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BENTHIC BIOLOGICAL MONITORING PROGRAM OF THE ELIZABETH RIVER WATERSHED (2006)

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EXECUTIVE SUMMARY

Macrobenthic communities of the Elizabeth River watershed have been quantitatively sampled since summer 1999. This report presents the data from the eigth year of sampling in 2006. 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 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. The areal extent of degraded bottom in 2006 was 80 ± 15.7%. 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, 72 ± 17.6 % in 2002, 80 ± 15.7 % in 2003, 84 ± 12.7% in 2004, 84 ± 12.7% in 2005, and 80 ± 15.7% in 2006. Average B-IBI values for the Elizabeth River watershed were 2.7, 2.6, 2.7, 2.4, 2.3, 2.2, 2.2 and 2.4 respectively for the years 1999-2006.

Trend analyses were conducted using the data from the 14 fixed point stations for the period 1999-2006. A single station in the Lafayette River showed an improving trend in the B-IBI (LFB1). Using the approach of the Chesapeake Bay Program, the status of each of the 14 fixed-point stations was characterized using the median value of the B-IBI for the last three years (2004-2006). A single station had a B-IBI value over 3.0 (ELD1), one station was Marginal (ELC1) and all other fixed-point stations had a degraded or severely degraded status. Of the 26 significant trends in individual B-IBI metrics, 19 were improving trends and seven were degrading trends. Of the seven degrading trends, four were in the diversity index metric.

In general for the Elizabeth River watershed, benthic community species diversity and biomass remain below reference condition levels while abundance was often above reference condition levels and considered excessive. 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 are 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, 2003, 2004, 2005, 2006). This study updates the benthic community characterization of the Elizabeth River watershed base upon data collected in 2006.

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). 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 16.

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 and 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 and have an equal probability of being sampled. 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 ºC and ashing at 550 ºC 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. Only the percent sand and percent silt-clay fraction were estimated. 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. Habitat specific metrics and scoring thresholds are presented in Appendix A.

Benthic community condition was classified into four levels based on the B-IBI. Values $\leq$ 2 were classified as **severely degraded**; values from 2.1 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. 2002a,b; Llansó et al 2004; Dauer et al. 2006, 2007).

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 and Appendix A of this report).

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 coded 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

Benthic Community Condition using Probability-Based Sampling

Environmental Parameters

All physical, chemical and sedimentary parameters are summarized in Table 1. Water depths varied from less than 1m to 16.5m reflecting shoal and channel depths. All salinity values were in the polyhaline range (18-32). No stations had bottom dissolved oxygen measurements below 2.0 ppm. Macrobenthic communities are generally not altered by low dissolved oxygen unless values fall below at least 2.0 ppm (Diaz and Rosenberg 1995). As in previous collection years, silt-clay content varied widely from less than 5% to greater than 95% and total volatile solids values were less than 3%.

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 2006 data, 80 ± 15.7 % 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. Density dominants changed little from previous years with polychaete and oligochaete species such as *Mediomastus ambiseta*, *Streblospio benedicti*, *Paraprionospio pinnata*, *Leitoscoloplos* spp., *Glycinde solitaria* and *Tubificoides* spp.

The B-IBI value, Shannon's index, abundance, biomass and the proportion of pollution sensitive and pollution indicative species for 1999-2006 are shown in Figs. 4-9. The 1999 value is the area-weighted average for the five strata sampled in that year.

Benthic Community Trends using 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.   Figure 7 lists the status of the 14 fixed-point stations. Status is determined by the three year (2004-2006) average B-IBI values at each station. Only station ELD1 had a B-IBI value of 3.0 or higher - a value meaning that the Benthic Restoration Goals of the B-IBI were met. One station had a marginal status value of the B-IBI (station ELC1 in the Mainstem) and all other stations had a degraded or severely degraded status.

One station showed a trend in the B-IBI at $p<0.05$ (LFB1). Of the 26 significant trends in individual B-IBI metrics, 19 were improving trends and only seven were degrading trends. Of the seven degrading trends, four were in the diversity index metric.

Summary Patterns in the B-IBI and Selected Metrics

Mainstem

- ❒ **Benthic Index of Biotic Integrity:** From 2004-2006, the B-IBI values for stations ELC1 and ELD1 were generally close to or above 3.0. Station ELF1 was consistently below 3.0.

- ❒ **Species Diversity:** The mouth stations (ELC1 and ELD1) had higher diversity values than Station ELF1 (2.9, 2.7, 2.4, respectively).

- ❒ **Abundance:** In general the Mainstem stations had the lowest abundances compared to the other branches of the river.

- ❒ **Biomass:** No patterns were obvious in biomass values. In all branches of the river most biomass values were around 1.0 g AFDW m^{-2}. All values were generally considered to be at insufficient levels relative to the Benthic Restoration Goals.

- ❒ **Community Composition:** The mouth stations (ELC1 and ELD1) had a percent composition of Pollution Indicative Species Abundance that was generally less than 30% while the relative abundance of Pollution Sensitive Species was above 50%.

Southern Branch

- ❒ **Benthic Index of Biotic Integrity:** In general the lowest B-IBI values were found in the Southern Branch with three of the sex stations having a severely degraded status. The upstream station (SBD4) had the highest value with the 2006 value at 3.0.

- ❒ **Species Diversity:** Compared to the Mainstem stations, species diversity values in the Southern Branch were more consistent with the upper Mainstem Station ELF1 and were generally lower than the two Mainstem Stations near the mouth of the Elizabeth River.

- ❒ **Abundance:** Community abundance values were much higher than in the Mainstem mouth stations (ELCI, ELDI) with three of the six stations having 2006 values exceeding 5,000 individuals m^{-2}. Such an abundance is considered to be excessive relative to the Benthic Restoration Goals.

- ❒ **Biomass:** No patterns were obvious in biomass values with most values less than 1.5 AFDW g m^{-2}. The farthest upstream stations generally had the lowest biomass. In all branches of the river most biomass values were around 1.0 g AFDW m^{-2} . All values were generally considered to be at insufficient levels relative to the Benthic Restoration Goals.

- ❒ **Community Composition:** After 1999 the level of Pollution Indicative Species Abundance declined and was mostly below 30%. There was a general increase in

Pollution Sensitive Species after 1999 due primarily to increased abundances of the pollution sensitive polychaete *Mediomastus ambiseta*.whose abundance changes over time are responsible for most of the patterns of change in community composition.

Western and Eastern Branches

- **Benthic Index of Biotic Integrity:** The B-IBI values for the Western Branch were generally below 3.0 and slightly higher at the upper station WBB5. However, the three year status values for both stations are in the degraded category. The Eastern Branch station was 3.3 in 2006 but the three year status value is still in the degraded category (2.6).

- **Species Diversity:** Species diversity values were low at both Western Branch stations and the at 2.65 in the Eastern Branch.

- **Abundance:** Community abundance values were higher than in the Mainstem Stations and exceeded 7,000 individuals m^{-2} at both Western Branch stations.

- **Biomass:** Biomass values at WBB5 and EBB1 were the two highest recorded in 2006 at the fixed-point stations. These high values were due to settlement of the bivalve *Macoma balthica*. In all branches of the river most biomass values were around 1.0 g AFDW m^{-2} with some stations reaching their highest value in the last year or two. All values were generally considered to be at insufficient levels relative to the Benthic Restoration Goals.

- **Community Composition:** In general in both branches Pollution Indicative Species declined while Pollution Sensitive Species composition increase - a pattern due to increased abundances of the pollution sensitive polychaete *Mediomastus ambiseta* and the pollution sensitive bivalve *Macoma balthica*.

Lafayette River

- **Benthic Index of Biotic Integrity:** Station LFB1 showed a significant, but slight increase in the B-IBI. Both station B-IBI values remain below the Benthic Restoration Goals.

- **Species Diversity:** Species diversity values were higher at the lower station and declined in the later years in the upper station.

- **Abundance:** Community abundance levels were more comparable to the Mainstem and these values were lower then the Southern Branch, Western Branch and Eastern Branch values. Abundance values were variable at the lower station and generally increased at the upper station. Values at LFA1were in the range of 3,000 to 5,000 individuals m^{-2}, a range often resulting in the maximum B-IBI metric score of 5.

- ❒ **Biomass:** In all branches of the river most biomass values were around 1.0 g AFDW m^{-2} with some stations reaching their highest value in the last year or two. All values were generally considered to be at insufficient levels relative to the Benthic Restoration Goals.

- ❒ **Community Composition:** Pollution Indicative Species Abundance has decreased in the later years while Pollution Sensitive Species Abundance pattern has increase particularly at station LFB1.

Water Quality of the Elizabeth River

Nutrient levels in all branches of the Elizabeth River are characterized by the Chesapeake Bay Program criteria as having a fair to poor status; however, there are several improving trends (Dauer et al. 2007). Surface nitrogen (STN and BTN) showed improving trends in almost all branches. The previously widespread improvements in dissolved inorganic nitrogen in all branches is now limited trends in surface DIN in the Southern Branch. Total phosphorus and dissolved inorganic phosphorus improving in all branches except the mainstem. Chlorophyl levels (SCHLA) had a good status in both the Southern Branch and the Eastern Branch, and fair status in the Mainstem and the Western Branch. Indicators of water clarity, total suspended solids (STSS, BTSS) generally showed improving trends an all branches. Finally, bottom dissolved oxygen status remains good to fair with improving trends in the Southern branch and Eastern Branch.

