMH | ANNUAL | S | PO4F | 0.0330 | -36.36 | 0.0000 | **Improving** |
| WBEMH | ANNUAL | S | CHLA | 22.0000 | -31.82 | 0.0086 | **Improving** |
| WBEMH | ANNUAL | S | SECCHI | 0.6000 | 0.00 | 0.0133 | **Improving** |
| WBEMH | ANNUAL | B | DO | 4.4000 | 26.56 | 0.0028 | **Improving** |
| WBEMH | ANNUAL | B | SALINITY | 16.6000 | 20.78 | 0.0002 | **Increasing** |
| WBEMH | ANNUAL | S | SALINITY | 16.9000 | 23.61 | 0.0000 | **Increasing** |
| SBEMH | ANNUAL | S | TN | 1.2088 | -31.77 | 0.0000 | **Improving** |
| SBEMH | ANNUAL | S | DIN | 0.7181 | -41.57 | 0.0000 | **Improving** |
| SBEMH | ANNUAL | B | DIN | 0.5400 | -21.39 | 0.0189 | **Improving** |
| SBEMH | ANNUAL | B | TP | 0.0700 | -38.57 | 0.0000 | **Improving** |
| SBEMH | ANNUAL | S | TP | 0.0805 | -27.95 | 0.0000 | **Improving** |
| SBEMH | ANNUAL | B | PO4F | 0.0465 | -41.94 | 0.0000 | **Improving** |
| SBEMH | ANNUAL | S | PO4F | 0.0520 | -25.96 | 0.0008 | **Improving** |
| SBEMH | ANNUAL | S | TSS | 9.0000 | -28.63 | 0.0416 | **Improving** |
| SBEMH | ANNUAL | B | TSS | 13.0500 | -46.93 | 0.0024 | **Improving** |
| SBEMH | ANNUAL | S | SECCHI | 0.9000 | 27.83 | 0.0027 | **Improving** |
| SBEMH | ANNUAL | B | DO | 2.7500 | 54.71 | 0.0000 | **Improving** |
| SBEMH | ANNUAL | S | SALINITY | 19.4500 | 22.60 | 0.0000 | **Increasing** |
| SBEMH | ANNUAL | B | WTEMP | 19.1000 | 21.73 | 0.0000 | **Increasing** |
| SBEMH | ANNUAL | S | WTEMP | 16.6000 | 13.55 | 0.0003 | **Increasing** |
| EBEMH | ANNUAL | S | TN | 0.9530 | -25.34 | 0.0003 | **Improving** |
| EBEMH | ANNUAL | B | TN | 0.8400 | -24.46 | 0.0000 | **Improving** |
| EBEMH | ANNUAL | S | DIN | 0.4874 | -41.85 | 0.0005 | **Improving** |
| EBEMH | ANNUAL | B | DIN | 0.4734 | -44.04 | 0.0000 | **Improving** |
| EBEMH | ANNUAL | B | TP | 0.0730 | -34.93 | 0.0000 | **Improving** |
| EBEMH | ANNUAL | S | TP | 0.0750 | -36.00 | 0.0000 | **Improving** |
| EBEMH | ANNUAL | B | PO4F | 0.0420 | -35.71 | 0.0000 | **Improving** |
| EBEMH | ANNUAL | S | PO4F | 0.0440 | -27.27 | 0.0002 | **Improving** |
| EBEMH | ANNUAL | S | SECCHI | 1.0000 | 16.65 | 0.0185 | **Improving** |
| EBEMH | ANNUAL | B | DO | 3.3500 | 45.04 | 0.0000 | **Improving** |
| EBEMH | ANNUAL | B | SALINITY | 17.7000 | 12.34 | 0.0295 | **Increasing** |
| EBEMH | ANNUAL | S | SALINITY | 19.4000 | 17.42 | 0.0000 | **Increasing** |
| EBEMH | ANNUAL | B | WTEMP | 17.7000 | 11.40 | 0.0009 | **Increasing** |
| EBEMH | ANNUAL | S | WTEMP | 16.8000 | 6.70 | 0.0482 | **Increasing** |

Table B-2. Continued

| Segment | Season | Layer | Parameter | Baseline | % Change | p Value | Direction |
|---|---|---|---|---|---|---|---|
| ELIMH | ANNUAL | S | TN | 0.7025 | -15.16 | 0.0448 | **Improving** |
| ELIMH | ANNUAL | S | DIN | 0.3409 | -34.76 | 0.0001 | **Improving** |
| ELIMH | ANNUAL | B | DIN | 0.2179 | -46.81 | 0.0002 | **Improving** |
| ELIMH | ANNUAL | B | TP | 0.0645 | -25.58 | 0.0008 | **Improving** |
| ELIMH | ANNUAL | S | TP | 0.0690 | -28.26 | 0.0000 | **Improving** |
| ELIMH | ANNUAL | B | PO4F | 0.0335 | -40.30 | 0.0000 | **Improving** |
| ELIMH | ANNUAL | S | PO4F | 0.0300 | -35.00 | 0.0000 | **Improving** |
| ELIMH | ANNUAL | B | DO | 4.1000 | 37.06 | 0.0000 | **Improving** |
| ELIMH | ANNUAL | S | SALINITY | 21.6000 | 18.26 | 0.0000 | **Increasing** |
| ELIMH | ANNUAL | B | WTEMP | 17.4000 | 15.02 | 0.0002 | **Increasing** |
| ELIMH | ANNUAL | S | WTEMP | 15.6000 | 10.44 | 0.0033 | **Increasing** |

# Appendix C

## Summary of benthic community status and trends for the Elizabeth River

**Preface:**

In this appendix status and trends in the benthic community for the Elizabeth River are summarized. These data are collected by the Virginia Benthic Monitoring Program as part of the Chesapeake Bay Restoration Program. Details of collection and laboratory methodology can be found in Dauer et al. 2003 which can be downloaded in pdf format from the Old Dominion University Chesapeake Bay Program website <www.chesapeakebay.odu.edu> under "Reports." This appendix presents a summary of status and trends for stations SBE2 and SBE5 which are located in the Southern Branch of the river. Shown are scatter plots of the B-IBI and for several benthic metrics for the period 1989 to 2002

