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BENTHIC BIOLOGICAL MONITORING PROGRAM OF THE ELIZABETH RIVER WATERSHED (2005)

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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 seventh year of sampling in 2005. 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 2005 areal estimate of degraded benthic bottom was the same as 2004, i.e., highest level recorded since the beginning of this program in 1999. 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, and 84 ± 12.7% in 2005. Average B-IBI values for the Elizabeth River watershed were 2.7, 2.6 , 2.7, 2.4, 2.3, 2.2 and 2.2 respectively for the years 1999-2005.

Trend analyses were conducted using the data from the 14 fixed point stations for the period 1999-2005. Four stations showed trends in the B-IBI at $p<0.05$ with two stations showing improvements (LFB1, ELD1) and two stations deterioration (EBB1, WBB1). 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 (2003-2005). No station had a B-IBI value over 3.0, ELD1was Marginal and all other fixed-point stations had a degraded or severely degraded status. Of the 29 significant trends in individual B-IBI metrics, 21 were improving trends and only 8 were degrading trends. Of the eight degrading trends, seven were in the diversity index metric.

In general for the Elizabeth River watershed, 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.

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 inorganic nitrogen levels (SDIN), and (3) widespread improvements in long-term trends in surface total phosphorus levels (STP).

Nutrient levels of the Elizabeth River exceed those of the lower section of the James River (Table 9). 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. Bottom dissolved oxygen are fair to good in all branches.

INTRODUCTION

A long-term monitoring program of the macrobenthic communities of the Elizabeth River watershed was initiated in summer 1999. The three objectives of the Benthic Biological Monitoring Program of the Elizabeth River watershed are: (1) To characterize the health of the tidal waters of the Elizabeth River watershed as indicated by the structure of the benthic communities. This characterization is based upon application of benthic restoration goals and the Benthic Index of Biotic Integrity (B-IBI) developed for the Chesapeake Bay to the Elizabeth River Watershed (Ranasinghe et al. 1994; Weisberg et al. 1997; Alden et al. 2002). In each year 25 samples are randomly allocated in a probability-based sampling design. A probability-based sampling design allows calculation of confidence intervals around estimates of condition of the benthic communities. (2) To conduct trend analyses on long-term data at 14 fixed-point stations to relate temporal trends in the benthic communities to changes in water and/or sediment quality. Trend analyses will be updated annually as new data are available. (3) To produce an historical data base that will allow annual evaluations of biotic impacts by comparing trends in status within probability-based strata and trends at fixed-point stations to changes in water and/or sediment quality.

The macrobenthic communities of the Elizabeth River have been studied since the 1969 sampling of Boesch (1973) with three stations in the Mainstem of the river. Other important studies were limited to the Southern Branch of the river including seasonal sampling at 10 sites in 1977-1978 (Hawthorne and Dauer 1983), seasonal sampling at the same 10 sites a decade later in 1987-1988 by Hunley (1993), the establishment of two long-term monitoring stations in 1989 as part of the Virginia Chesapeake Bay Benthic Monitoring Program (Dauer et al. 1999) and summarizations of the two Southern Branch long-term monitoring stations (Dauer 1993; Dauer et al. 1993). The condition of the benthic community of the Elizabeth River watershed was characterized by spatially extensive sampling of the river in 1999 with 175 locations sampled among seven strata (Dauer 2000; Dauer and Llansó 2003). Beginning in 2000 the Elizabeth River watershed was sampled as a single stratum with the benthic community condition characterized at 25 random locations (Dauer 2001, 2002, 2003, 2004, 2005). This study updates the benthic community characterization of the Elizabeth River watershed base upon data collected in 2005.

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 19.

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. 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:

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

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 ^{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 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 $\geq$ 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).

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.

Fixed-Point Stations in the Elizabeth River from the Chesapeake Bay Program

Data concerning benthic community status and trends for James River, including the Elizabeth River, are collected by the Virginia Benthic Monitoring Program as part of the Chesapeake Bay Restoration Program. These data have been updated recently to include all data through 2004 and are presented here to summarize patterns for the five James River stations and two Elizabeth River stations that are part of that program. Details of collection and laboratory methodology can be found in Dauer et al. 2005 which can be downloaded in pdf format from the Old Dominion University Chesapeake Bay Program website <www.chesapeakebay.odu.edu>

under "Reports." The James River Report includes the Elizabeth River, the Chickahominy River and the Appomattox River.

Water Quality of the Elizabeth River

Data concerning water quality status and trends for the Elizabeth River are collected by the Virginia Water Quality Monitoring Program as part of the Chesapeake Bay Restoration Program. These data have been updated recently to include all data through 2004 and are presented here to summarize water quality of the Elizabeth River. Details of collection and laboratory methodology can be found in Dauer et al. 2005 which can be downloaded in pdf format from the Old Dominion University Chesapeake Bay Program website <www.chesapeakebay.odu.edu> under "Reports." The James River Report includes the Elizabeth River, the Chickahominy River and the Appomattox River. Also available at this website are appendices that include (1) tables of status for all parameters measured at all stations sampled by each program, (2) tables of all parameters and metrics for which there was a significant trend, and (3) scatter plots of all parameters over time. There are five appendices: water quality, phytoplankton, primary productivity, zooplankton and benthos.

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 18m reflecting shoal and channel depths. In 1999-2002 most stations had salinity values in the polyhaline range, in 2003-2004 salinity values were mostly in the high mesohaline range and in 2005 most salinity values were in the polyhaline range. In 2005 nine 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 2.2. The distribution of the random sites and benthic community condition designations are shown in Figure 3. For the 2005 data, 84 ± 12.7 % 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 in 2005 with polychaete and oligochaete species such as *Mediomastus ambiseta*, *Streblospio benedicti*, *Paraprionospio pinnata*, *Leitoscoloplos* spp., *Neanthes succinea* and

Tubificoides spp.

The B-IBI value, Shannon's index, abundance, biomass and the proportion of pollution sensitive and pollution indicative species for 1999-2005 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 (2003-2005) average B-IBI values at each station. No station had a B-IBI value over 3.0 - 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 ELD1 in the Mainstem) and all other stations had a degraded or severely degraded status.

Four stations showed a trend in the B-IBI at $p<0.05$ with two stations showing improvements (LFB1, ELD1) and two stations deterioration (EBB1, WBB1). Of the 29 significant trends in individual B-IBI metrics, 22 were improving trends and only 8 were degrading trends. Of the eight degrading trends, seven were in the diversity index metric.

Summary Patterns in the B-IBI and Selected Metrics

Mainstem

- ❒ **Benthic Index of Biotic Integrity:** From 1999-2004, the B-IBI values for stations ELC1 and ELD1 were generally close to or above 3.0. Station ELF1 was consistently below 3.0. There was a significantly improving trend at Station ELD1 due in part to reaching a peak value in 2004.

- ❒ **Species Diversity:** The mouth stations (ELC1 and ELD1) generally had higher diversity values with the index typically above 2.2, while Station ELF1 generally had lower values, generally below 2.2. Species diversity values at Station ELF1 were very low the last three years (2003-2005).

- ❒ **Abundance:** The mouth stations (ELC1 and ELD1) generally had community abundance values between 2,000 - 3,000 individuals m^{-2} from 1999-2002 with highest values in 2002-2003 around 6,000 individuals m^{-2}. The data for 2004-2005 indicate a decrease to previous values of the earlier years. At station ELF1 in 2004-2005 values exceeding 10,000 individuals m^{-2}. In general the Mainstem stations had the lowest abundances compared to the other branches of the river. For high salinity benthic habitat types, an abundance in excess of 5,000 - 8,000 individuals m^{-2} is considered excessive and results in a low score for this metric.