DISCUSSION

Watershed Level Condition of Benthic Communities

Probability-based sampling allows an annual characterization of the overall condition of the benthic communities of the Elizabeth River watershed. 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 all future analyses. 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 has been sampled as a single stratum of 25 random samples.

In 2004 and 2005 the average watershed-level value for the B-IBI was the lowest recorded since 1999 and the area of benthic not meeting the Chesapeake Bay Benthic Restoration Goals was the highest recorded since 1999. Average B-IBI values for the Elizabeth River watershed were 2.4 (2006), 2.2 (2005), 2.2 (2004), 2.3 (2003), 2.4 (2002), 2.7 (2001), 2.6 (2000), 2.7 (1999) (see Dauer and Rodi 1999; Dauer 2000, 2001, 2002, 2003, 2004, 2005,2006). Based upon probability-based sampling, the estimate of benthic bottom not meeting the benthic restoration goals were 80 ± 15.7 % in 2006, 84 ± 12.7% in 2005, 84 ± 12.7% in 2004, 80 ± 15.7 % in 2003, 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).

Long-term trends of Benthic Communities

Long-trend analyses in values of the B-IBI were conducted for the period 1999-2006. One station showed a trend in the B-IBI at $p<0.05$ with two stations showing improvements (LFB1). Of the 26 significant trends in individual B-IBI metrics, 19 were improving trends and seven were degrading trends. Of the seven degrading trends, four were in the diversity index metric.

Water Quality of the Elizabeth River

The water quality of the Elizabeth River can be generally characterized as follows: (1) nutrients have a poor status indicating high concentration levels, (2) there were improvements in long-term trends in surface total nitrogen levels (STN), and (3) widespread improvements in long-term trends in surface total phosphorus levels (STP) (Dauer et al. 2007). Nitrogen levels are highest in the Southern Branch with smaller differences between the branches of the river for phosphorus levels. The nutrient level in the Elizabeth River are more comparable to levels in the upper reaches of the James River in oligohaline and tidal freshwater regions (Dauer et al. 2003a,b; 2005). Chlorophyll levels, indicative of algal blooms when high, are good in both the Eastern Branch and Southern Branch in spite of high nutrient levels and good water clarity. Chlorophyll levels are fair in the Western Branch but there is an improving long-term trend. The status of bottom dissolved oxygen was fair to good in all branches.

REFERENCES

Alden, R.W. III, D.M. Dauer, J.A. Ranasinghe, L.C. Scott, and R.J. Llansó. 2002. Statistical Verification of the Chesapeake Bay Benthic Index of Biotic Integrity. *Environmetrics* 13: 473- 498.

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

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

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

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

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

Dauer, D.M. 2001. Benthic Biological Monitoring Program of the Elizabeth River Watershed (2000). Final Report to the Virginia Department of Environmental Quality, Chesapeake Bay Program, 35 pp. Plus Appendix.

Dauer, D.M. 2002. Benthic Biological Monitoring Program of the Elizabeth River Watershed (2001) with a study of Paradise Creek. Final Report to the Virginia Department of Environmental Quality, Chesapeake Bay Program, 45 pp.

Dauer, D.M. 2003. Benthic Biological Monitoring Program of the Elizabeth River Watershed (2002). Final Report to the Virginia Department of Environmental Quality, Chesapeake Bay Program, 56 pp.

Dauer, D.M. 2004. Benthic Biological Monitoring Program of the Elizabeth River Watershed (2003). Final Report to the Virginia Department of Environmental Quality, Chesapeake Bay Program, 88 pp.

Dauer, D.M. 2005. Benthic Biological Monitoring Program of the Elizabeth River Watershed (2004). Final Report to the Virginia Department of Environmental Quality, Chesapeake Bay Program, 178 pp.

Dauer, D.M. 2006. Benthic Biological Monitoring Program of the Elizabeth River Watershed

(2005). Final Report to the Virginia Department of Environmental Quality, Chesapeake Bay Program, 171 pp.

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

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

Dauer, D.M. and R. J. Llansó. 2003. Spatial scales and probability based sampling in determining levels of benthic community degradation in the Chesapeake Bay. *Environmental Monitoring and Assessment* 81: 175-186.

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

Dauer, D.M., H.G. Marshall, K.E. Carpenter, J.R. Donat and M. F. Lane. 2003a. Status and trends in water quality and living resources in the Virginia Chesapeake Bay: James River (1985-2001). Final report to the Virginia Department of Environmental Quality. 108 pp.

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

Dauer, D.M., H.G. Marshall, J.R. Donat, M. F. Lane, S.C. Doughten and F.A. Hoffman. 2003b. Status and trends in water quality and living resources in the Virginia Chesapeake Bay: James River (1985-2002). Final report to the Virginia Department of Environmental Quality. 94 pp.

Dauer, D.M., H.G. Marshall, J.R. Donat, M. F. Lane, S.C. Doughten and F.A. Hoffman. 2005. Status and trends in water quality and living resources in the Virginia Chesapeake Bay: James River (1985-2003). Final report to the Virginia Department of Environmental Quality. 74 pp.

Dauer, D.M., H.G. Marshall, J.R. Donat, M. F. Lane, S. Doughten, P.l. Morton and F.J. Hoffman. 2006. Status and trends in water quality and living resources in the Virginia Chesapeake Bay: James River (1985-2004). Final report to the Virginia Department of Environmental Quality. 73 pp.

Dauer, D.M., H.G. Marshall, J.R. Donat, M. F. Lane, S. Doughten, P.l. Morton and F.J. Hoffman. 2007. Status and trends in water quality and living resources in the Virginia Chesapeake Bay: Rappahannock River (1985-2005). Final report to the Virginia Department of Environmental

Quality. 46 pp.

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

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

Diaz, R. J. and R. Rosenberg. 1995. Marine benthic hypoxia: a review of its ecological effects and the behavioural responses of benthic macrofauna. *Oceanography and Marine Biology Annual Review* 33:245-303.

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

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

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

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

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

Llansó, R.J., F.S. Kelley and L.S. Scott. 2004. Long-term benthic monitoring and assessment component. Level I Comprehensive Report. July 1984 – December 2003. Final report to the Maryland Department of Natural Resources.

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

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

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

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

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

Schenker, N. and J.F. Gentleman. 2001. On judging the significance of differences by examining the overlap between confidence intervals. *The American Statistician* 55: 182-186

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

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

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

Glossary of selected terms

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

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

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

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

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

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

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

Random Station - a station selected 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