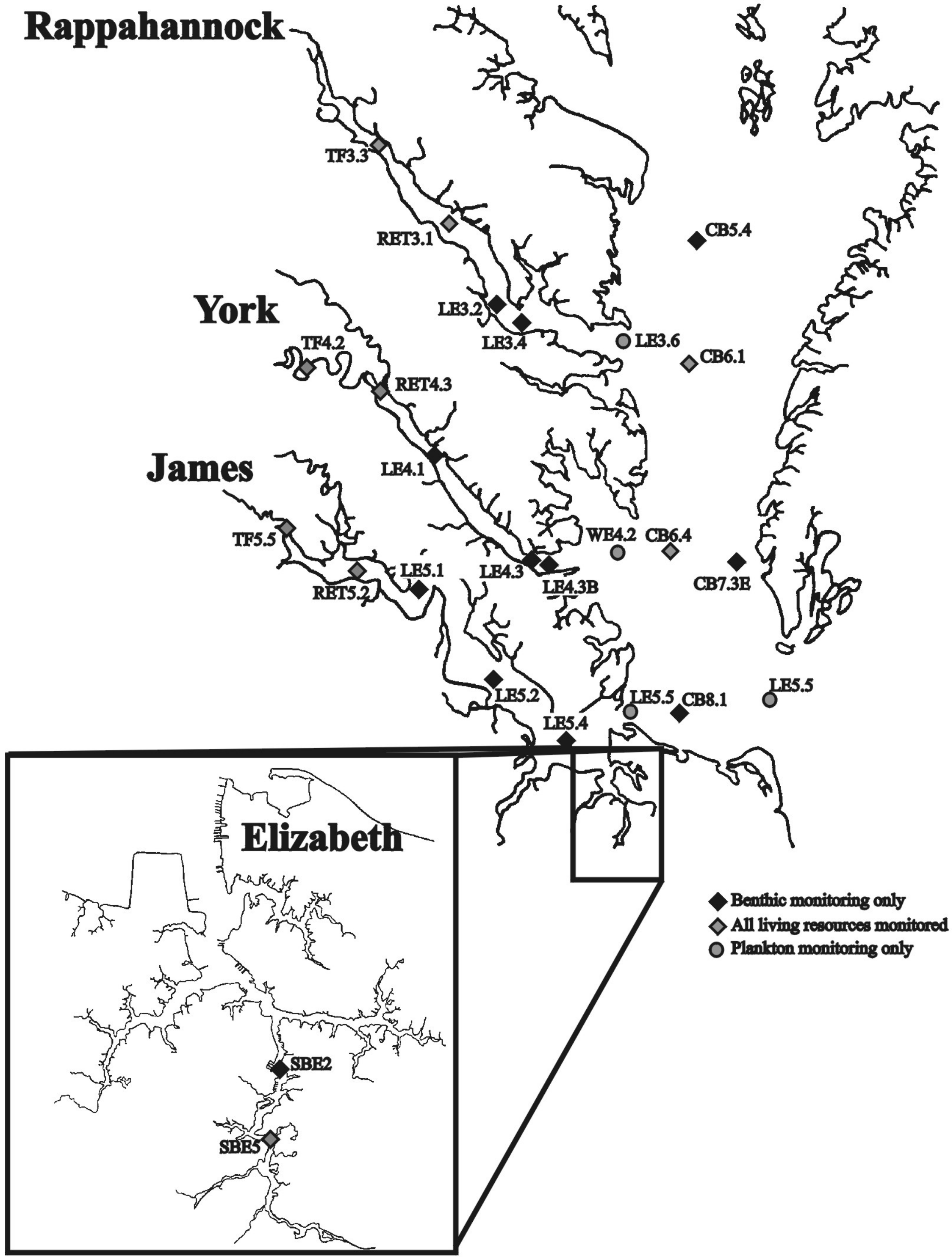
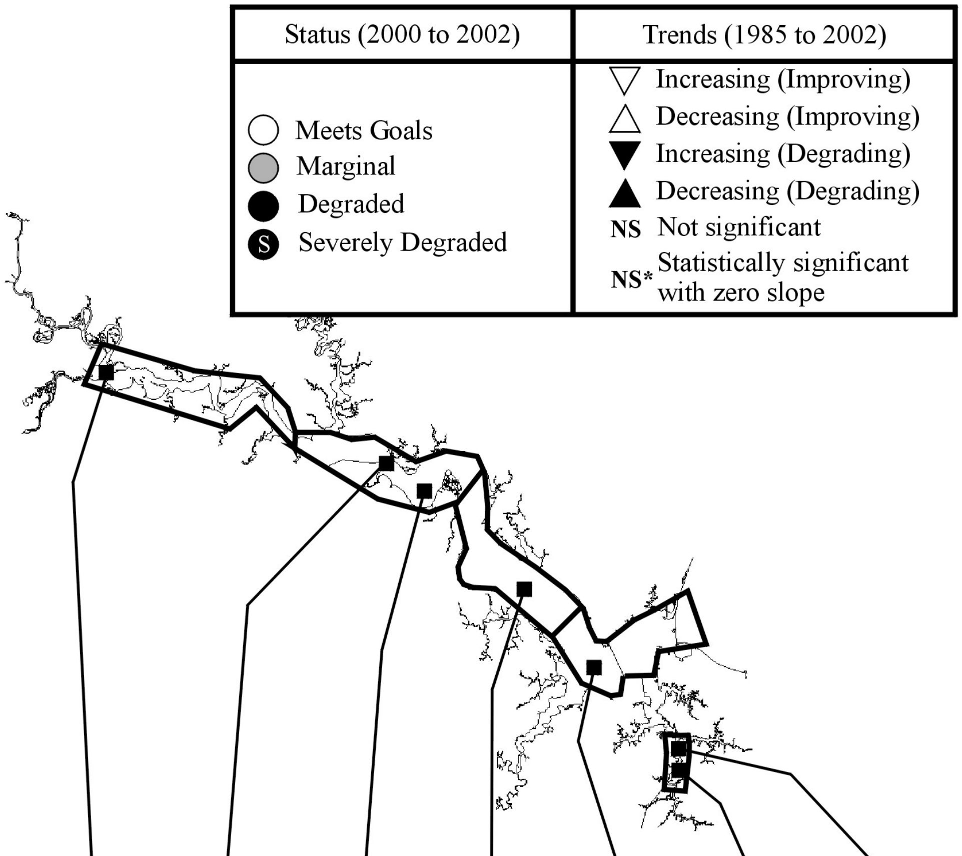



**Figure C1.** Location of living resource monitoring stations in the Virginia tributaries and the Lower Chesapeake Bay Mainstem. Insert shows benthic monitoring stations in the Southern Branch (SBE2 and SBE5) established in 1989.




| | TF5.5 | RET5.2 | LE5.1 | LE5.2 | LE5.4 | SBE5 | SBE2 |
|---|---|---|---|---|---|---|---|
| Benthic IBI | ○ △ | ○ △ | ○ **NS** | ● **NS** | ○ **NS** | ● △ | ● **NS** |
| Total Abundance | △ | **NS** | **NS** | △ | **NS** | **NS** | △ |
| Total Biomass | △ | **NS** | **NS** | **NS** | **NS** | △ | △ |
| Pollution Sensitive Species Abundance (%) | △ | △ | **NS** | △ | **NS** | △ | △ |
| Pollution Indicative Species Abundance (%) | ▽ | **NS** | **NS*** | **NS** | ▽ | ▽ | ▽ |
| Pollution Sensitive Species Biomass (%) | △ | △ | **NS** | **NS** | ▼ | △ | △ |
| Pollution Indicative Species Biomass (%) | ▽ | **NS** | **NS** | **NS** | **NS** | ▽ | **NS** |
| Shannon-Weiner Diversity Index | **NS** | △ | △ | **NS** | **NS** | △ | **NS** |

**Figure C2.** Summary of trends in benthic community inn the James River watershed. Elizabeth River stations are SBE2 and SBE5 located in the Southern Branch.