- **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} 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:** The mouth stations (ELC1 and ELD1) had a percent composition of Pollution Indicative Species Abundance that was generally less than 30% while Station ELF1 generally had values above 30%. As would be expected, the relative abundance of Pollution Sensitive Species was inversely related to the patterns for Pollution Indicative Species.

Southern Branch

- **Benthic Index of Biotic Integrity:** The B-IBI values for all stations were consistently below 3.0 with the highest values at upstream station SBD4.

- **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. Lowest species diversity values generally occurred in the last four years (2002 - 2005).

- **Abundance:** Community abundance values were much higher than in the Mainstem mouth stations (ELCI, ELDI) and often exceeded 10,000 individuals m^{-2}. Such an abundance is considered to be excessive relative to the Benthic Restoration Goals. Station SBA1 had highest values in the last three years (2003-2005); Station SBB1 had generally high values since 2002; the middle station SBC1 peaked in 2001 but retained high values in the last four years; station SBD1had the lowest abundance; and the two upper stations, SBD2 and SBD4, reached their highest values in 2003 with a decline in 2004.

- **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} 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:** 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. The Eastern Branch station was near 3.0 in 1999-2000 and had lower values in recent years. The Eastern Branch station, EBB1, showed a significant deteriorating trend.

- **Species Diversity:** Species diversity values were generally at lowest levels in the last four years (2002-2005).

- **Abundance:** Community abundance values were higher than in the Mainstem Stations and typically exceeded 6,000 to 10,000 individuals m^{-2} particularly in the later years of 2001 through 2005. In these years each station was dominated by the pollution sensitive polychaete *Mediomastus ambiseta*.

- **Biomass:** Biomass values peaked at all stations in 2003 due to a high settlement of the bivalve *Macoma balthica*; however, all three stations declined in 2004 to pre-2003 levels. The peak in biomass in 2005 was also due mainly to settlement of *M. 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 LAFA1were 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:** Biomass values increased at both stations to their highest levels in 2003 with a decline in 2004-2005. The pattern was generally due to the 2003 settlement of the bivalve *Macoma balthica* and the lack of persistence of this species in 2004. 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 (Appendix B, Fig. B2 and Tables B1, B3). Surface and bottom 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 and bottom DIN in the Eastern 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 (Appendix B, Fig. B3). Indicators of water clarity, total suspended solids (STSS, BTSS) and secchi depth (SECCHI) generally showed improving trends an all branches. Finally, previously reported improving trends in bottom dissolved oxygen were no longer significant but dissolved oxygen status remains good to fair(Appendix B, Fig. B3, Table B3).

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 2.2 (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). Based upon probability-based sampling, the estimate of benthic bottom not meeting the benthic restoration goals were 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). However, there are some positive indications with the increase in the proportion of pollution sensitive species (Fig. 9).

Long-term trends of Benthic Communities

Long-trend analyses in values of the B-IBI were conducted for the period 1999-2005. Four stations showed a trend in the B-IBI at $p<0.05$ with two stations showing improvements (LFB1, ELD1) and two stations deterioration (EBB1, WBB1). Of the 29 significant trends in individual B-IBI metrics, 21 were improving trends and only 8 were degrading trends. Of the eight degrading trends, seven 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 inorganic nitrogen levels (SDIN), and (3) widespread improvements in long-term trends in surface total phosphorus levels (STP). Nutrient levels of the Elizabeth River exceed those of the lower section of the James River (Table 9). 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 (Appendix B, Fig. B3). 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.

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Glossary of selected terms

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

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

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

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

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

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

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

Random Station - a station selected randomly within a stratum. In every succeeding sampling event new random locations are selected.

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

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

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

Stratum - a geographic region of unique ecological condition or managerial interest. In the1999 study the primary strata were the Mainstem of the river, the Lafayette River, the Eastern Branch, Western Branch and Southern Branch. In succeeding years the entire Elizabeth River watershed was sampled as a single stratum.

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

Figures

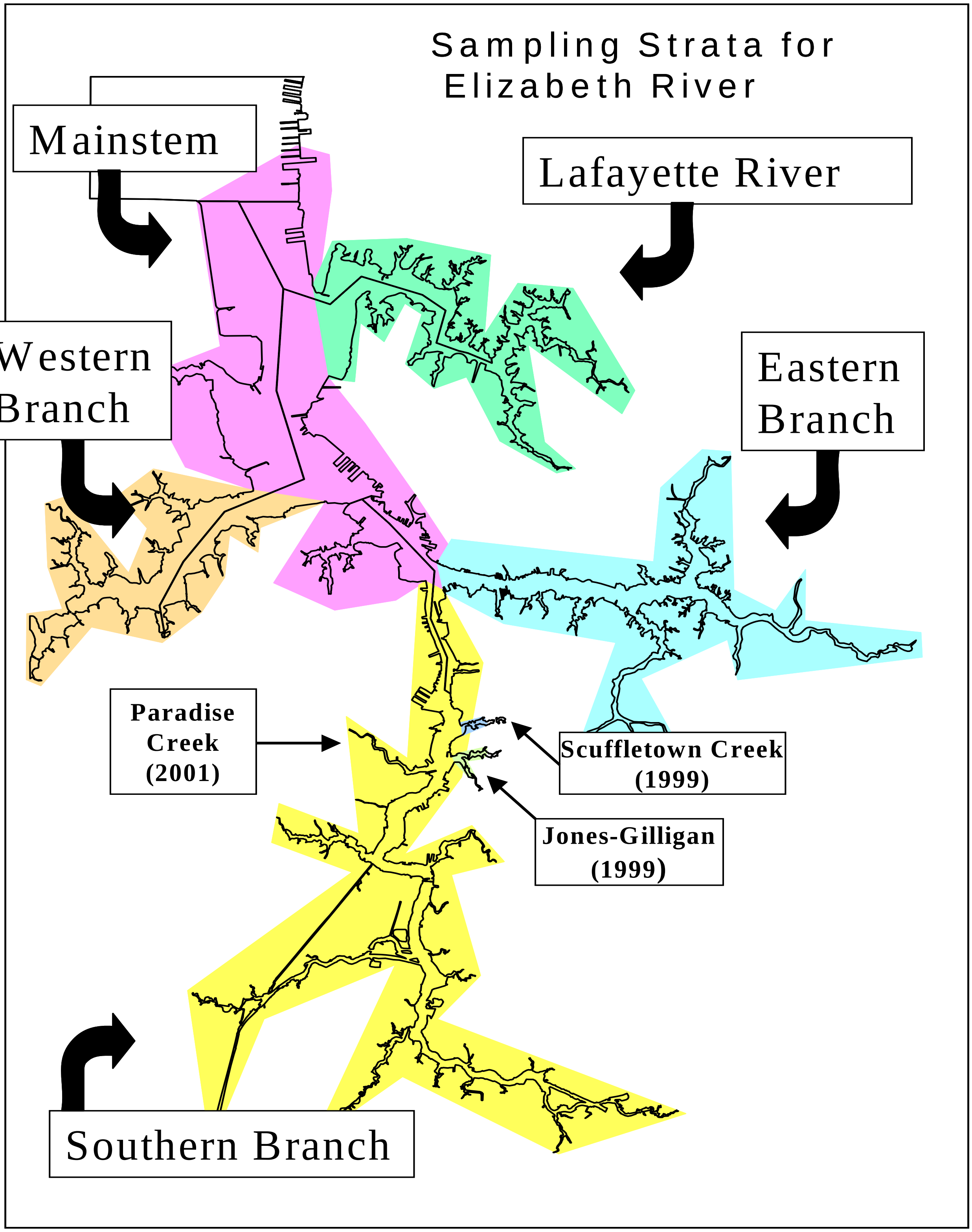

Figure 1. Elizabeth River watershed showing the five major segments sampled in 1999. Insert shows Scuffletown Creek and the Jones-Gilligan Creek strata also sampled in 1999 and Paradise Creek stratum sampled in 2001.