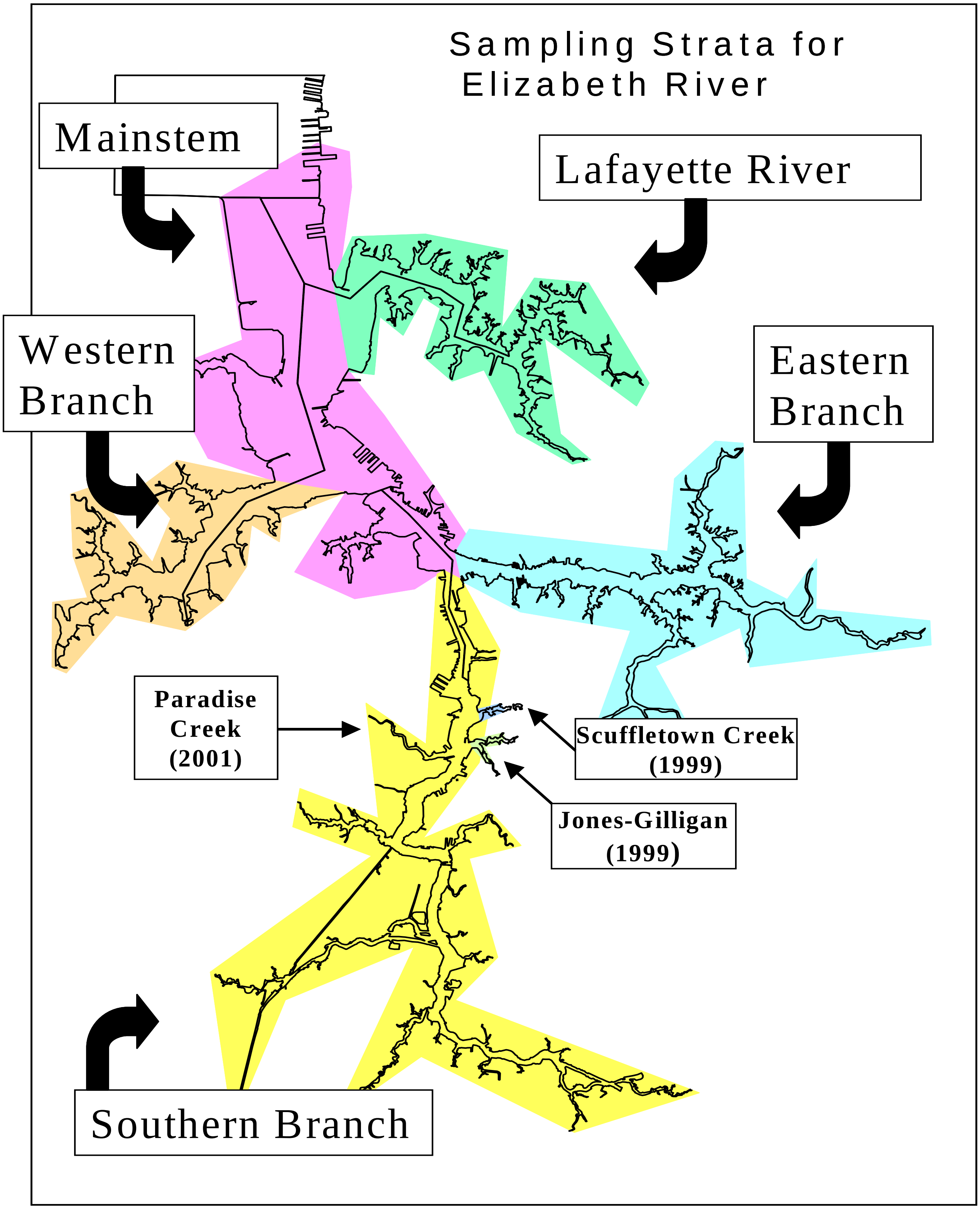

Figure 1. Elizabeth River watershed showing the five major segments sampled in 1999. Insert shows Scuffletown Creek and the Jones-Gilligan Creek strata also sampled in 1999 and Paradise Creek stratum sampled in 2001.

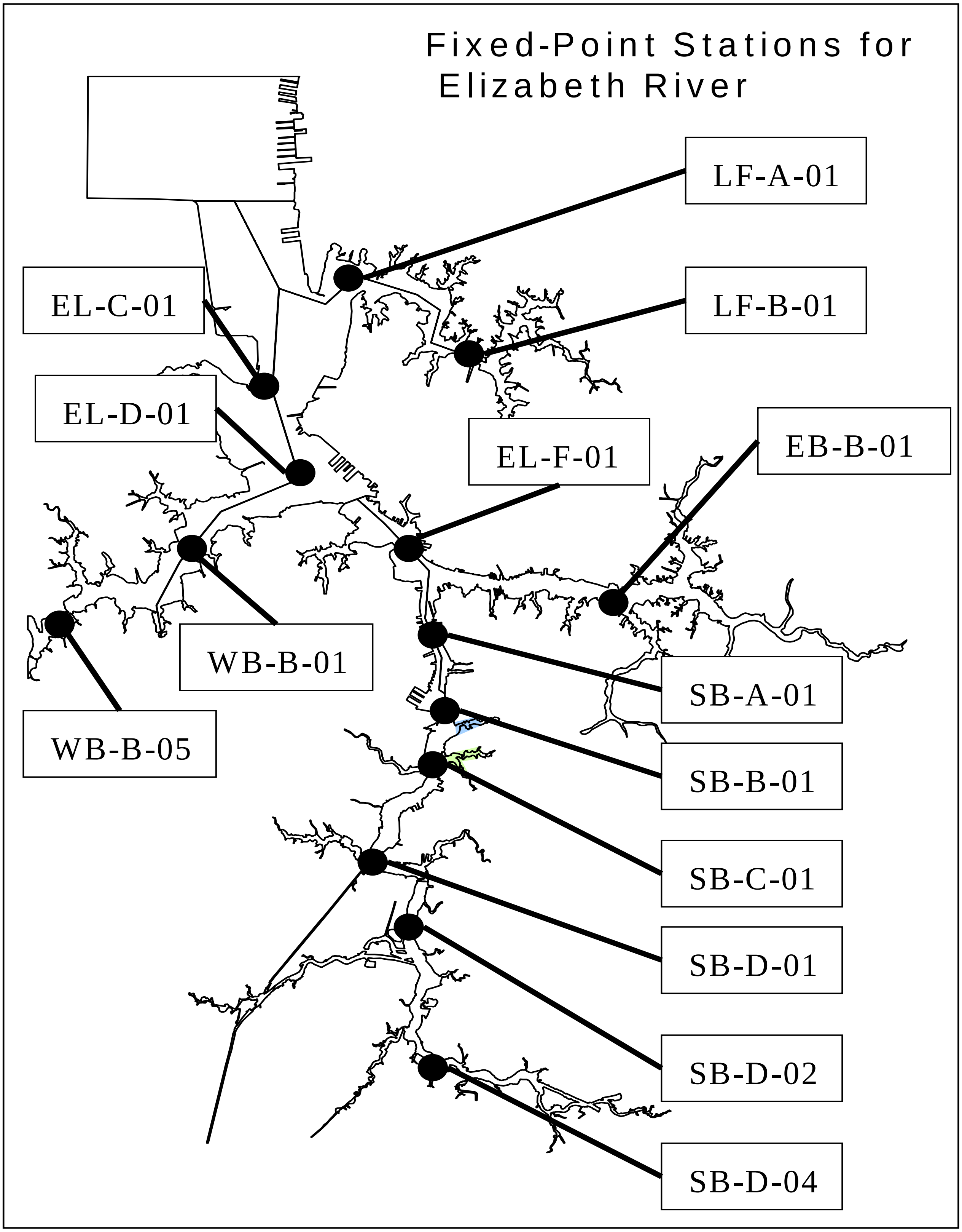

Figure 2. Elizabeth River watershed showing the 14 fixed-point stations for long-term trend analyses.

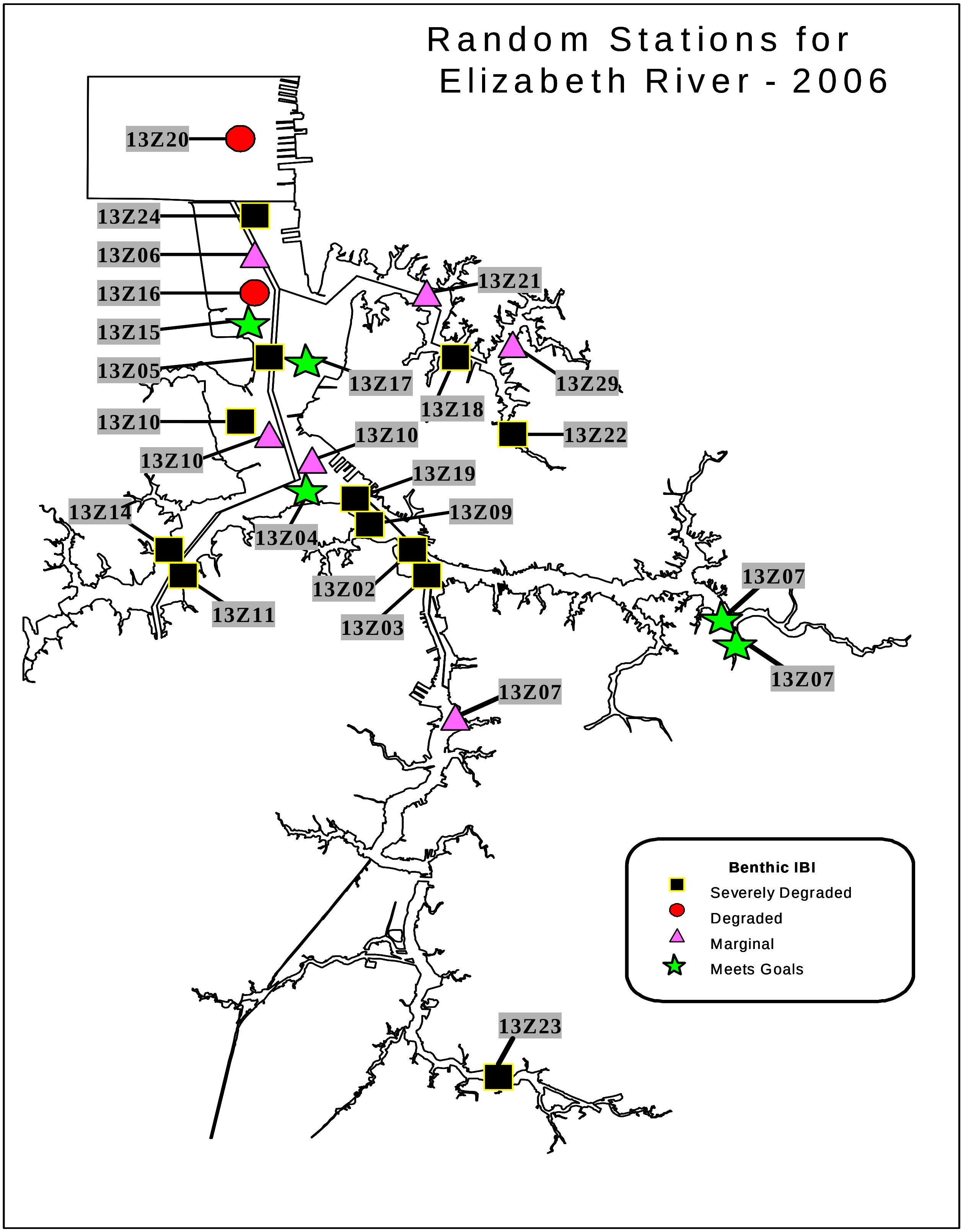

Figure 3. Random samples collected in 2006. Shown is the condition of the benthic communities using the B-IBI value.