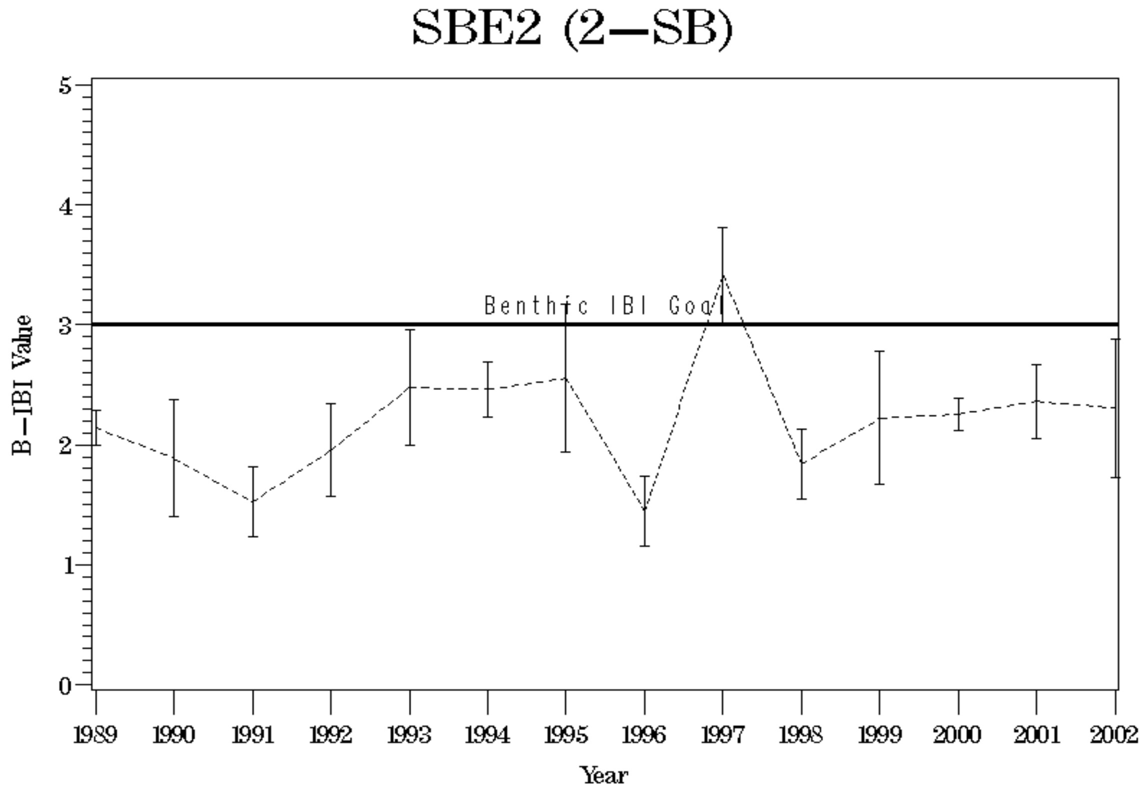



Figure C3. Benthic IBI at station SBE2 for the period of 1985 through 2002.

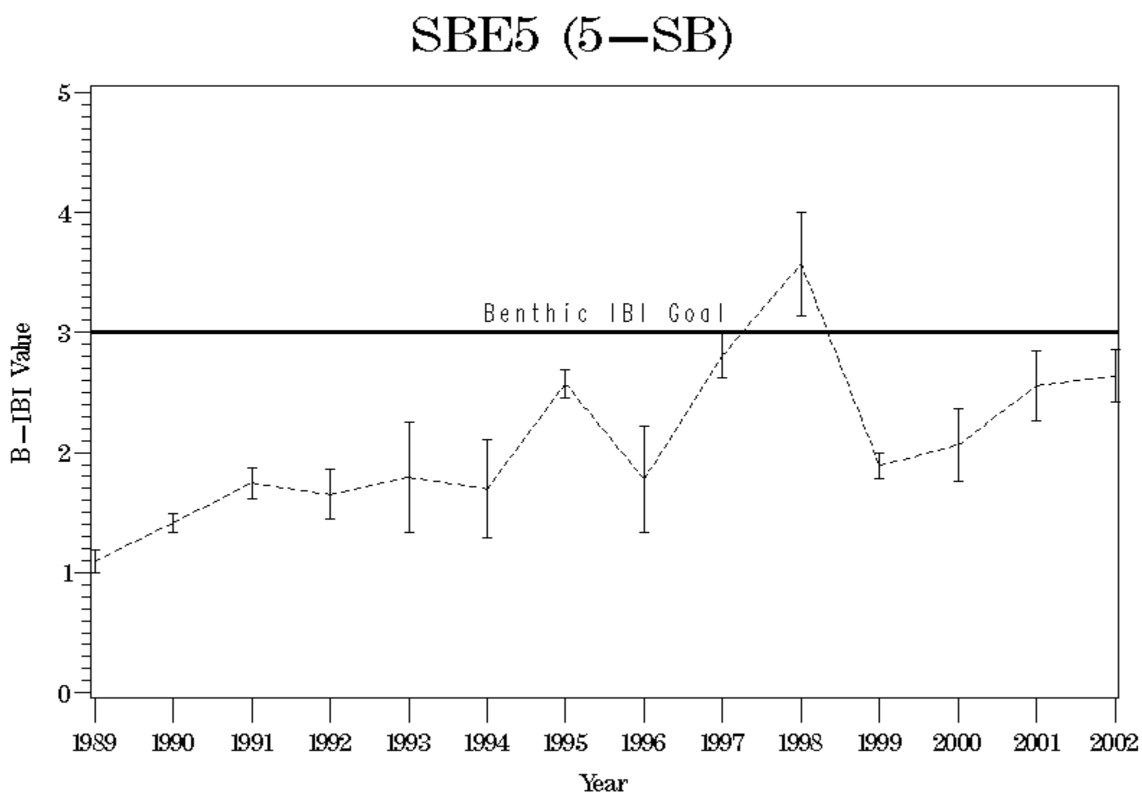



Figure C4. Benthic IBI at station SBE5 for the period of 1985 through 2002.

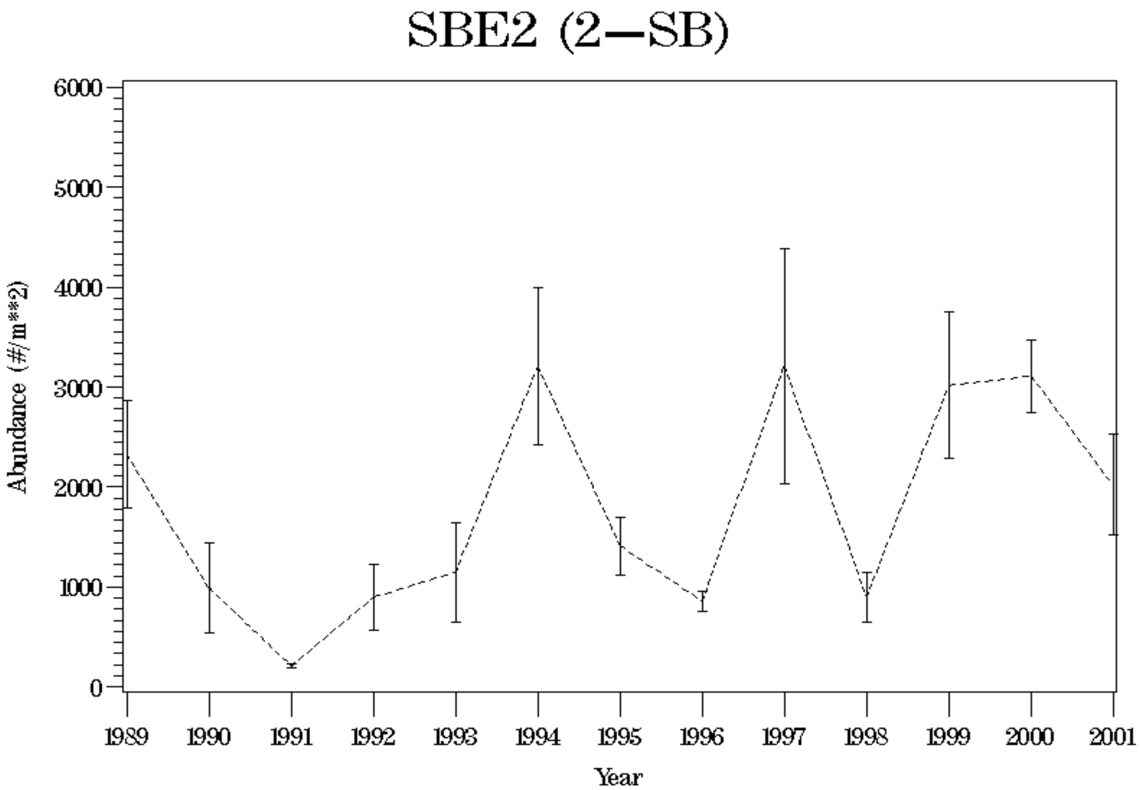



Figure C5 Benthic community abundance at station SBE2 (1985 - 2002).

