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# BENTHIC BIOLOGICAL MONITORING PROGRAM OF THE ELIZABETH RIVER WATERSHED (2001) WITH A STUDY OF PARADISE CREEK

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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 third year of sampling in 2001. 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. During the 2001 sampling the benthic community condition of Paradise Creek of the Southern Branch of the Elizabeth River was also characterized.

The health of the benthic communities of the Elizabeth River watershed is characterized in this report by combining previously developed benthic restoration goals, the Benthic Index of Biotic Integrity (BIBI) 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. In 2000 and in succeeding years a single stratum, the entire Elizabeth River watershed, will be sampled with 25 random samples. In 2001 Paradise Creek was sampled as a separate stratum of 25 random samples.

Based upon probability-based sampling the estimate of benthic bottom not meeting the benthic restoration goals was 52 % in 2001, 72 % in 2000, and 64 % in 1999. 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. The level of degradaton in Paradise Creek was 92% compared to 52% for the entire Elizabeth River watershed in 2001. Previously this same level of degradation was reported for the Southern Branch in the 1999 intensive sampling effort (Dauer 2000; Dauer and Llansó 2002). The higher levels of degradation in Paradise Creek were associated with extremely high abundances, low species diversity due to high dominance by a few species, and low levels of biomass and pollution sensitive species compared to the Elizabeth River watershed as a whole.

## 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 (BIBI) developed for the Chesapeake Bay to the Elizabeth River Watershed (Ranasinghe et al. 1994; Weisberg et al. 1997). 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). In 2000 the Elizabeth River watershed was sampled as a single stratum with the benthic community condition characterized at 25 random locations (Dauer 2001). This study updates the benthic community characterization of the Elizabeth River watershed base upon data collected in 2001.

## 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). 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. In 2000 and 2001 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 2002)

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 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.

### *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 limits for these percentages can be calculated as:

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

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

For each stratum, 50 random points were 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 $^{o}$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). 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 wight 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 form 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 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 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 $ 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 13 m reflecting shoal and channel depths. All salinity

values were in the polyhaline range with values from 19.0 to 28.6 ppt. Bottom dissolved oxygen was generally high and varied from 2.5 to 8.1 ppm. Silt-clay content varied from 1.9 to 97.3 % and total volatile solids from 0.3 to 14.8 %.

### 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 BIBI values for the 25 random sites was 2.7. The distribution of the random sites and benthic community condition designations are shown in Figure 3. For the 2001 data 52 ± 9.7 % 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 and 2001 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.

## *Paradise Creek - Probability-Based Sampling*

### Environmental Parameters

All physical, chemical and sedimentary parameters are summarized in Table 7. Water depths varied from less than 1m to over 11 m reflecting shoal and channel depths. All salinity values were in high mesohaline to the polyhaline range with values from 17.6 to 22.6 ppt. Bottom dissolved oxygen varied from 2.9 to 5.6 ppm. Silt-clay content was generally in the high range with most values in excess of 50%. Reflecting the high silt-clay content, most total

volatile solids values were greater than than 5 %.

### Benthic Community Condition

Benthic community parameters including the B-IBI value, abundance, biomass, Shannon diversity and selected metrics are summarized by station in Table 8. The average BIBI values for the 25 random sites was 2.1. The distribution of the random sites and benthic community condition designations are shown in Figure 10. For the 2001 data 92 ± 10.6 % of the creek had degraded benthos. Individual metric scores incorporated in the B-IBI are presented in Table 9. The dominant taxa of the random sites are summarized in Table 10.

The B-IBI value, Shannon's index, abundance, biomass and the proportion of pollution sensitive and pollution indicative species are shown in Figs. 11-16. In these figures the Paradise Creek data are compared to the Elizabeth River watershed values for 1999, 2000 and 2001.

## 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 value of 2.6 (Dauer 2001) and in 2001 the values was 2.7. The estimated levels of degradation for the thee year period were 52 % in 2001, 72 % in 2000, and 64 % in 1999. Consistent with the use of the B-IBI in the Chesapeake Bay Benthic Monitoring Program (Dauer et al. 1998a, 1998b, 2002) 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. 4-9). However, there are some positive indications with the increase in the proportion of pollution sensitive species (Fig. 9).

***Paradise Creek***

The level of degradation in Paradise Creek was 92%, the same value for the entire Southern Branch from the intensive 1999 sampling (Dauer 2000). Over 50% of the stations sampled in Paradise Creek had BIBI values equal to or less than 2.0. The average BIBI value for Paradise Creek was 2.1, lower than the Elizabeth River in general (Fig. 11). In general the condition of the benthos of Paradise Creek is consistent with the description of the Elizabeth River: (1) lower than expected species diversity and biomass (Figs. 12,14), (2) abundance levels generally higher than reference conditions (Fig. 13) and (3) species composition with levels of pollution indicative species higher than reference conditions (Fig. 15) and levels of pollution sensitive species within reference conditions (Fig. 16). There are no major differences in the dominant species of Paradise Creek compared to the Elizabeth River (compare Tables 4 and 10). Both are dominated by the polychaetes *Mediomastus ambiseta* and *Streblospio benedicti* which account for 86 % of all individuals in the Elizabeth River and 81% of the individuals in Paradise Creek.

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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 this study the primary strata were the Mainstem of the river, the Lafayette River, the Eastern Branch, Western Branch and Southern Branch. In future 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

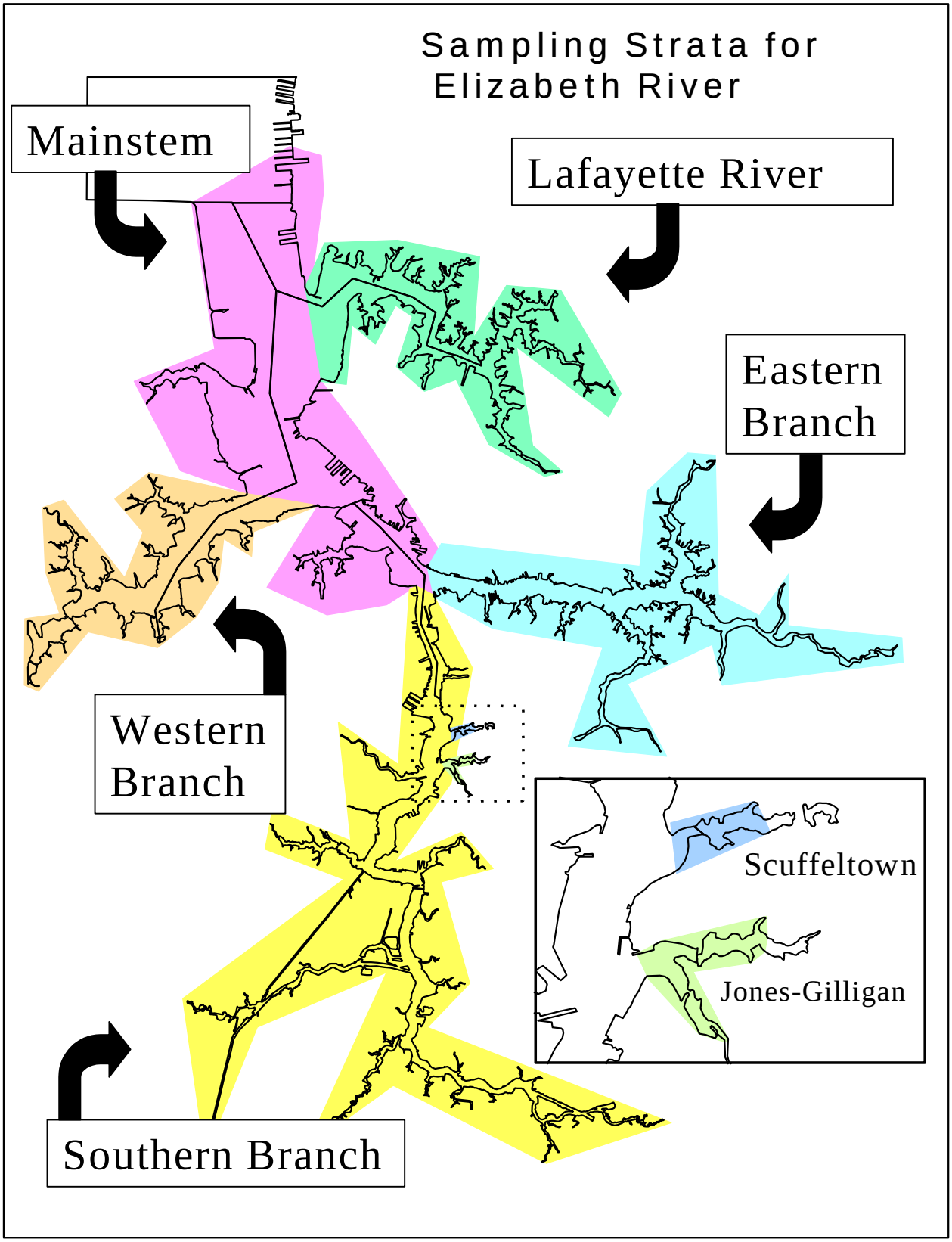


**Figure 1**. Elizabeth River watershed showing the five major segments sampled in 1999. Insert shows Scuffletown Creek and the Jones-Gilligan Creek strata also sampled in 1999.