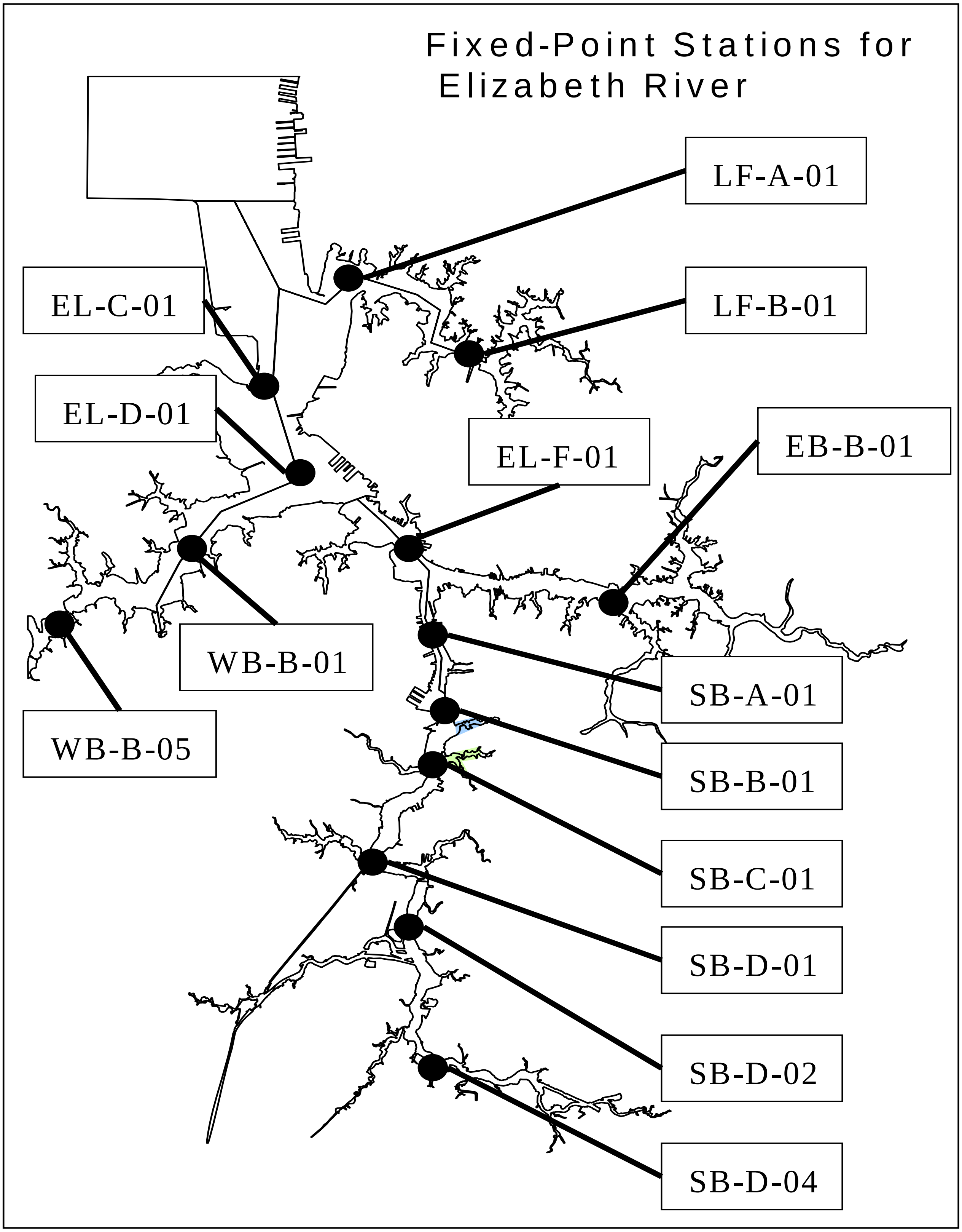

Figure 2. Elizabeth River watershed showing the 14 fixed-point stations for long-term trend analyses.