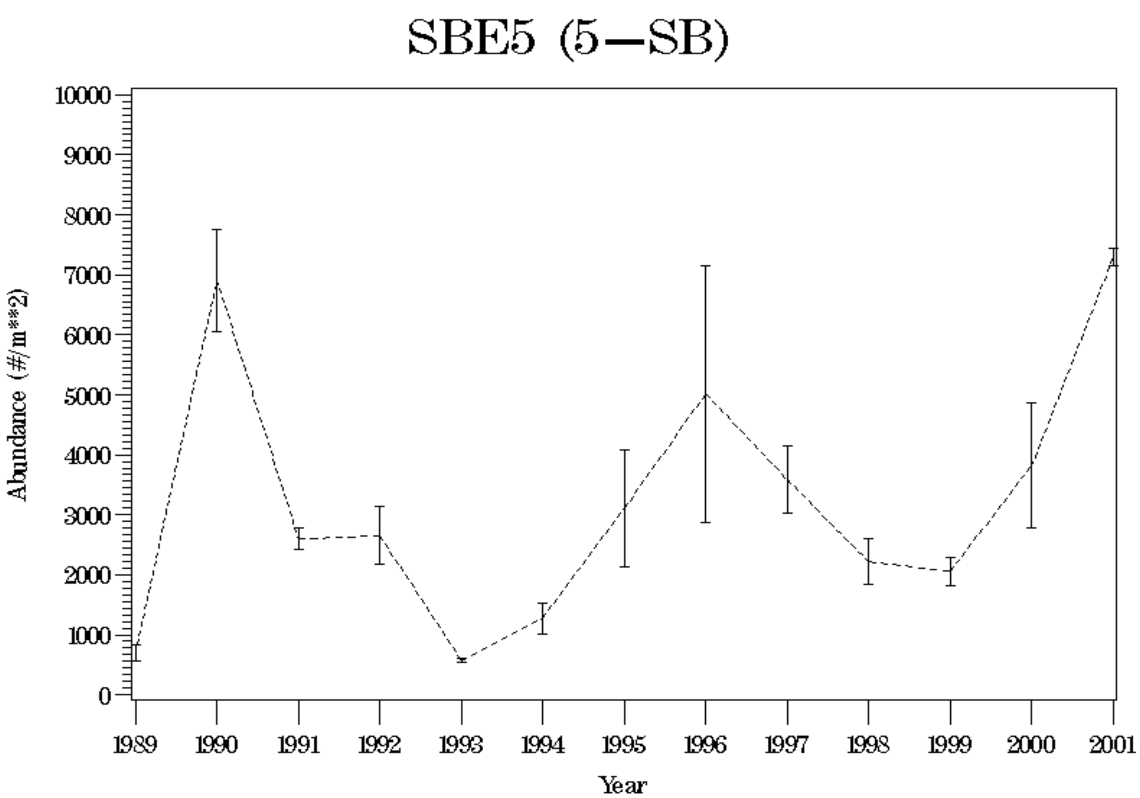



Figure C6 Benthic community abundance at station SBE5 (1985 - 2002).

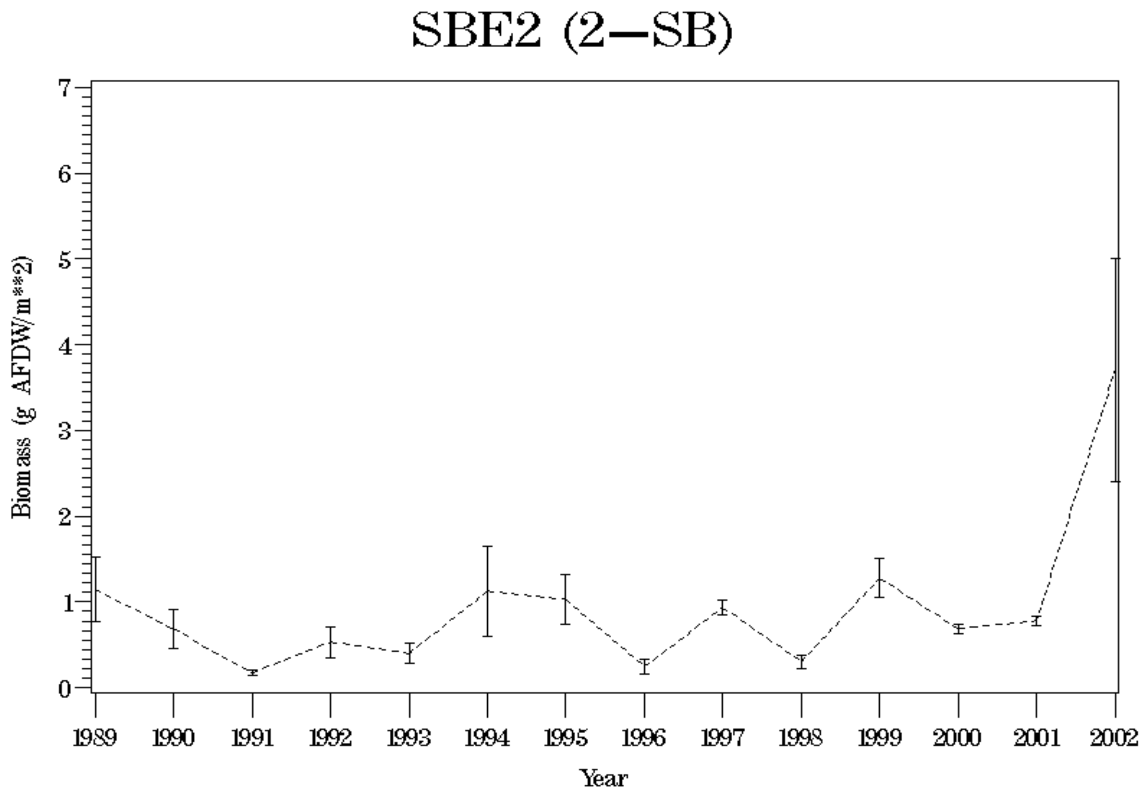



Figure C7. Benthic community biomass at station SBE2 (1985 - 2002).

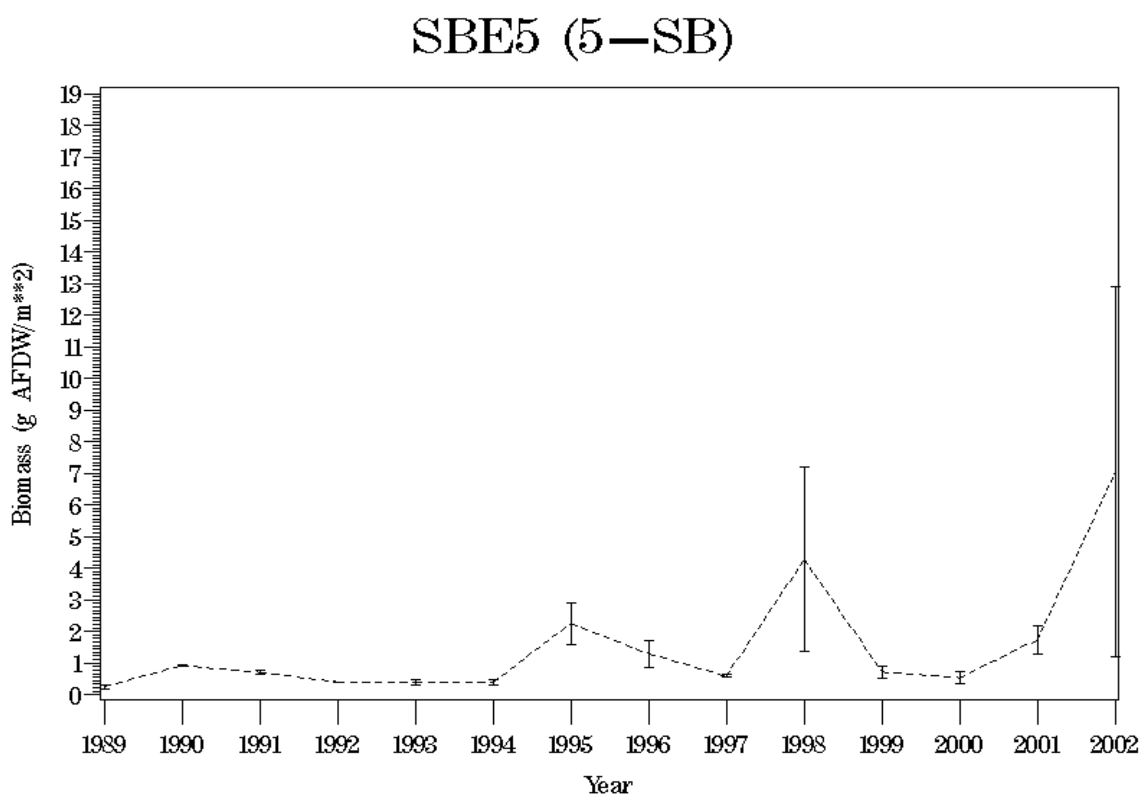



Figure C8. Benthic community biomass at station SBE5 (1985 - 2002).