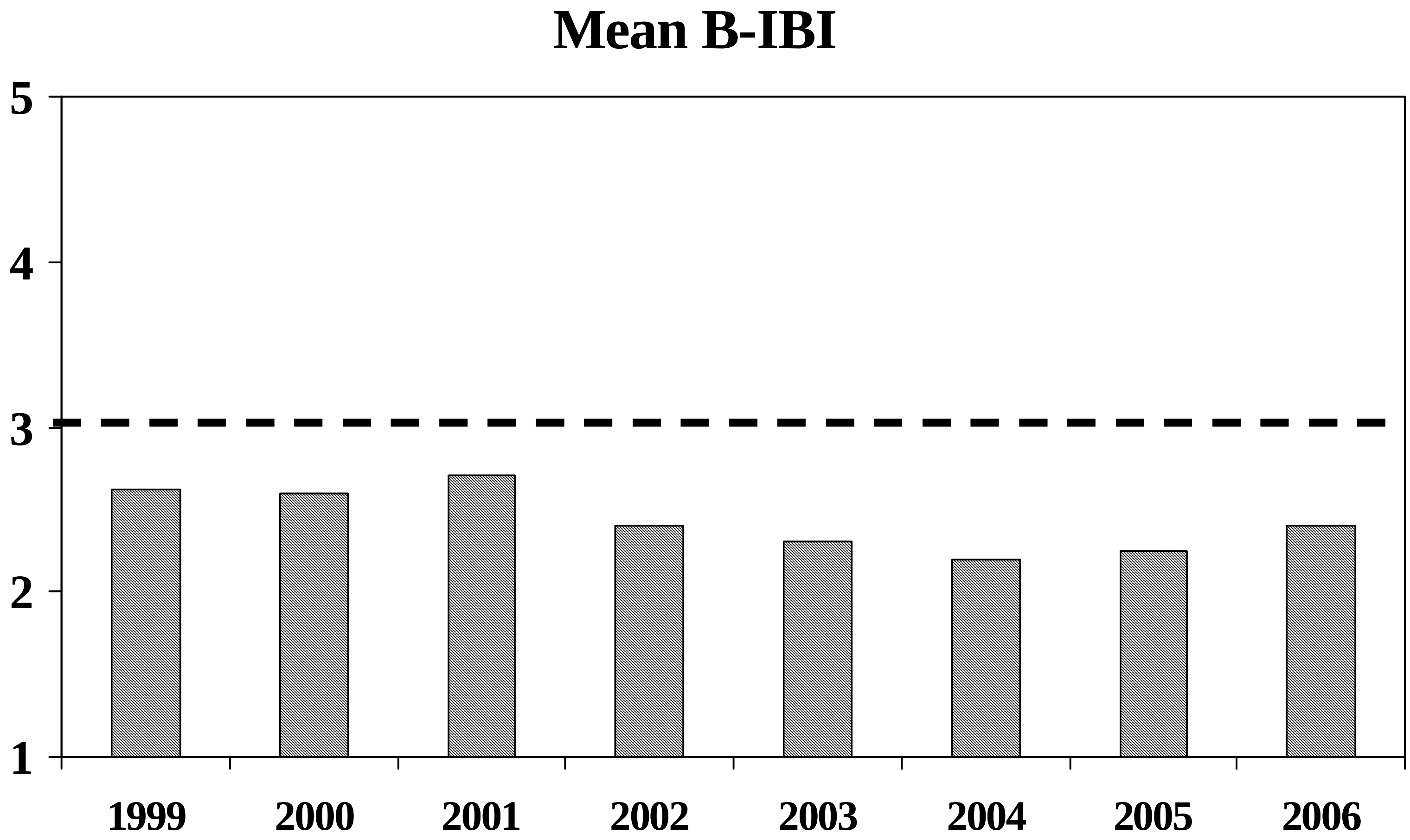

Figure 4. Benthic Index of Biotic Integrity. Shown are mean values for the entire Elizabeth River watershed from the probability-based program. Dashed line indicates restoration goal.

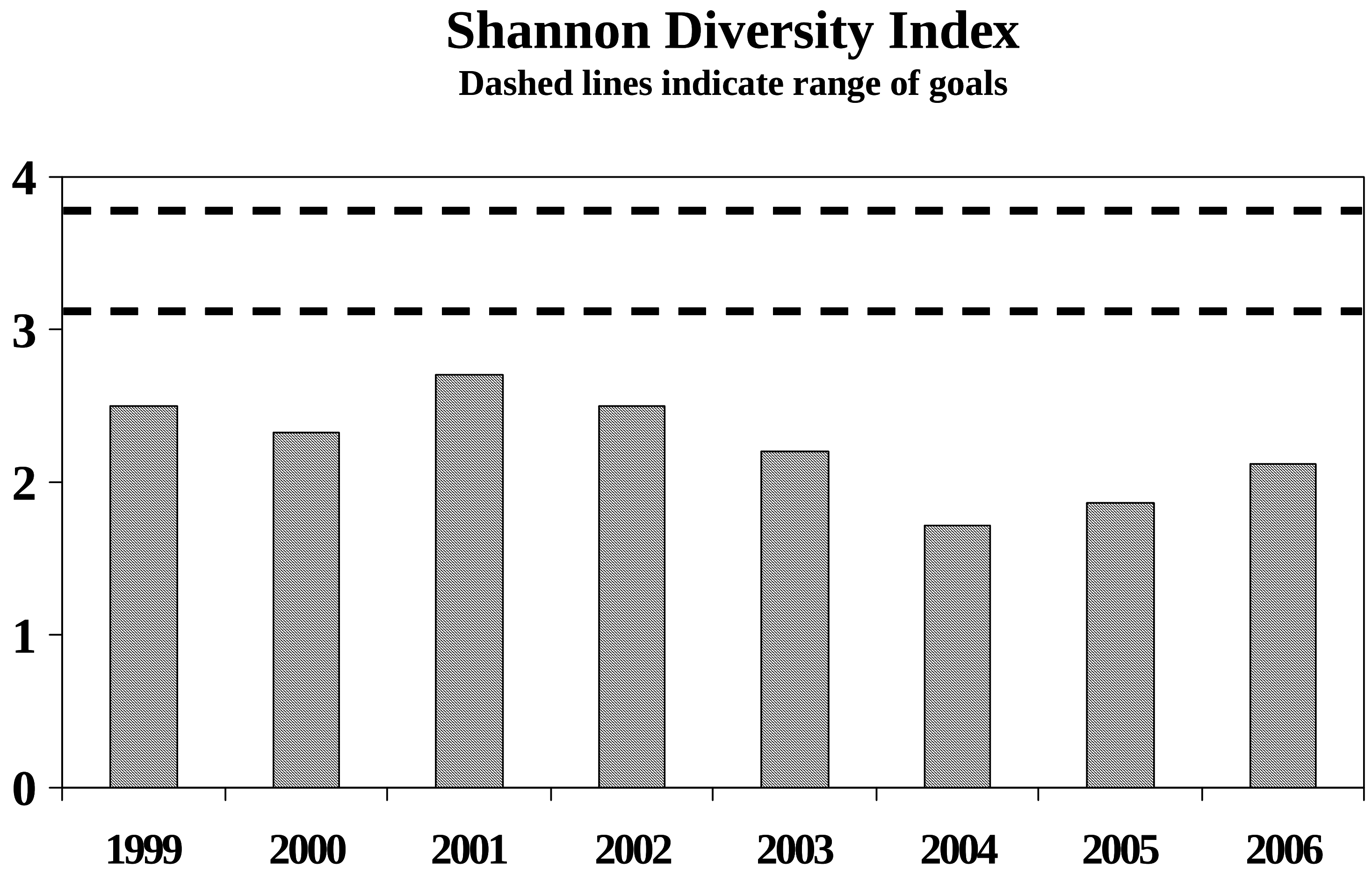

Figure 5. Shannon-Weiner Diversity Index. Shown are mean values for the entire Elizabeth River watershed from the probability-based program. Dashed Lines indicate range of restoration goals.