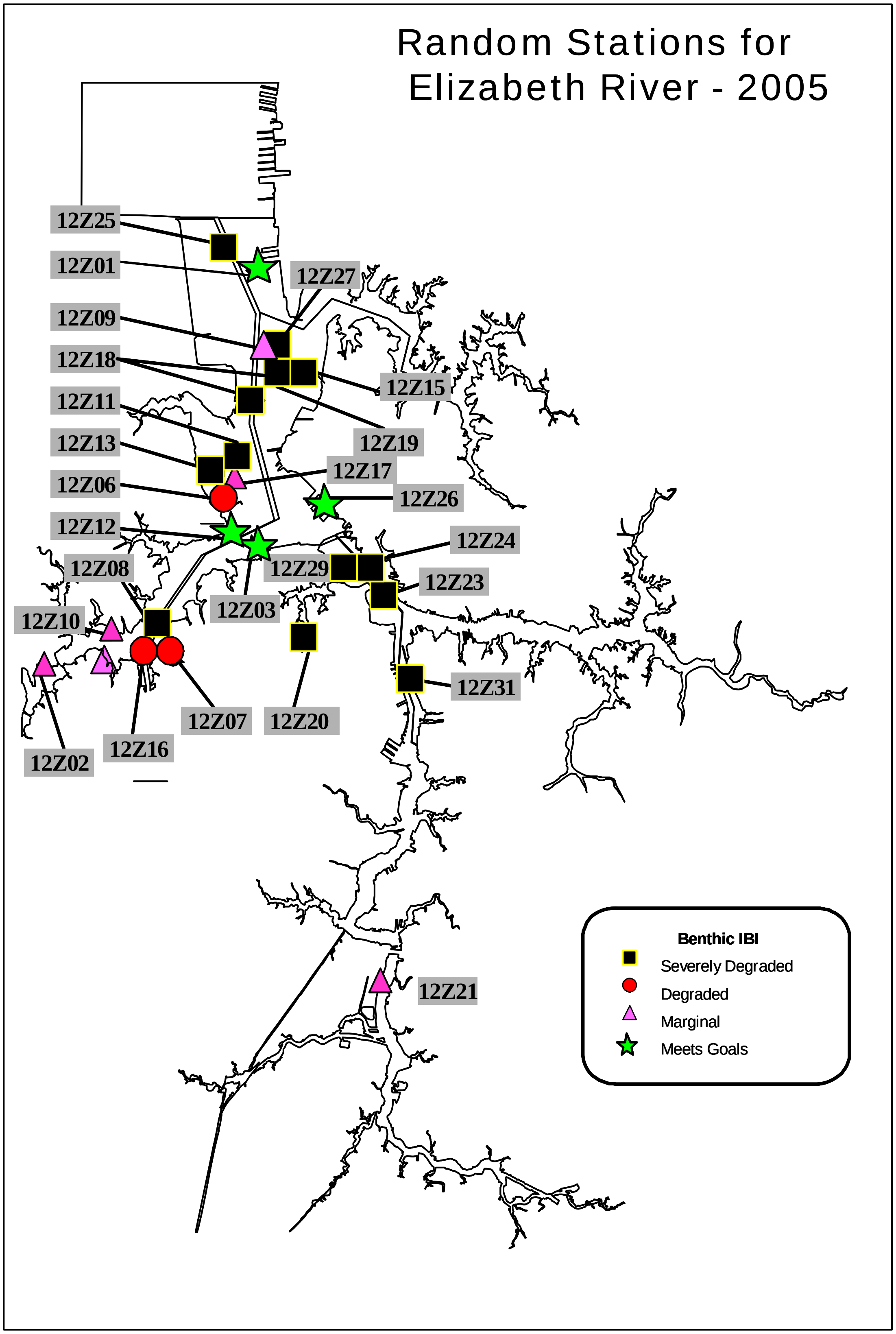

Figure 3. Random samples collected in 2005. Shown is the condition of the benthic communities using the B-IBI value.

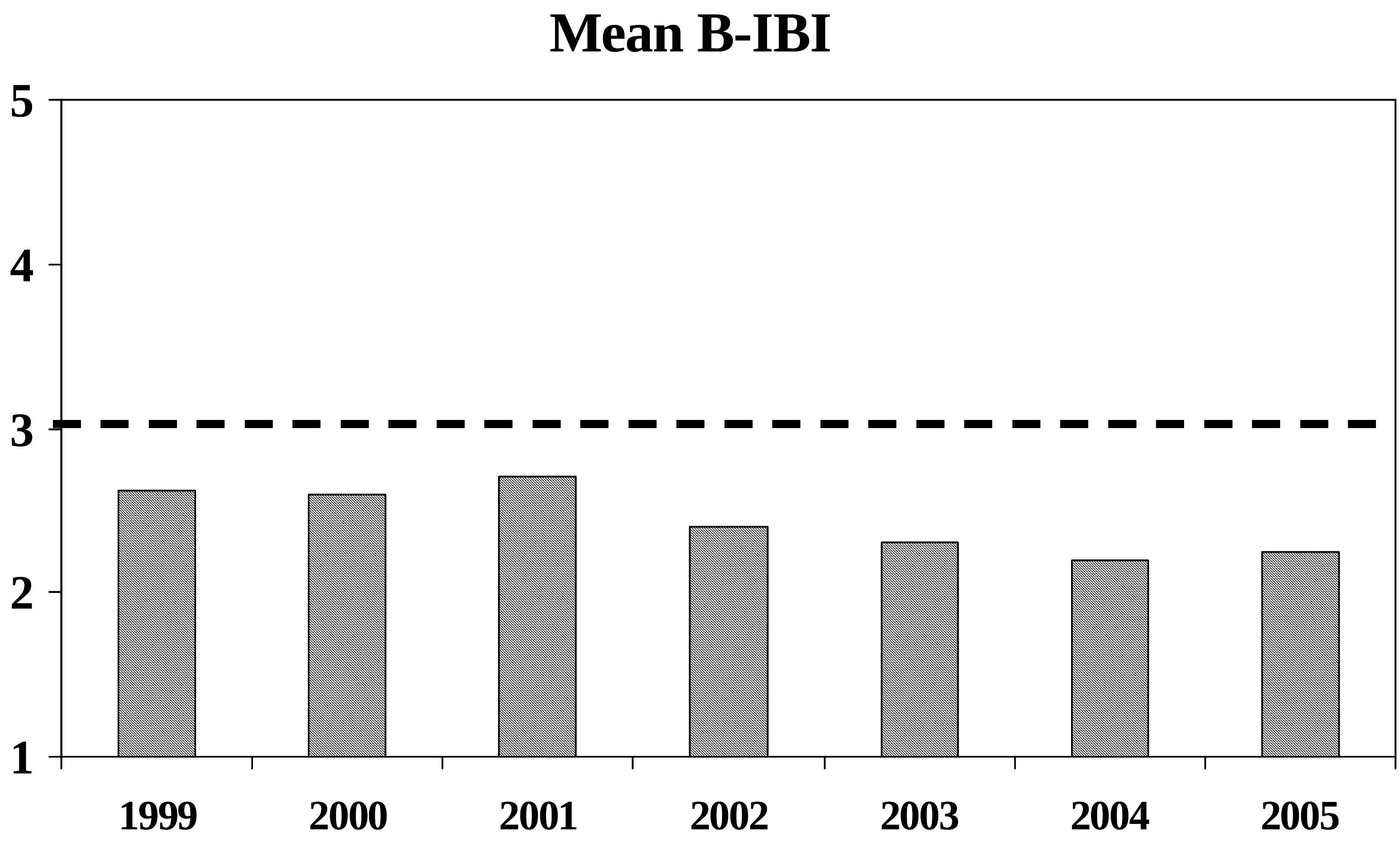

Figure 4. Benthic Index of Biotic Integrity. Shown are mean values for the entire Elizabeth River watershed from the probability-based program. Dashed line indicates restoration goal.