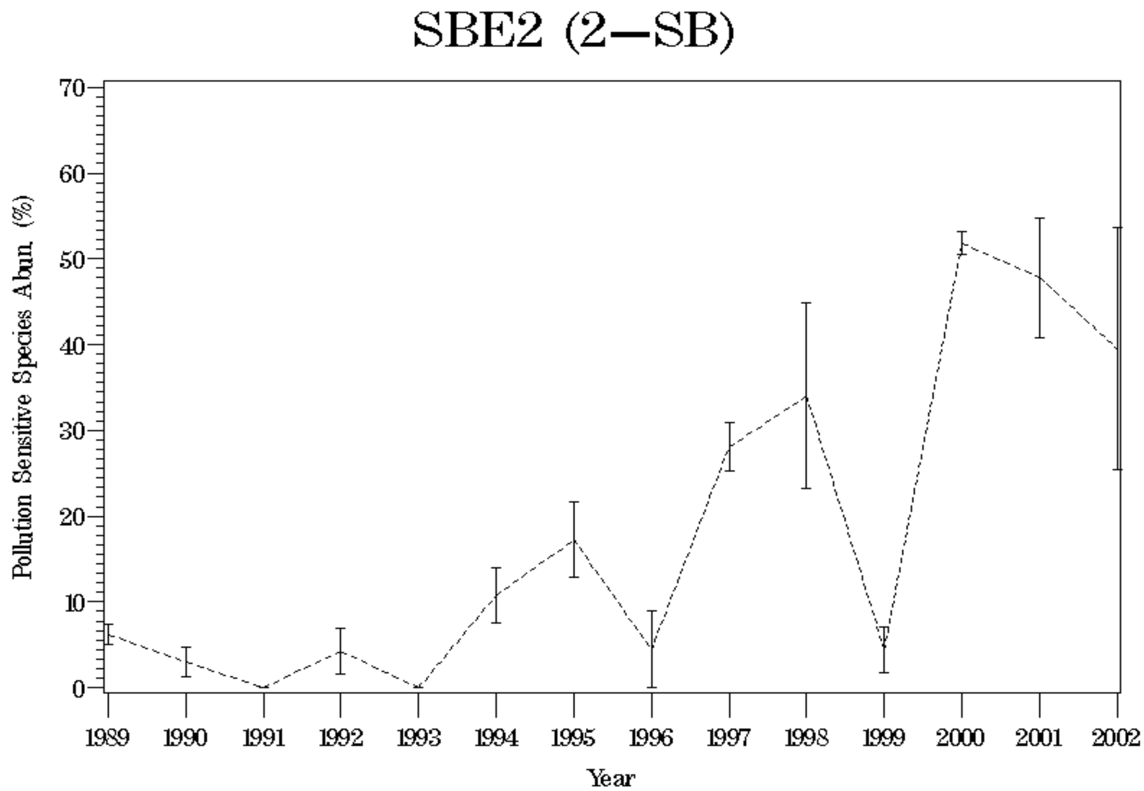



Figure C9. Pollution sensitive species abundance at SBE2 (1989-2002).

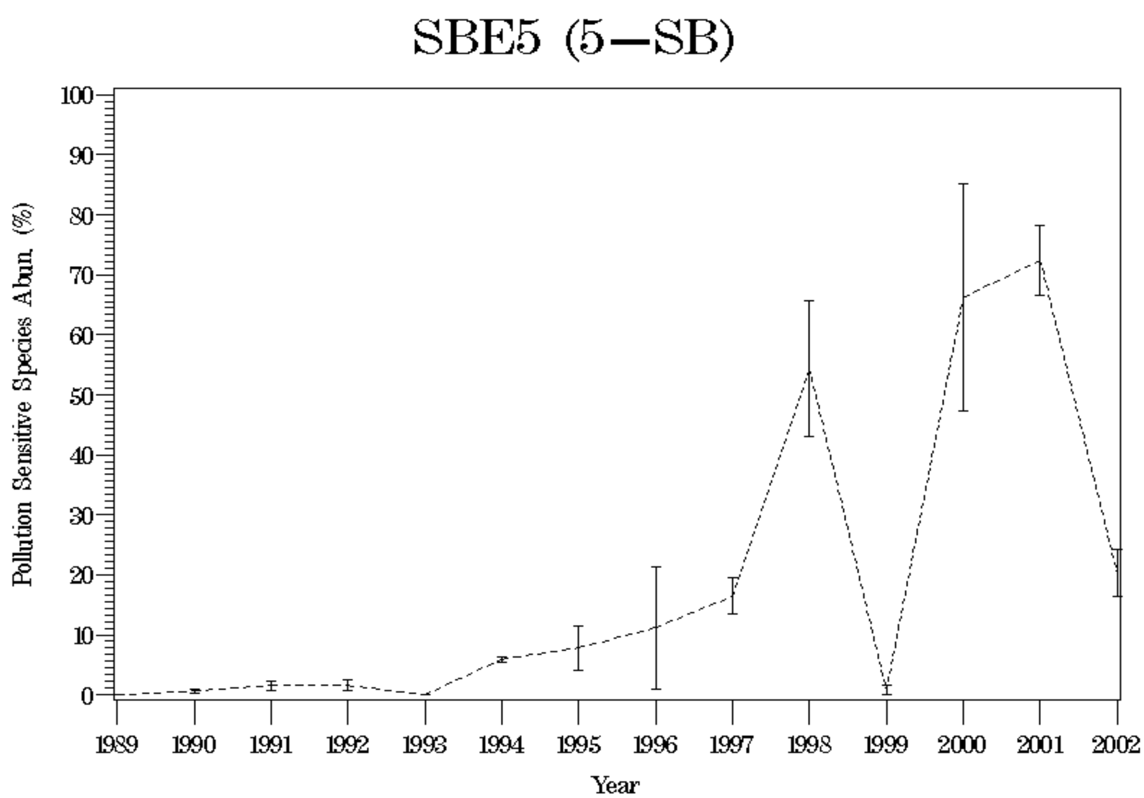



Figure C10. Pollution sensitive species abundance at SBE5 (1989-2002).