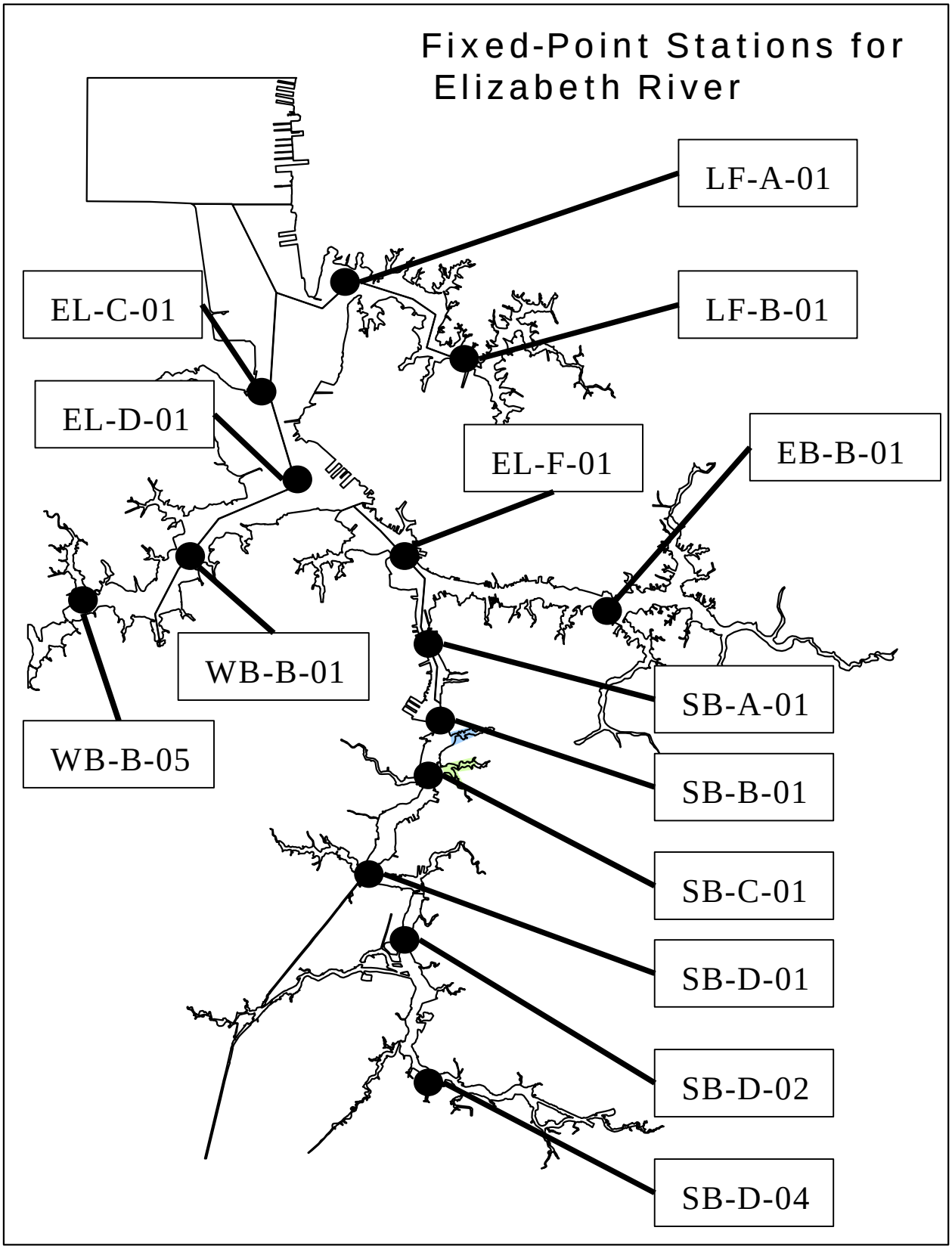


**Figure 2**. Elizabeth River watershed showing the 14 fixed-point stations for long-term trend analyses.

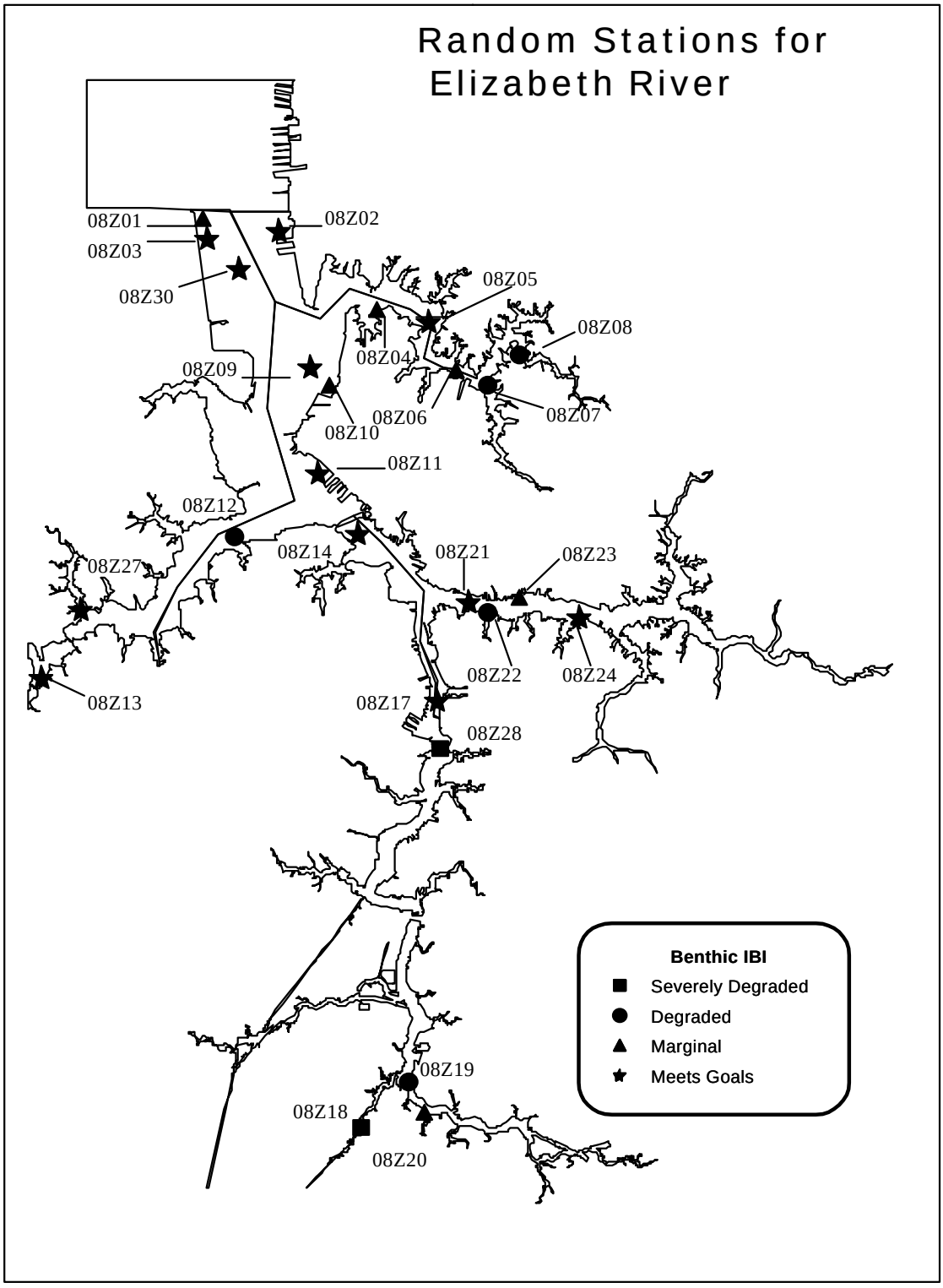


**Figure 3**. Map showing the 25 random locations sampled in 2001 and indicating the station numbers and condition of the benthic communities.

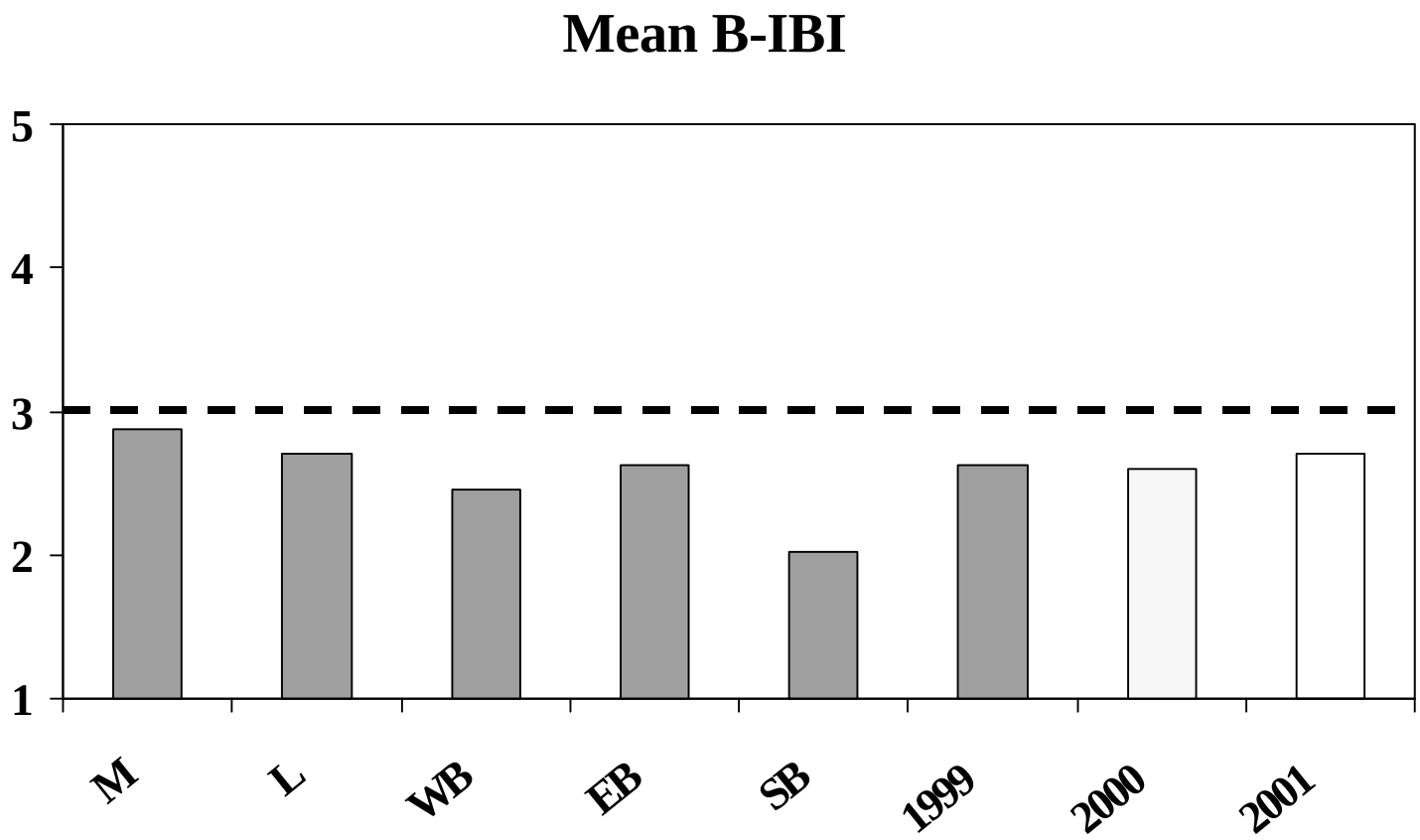


**Figure 4**. Average B-IBI values. Dashed line indicates a B-IBI value of 3.0, the goal for benthic restoration. Shown are the five strata from the 1999 sampling compared with the area weighted value for 1999 and the values for 2000 and 2001 based upon a single stratum for the entire watershed. Abbreviations: Bay - Mainstem of Chesapeake Bay, M - Mainstem of Elizabeth River, L - Lafayette River, WB - Western Branch, EB - Eastern Branch, SB - Southern Branch.

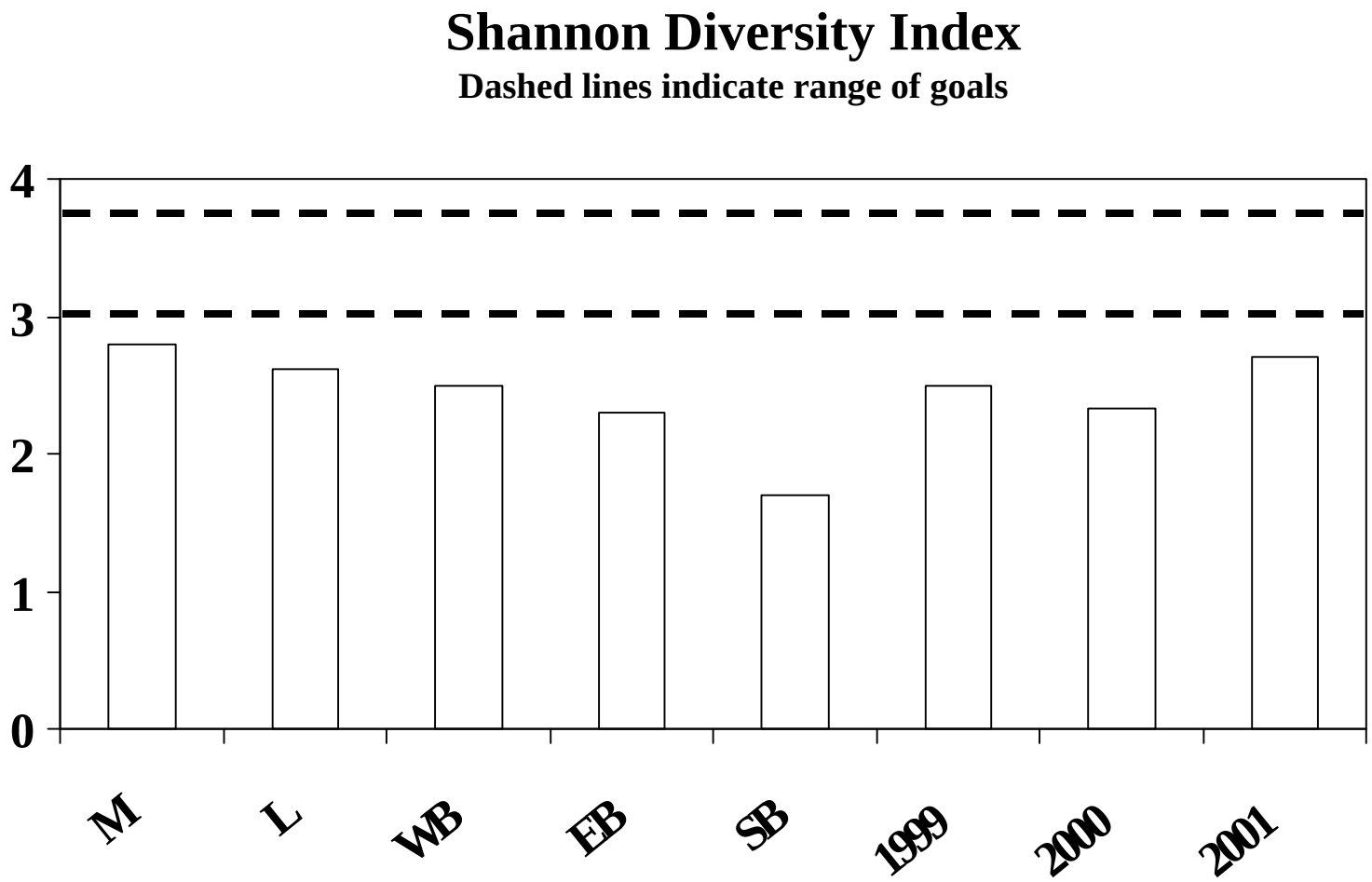


**Figure** 5. Average Shannon diversity index values. Shown are the five strata from the 1999 sampling, the 1999 area weighted average for the entire watershed and the 2000 and 2001 results. See Figure 5 for abbreviations.