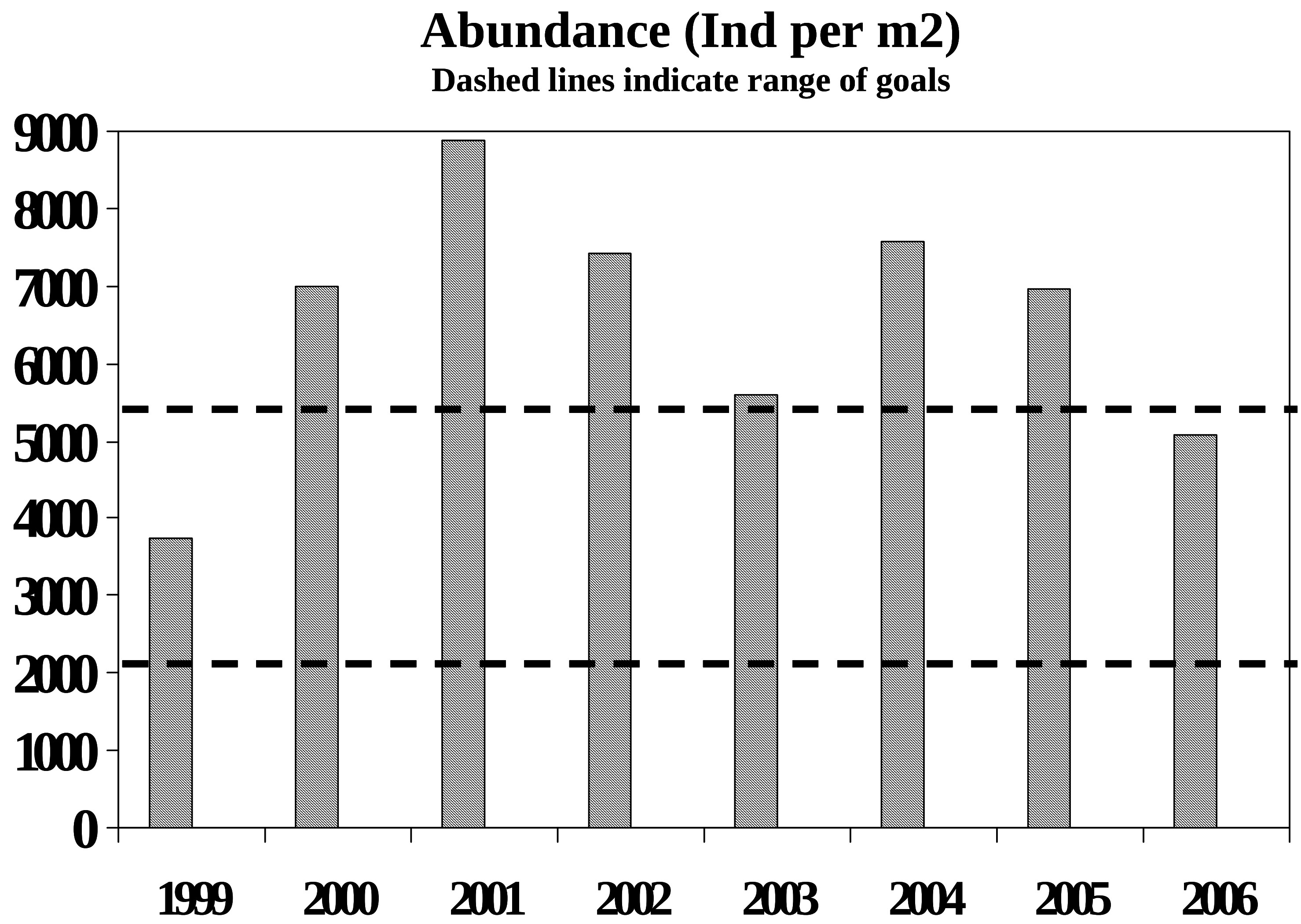

Figure 6. Abundance per m^2. Shown are mean values for the entire Elizabeth River watershed from the probability based program. Dashed lines indicates range of restoration goals.

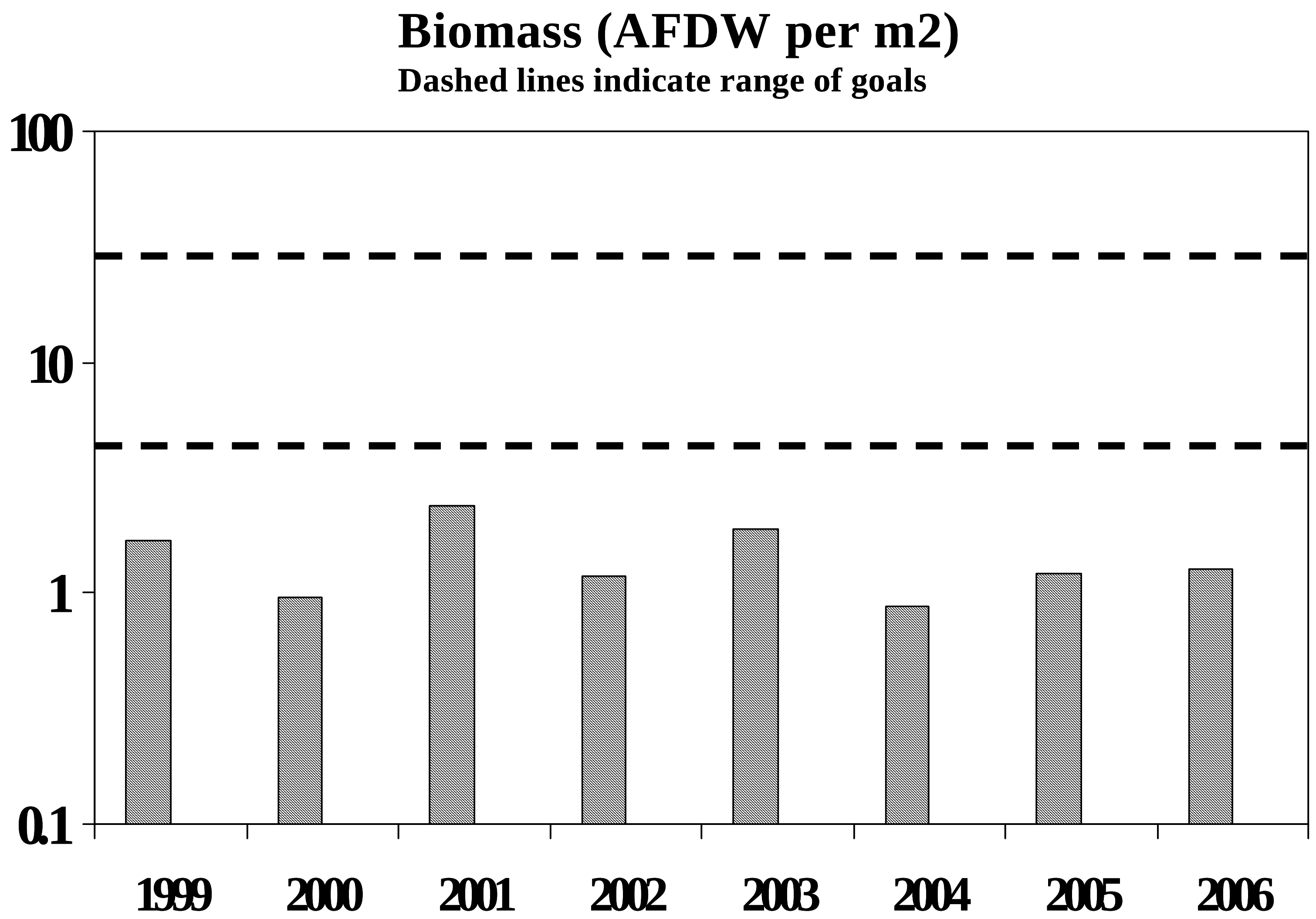

Figure 7. AFDW biomass per m_2. Shown are mean values for the entire Elizabeth River watershed from the probability based program. Dashed lines indicates range of restoration goals.