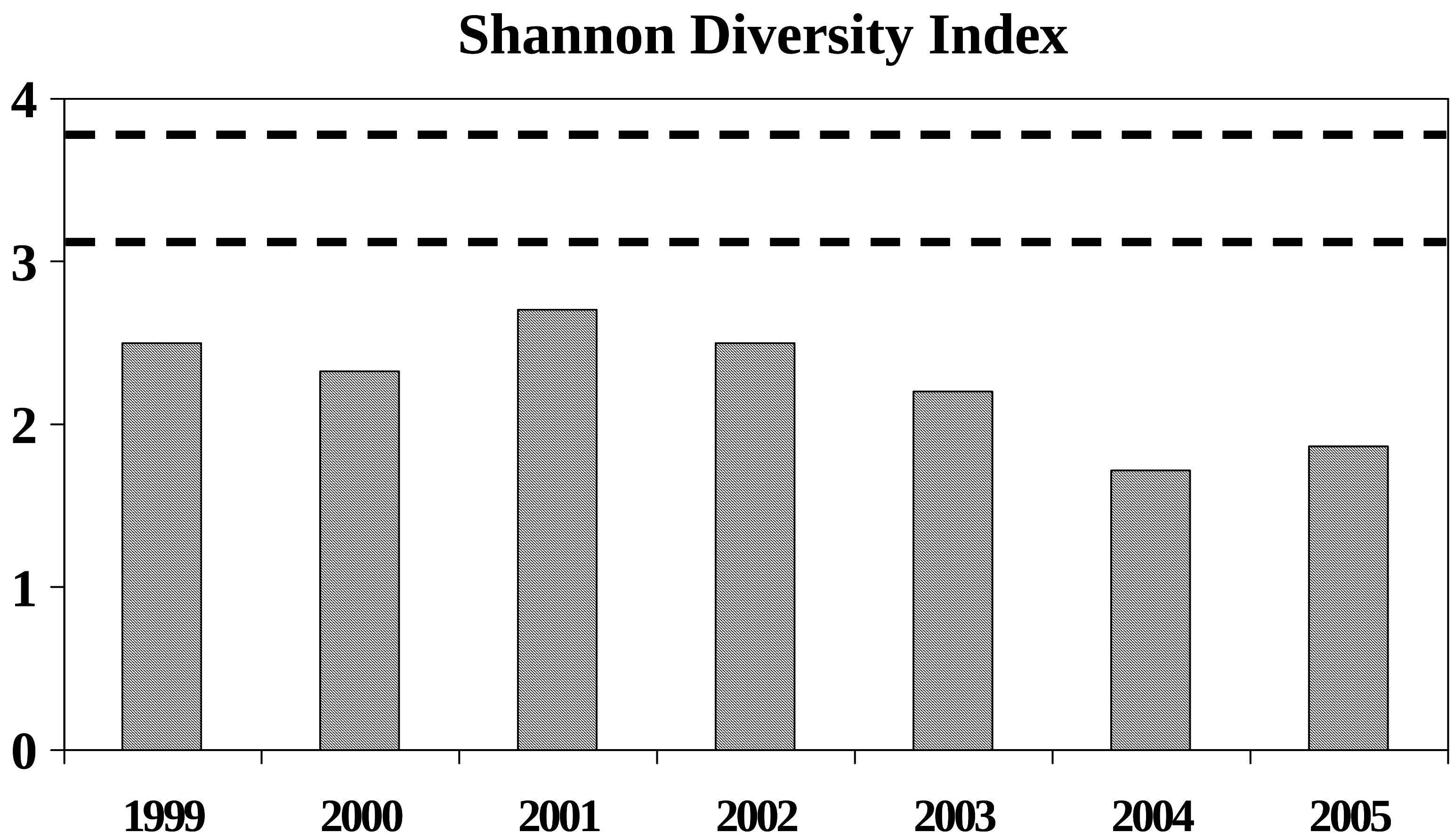

Figure 5 Shannon-Weiner Diversity Index. Shown are mean values for the entire Elizabeth River watershed from the probability-based program. Dashed Lines indicate range of restoration goals..

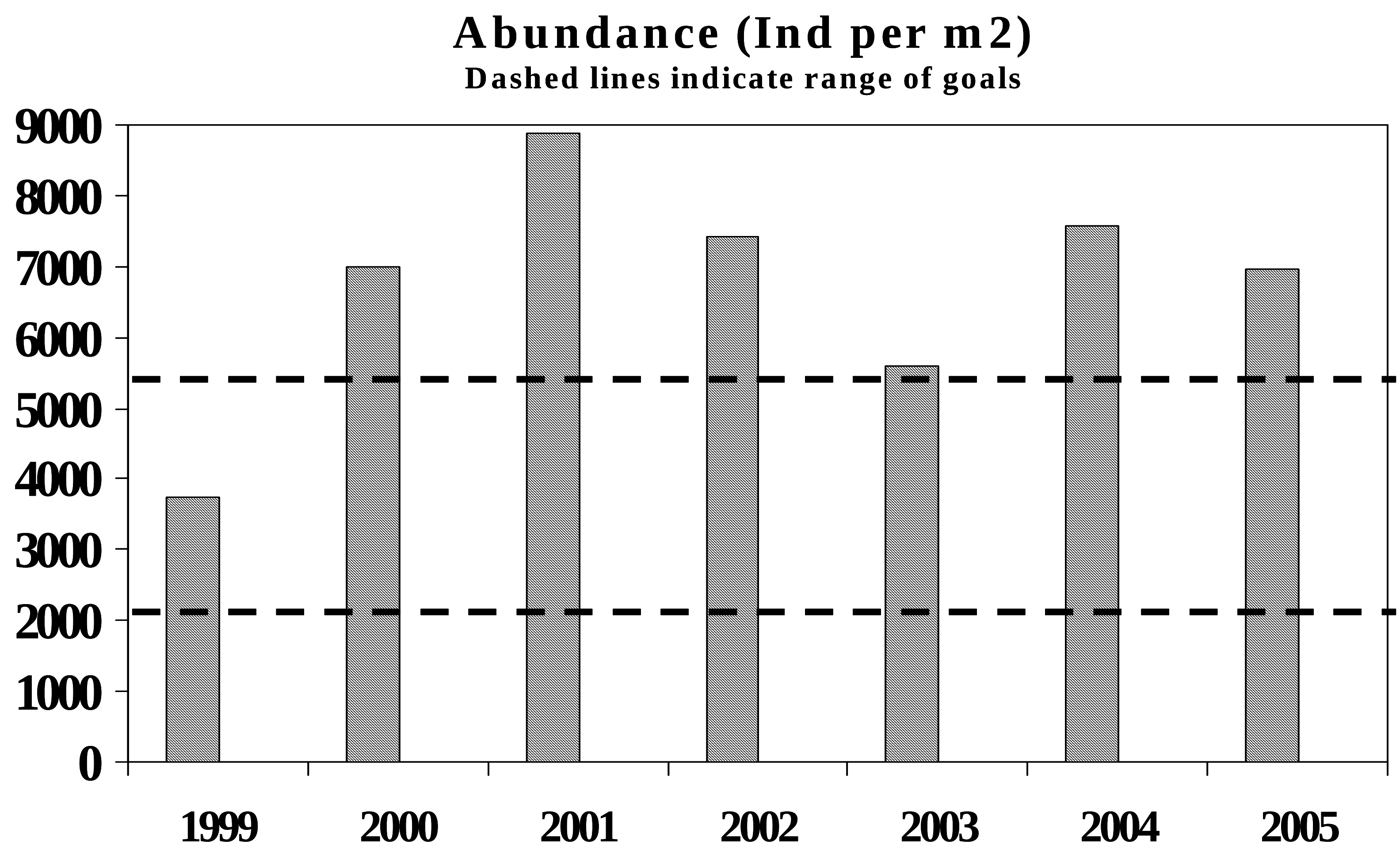

Figure 6. Abundance per m^2. Shown are mean values for the entire Elizabeth River watershed from the probability-based program. Dashed lines indicates range of restoration goals.