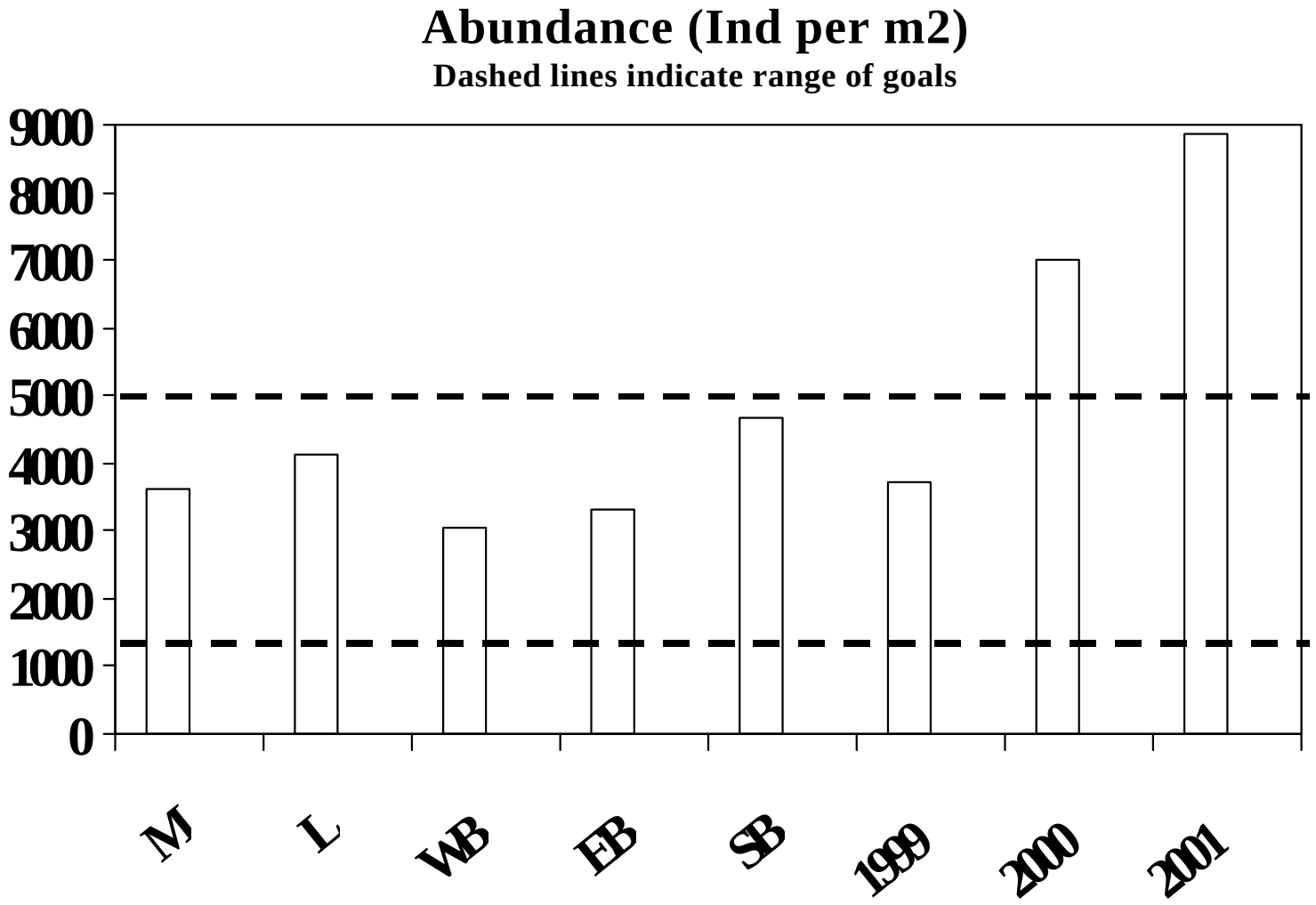


**Figure 6**. Average abundance of individuals per $m^2$. Shown are the five strata from the 1999 sampling, the 1999 area weighted average for the entire watershed and the 2000 and 2001 results. See Figure 5 for abbreviations.

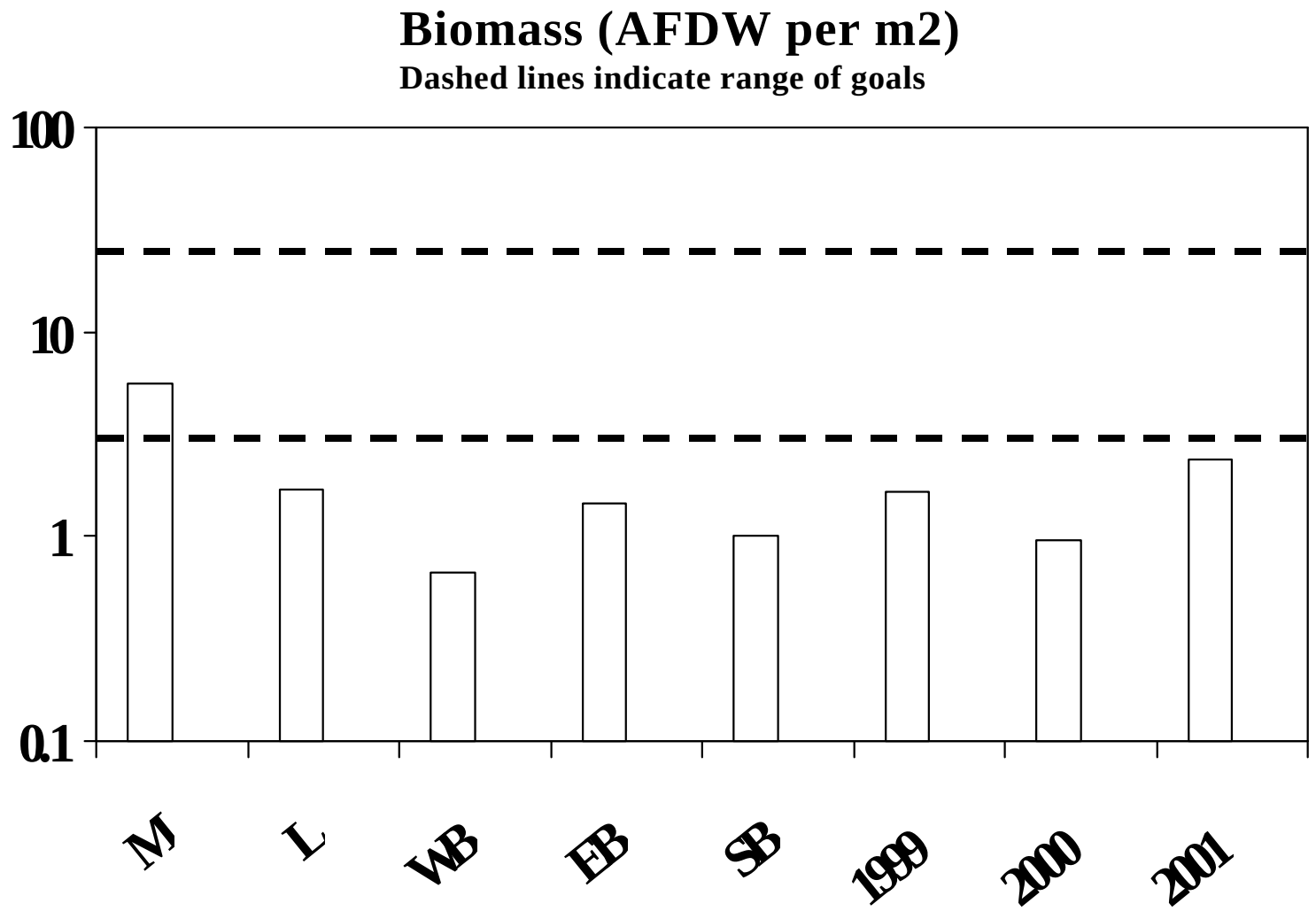


**Figure 7**. Average AFDW biomass in g per $m^2$. Shown are the five strata from the 1999 sampling, the 1999 area weighted average for the entire watershed and the 2000 and 2001 results. See Figure 5 for abbreviations.

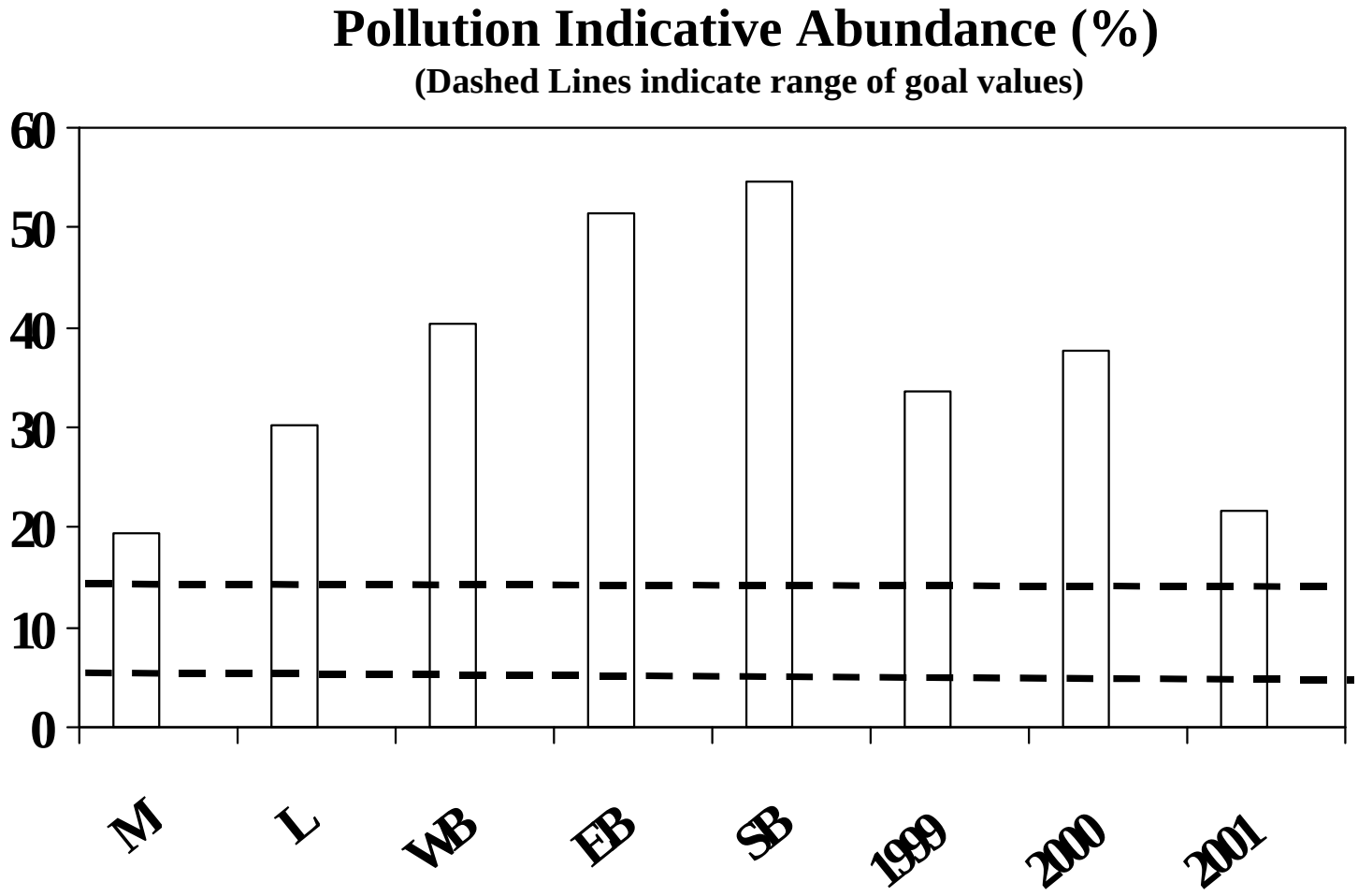


**Figure 8**. Average percentage of pollution indicative species abundance. Shown are the five strata from the 1999 sampling, the 1999 area weighted average for the entire watershed and the 2000 and 2001 results. See Figure 5 for abbreviations.