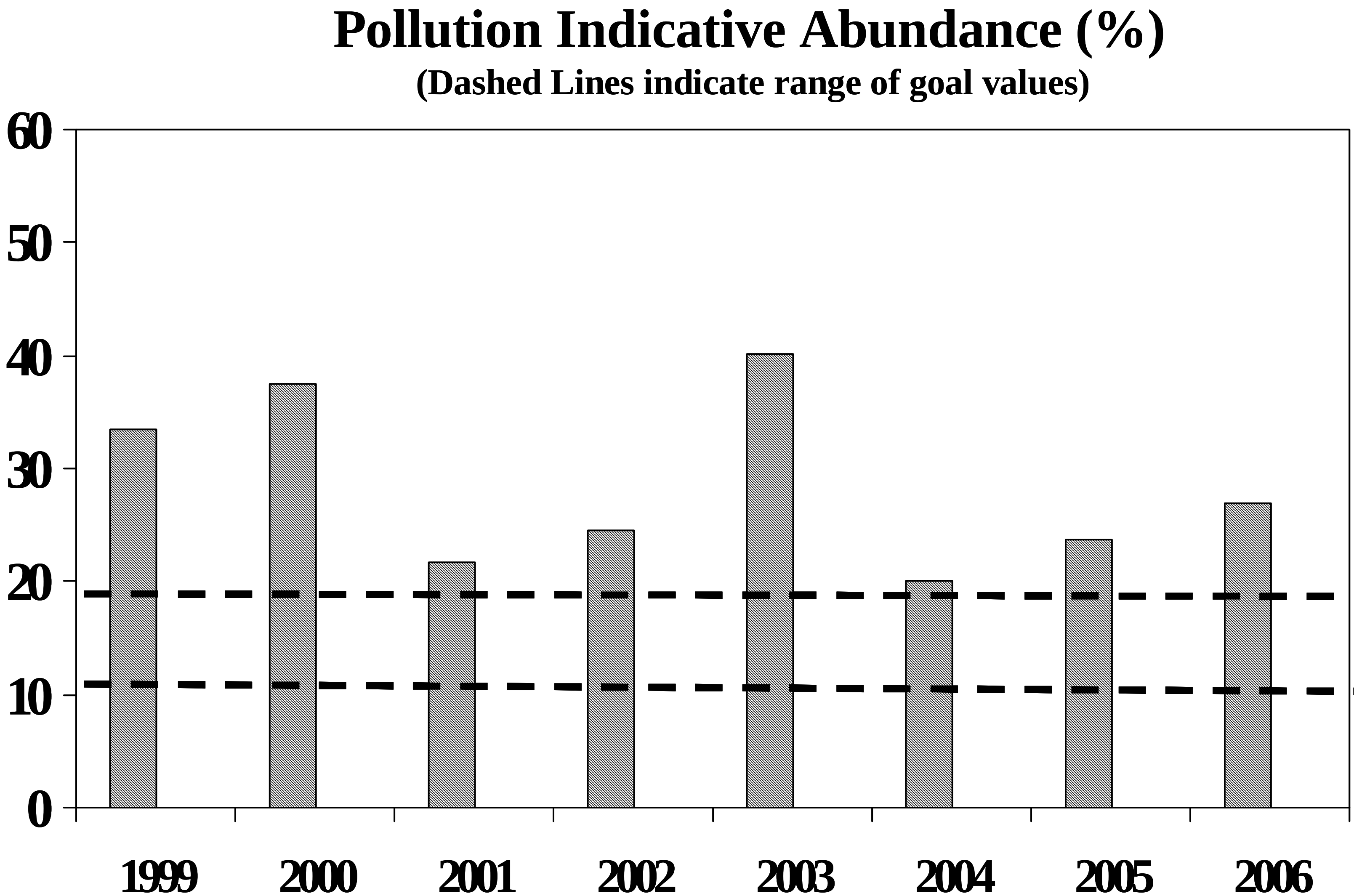

Figure 8. Percentage of Pollution Indicative Species Abundance. Shown are mean values for the entire Elizabeth River watershed from the probability-based program. Dashed lines indicates range of restoration goals.

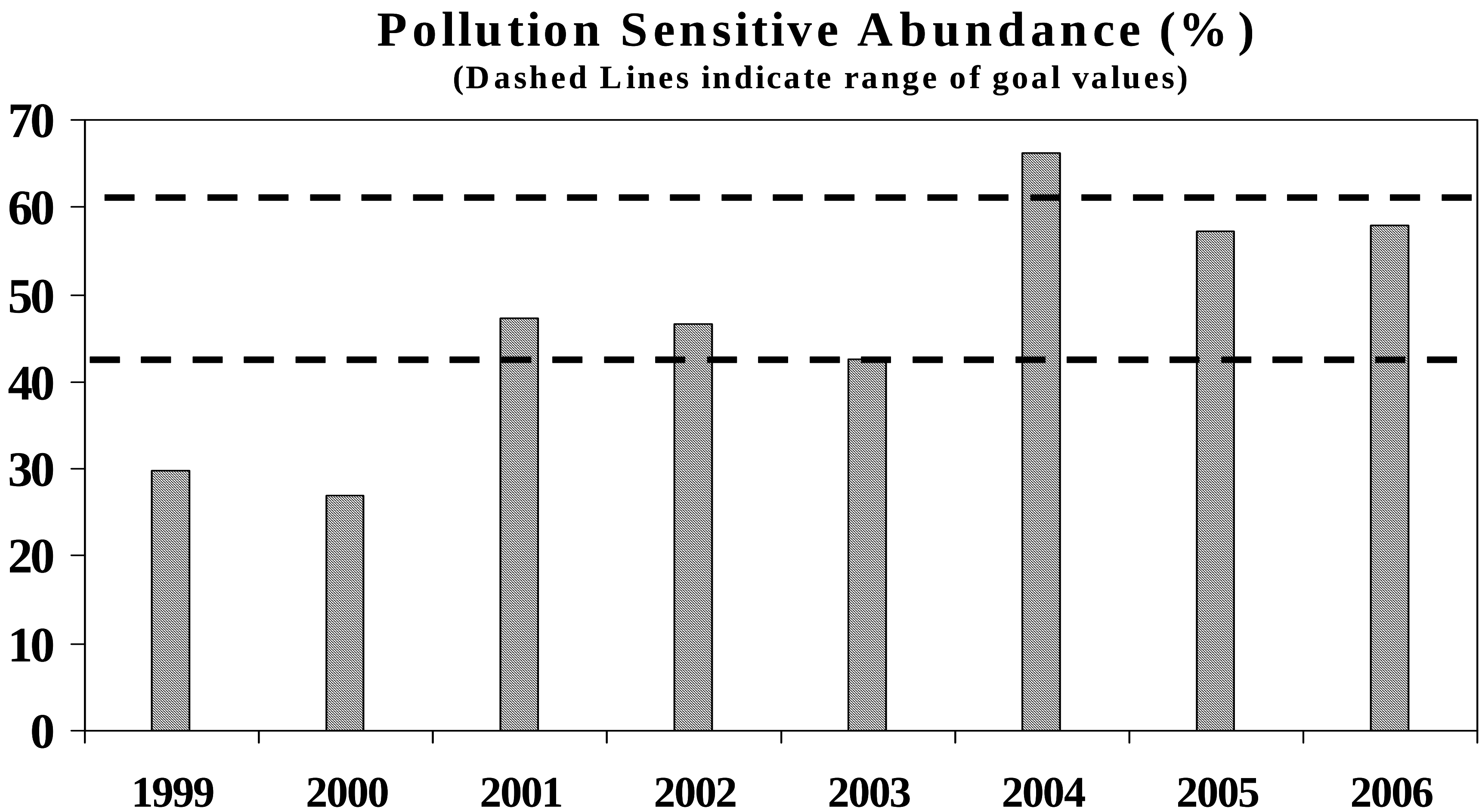

Figure 9. Percentage of Pollution Sensitive Species Abundance. Shown are mean values for the entire Elizabeth River watershed from the probability-based program. Dashed lines indicates range of restoration goals.

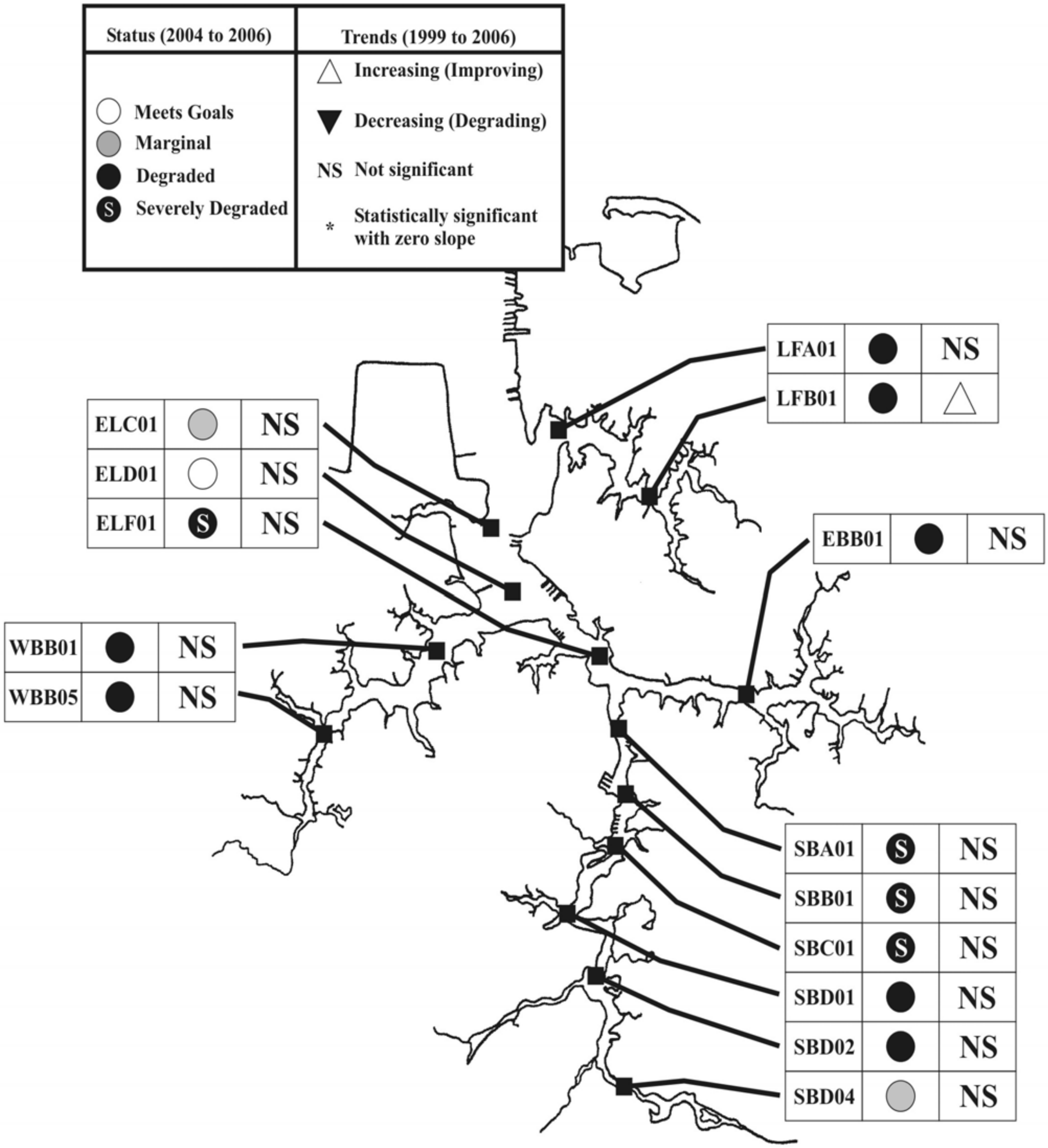

Figure 10. Status of and long-term trends in the Benthic IBI for the Elizabeth River Project monitoring stations for the period of 1999 through 2005. All trends shown were significant at $p \leq 0.05$.