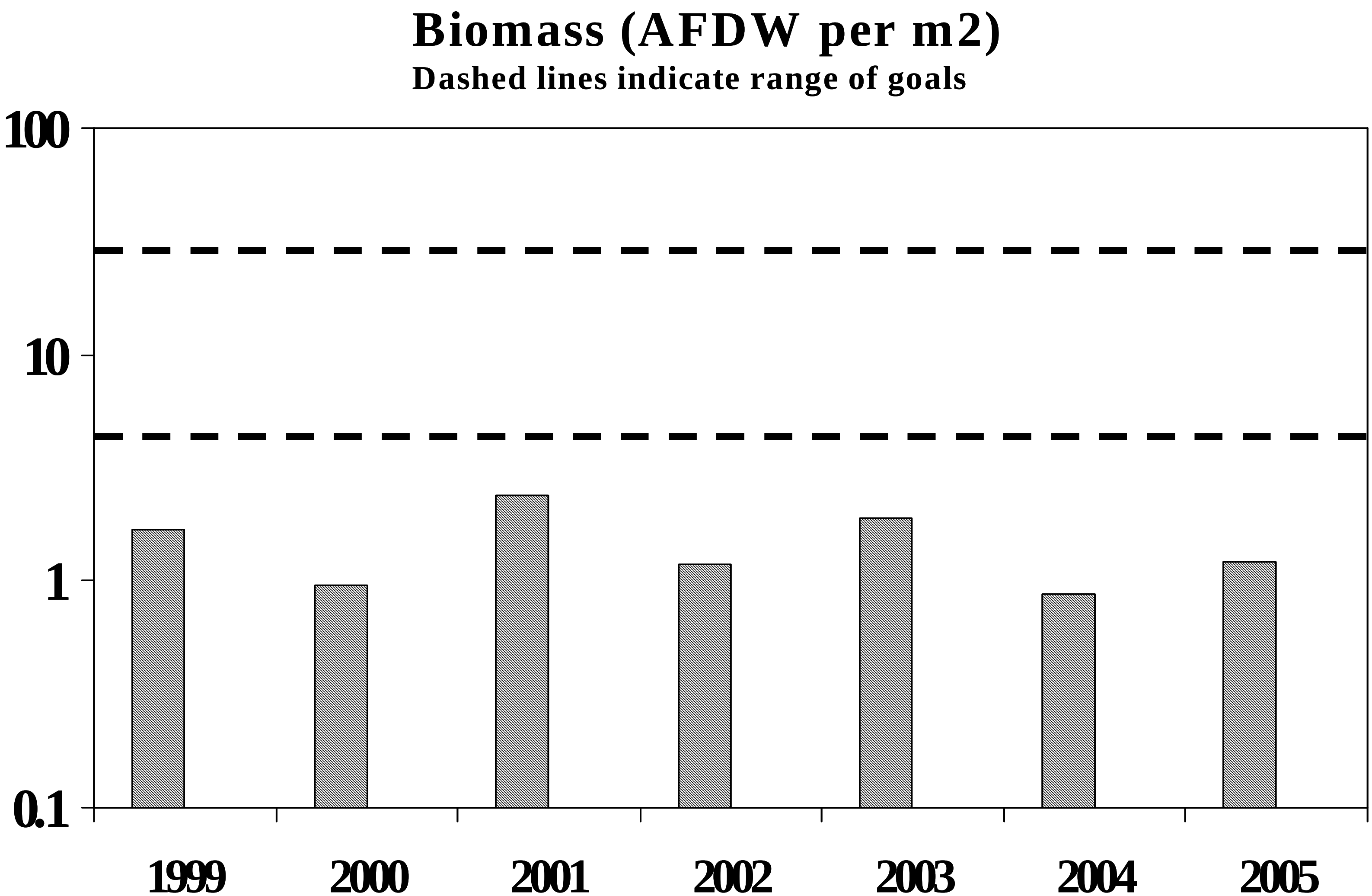

Figure 7. AFDW biomass per m^2. Shown are mean values for the entire Elizabeth River watershed from the probability-based program. Dashed lines indicates range of restoration goals.

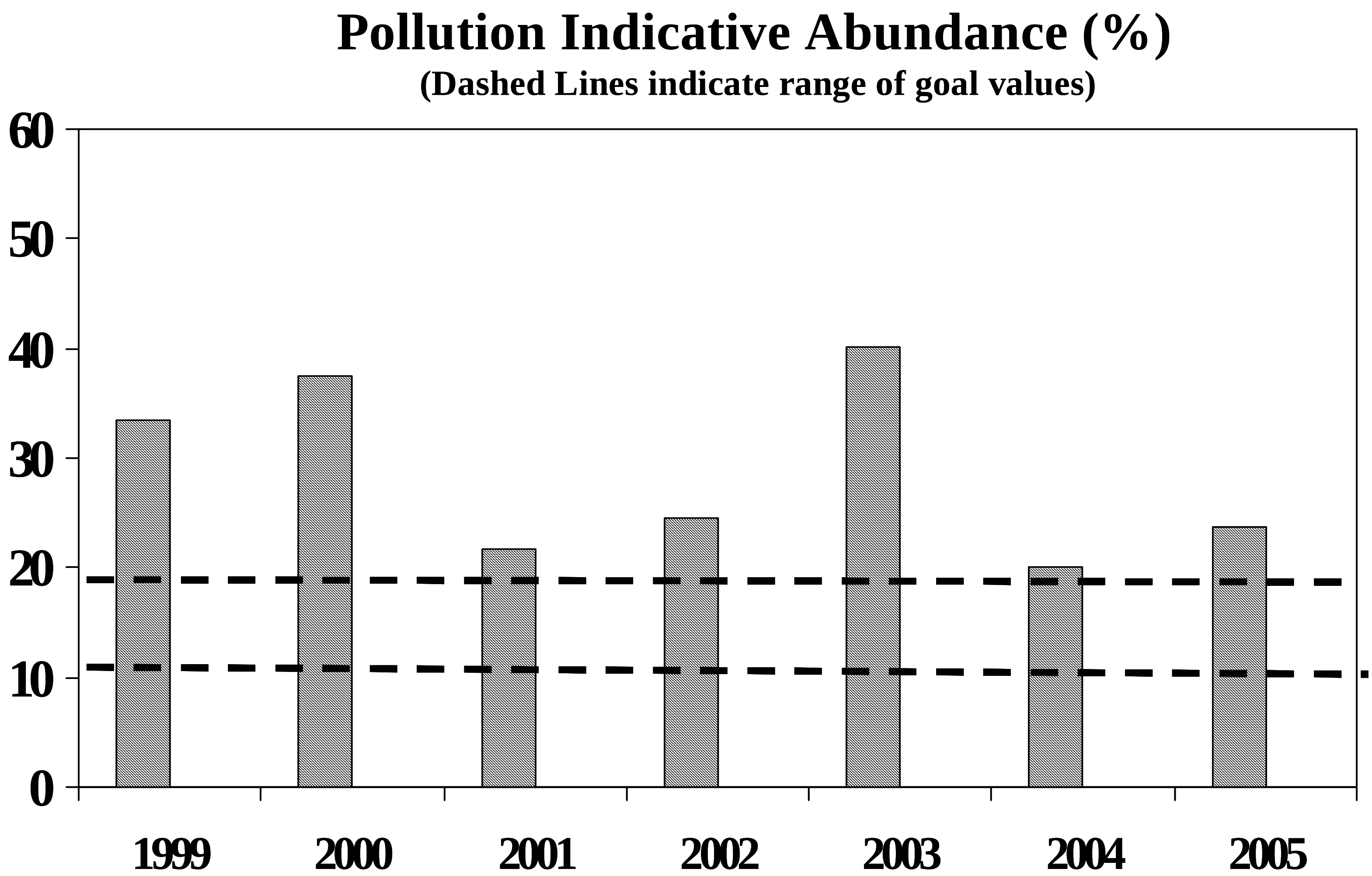

Figure 8 Percentage of Pollution Indicative Species Abundance. Shown are mean values for the entire Elizabeth River watershed from the probability-based program. Dashed lines indicates range of restoration goals.