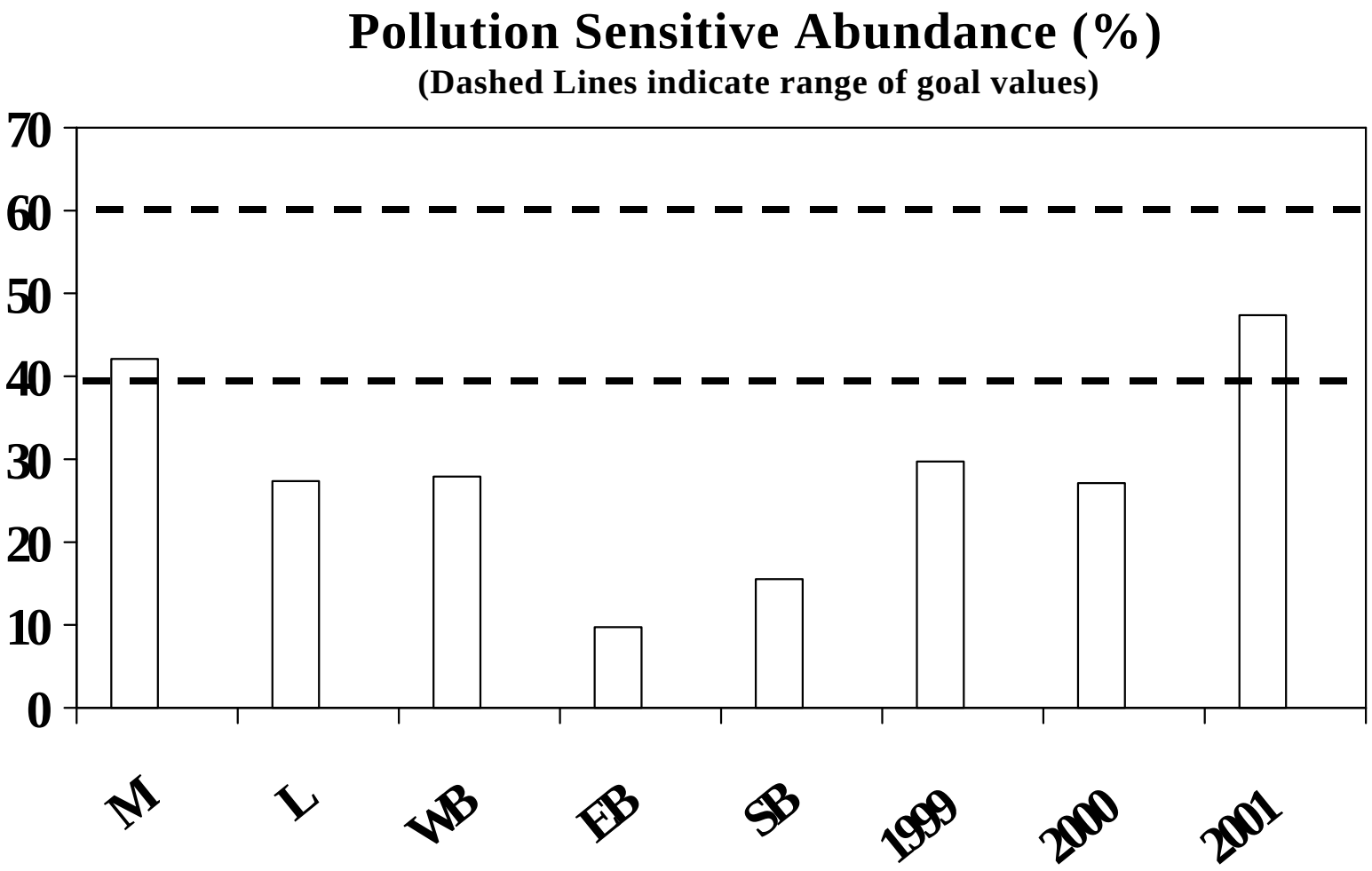


**Figure** 9. Average percentage of pollution sensitive species abundance. Shown are the five strata from the 1999 sampling, the 1999 area weighted average for the entire watershed and the 2000 and 2001 results. See Figure 5 for abbreviations.

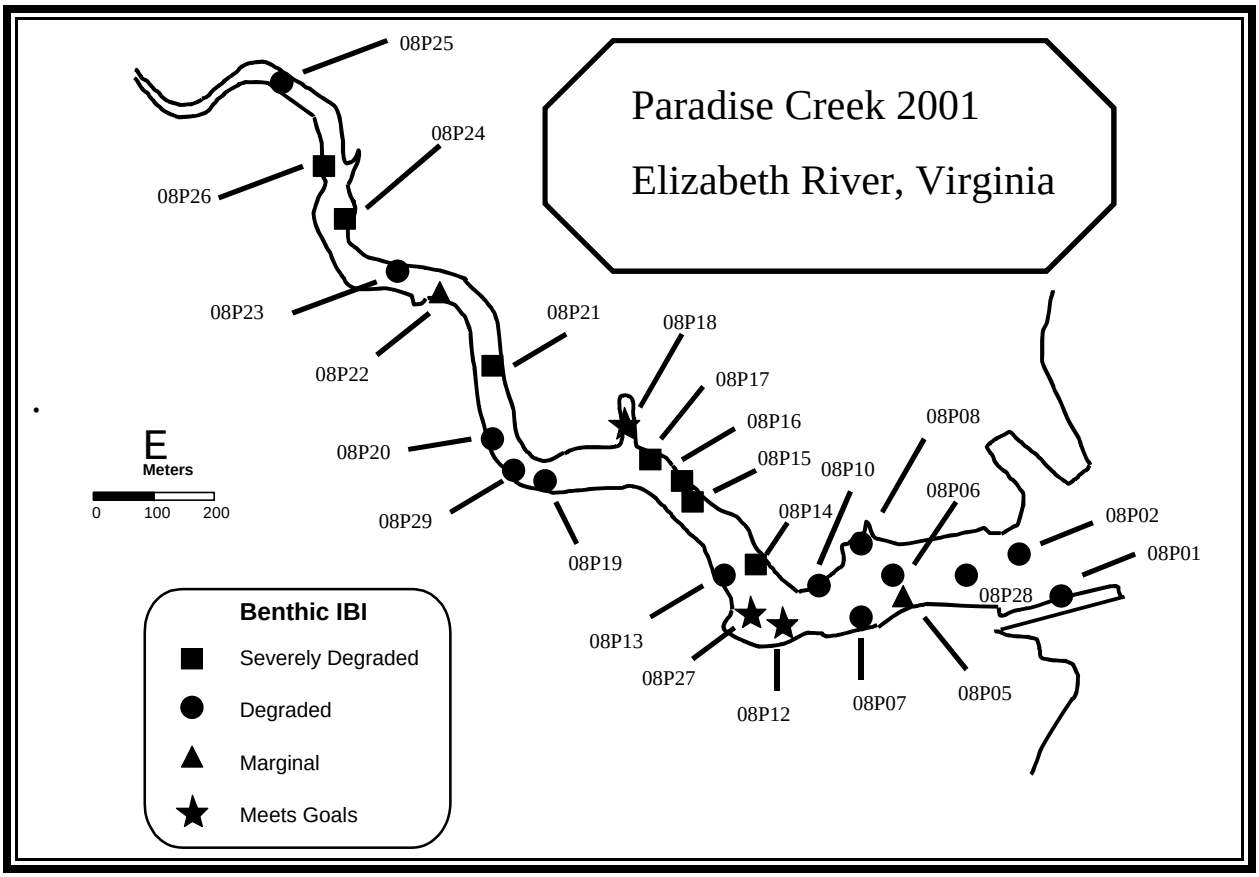


**Figure 10**. Location of 25 random stations in Paradise Creek and the condition of the benthic community at each station.

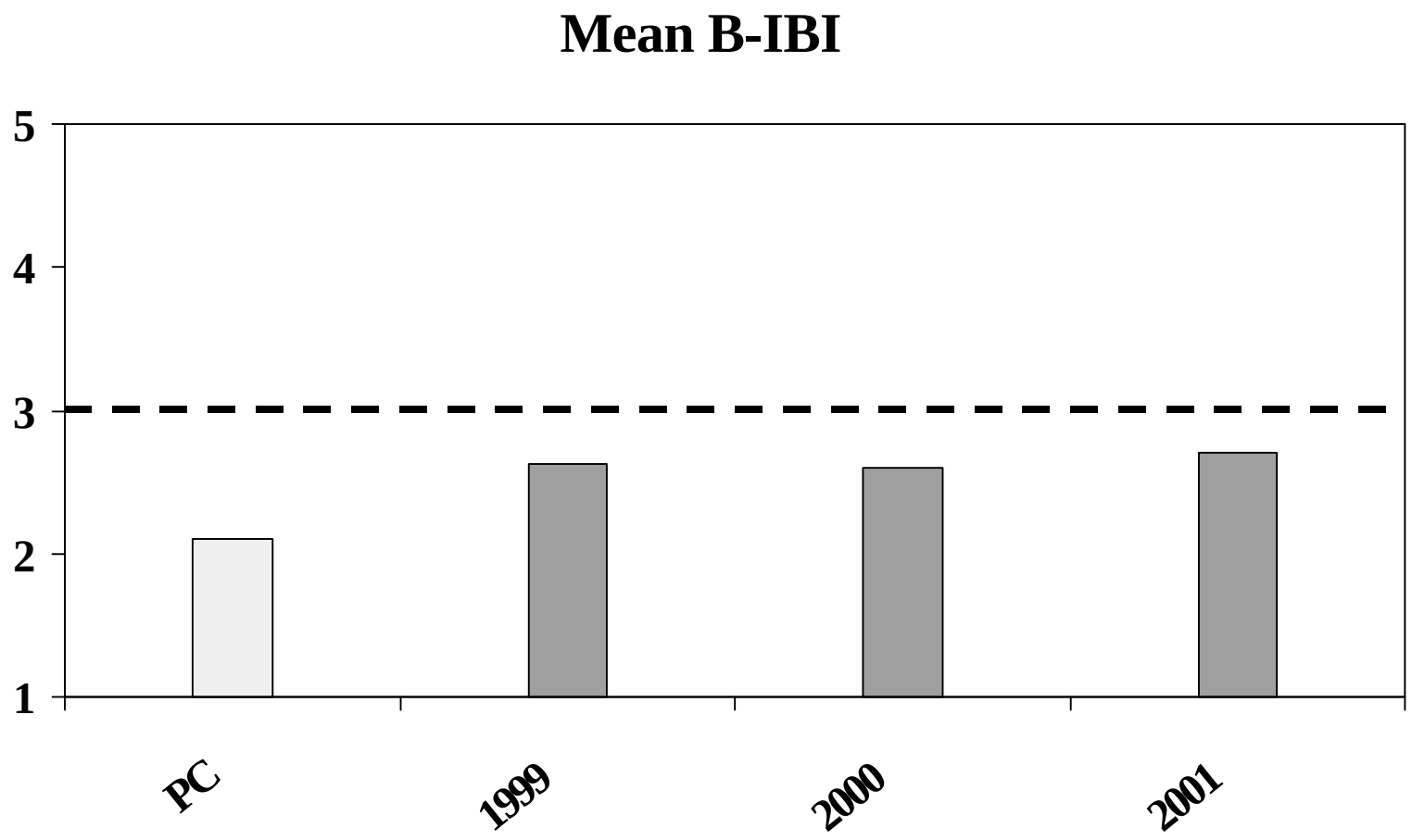


**Figure 11**. Average B-IBI values. Dashed line indicates a B-IBI value of 3.0, the goal for benthic restoration. Shown are the vales for Paradise Creek (PC) compared to the average values for 1999 (Dauer 2000), 2000 (Dauer 2001) and 2001 data (this report).

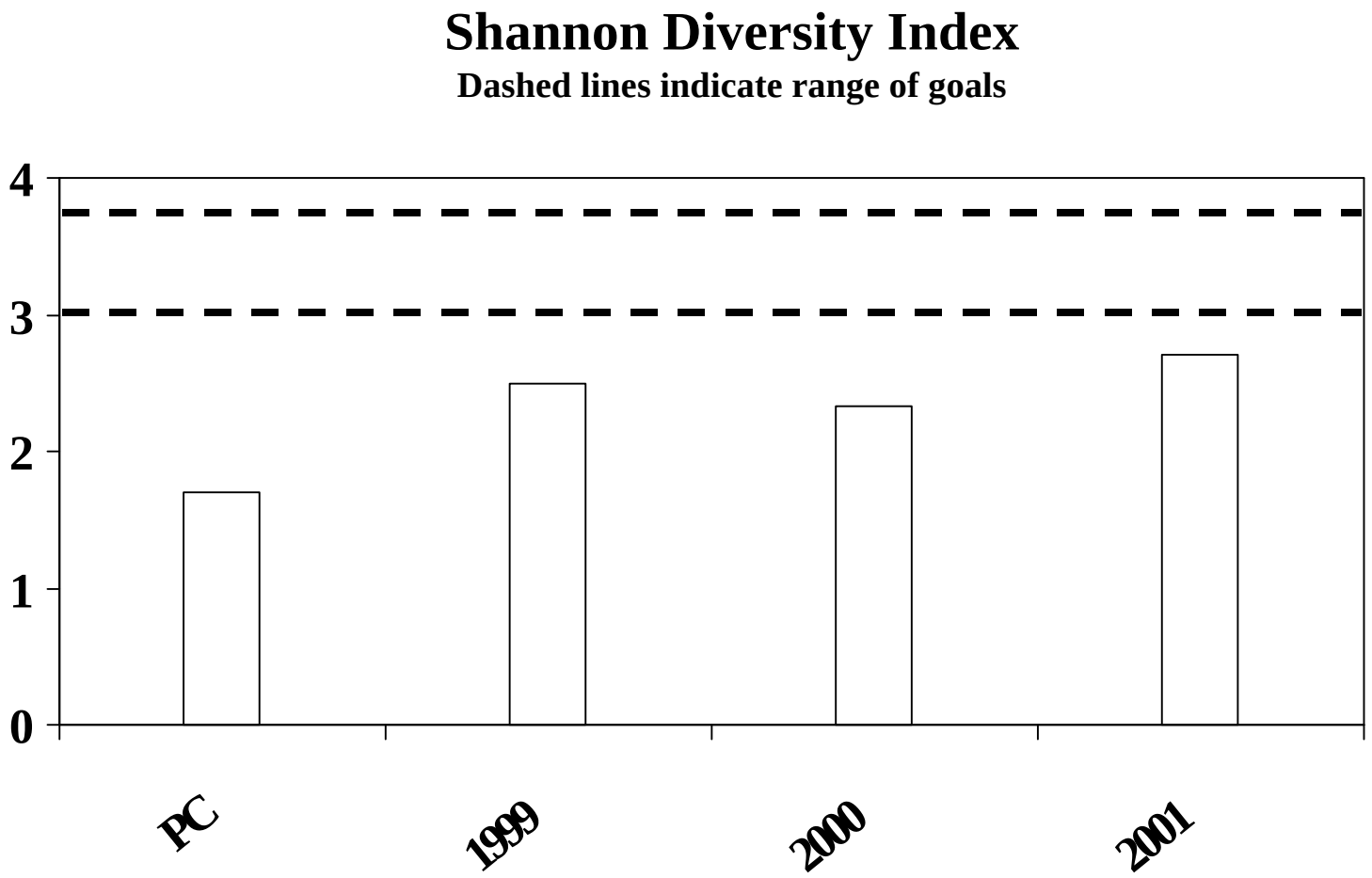


**Figure 12**. Average Shannon diversity index values. Dashed lines indicates range of values for the benthic restoration goals. Shown are the values for Paradise Creek (PC) compared to the average values for 1999 (Dauer 2000), 2000 (Dauer 2001) and 2001 data (this report).