Tables

Table1. Random Stations of the Elizabeth River sampled in 2006.
Summary of physical-chemical parameters.

STATION	Date	LATITUDE	LONGITUDE	Water depth (m)	Temperature (ºC)	Salinity (ppt)	Dissolved oxygen (ppm)	Silt_clay content (%)	Volatile organics (%)
13Z02	8/17/2006	36.853428	-76.303732	11.0	26.9	22.2	3.8	96.1	2.4
13Z03	8/17/2006	36.844805	-76.299310	5.5	27.3	22.4	3.8	89.8	2.4
13Z04	8/17/2006	36.859287	-76.326089	5.0	26.9	22.1	4.5	19.3	0.6
13Z05	8/21/2006	36.891081	-76.337671	9.2	26.5	22.6	4.4	61.4	1.4
13Z06	8/21/2006	36.913102	-76.340995	7.9	26.6	22.0	5.3	91.2	1.7
13Z07	8/15/2006	36.808760	-76.288070	3.5	28.7	22.5	3.4	20.6	2.1
13Z09	8/17/2006	36.851170	-76.313140	1.5	27.0	22.1	4.8	69.5	2.2
13Z10	8/21/2006	36.866323	-76.323279	14.2	25.5	24.2	3.9	94.7	2.3
13Z11	8/17/2006	36.837865	-76.360787	2.0	26.6	22.0	5.6	85.4	2.2
13Z12	8/21/2006	36.871749	-76.336352	6.0	26.5	22.3	5.1	32.8	1.3
13Z13	8/17/2006	36.831887	-76.214522	2.9	27.3	20.6	4.0	98.6	3.3
13Z14	8/17/2006	36.845215	-76.363131	2.0	26.8	22.0	4.8	90.4	2.2
13Z15	8/21/2006	36.895429	-76.341922	2.5	27.3	21.9	5.8	4.1	0.2
13Z16	8/21/2006	36.902945	-76.340237	6.8	26.7	22.1	5.2	58.4	1.7
13Z17	8/21/2006	36.885005	-76.323303	1.5	26.6	21.9	5.7	3.7	0.2
13Z18	8/21/2006	36.889929	-76.286041	1.0	29.6	21.4	6.9	84.2	2.3
13Z19	8/17/2006	36.859959	-76.319517	4.0	26.9	22.1	4.8	21.1	1.1
13Z20	8/21/2006	36.931137	-76.338063	15.8	25.1	25.8	3.8	97.0	2.6
13Z21	8/21/2006	36.903257	-76.299188	1.1	29.1	21.7	5.9	89.3	2.1
13Z22	8/21/2006	36.872686	-76.271968	0.7	31.1	19.1	11.2	97.7	4.1
13Z23	8/15/2006	36.731794	-76.278101	0.8	26.9	18.0	3.7	12.2	1.1
13Z24	8/21/2006	36.918987	-76.339651	16.5	25.1	25.5	4.0	98.5	2.8
13Z25	8/17/2006	36.827995	-76.214230	1.0	26.7	17.9	5.8	95.4	4.4
13Z27	8/21/2006	36.874848	-76.342680	6.0	26.6	22.2	5.2	45.4	1.4

Table 2. Random Stations of the Elizabeth River sampled in 2006. Summary of benthic community parameters. Abundance reported in ind/m2, 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
13Z02	2.0	4,513	1.27	2.26	34.67	56.78	35.71	53.57	3.52	57.79
13Z03	1.7	3,924	0.68	1.75	34.68	61.27	53.33	23.33	2.89	65.32
13Z04	3.3	5,693	1.09	2.33	14.34	72.91	14.58	33.33	8.37	66.53
13Z05	2.0	3,470	1.04	2.95	18.30	43.79	52.17	28.26	9.80	56.21
13Z06	2.7	2,631	0.75	2.77	37.07	36.21	48.48	30.30	10.34	40.52
13Z07	2.7	2,132	0.43	2.06	10.64	77.66	21.05	26.32	23.4	67.02
13Z09	2.0	9,208	2.36	1.22	5.42	86.95	9.62	50.96	3.69	87.44
13Z10	2.7	2,177	1.09	2.41	43.75	42.71	47.92	41.67	5.21	48.96
13Z11	2.0	4,128	0.93	1.92	17.58	74.73	36.59	43.90	12.09	73.08
13Z12	2.7	3,062	0.82	2.53	37.78	48.89	58.33	27.78	7.41	37.78
13Z13	3.0	10,660	3.81	1.12	11.91	81.91	2.38	91.67	2.77	82.34
13Z14	2.0	4,649	1.00	1.68	12.68	81.46	34.09	36.36	10.73	78.54
13Z15	3.3	3,447	0.91	3.01	11.18	53.95	17.50	37.50	7.24	30.92
13Z16	2.3	3,198	0.98	2.99	31.91	45.39	46.51	34.88	12.77	44.68
13Z17	3.0	2,245	0.59	2.89	26.26	51.52	15.38	46.15	8.08	43.43
13Z18	2.3	6,963	1.29	1.20	8.79	84.69	19.30	57.89	5.21	84.36
13Z19	2.0	2,903	0.88	2.09	66.41	25.78	15.38	58.97	6.25	14.06
13Z20	2.3	1,882	1.22	2.80	46.99	12.05	48.15	9.26	8.43	33.73
13Z21	2.7	4,944	1.86	1.70	12.84	78.44	15.85	69.51	8.26	77.06
13Z22	2.3	6,441	0.88	1.50	31.34	61.62	15.38	56.41	3.17	65.49
13Z23	2.3	9,639	0.84	2.19	33.18	48.00	10.81	27.03	11.76	44.24
13Z24	2.0	2,676	0.95	1.86	67.80	22.88	80.95	7.14	0.00	33.90
13Z25	3.0	15,354	2.70	2.06	11.23	63.66	18.49	43.70	11.82	73.26
13Z27	2.0	3,674	1.41	2.25	29.01	62.96	35.48	54.84	9.26	56.79
13Z29	2.7	7,235	1.70	1.51	19.44	73.98	8.00	84.00	5.64	69.28
Mean	2.4	5,074	1.26	2.12	27.01	58.01	30.46	42.99	7.92	57.31

Table 3. Random Stations of the Elizabeth River sampled in 2006. Summary of benthic community parameters scores of the BIBI.												
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 Feeder Abundance
13Z02	2.0	5	2	1.00	3.00	3.00	.	.	1.00	3.00	1.00	.
13Z03	1.7	5	2	1.00	3.00	3.00	.	.	1.00	1.00	1.00	.
13Z04	3.3	5	1	1.00	3.00	3.00	.	5.00	3.00	.	.	5.00
13Z05	2.0	5	2	3.00	3.00	3.00	.	.	1.00	1.00	1.00	.
13Z06	2.7	5	2	3.00	5.00	3.00	.	.	1.00	3.00	1.00	.
13Z07	2.7	5	1	1.00	3.00	1.00	.	5.00	1.00	.	.	5.00
13Z09	2.0	5	2	1.00	1.00	3.00	.	.	3.00	3.00	1.00	.
13Z10	2.7	5	2	3.00	5.00	3.00	.	.	1.00	3.00	1.00	.
13Z11	2.0	5	2	1.00	3.00	3.00	.	.	1.00	3.00	1.00	.
13Z12	2.7	5	1	1.00	5.00	1.00	.	3.00	1.00	.	.	5.00
13Z13	3.0	5	2	1.00	1.00	5.00	.	.	5.00	5.00	1.00	.
13Z14	2.0	5	2	1.00	3.00	3.00	.	.	1.00	3.00	1.00	.
13Z15	3.3	5	1	3.00	5.00	1.00	.	5.00	1.00	.	.	5.00
13Z16	2.3	5	2	3.00	3.00	3.00	.	.	1.00	3.00	1.00	.
13Z17	3.0	5	1	3.00	3.00	1.00	.	5.00	1.00	.	.	5.00
13Z18	2.3	5	2	1.00	3.00	3.00	.	.	3.00	3.00	1.00	.
13Z19	2.0	5	1	1.00	3.00	1.00	.	3.00	1.00	.	.	3.00
13Z20	2.3	5	2	3.00	5.00	3.00	.	.	1.00	1.00	1.00	.
13Z21	2.7	5	2	1.00	3.00	3.00	.	.	3.00	5.00	1.00	.
13Z22	2.3	5	2	1.00	3.00	3.00	.	.	3.00	3.00	1.00	.
13Z23	2.3	5	1	1.00	1.00	1.00	.	3.00	3.00	.	.	5.00
13Z24	2.0	5	2	1.00	5.00	3.00	.	.	1.00	1.00	1.00	.
13Z25	3.0	4	2	3.00	1.00	5.00	.	.	3.00	3.00	3.00	.
13Z27	2.0	5	2	1.00	3.00	3.00	.	.	1.00	3.00	1.00	.
13Z29	2.7	5	2	1.00	3.00	3.00	.	.	3.00	5.00	1.00	.