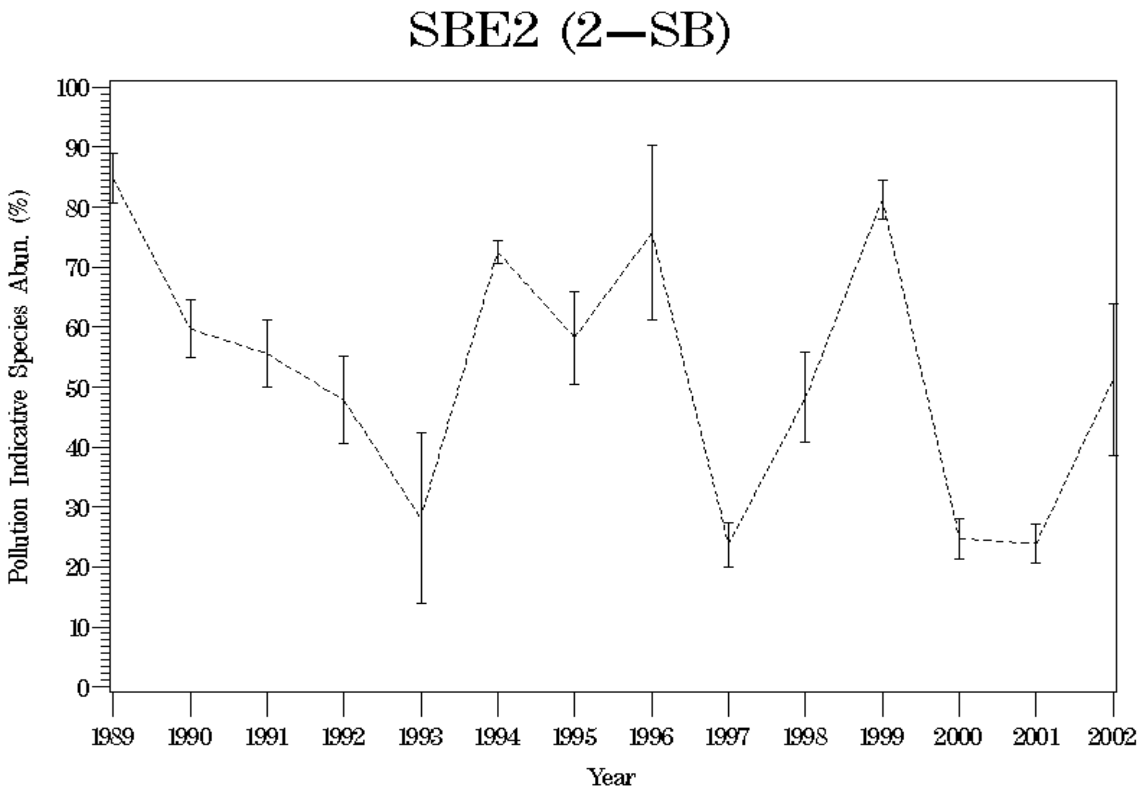



Figure C11. Pollution indicative species abundance at SBE2 (1985 - 2002).

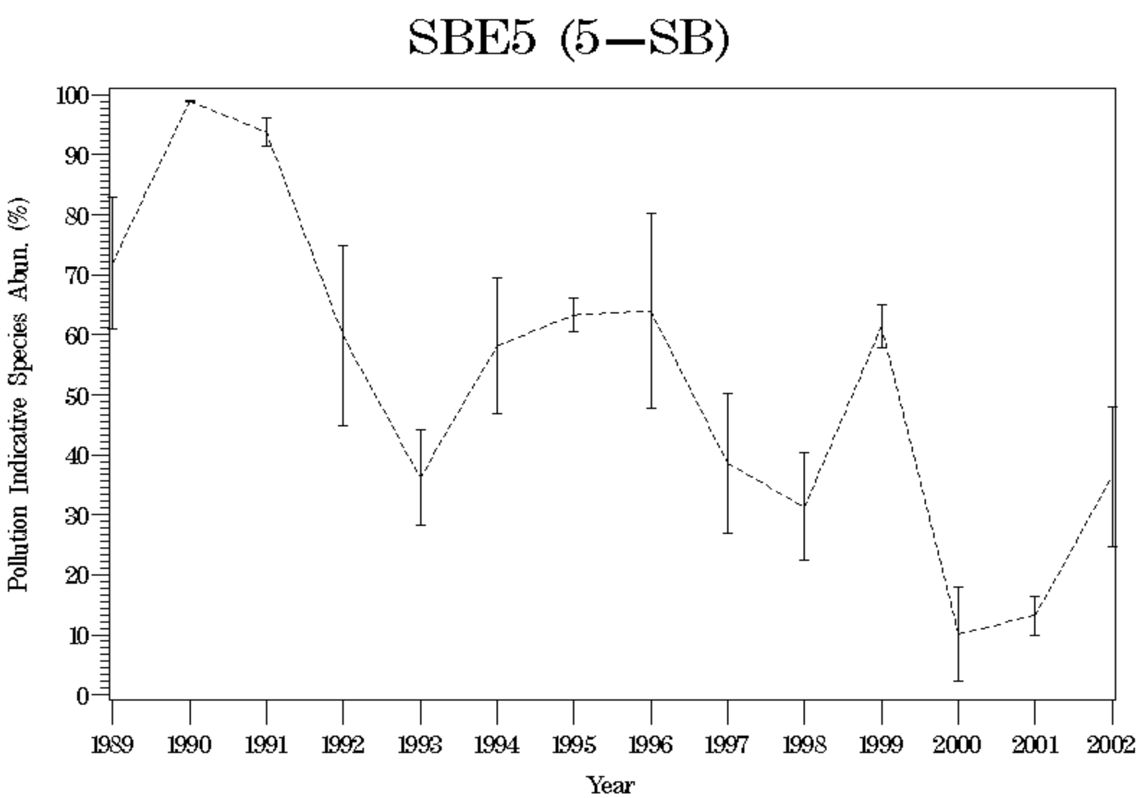



Figure C12. Pollution indicative species abundance at SBE5 (1985 - 2002).

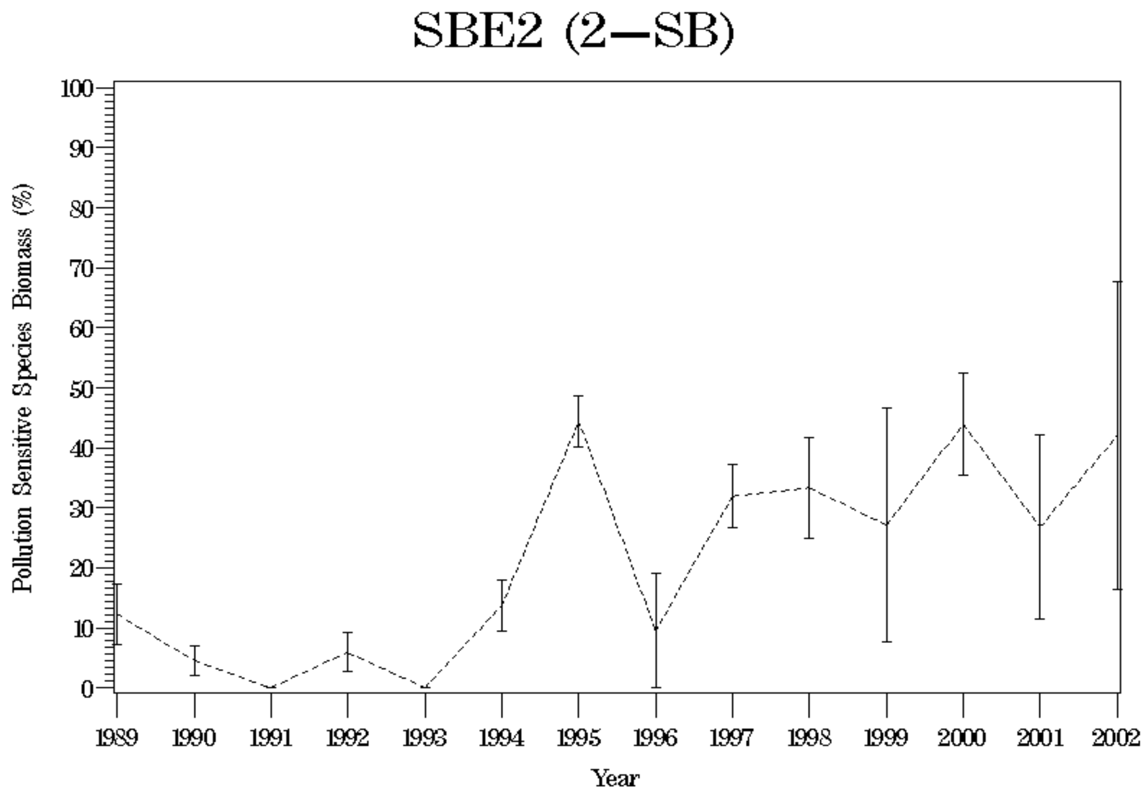



Figure C13. Pollution sensitive species biomass at SBE2 (1985 - 2002).