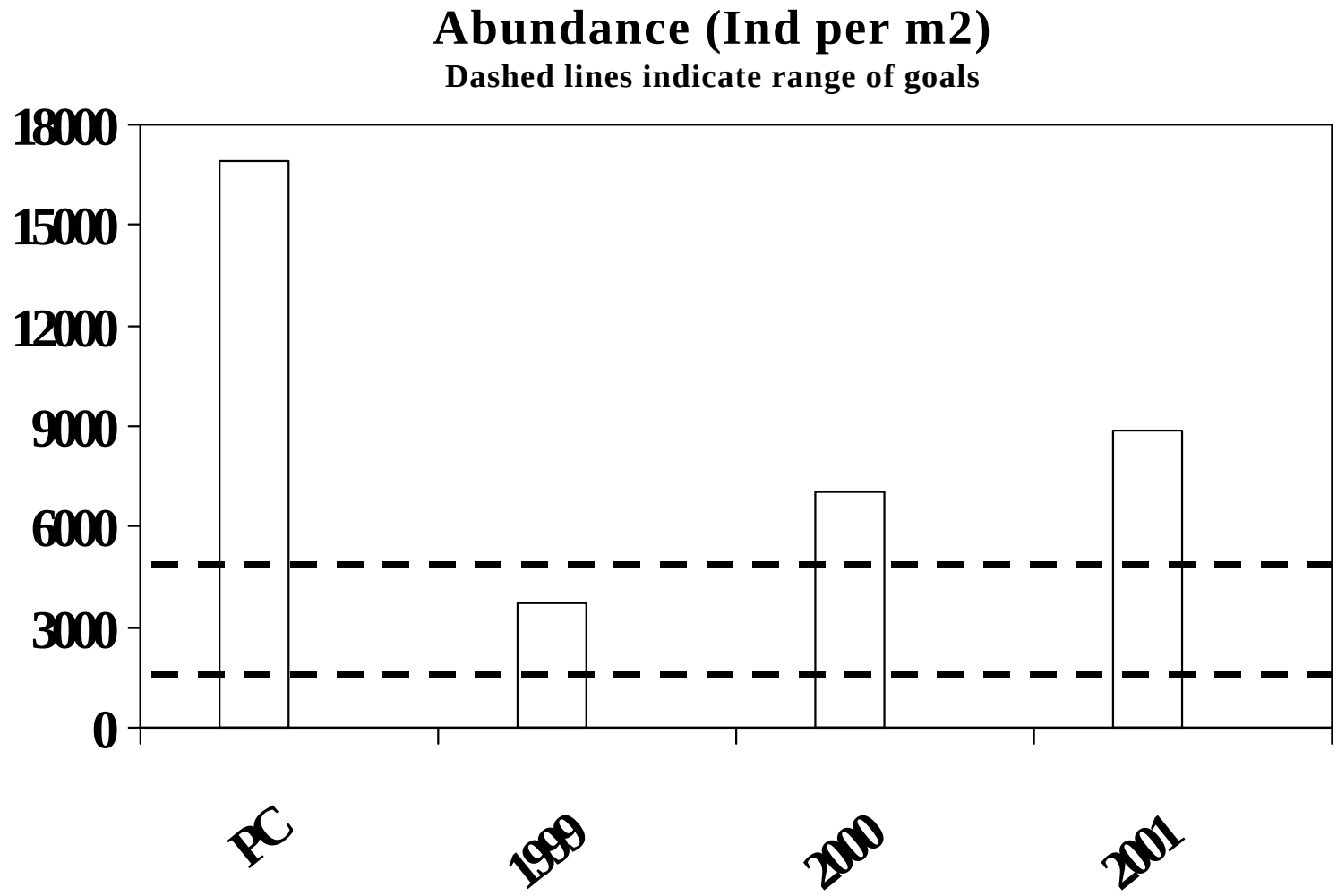


**Figure 13**. Average abundance values. Dashed lines indicates range of values for the benthic restoration goals. Shown are the values for Paradise Creek (PC) compared to the average values for 1999 (Dauer 2000), 2000 (Dauer 2001) and 2001 data (this report).

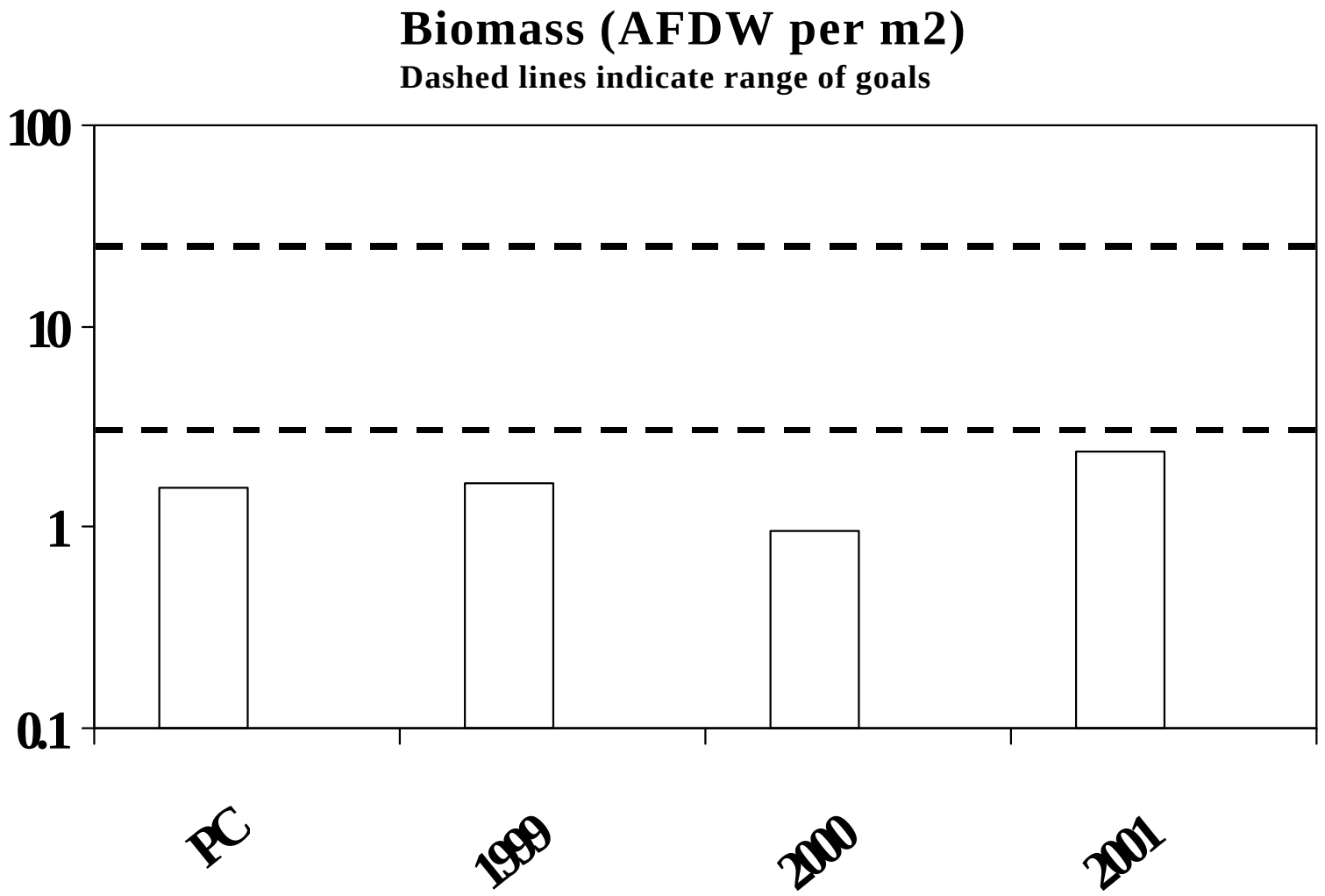


**Figure 14**. Average biomass values. Dashed lines indicates range of values for the benthic restoration goals. Shown are the values for Paradise Creek (PC) compared to the average values for 1999 (Dauer 2000), 2000 (Dauer 2001) and 2001 data (this report).

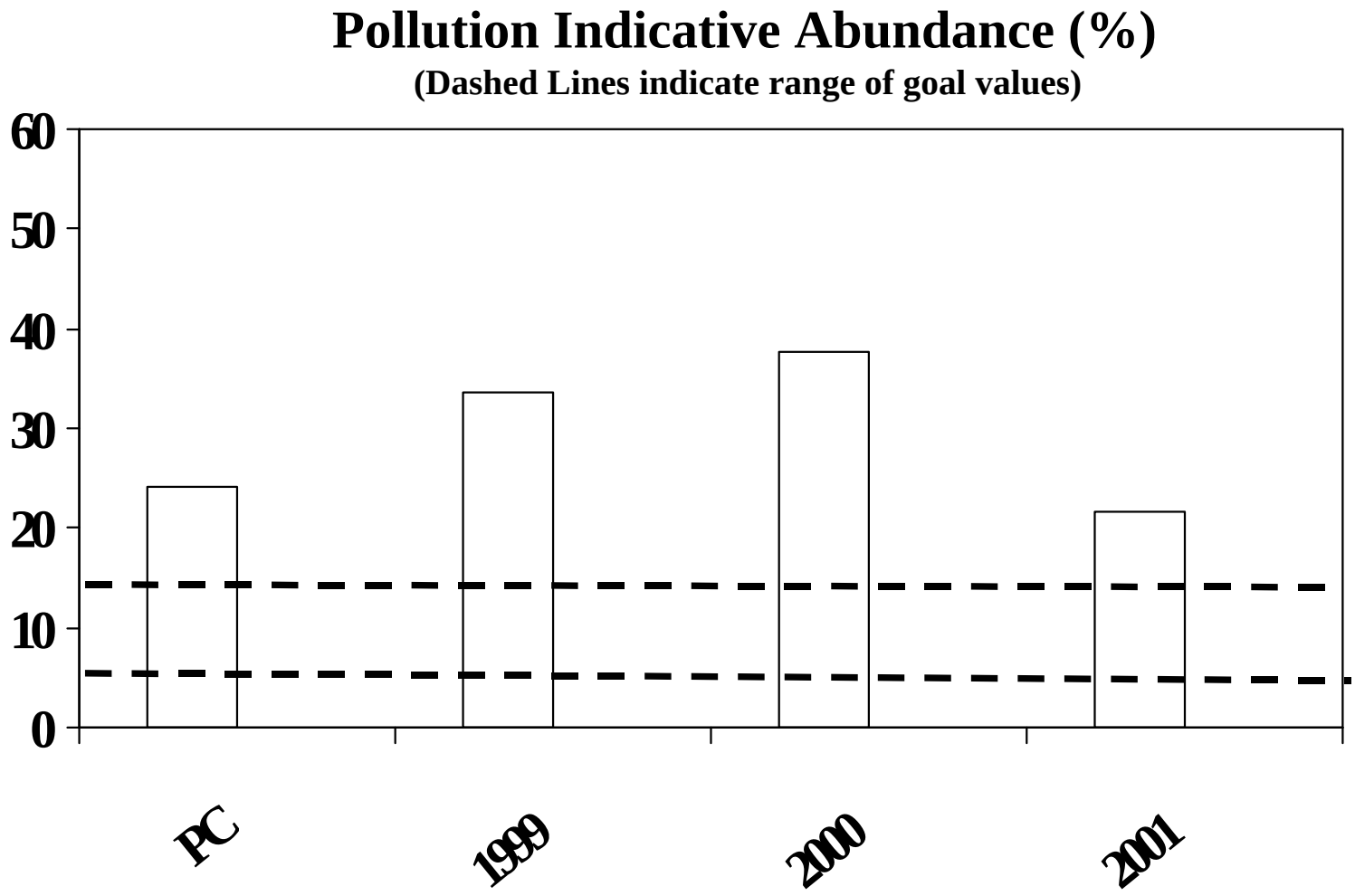


**Figure 15**. Average values for pollution indicative abundance as a percentage of the community. . Dashed lines indicates range of values for the benthic restoration goals. Shown are the values for Paradise Creek (PC) compared to the average values for 1999 (Dauer 2000), 2000 (Dauer 2001) and 2001 data (this report).