Table 4. Random Stations of the Elizabeth River sampled in 2006. Dominant tax by abundance. Taxon code: A = Amphipod, B = bivalve, C = cumacean, N = nemertean, O = oligochaete, P = polychaete, PH =phoronid.

Rank	Taxon	Abundance per m^2
1	Mediomastus ambiseta (P)	2,930
2	Streblospio benedicti (P)	550
3	Paraprionospio pinnata (P)	415
4	Tubificoides spp. Group I (O)	142
5	Leptocheirus plumulosus (A)	116
6	Glycinde solitaria (P)	112
7	Leitoscoloplos spp. (P)	97
8	Phoronis spp. (PH)	84
9	Eteone heteropoda (P)	58
10	Parahesione luteola (P)	55
11	Nemertea spp. (N)	52
12	Caulleriella killariensis (P)	51
13	Leucon americanus (C)	42
14	Listriella barnardi (A)	40
15	Macoma balthica (B)	28

Table 5. Fixed Stations of the Elizabeth River sampled in 2006. Summary of physical-chemical parameters.									
STATION	Date collected	Latitide	Longitude	Water depth (m)	Temperature (ºC)	Salinity (ppt)	Dissolved oxygen (ppm)	Silt_clay content (%)	Volatile Organics (%)
EBB1	8/17/2006	36.837928	-76.241881	1.50	27.40	22.00	5.60	57.78	2.58
ELC1	8/21/2006	36.879748	-76.347215	2.50	26.40	22.20	4.60	39.93	1.27
ELD1	8/21/2006	36.861566	-76.335395	2.00	26.20	22.30	4.80	4.89	0.29
ELF1	8/17/2006	36.848930	-76.297160	10.50	27.10	22.40	3.60	64.69	2.38
LFA1	8/21/2006	36.909328	-76.313444	2.00	27.40	22.00	5.70	78.04	1.70
LFB1	8/21/2006	36.889728	-76.282693	2.50	28.30	21.30	4.00	97.32	2.29
SBA1	8/15/2006	36.825670	-76.291360	13.50	27.50	22.40	3.30	96.10	3.29
SBB1	8/15/2006	36.811815	-76.288274	2.00	29.30	22.50	4.20	45.31	4.37
SBC1	8/15/2006	36.799498	-76.294061	11.00	28.10	22.50	2.80	92.49	3.55
SBD1	8/15/2006	36.779765	-76.310245	8.50	28.90	22.40	2.70	80.38	4.27
SBD2	8/15/2006	36.766840	-76.296970	4.00	30.20	21.70	3.10	40.64	2.33
SBD4	8/15/2006	36.740357	-76.298757	1.00	27.80	19.50	3.90	17.14	0.93
WBB1	8/17/2006	36.846368	-76.357273	2.50	26.70	22.00	5.20	91.01	2.52
WBB5	8/17/2006	36.829408	-76.392823	1.50	27.10	21.50	5.50	84.37	3.13

Table 6. Fixed Point Stations of the Elizabeth River sampled in 2006. Summary of benthic community parameters. All values are station means (n=3). Abundance reported as ind/m^2, biomass reported as grams/m^2, all other abundance and biomass metrics are percentages.

Station	BIBI	Abundance	Biomass	Shannon Index	Pollution Indicative Abundance	Pollution Sensitive Abundance	Pollution Indicative Biomass	Pollution Sensitive Biomass	Carnivore Omnivore Abundance	Deep Deposit Feeder Abundance
EBB1	3.3	4,460	3.80	2.45	19.42	65.49	8.46	80.9	12.56	60.42
ELC1	2.9	1,701	0.51	2.87	9.81	50.57	9.96	47.06	26.24	44.33
ELD1	3.0	2,706	0.82	2.69	20.97	59.76	21.72	26.44	6.45	52.45
ELF1	2.4	3,893	1.00	2.34	20.56	59.46	35.91	51.10	10.29	57.46
LFA1	2.0	6,101	0.68	1.63	21.18	74.90	44.28	37.94	2.91	68.46
LFB1	2.7	5,957	1.03	1.08	21.66	75.05	10.95	66.92	2.59	75.79
SBA1	2.0	8,248	1.48	1.87	15.49	69.99	26.78	58.27	4.31	74.70
SBB1	1.6	2,744	0.36	1.84	24.82	70.30	41.58	36.10	16.42	68.66
SBC1	1.8	7,552	1.22	1.50	27.24	62.06	41.04	42.68	5.28	62.34
SBD1	2.3	2,321	0.70	2.58	25.80	40.97	29.79	29.78	11.94	40.22
SBD2	2.0	673	0.24	1.67	9.52	70.71	8.97	24.71	26.79	63.10
SBD4	3.0	5,625	0.35	1.09	2.17	92.70	9.17	54.59	14.55	79.99
WBB1	2.2	7,613	0.94	1.14	11.89	83.09	8.06	52.18	3.97	81.94
WBB5	2.6	7,787	2.46	1.72	14.84	73.88	10.54	73.70	6.90	76.72
Mean	2.4	4,813	1.11	1.89	17.53	67.78	21.94	48.74	10.80	64.76

Table 7. Status in benthic community condition based on the Benthic IBI at the Elizabeth River Project monitoring stations for the period of 2004 through 2006.

Station	Mean IBI	Status
Mainstem		
ELC1	2.8	Marginal
ELD1	3.2	Meets Goals
ELF1	1.9	Severely degraded
Southern Branch		
SBA1	1.9	Severely degraded
SBB1	1.9	Severely degraded
SBC1	1.9	Severely degraded
SBD1	2.1	Degraded
SBD2	2.2	Degraded
SBD4	2.9	Marginal
Southern Branch		
WBB1	2.1	Degraded
WBB5	2.2	Degraded
Eastern Branch		
EBB1	2.6	Degraded
Lafayette River		
LFA1	2.1	Degraded
LFB1	2.4	Degraded

Table 8. Significant long term trends in the Benthic IBI and associated bioinidcators for the Elizabeth River Project monitoring stations for the period of 1999 through 2006. All trends shown were significant a P $\leq$ 0.10.

Station	Parameter	*P* value	Slope	Baseline	Absolute Change	% Change	Direction
ELC1	Total Biomass per square meter	0.0603	-0.26	12.45	-2.11	-16.96	Degrading
ELC1	Pollution Indicative Species Abundance	0.0242	-1.83	18.79	-14.65	-77.96	Improving
ELF1	Pollution Sensitive Species Abundance	0.0242	6.09	24.27	48.69	200.60	Improving
SBA1	Total Abundance per square meter	0.0603	2,499	3,863	19,993	517.55	Degrading
SBA1	Shannon-Weiner Diversity Index	0.0603	-0.13	2.44	-1.00	-40.96	Degrading
SBA1	Pollution Sensitive Species Biomass	0.0603	2.19	26.30	17.54	66.69	Improving
SBB1	Pollution Sensitive Species Abundance	0.0242	5.78	31.75	46.25	145.64	Improving
SBB1	Pollution Sensitive Species Biomass	0.0603	2.81	19.53	22.50	115.19	Improving
SBC1	Shannon-Weiner Diversity Index	0.0603	-0.16	2.46	-1.30	-52.83	Degrading
SBD2	Pollution Indicative Species Abundance	0.0603	-4.76	40.98	-38.08	-92.92	Improving
SBD4	Shannon-Weiner Diversity Index	0.0242	-0.21	2.41	-1.64	-68.16	Degrading
SBD4	Pollution Sensitive Species Abundance	0.0603	7.68	43.81	61.41	140.18	Improving
SBD4	Pollution Indicative Species Abundance	0.0603	-4.23	33.12	-33.81	-102.09	Improving
EBB1	Pollution Sensitive Species Abundance	0.0864	6.92	16.07	55.40	344.69	Improving
EBB1	Pollution Indicative Species Abundance	0.0071	-4.85	42.80	-38.76	-90.57	Improving
WBB5	Pollution Sensitive Species Abundance	0.0603	9.30	24.58	74.40	302.67	Improving
WBB1	Total Abundance per square meter	0.0603	868	2,536	6,950	274.02	Degrading
WBB1	Pollution Sensitive Species Abundance	0.0026	6.22	52.08	49.72	95.47	Improving
WBB1	Pollution Indicative Species Abundance	0.0085	-4.55	37.11	-36.39	-98.07	Improving
WBB1	Pollution Sensitive Species Biomass	0.0242	5.77	13.60	46.16	339.34	Improving
WBB1	Pollution Indicative Species Biomass	0.0242	-4.04	35.87	-32.28	-89.99	Improving
LFB1	Benthic Index of Biotic Integrity	0.0163	0.09	1.94	0.73	37.33	Improving
LFB1	Total Abundance per square meter	0.0547	514	3,738	4,115	110.08	Degrading
LFB1	Total Biomass per square meter	0.0547	0.11	0.49	0.88	180.88	Improving
LFB1	Shannon-Weiner Diversity Index	0.0547	-0.13	1.96	-1.02	-52.35	Degrading
LFB1	Pollution Sensitive Species Abundance	0.0163	12.33	6.36	98.65	1551.40	Improving
LFB1	Pollution Sensitive Species Biomass	0.0547	10.03	22.21	80.23	361.28	Improving

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 ≥^{3}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