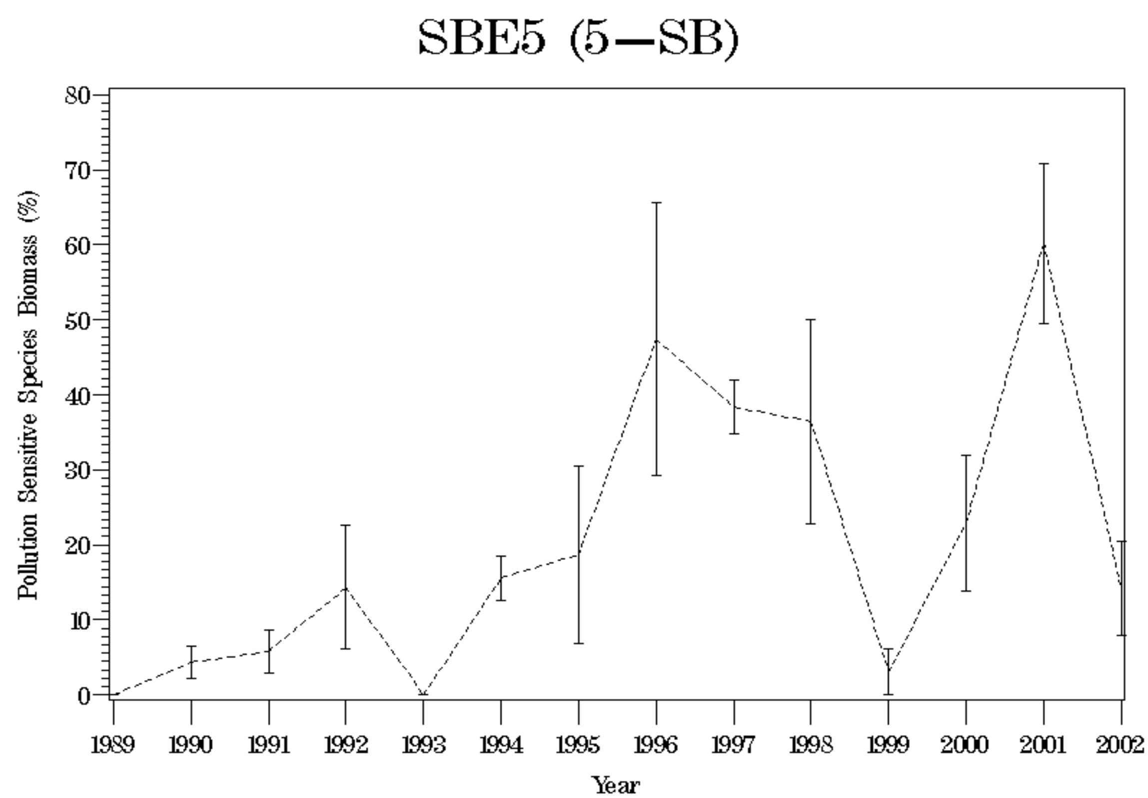



Figure C14. Pollution sensitive species biomass at SBE5 (1985 - 2002).

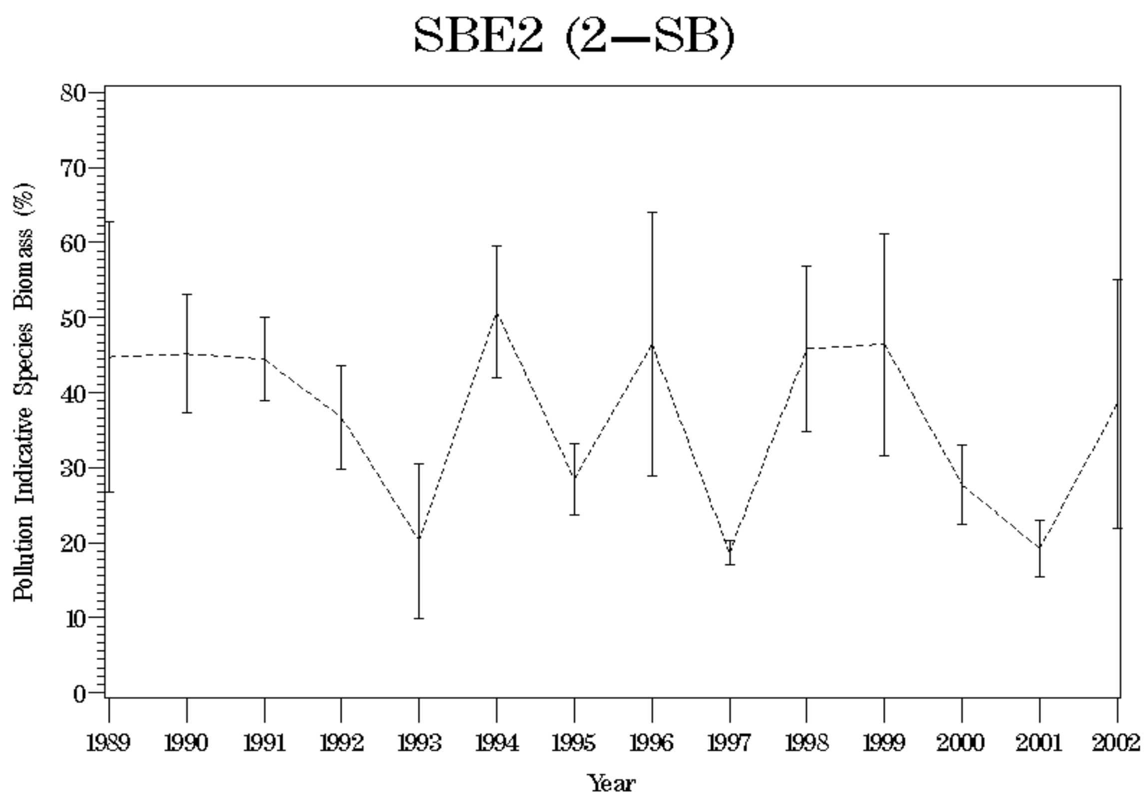



Figure C15. Pollution indicative species biomass at SBE2 (1985 - 2002).