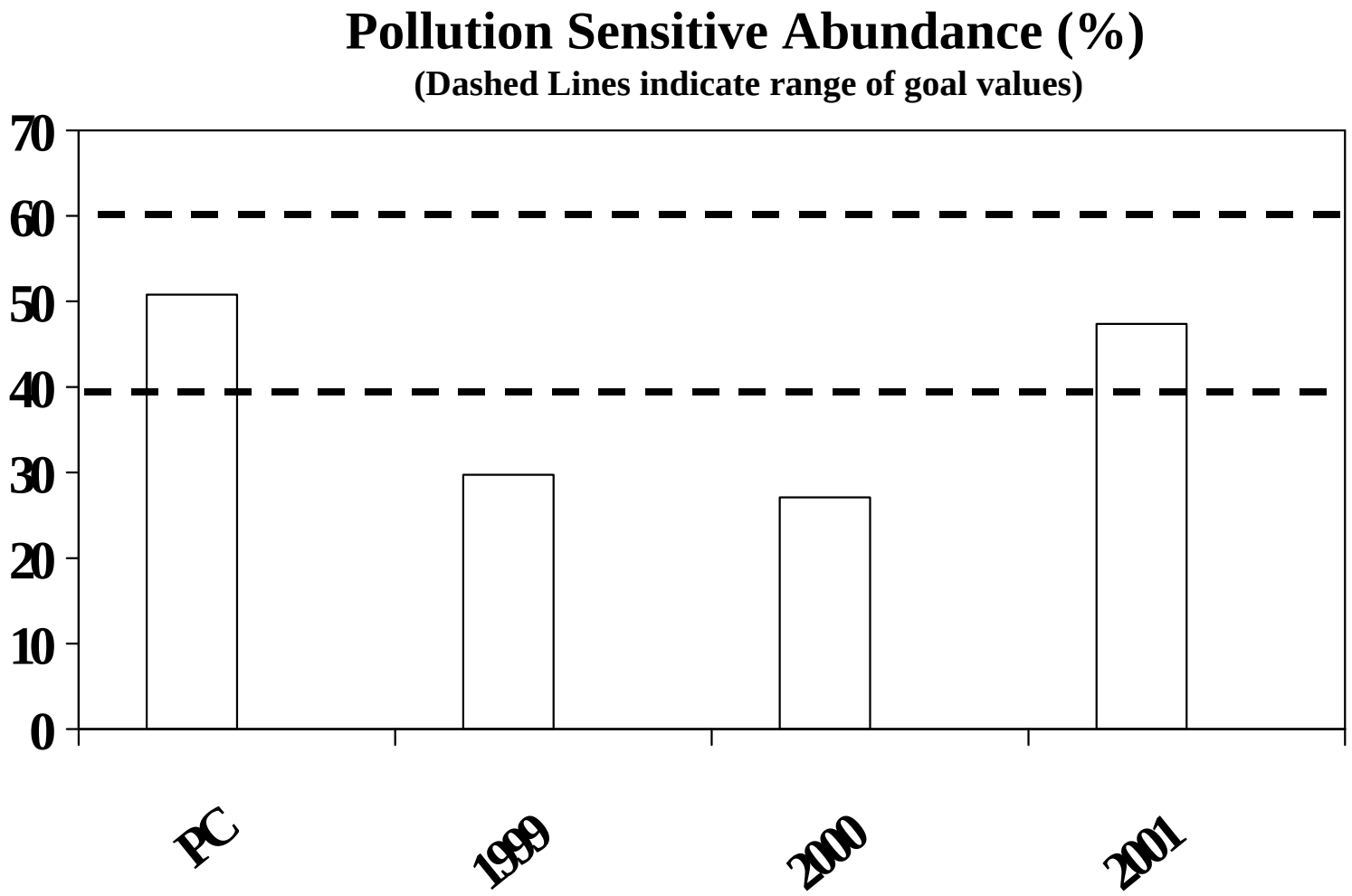


**Figure** 16. Average values for pollution sensitive abundance as a percentage of the community. . Dashed lines indicates range of values for the benthic restoration goals. Shown are the values for Paradise Creek (PC) compared to the average values for 1999 (Dauer 2000), 2000 (Dauer 2001) and 2001 data (this report).

# Tables

Table 1. Random Stations of the Elizabeth River sampled in 2001. Summary of physical parameters.

| Station | Date collected | Latitude | Longitude | Water Depth (m) | Salinity (ppt) | Dissolved oxygen (ppm) | Silt-clay Content (%) | Volatile Organics (%) |
|---|---|---|---|---|---|---|---|---|
| 08Z01 | 8/21/01 | 36.9220 | -76.3521 | 3.7 | 21.6 | 6.2 | 57.5 | 3.5 |
| 08Z02 | 8/21/01 | 36.9200 | -76.3332 | 4.6 | 22.3 | 5.2 | 57.2 | 3.0 |
| 08Z03 | 8/21/01 | 36.9173 | -76.3519 | 3.7 | 21.6 | 6.2 | 80.1 | 39.0 |
| 08Z04 | 8/13/01 | 36.9017 | -76.3082 | 1.0 | 21.6 | 6.0 | 4.6 | 0.6 |
| 08Z05 | 8/13/01 | 36.9006 | -76.2898 | 2.5 | 21.1 | 2.5 | 75.2 | 4.7 |
| 08Z06 | 8/13/01 | 36.8905 | -76.2863 | 2.8 | 20.9 | 4.9 | 88.0 | 6.2 |
| 08Z07 | 8/13/01 | 36.8898 | -76.2745 | 2.0 | 20.5 | 6.0 | 92.2 | 6.9 |
| 08Z08 | 8/30/01 | 36.8934 | -76.2660 | 0.7 | 19.0 | 4.8 | 96.5 | 8.9 |
| 08Z09 | 8/21/01 | 36.8900 | -76.3250 | 3.7 | 22.2 | 5.3 | 38.4 | 2.2 |
| 08Z10 | 8/21/01 | 36.8854 | -76.3176 | 0.9 | 21.5 | 8.1 | 5.1 | 2.1 |
| 08Z11 | 8/21/01 | 36.8687 | -76.3196 | 1.8 | 22.5 | 4.1 | 2.7 | 0.3 |
| 08Z12 | 8/14/01 | 36.8552 | -76.3438 | 2.0 | 27.2 | 2.6 | 57.4 | 4.1 |
| 08Z13 | 8/14/01 | 36.8267 | -76.3958 | 1.0 | 28.6 | 2.5 | 94.8 | 7.3 |
| 08Z14 | 8/21/01 | 36.8559 | -76.3114 | 12.8 | 22.4 | 4.6 | 83.8 | 6.5 |
| 08Z17 | 8/20/01 | 36.8212 | -76.2918 | 11.6 | 22.2 | 3.5 | 95.5 | 8.3 |
| 08Z18 | 8/20/01 | 36.7304 | -76.3094 | 1.1 | 19.1 | 3.9 | 93.7 | 15.7 |
| 08Z19 | 8/20/01 | 36.7411 | -76.2991 | 2.7 | 20.8 | 2.8 | 19.5 | 3.0 |
| 08Z20 | 8/20/01 | 36.7339 | -76.2930 | 2.7 | 20.0 | 2.9 | 9.2 | 2.0 |
| 08Z21 | 8/20/01 | 36.8391 | -76.2830 | 1.2 | 21.5 | 3.8 | 17.0 | 2.0 |
| 08Z22 | 8/20/01 | 36.8388 | -76.2780 | 5.8 | 21.8 | 3.1 | 58.1 | 5.4 |
| 08Z23 | 8/20/01 | 36.8408 | -76.2688 | 6.1 | 21.6 | 2.9 | 67.3 | 7.8 |
| 08Z24 | 8/20/01 | 36.8371 | -76.2536 | 1.2 | 19.7 | 5.2 | 20.1 | 2.1 |
| 08Z27 | 8/14/01 | 36.8402 | -76.3851 | 0.8 | 20.1 | 4.0 | 96.5 | 6.9 |
| 08Z28 | 8/20/01 | 36.8082 | -76.2877 | 1.2 | 22.1 | 3.5 | 62.9 | 6.3 |
| 08Z30 | 8/21/01 | 36.9129 | -76.3437 | 4.9 | 22.3 | 5.0 | 84.8 | 5.2 |

Table 2. Random Stations of the Elizabeth Rive sampled in 2001. 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 | Deep Deposit Feeder Abundance |
|---|---|---|---|---|---|---|---|---|---|---|
| 08Z01 | 2.7 | 3742 | 1.406 | 2.68 | 13.9 | 57.6 | 14.5 | 54.8 | 10.3 | 60.0 |
| 08Z02 | 3.7 | 2177 | 0.590 | 3.17 | 16.7 | 54.2 | 7.7 | 57.7 | 51.0 | 16.7 |
| 08Z03 | 3.3 | 3107 | 0.635 | 3.20 | 14.6 | 54.0 | 10.7 | 39.3 | 42.3 | 23.4 |
| 08Z04 | 2.7 | 3243 | 0.680 | 2.87 | 38.5 | 23.1 | 13.3 | 20.0 | 14.7 | 20.3 |
| 08Z05 | 3.0 | 7847 | 3.289 | 2.52 | 41.9 | 30.1 | 6.2 | 31.7 | 4.9 | 46.5 |
| 08Z06 | 2.7 | 7416 | 1.520 | 2.48 | 43.1 | 12.2 | 6.0 | 59.7 | 7.3 | 35.2 |
| 08Z07 | 2.0 | 9571 | 1.134 | 1.81 | 55.9 | 29.6 | 18.0 | 50.0 | 3.8 | 32.7 |
| 08Z08 | 2.0 | 30346 | 0.998 | 2.12 | 18.4 | 46.7 | 11.4 | 38.6 | 1.3 | 76.5 |
| 08Z09 | 3.3 | 2880 | 1.043 | 3.23 | 23.6 | 45.7 | 6.5 | 71.7 | 16.5 | 38.6 |
| 08Z10 | 2.7 | 7552 | 1.293 | 2.08 | 9.6 | 0.9 | 7.0 | 3.5 | 14.4 | 78.7 |
| 08Z11 | 4.0 | 3107 | 1.429 | 3.07 | 1.5 | 37.2 | 3.2 | 15.9 | 10.2 | 82.5 |
| 08Z12 | 2.0 | 2563 | 0.544 | 2.19 | 15.9 | 68.1 | 29.2 | 20.8 | 13.3 | 63.7 |
| 08Z13 | 3.3 | 7167 | 1.542 | 2.40 | 19.9 | 39.9 | 1.5 | 77.9 | 5.7 | 50.0 |
| 08Z14 | 3.0 | 3538 | 1.270 | 2.85 | 10.3 | 59.6 | 10.7 | 69.6 | 12.8 | 61.5 |
| 08Z17 | 3.0 | 2223 | 0.522 | 2.61 | 27.6 | 33.7 | 13.0 | 39.1 | 4.1 | 61.2 |
| 08Z18 | 1.3 | 28509 | 1.746 | 1.82 | 22.3 | 59.0 | 20.8 | 27.3 | 14.1 | 63.9 |
| 08Z19 | 2.3 | 10002 | 0.544 | 0.98 | 7.0 | 91.4 | 16.7 | 62.5 | 9.3 | 82.8 |
| 08Z20 | 2.7 | 8278 | 0.703 | 1.71 | 19.5 | 76.2 | 6.5 | 71.0 | 7.9 | 67.4 |
| 08Z21 | 3.0 | 12723 | 1.111 | 1.87 | 16.6 | 66.7 | 6.1 | 40.8 | 4.3 | 78.1 |
| 08Z22 | 2.0 | 20208 | 1.429 | 2.05 | 20.0 | 58.8 | 15.9 | 36.5 | 2.4 | 76.9 |
| 08Z23 | 2.7 | 1429 | 0.680 | 3.30 | 30.2 | 20.6 | 6.7 | 13.3 | 14.3 | 38.1 |
| 08Z24 | 3.0 | 15241 | 0.862 | 1.68 | 15.6 | 68.0 | 2.6 | 31.6 | 2.4 | 79.6 |
| 08Z27 | 3.3 | 5194 | 1.202 | 2.43 | 16.2 | 41.0 | 3.8 | 62.3 | 7.0 | 49.3 |
| 08Z28 | 1.7 | 21569 | 0.885 | 1.27 | 27.9 | 68.5 | 20.5 | 43.6 | 1.6 | 70.0 |
| 08Z30 | 3.3 | 2223 | 0.658 | 3.14 | 15.3 | 38.8 | 13.8 | 41.4 | 33.7 | 31.6 |
| Mean | 2.7 | 8874 | 1.109 | 2.38 | 21.7 | 47.3 | 10.9 | 43.2 | 12.4 | 55.4 |
| Std error | 0.1 | 1650 | 0.117 | 0.13 | 2.5 | 4.3 | 1.3 | 4.0 | 2.5 | 4.2 |