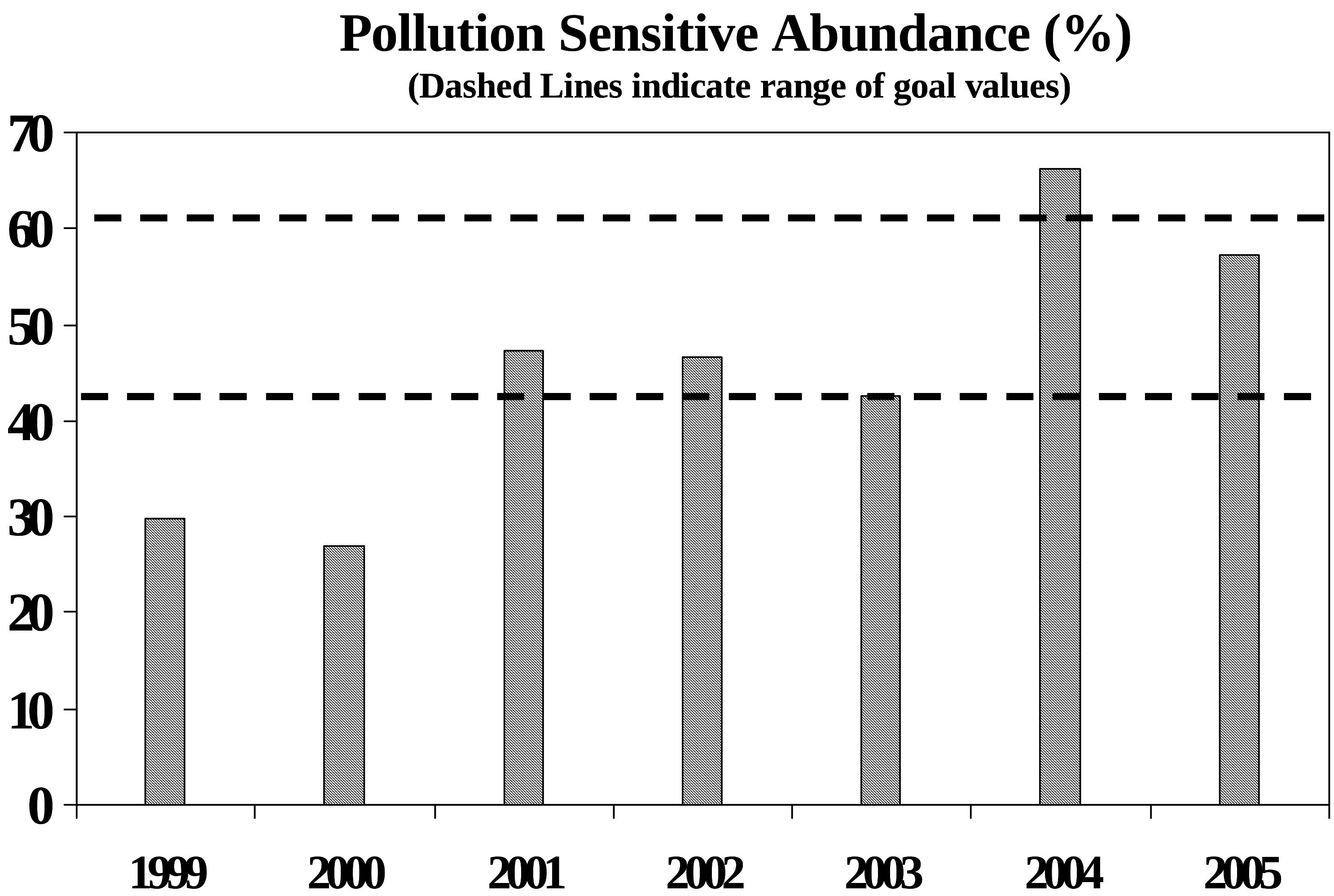

Figure 9. Percentage of Pollution Sensitive Species Abundance. Shown are mean values for the entire Elizabeth River watershed from the probability-based program. Dashed lines indicates range of restoration goals.

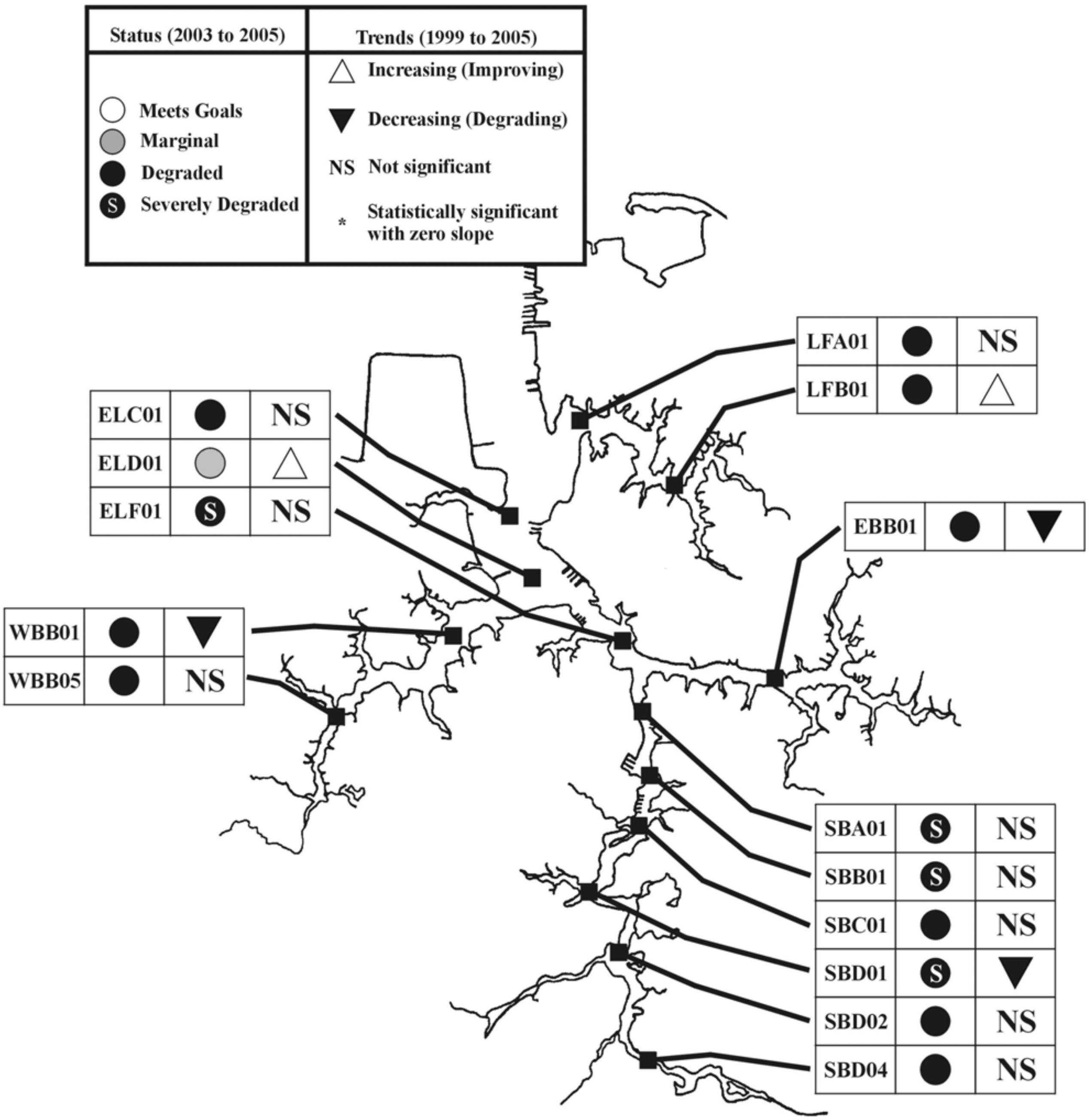

Figure 10. Status of and long-term trends in the Benthic IBI for the Elizabeth River Project monitoring stations for the period of 1999 through 2005. All trends shown were significant at $p \leq 0.05$.