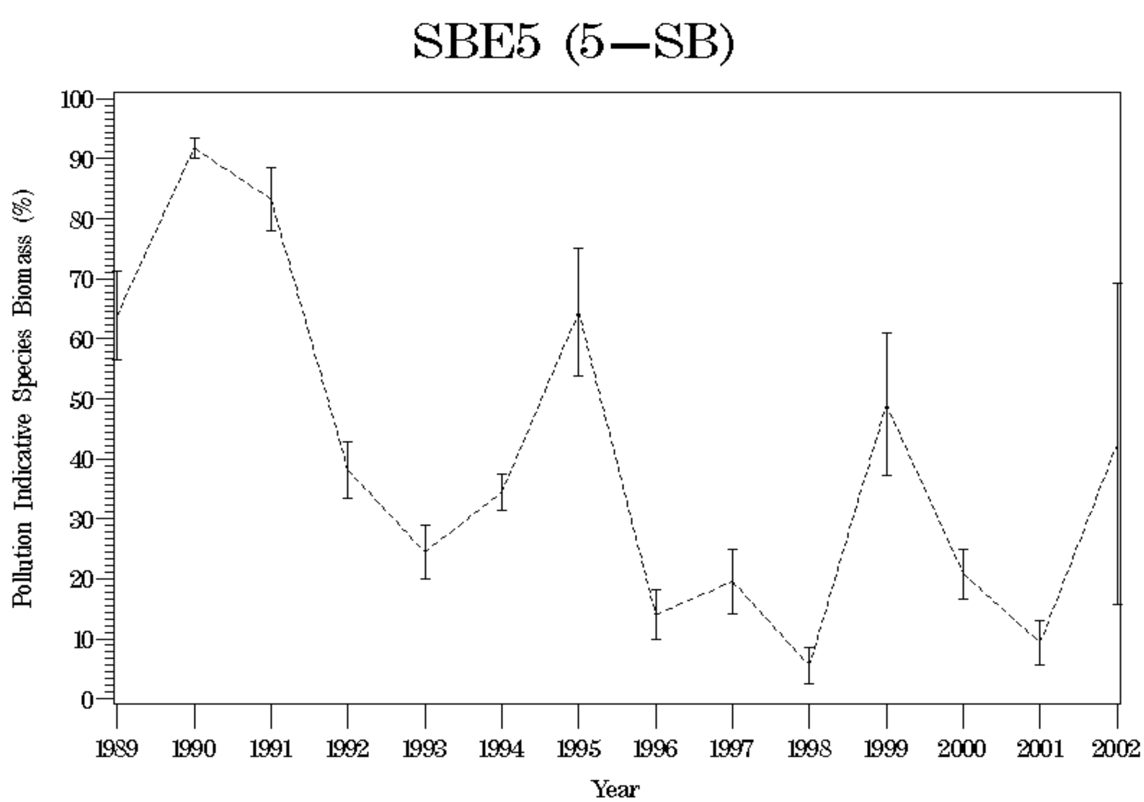



Figure C16. Pollution indicative species biomass at SBE5 (1985 - 2002).

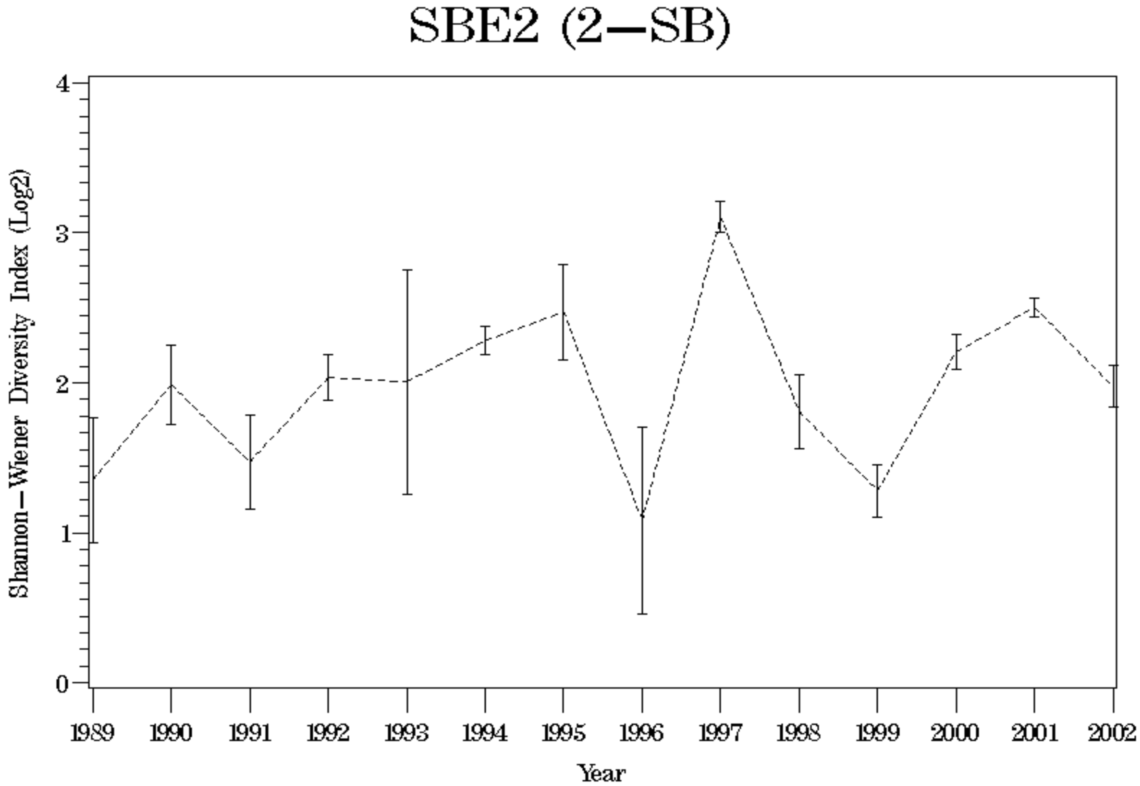



Figure C17. Shannon-Weiner diversity index at SBE2 (1985 - 2002).

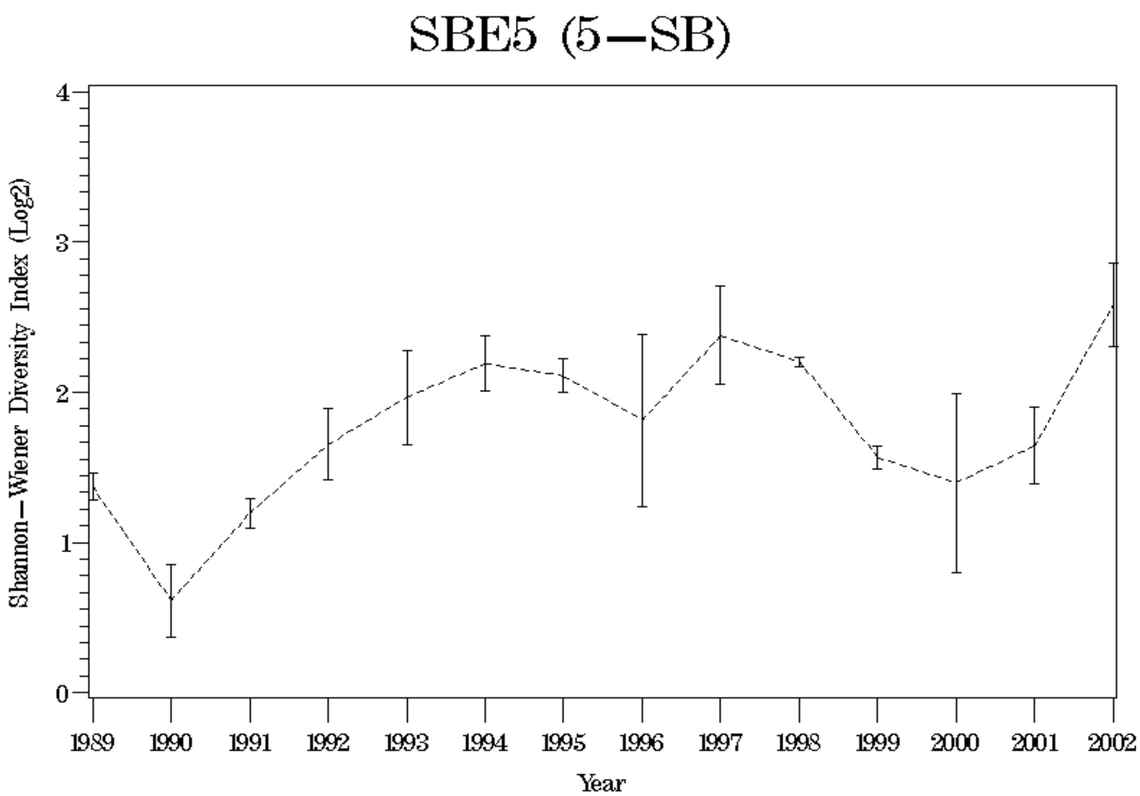



Figure C18. Shannon-Weiner diversity index at SBE5 (1985 - 2002).