Table 3. Random Stations of the Elizabeth River sampled in 2001. 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 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 08Z01 | 2.7 | 5 | 2 | 3 | 3 | 3 | | | 3 | 3 | 1 | |
| 08Z02 | 3.7 | 5 | 2 | 3 | 5 | 3 | | | 3 | 3 | 5 | |
| 08Z03 | 3.3 | 5 | 2 | 3 | 3 | 3 | | | 3 | 3 | 5 | |
| 08Z04 | 2.7 | 5 | 1 | 3 | 5 | 1 | | 1 | 3 | | | 3 |
| 08Z05 | 3.0 | 5 | 2 | 3 | 3 | 5 | | | 3 | 3 | 1 | |
| 08Z06 | 2.7 | 5 | 2 | 3 | 3 | 3 | | | 3 | 3 | 1 | |
| 08Z07 | 2.0 | 5 | 2 | 1 | 1 | 3 | | | 3 | 3 | 1 | |
| 08Z08 | 2.0 | 5 | 2 | 1 | 1 | 3 | | | 3 | 3 | 1 | |
| 08Z09 | 3.3 | 5 | 1 | 3 | 3 | 3 | | 3 | 3 | | | 5 |
| 08Z10 | 2.7 | 5 | 1 | 1 | 3 | 3 | | 1 | 3 | | | 5 |
| 08Z11 | 4.0 | 5 | 1 | 3 | 5 | 3 | | 3 | 5 | | | 5 |
| 08Z12 | 2.0 | 5 | 2 | 1 | 5 | 3 | | | 1 | 1 | 1 | |
| 08Z13 | 3.3 | 5 | 2 | 3 | 3 | 3 | | | 5 | 5 | 1 | |
| 08Z14 | 3.0 | 5 | 2 | 3 | 3 | 3 | | | 3 | 5 | 1 | |
| 08Z17 | 3.0 | 5 | 2 | 3 | 5 | 3 | | | 3 | 3 | 1 | |
| 08Z18 | 1.3 | 5 | 2 | 1 | 1 | 3 | | | 1 | 1 | 1 | |
| 08Z19 | 2.3 | 5 | 1 | 1 | 1 | 1 | | 5 | 1 | | | 5 |
| 08Z20 | 2.7 | 5 | 1 | 1 | 1 | 1 | | 5 | 3 | | | 5 |
| 08Z21 | 3.0 | 5 | 1 | 1 | 1 | 3 | | 5 | 3 | | | 5 |
| 08Z22 | 2.0 | 5 | 2 | 1 | 1 | 3 | | | 3 | 3 | 1 | |
| 08Z23 | 2.7 | 5 | 2 | 5 | 3 | 3 | | | 3 | 1 | 1 | |
| 08Z24 | 3.0 | 5 | 1 | 1 | 1 | 1 | | 5 | 5 | | | 5 |
| 08Z27 | 3.3 | 5 | 2 | 3 | 3 | 3 | | | 5 | 5 | 1 | |
| 08Z28 | 1.7 | 5 | 2 | 1 | 1 | 3 | | | 1 | 3 | 1 | |
| 08Z30 | 3.3 | 5 | 2 | 3 | 5 | 3 | | | 3 | 3 | 3 | |

Table 4. Random Stations of the Elizabeth River sampled in 2001. Dominant taxa by abundance. Taxon code: A = amphipod, An=Anemone B = bivalve, G = gastropod, I = isopod, O = oligochaete, P = polychaete.

| Taxon | | Abundance per $m^2$ |
|---|---|---|
| 1 | Mediomastus ambiseta (P) | 4282 |
| 2 | Streblospio benedicti (P) | 1761 |
| 3 | Tubificoides spp. Group I (O) | 607 |
| 4 | Tubificoides heterochaetus (O) | 378 |
| 5 | Leptocheirus plumulosus (A) | 233 |
| 6 | Capitella capitata (P) | 220 |
| 7 | Glycinde solitaria (P) | 170 |
| 8 | Paraprionospio pinnata (P) | 155 |
| 9 | Heteromastus filiformis (P) | 128 |
| 10 | Laeonereis culveri (P) | 113 |
| 11 | Leitoscoloplos spp.(P) | 113 |
| 12 | Acteocina canaliculata (G) | 84 |
| 13 | Leucon americanus (C) | 72 |
| 14 | Edwardsia elegans (An) | 67 |
| 15 | Cyathura polita (I) | 54 |

Table 5. Fixed Point Stations of the Elizabeth River sampled in 2001. Summary of physical parameters.

| Station | Date collected | Latitude | Longitude | Water Depth (m) | Salinity (ppt) | Dissolved oxygen (ppm) | Silt-clay Content (%) | Volatile Organics (%) |
|---|---|---|---|---|---|---|---|---|
| EBB1 | 8/20/01 | 36.8378 | -76.2422 | 1.2 | 18.6 | 8.0 | 71.6 | 8.5 |
| ELC1 | 8/21/01 | 36.8796 | -76.3476 | 3.1 | 22.4 | 5.1 | 27.6 | 1.2 |
| ELD1 | 8/21/01 | 36.8614 | -76.3357 | 2.1 | 22.5 | 4.8 | 4.2 | 0.4 |
| ELF1 | 8/21/01 | 36.8486 | -76.2967 | 11.9 | 22.4 | 4.0 | 95.9 | 7.8 |
| LFA1 | 8/13/01 | 36.9092 | -76.3138 | 1.8 | 21.5 | 6.9 | 79.5 | 3.8 |
| LFB1 | 8/13/01 | 36.8896 | -76.2830 | 3.5 | 20.8 | 3.8 | 98.9 | 7.8 |
| SBA1 | 8/20/01 | 36.8255 | -76.2907 | 10.4 | 22.3 | 3.1 | 90.2 | 7.9 |
| SBB1 | 8/20/01 | 36.8117 | -76.2886 | 3.7 | 22.1 | 3.6 | 38.6 | 5.6 |
| SBC1 | 8/20/01 | 36.7994 | -76.2944 | 10.7 | 22.2 | 2.9 | 92.7 | 0.4 |
| SBD1 | 8/20/01 | 36.7796 | -76.3106 | 9.1 | 21.5 | 3.6 | 87.9 | 10.0 |
| SBD2 | 8/20/01 | 36.7668 | -76.2969 | 0.9 | 21.2 | 3.1 | 42.1 | 6.5 |
| SBD4 | 8/20/01 | 36.7402 | -76.2990 | 1.5 | 20.5 | 2.7 | 17.3 | 2.3 |
| WBB1 | 8/14/01 | 36.8462 | -76.3576 | 1.5 | 21.4 | 3.9 | 92.7 | 5.6 |
| WBB5 | 8/14/01 | 36.8293 | -76.3932 | 0.5 | 19.6 | 4.7 | 68.5 | 5.3 |

Table 6. Fixed Point Stations of the Elizabeth River sampled in 2001. 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 | 2.0 | 12126 | 2.374 | 2.40 | 39.0 | 37.0 | 5.5 | 15.3 | 5.7 | 52.7 |
| ELC1 | 4.2 | 2351 | 1.565 | 3.60 | 12.5 | 54.9 | 5.2 | 49.0 | 21.1 | 48.1 |
| ELD1 | 3.2 | 2049 | 0.627 | 3.33 | 3.2 | 69.7 | 7.9 | 43.0 | 28.9 | 45.2 |
| ELF1 | 1.9 | 2260 | 0.461 | 2.78 | 22.1 | 36.2 | 16.4 | 18.0 | 12.1 | 49.9 |
| LFA1 | 2.2 | 4287 | 1.187 | 2.59 | 32.9 | 57.0 | 30.5 | 41.0 | 7.4 | 40.7 |
| LFB1 | 2.3 | 4778 | 0.847 | 2.20 | 26.1 | 13.5 | 8.9 | 47.4 | 6.1 | 45.9 |
| SBA1 | 2.7 | 4339 | 1.610 | 2.53 | 16.3 | 33.9 | 10.0 | 47.4 | 6.7 | 73.2 |
| SBB1 | 2.9 | 2019 | 0.544 | 2.63 | 4.4 | 58.8 | 8.2 | 34.7 | 28.4 | 57.8 |
| SBC1 | 2.1 | 22960 | 2.026 | 1.20 | 15.2 | 79.7 | 15.9 | 63.2 | 1.8 | 82.6 |
| SBD1 | 2.4 | 17743 | 1.520 | 1.20 | 3.0 | 90.4 | 12.1 | 63.4 | 26.8 | 68.2 |
| SBD2 | 2.7 | 9208 | 0.680 | 1.63 | 12.3 | 83.8 | 11.1 | 64.4 | 26.5 | 59.9 |
| SBD4 | 3.2 | 4135 | 0.559 | 1.70 | 3.8 | 88.5 | 5.3 | 69.2 | 29.7 | 60.8 |
| WBB1 | 2.3 | 3825 | 1.036 | 1.94 | 28.1 | 61.3 | 6.8 | 24.7 | 7.1 | 60.5 |
| WBB5 | 2.4 | 10108 | 1.308 | 1.82 | 17.3 | 69.8 | 5.2 | 58.5 | 7.1 | 71.2 |

Table 7. Random Stations of Paradise Creek sampled in 2001. Summary of physical parameters.

| Station | Date collected | Latitude | Longitude | Water Depth (m) | Salinity (ppt) | Dissolved oxygen (ppm) | Silt-clay Content (%) | Volatile Organics (%) |
|---|---|---|---|---|---|---|---|---|
| 08P01 | 9/6/01 | 36.7984 | -76.2951 | 10.4 | 22.3 | 3.0 | 91.6 | 9.3 |
| 08P02 | 9/6/01 | 36.7991 | -76.2959 | 11.1 | 22.6 | 2.9 | 96.7 | 9.8 |
| 08P05 | 9/6/01 | 36.7983 | -76.2982 | 0.7 | 22.2 | 4.1 | 5.0 | 1.0 |
| 08P06 | 9/6/01 | 36.7988 | -76.2983 | 2.0 | 22.3 | 3.5 | 96.9 | 9.5 |
| 08P07 | 9/6/01 | 36.7980 | -76.2988 | 0.7 | 22.2 | 4.0 | 6.2 | 1.1 |
| 08P08 | 9/6/01 | 36.7991 | -76.2992 | 1.2 | 22.3 | 3.9 | 54.4 | 7.5 |
| 08P10 | 9/6/01 | 36.7985 | -76.3001 | 1.5 | 22.3 | 3.8 | 95.5 | 10.6 |
| 08P12 | 9/6/01 | 36.7979 | -76.3008 | 0.7 | 22.1 | 4.1 | 23.0 | 3.3 |
| 08P13 | 9/6/01 | 36.7986 | -76.3018 | 0.7 | 22.1 | 5.6 | 42.6 | 6.2 |
| 08P14 | 9/6/01 | 36.7989 | -76.3010 | 1.5 | 22.2 | 4.7 | 97.5 | 10.7 |
| 08P15 | 9/6/01 | 36.7999 | -76.3026 | 1.5 | 22.2 | 4.2 | 94.2 | 10.6 |
| 08P16 | 9/6/01 | 36.8000 | -76.3026 | 1.5 | 22.2 | 4.3 | 93.3 | 10.6 |
| 08P17 | 9/6/01 | 36.8005 | -76.3033 | 1.5 | 22.2 | 4.2 | 95.3 | 10.8 |
| 08P18 | 9/6/01 | 36.8011 | -76.3039 | 1.0 | 22.1 | 4.9 | 15.6 | 1.7 |
| 08P19 | 9/6/01 | 36.8002 | -76.3056 | 0.7 | 22.1 | 4.7 | 48.0 | 7.5 |
| 08P20 | 8/30/01 | 36.8012 | -76.3068 | 1.1 | 19.9 | 4.2 | 81.6 | 12.2 |
| 08P21 | 8/30/01 | 36.8017 | -76.3065 | 1.0 | 18.7 | 4.8 | 84.2 | 9.3 |
| 08P22 | 8/30/01 | 36.8030 | -76.3078 | 0.9 | 17.6 | 5.3 | 74.1 | 11.6 |
| 08P23 | 8/30/01 | 36.8035 | -76.3087 | 1.0 | 18.7 | 4.2 | 83.3 | 10.6 |
| 08P24 | 8/30/01 | 36.8042 | -76.3098 | 1.0 | 18.5 | 3.9 | 94.8 | 11.0 |
| 08P25 | 8/30/01 | 36.8064 | -76.3112 | 1.0 | 17.4 | 3.2 | 93.5 | 12.2 |
| 08P26 | 8/30/01 | 36.8049 | -76.3103 | 1.0 | 19.4 | 3.0 | 58.1 | 8.3 |
| 08P27 | 8/30/01 | 36.7981 | -76.3012 | 0.7 | 20.4 | 4.7 | 13.2 | 1.1 |
| 08P28 | 8/30/01 | 36.7987 | -76.2970 | 1.1 | 21.5 | 4.6 | 51.7 | 4.2 |
| 08P29 | 8/30/01 | 36.8005 | -76.3063 | 1.0 | 19.5 | 4.5 | 54.2 | 49.3 |

Table 8. Random Stations of Paradise Creek sampled in 2001. 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 | Deep Deposit Feeder Abundance |
|---|---|---|---|---|---|---|---|---|---|---|
| 08P01 | 2.3 | 25787 | 1.383 | 1.12 | 20.3 | 74.8 | 13.1 | 78.7 | 0.5 | 76.9 |
| 08P02 | 2.3 | 22431 | 1.905 | 1.14 | 15.5 | 80.4 | 10.7 | 61.9 | 1.0 | 82.3 |
| 08P05 | 2.7 | 7416 | 2.268 | 2.05 | 5.2 | 11.3 | 2.0 | 52.0 | 63.9 | 23.5 |
| 08P06 | 2.3 | 36016 | 2.041 | 0.89 | 18.3 | 79.8 | 7.8 | 70.0 | 0.6 | 80.9 |
| 08P07 | 2.3 | 8664 | 1.928 | 2.07 | 6.5 | 17.3 | 9.4 | 10.6 | 66.2 | 29.3 |
| 08P08 | 2.3 | 23406 | 2.291 | 1.56 | 12.1 | 74.9 | 4.0 | 32.7 | 10.3 | 76.7 |
| 08P10 | 2.0 | 7847 | 0.930 | 1.81 | 17.1 | 64.7 | 7.3 | 26.8 | 3.8 | 72.3 |
| 08P12 | 3.0 | 13132 | 3.107 | 2.79 | 20.9 | 8.6 | 2.9 | 9.5 | 33.7 | 45.3 |
| 08P13 | 2.0 | 13177 | 2.109 | 2.55 | 27.5 | 15.5 | 7.5 | 20.4 | 19.3 | 54.0 |
| 08P14 | 1.7 | 14855 | 1.452 | 1.70 | 15.9 | 68.7 | 6.3 | 25.0 | 6.4 | 71.6 |
| 08P15 | 1.7 | 27874 | 2.132 | 1.29 | 17.1 | 75.3 | 6.4 | 24.5 | 2.5 | 79.5 |
| 08P16 | 1.7 | 21909 | 1.270 | 1.52 | 35.0 | 58.2 | 14.3 | 21.4 | 2.6 | 61.6 |
| 08P17 | 1.7 | 28327 | 2.064 | 1.28 | 20.8 | 69.0 | 7.7 | 28.6 | 0.4 | 78.5 |
| 08P18 | 3.0 | 32568 | 2.087 | 1.59 | 13.6 | 67.8 | 9.8 | 44.6 | 5.4 | 81.4 |
| 08P19 | 2.0 | 12429 | 2.563 | 2.45 | 21.9 | 45.3 | 7.1 | 17.7 | 17.9 | 63.1 |
| 08P20 | 2.0 | 36560 | 1.565 | 1.09 | 8.7 | 82.0 | 5.8 | 47.8 | 2.9 | 88.5 |
| 08P21 | 1.7 | 12723 | 0.680 | 1.29 | 31.2 | 62.9 | 20.0 | 20.0 | 0.5 | 67.4 |
| 08P22 | 2.7 | 3674 | 1.043 | 2.29 | 23.5 | 32.1 | 2.2 | 13.0 | 4.3 | 71.6 |
| 08P23 | 2.0 | 3651 | 0.544 | 1.53 | 62.7 | 20.5 | 8.3 | 8.3 | 1.9 | 34.8 |
| 08P24 | 1.3 | 11589 | 0.635 | 1.65 | 53.8 | 21.9 | 32.1 | 3.6 | 1.2 | 45.0 |
| 08P25 | 2.0 | 8891 | 1.134 | 1.99 | 52.6 | 3.1 | 18.0 | 2.0 | 13.8 | 34.2 |
| 08P26 | 1.3 | 6668 | 0.454 | 1.45 | 59.5 | 29.3 | 30.0 | 30.0 | 0.7 | 39.1 |
| 08P27 | 3.0 | 13041 | 1.701 | 1.58 | 13.6 | 72.3 | 8.0 | 25.3 | 13.0 | 73.6 |
| 08P28 | 2.3 | 30119 | 1.633 | 0.87 | 13.6 | 84.4 | 5.6 | 72.2 | 1.7 | 84.6 |
| 08P29 | 2.3 | 272 | 0.249 | 2.86 | 16.7 | 50.0 | 27.3 | 45.5 | 58.3 | 16.7 |
| Mean | 2.1 | 16921 | 1.567 | 1.70 | 24.1 | 50.8 | 10.9 | 31.7 | 13.3 | 61.3 |
| Std. error | 0.02 | 428 | 0.029 | 0.02 | 0.7 | 1.1 | 0.3 | 0.9 | 0.8 | 0.9 |

Table 9. Random Stations of Paradise Creek sampled in 2001. 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 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 08P01 | 2.3 | 5 | 2 | 1 | 1 | 3 | | | 3 | 5 | 1 | |
| 08P02 | 2.3 | 5 | 2 | 1 | 1 | 3 | | | 3 | 5 | 1 | |
| 08P05 | 2.7 | 5 | 1 | 1 | 3 | 3 | | 1 | 5 | | | 3 |
| 08P06 | 2.3 | 5 | 2 | 1 | 1 | 3 | | | 3 | 5 | 1 | |
| 08P07 | 2.3 | 5 | 1 | 1 | 1 | 3 | | 1 | 3 | | | 5 |
| 08P08 | 2.3 | 5 | 2 | 1 | 1 | 3 | | | 5 | 3 | 1 | |
| 08P10 | 2.0 | 5 | 2 | 1 | 3 | 3 | | | 3 | 1 | 1 | |
| 08P12 | 3.0 | 5 | 1 | 3 | 1 | 3 | | 1 | 5 | | | 5 |
| 08P13 | 2.0 | 5 | 2 | 3 | 1 | 3 | | | 3 | 1 | 1 | |
| 08P14 | 1.7 | 5 | 2 | 1 | 1 | 3 | | | 3 | 1 | 1 | |
| 08P15 | 1.7 | 5 | 2 | 1 | 1 | 3 | | | 3 | 1 | 1 | |
| 08P16 | 1.7 | 5 | 2 | 1 | 1 | 3 | | | 3 | 1 | 1 | |
| 08P17 | 1.7 | 5 | 2 | 1 | 1 | 3 | | | 3 | 1 | 1 | |
| 08P18 | 3.0 | 5 | 1 | 1 | 1 | 3 | | 5 | 3 | | | 5 |
| 08P19 | 2.0 | 5 | 2 | 3 | 1 | 3 | | | 3 | 1 | 1 | |
| 08P20 | 2.0 | 5 | 2 | 1 | 1 | 3 | | | 3 | 3 | 1 | |
| 08P21 | 1.7 | 5 | 2 | 1 | 1 | 3 | | | 3 | 1 | 1 | |
| 08P22 | 2.7 | 4 | 2 | 3 | 3 | 3 | | | 5 | 1 | 1 | |
| 08P23 | 2.0 | 5 | 2 | 1 | 3 | 3 | | | 3 | 1 | 1 | |
| 08P24 | 1.3 | 5 | 2 | 1 | 1 | 3 | | | 1 | 1 | 1 | |
| 08P25 | 2.0 | 4 | 2 | 1 | 1 | 3 | | | 3 | 1 | 3 | |
| 08P26 | 1.3 | 5 | 2 | 1 | 3 | 1 | | | 1 | 1 | 1 | |
| 08P27 | 3.0 | 5 | 1 | 1 | 1 | 3 | | 5 | 3 | | | 5 |
| 08P28 | 2.3 | 5 | 2 | 1 | 1 | 3 | | | 3 | 5 | 1 | |
| 08P29 | 2.3 | 5 | 2 | 3 | 1 | 1 | | | 1 | 3 | 5 | |

Table 10. Dominant taxa of random stations of Paradise Creek sampled in 2001. Dominant taxa by abundance. Taxon code: A = amphipod, B = bivalve, G = gastropod, I = isopod, N = Nemertean, O = oligochaete, P = polychaete.

| | Taxon | Abundance per $m^2$ |
|---|---|---|
| 1 | Mediomastus ambiseta (P) | 10368 |
| 2 | Streblospio benedicti (P) | 3261 |
| 3 | Tubificoides heterochaetus (O) | 1157 |
| 4 | Laeonereis culveri (P) | 867 |
| 5 | Cyathura polita (I) | 174 |
| 6 | Leitoscoloplos spp.(P) | 154 |
| 7 | Tubificidae spp.(O) | 149 |
| 8 | Leucon americanus | 134 |
| 9 | Eteone heteropoda (P) | 129 |
| 10 | Tubificoides spp. Group I (O) | 97 |
| 11 | Heteromastus filiformis (P) | 80 |
| 12 | Capitella capitata (P) | 76 |
| 13 | Paraprionospio pinnata (P) | 35 |
| 14 | Nemertea spp.(N) | 31 |
| 15 | Hobsonia florida (P) | 27 |

# Appendix

Table 1. 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 (#/$m^2$) | ³1050-4000 | 800-1050 or ³4000-5500 | <800 or ³5500 |
| 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 (#/$m^2$) | ³450-3350 | 180-450 or ³3350-4050 | <180 or ³4050 |
| Abundance of pollution-indicative taxa (%) | £27 | 27-95 | >95 |
| Abundance of pollution-sensitive taxa (%) | ³26 | 0.2-26 | <0.2 |
| Abundance of carnivores and omnivores (%) | ³35 | 15-35 | <15 |
| Tolerance Score | £6 | 6-9.05 | >9.05 |
| Tanypodini to Chironomidae abundance ratio (%) | £17 | 17-64 | >64 |
| **Low Mesohaline** | | | |
| Shannon-Wiener | ³2.5 | 1.7-2.5 | <1.7 |
| Abundance (#/$m^2$) | ³1500-2500 | 500-1500 or ³2500-6000 | <500 or ³6000 |
| Biomass (g/$m^2$) | ³5-10 | 1-5 or ³10-30 | <1 or ³30 |
| Abundance of pollution-indicative taxa (%) | £10 | 10-20 | >20 |
| Biomass of pollution-sensitive taxa (%) | ³80 | 40-80 | <40 |
| Biomass deeper than 5 cm (%) | ³80 | 10-80 | <10 |

Table 1. Continued.

| | Scoring Criteria | | |
|---|---|---|---|
| | **5** | **3** | **1** |
| **High Mesohaline Sand** | | | |
| Shannon-Wiener | ³3.2 | 2.5-3.2 | <2.5 |
| Abundance (#/$m^2$) | ³1500-3000 | 1000-1500 or ³3000-5000 | <1000 or ³5000 |
| Biomass (g/$m^2$) | ³3-15 | 1-3 or ³15-50 | <1 or ³50 |
| Abundance of pollution-indicative taxa (%) | £10 | 10-25 | >25 |
| Abundance of pollution-sensitive taxa (%) | ³40 | 10-40 | <10 |
| Abundance of carnivores and omnivores (%) | ³35 | 20-35 | <20 |
| **High Mesohaline Mud** | | | |
| Shannon-Wiener | ³3.0 | 2.0-3.0 | <2.0 |
| Abundance (#/$m^2$) | ³1500-2500 | 1000-1500 or ³2500-5000 | <1000 or ³5000 |
| Biomass (g/$m^2$) | ³2-10 | 0.5-2 or ³10-50 | <0.5 or ³50 |
| Biomass of pollution-indicative taxa (%) | £5 | 5-30 | >30 |
| Biomass of pollution-sensitive taxa (%) | ³60 | 30-60 | <30 |
| Abundance of carnivores and omnivores (%) | ³25 | 10-25 | <10 |
| Biomass deeper than 5 cm (%) | ³60 | 10-60 | <10 |
| **Polyhaline Sand** | | | |
| Shannon-Wiener | ³3.5 | 2.7-3.5 | <2.7 |
| Abundance (#/$m^2$) | ³3000-5000 | 1500-3000 or ³5000-8000 | <1500 or ³8000 |
| Biomass (g/$m^2$) | ³5-20 | 1-5 or ³20-50 | <1 or ³50 |
| Biomass of pollution-indicative taxa (%) | £5 | 5-15 | >15 |
| Abundance of pollution-sensitive taxa (%) | ³50 | 25-50 | <25 |
| Abundance of deep-deposit feeders (%) | ³25 | 10-25 | <10 |

Table 1. Continued.

| | Scoring Criteria | | |
|---|---|---|---|
| | **5** | **3** | **1** |
| **Polyhaline Mud** | | | |
| Shannon-Wiener | ³3.3 | 2.4-3.3 | <2.4 |
| Abundance (#/$m^2$) | ³1500-3000 | 1000-1500 or ³3000-8000 | <1000 or ³8000 |
| Biomass ($g/m^2$) | ³3-10 | 0.5-3 or ³10-30 | <0.5 or ³30 |
| Biomass of pollution-indicative taxa (%) | £5 | 5-20 | >20 |
| Biomass of pollution-sensitive taxa (%) | ³60 | 30-60 | <30 |
| Abundance of carnivores and omnivores | ³40 | 25-40 | <25 |
| Number of taxa >5 cm below the sediment-water interface (%) | ³40 | 10-40 | <10 |