Tables

Table1. Random Stations of the Elizabeth River sampled in 2005. Summary of physical-chemical parameters									
Station	Date	Latitude	Longitude	Water depth (m)	Dissolved oxygen (ppm)	Salinity (psu)	Temperature (^oC)	Silt-clay contents (%)	Volatile organics (%)
12Z01	7/22/05	36.91	-76.33	1.5	5.6	19.8	28.9	18.30	0.49
12Z02	8/10/05	36.83	-76.39	2.9	1.9	17.2	28.9	93.56	2.15
12Z03	8/10/05	36.86	-76.33	2.7	5.7	20.2	29.0	4.48	0.15
12Z06	7/25/05	36.87	-76.34	1.1	7.8	19.8	28.6	2.81	0.23
12Z07	8/10/05	36.83	-76.36	0.7	4.0	14.2	31.4	94.26	2.60
12Z08	8/10/05	36.84	-76.36	1.0	6.7	16.2	29.9	3.27	0.30
12Z09	7/25/05	36.90	-76.33	5.5	4.7	19.9	27.8	70.62	1.09
12Z10	8/10/05	36.84	-76.38	2.8	2.6	18.6	28.8	95.76	2.06
12Z11	7/25/05	36.87	-76.34	6.7	4.7	19.8	28.5	93.08	1.71
12Z12	8/10/05	36.86	-76.34	1.4	5.5	20.0	28.6	4.67	0.25
12Z13	7/25/05	36.87	-76.34	1.5	7.0	19.8	29.0	2.70	0.23
12Z15	7/25/05	36.89	-76.32	1.5	5.3	19.7	27.9	3.15	0.19
12Z16	8/10/05	36.84	-76.37	3.0	3.2	19.8	28.5	94.68	2.16
12Z17	7/25/05	36.87	-76.34	1.8	7.0	19.8	28.9	3.68	0.21
12Z18	7/25/05	36.89	-76.34	18.3	4.5	20.0	28.2	99.57	2.23
12Z19	7/25/05	36.89	-76.33	4.0	4.8	19.8	27.9	62.99	1.39
12Z20	8/10/05	36.84	-76.32	0.8	5.7	12.0	30.0	23.97	2.06
12Z21	8/10/05	36.77	-76.30	5.2	2.8	18.9	31.2	25.34	2.13
12Z23	8/10/05	36.84	-76.30	6.5	3.2	20.2	28.4	82.02	2.05
12Z24	8/10/05	36.85	-76.30	5.5	2.8	20.1	28.4	54.06	2.43
12Z25	7/22/05	36.92	-76.34	11.0	5.4	20.5	27.5	97.30	2.11
12Z26	7/25/05	36.87	-76.32	11.0	3.4	19.7	28.5	89.50	2.16
12Z27	7/25/05	36.90	-76.33	5.1	4.9	19.9	27.8	50.24	0.95
12Z29	8/10/05	36.85	-76.30	14.3	2.6	23.6	25.9	92.86	1.86

Table 2. Random Stations of the Elizabeth River sampled in 2005. Summary of benthic community parameters. Abundance reported in 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
12Z01	3.00	5,352	2.132	2.62	10.6	77.1	22.3	57.4	8.5	66.5
12Z02	2.67	11,930	1.452	1.22	3.2	79.1	4.7	82.8	2.5	92.8
12Z03	3.00	2,381	0.476	2.28	6.7	85.7	14.3	52.4	10.5	46.7
12Z06	2.33	2,790	1.383	2.49	56.1	13.8	37.7	13.1	10.6	25.2
12Z07	2.33	11,567	2.472	1.80	14.9	61.6	8.3	34.9	5.7	78.8
12Z08	2.00	1,973	0.454	2.30	34.5	36.8	10.0	15.0	5.7	60.9
12Z09	2.67	2,132	0.680	2.83	39.4	47.9	40.0	33.3	12.8	41.5
12Z10	2.67	9,662	1.247	0.74	3.1	90.1	1.8	87.3	0.7	93.9
12Z11	2.00	7,394	0.907	1.36	21.8	75.8	45.0	47.5	4.6	74.8
12Z12	3.67	3,130	0.771	3.08	18.1	36.2	2.9	23.5	5.8	63.0
12Z13	1.67	1,656	0.340	2.63	54.8	20.5	20.0	33.3	13.7	24.7
12Z15	2.00	1,701	0.567	2.64	49.3	22.7	28.0	24.0	9.3	37.3
12Z16	2.33	8,891	1.066	0.81	11.2	86.7	10.6	83.0	0.5	87.2
12Z17	2.67	2,744	0.612	2.36	44.6	39.7	14.8	37.0	5.0	35.5
12Z18	1.67	1,111	0.703	2.32	63.3	22.4	87.1	3.2	2.0	53.1
12Z19	1.67	7,847	1.157	1.53	22.5	74.0	60.8	23.5	2.6	77.5
12Z20	2.00	25,787	2.812	0.70	0.8	0.0	0.8	0.0	12.8	86.3
12Z21	2.67	9,503	0.476	1.22	9.8	83.8	9.5	71.4	7.2	82.3
12Z23	1.67	5,352	0.635	1.04	9.7	88.1	60.7	28.6	4.7	89.0
12Z24	1.33	9,616	1.724	1.35	20.8	75.2	84.2	10.5	2.8	83.5
12Z25	1.67	3,175	0.544	1.92	20.0	61.4	58.3	16.7	5.0	77.1
12Z26	3.00	17,146	4.241	1.40	28.3	66.0	4.8	85.6	0.8	68.8
12Z27	2.00	3,221	0.953	2.96	22.5	34.5	35.7	11.9	20.4	36.6
12Z29	1.67	7,484	1.338	1.86	17.6	70.0	61.0	20.3	6.7	78.5
12Z31	1.67	10,342	0.998	1.21	10.1	84.2	50.0	36.4	3.7	87.1
Mean	2.24	6,955	1.206	1.87	23.7	57.3	30.9	37.3	6.6	65.9

Table 3. Random Stations of the Elizabeth River sampled in 2005. 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
12Z01	3.00	5	1	1	3	3	.	5	1	.	.
12Z02	2.67	4	2	1	1	3	.	.	5	5	1
12Z03	3.00	5	1	1	3	1	.	5	3	.	.
12Z06	2.33	5	1	1	3	3	.	1	1	.	.
12Z07	2.33	4	2	1	1	5	.	.	3	3	1
12Z08	2.00	4	1	1	5	1	1	3	.	.	1
12Z09	2.67	5	2	3	5	3	.	.	1	3	1
12Z10	2.67	5	2	1	1	3	.	.	5	5	1
12Z11	2.00	5	2	1	3	3	.	.	1	3	1
12Z12	3.67	5	1	3	5	1	.	3	5	.	.
12Z13	1.67	5	1	1	3	1	.	1	1	.	.
12Z15	2.00	5	1	1	3	1	.	1	1	.	.
12Z16	2.33	5	2	1	1	3	.	.	3	5	1
12Z17	2.67	5	1	1	3	1	.	3	3	.	.
12Z18	1.67	5	2	1	3	3	.	.	1	1	1
12Z19	1.67	5	2	1	3	3	.	.	1	1	1
12Z20	2.00	4	1	1	1	3	5	1	.	.	1
12Z21	2.67	5	1	1	1	1	.	5	3	.	.
12Z23	1.67	5	2	1	3	3	.	.	1	1	1
12Z24	1.33	5	2	1	1	3	.	.	1	1	1
12Z25	1.67	5	2	1	3	3	.	.	1	1	1
12Z26	3.00	5	2	1	1	5	.	.	5	5	1
12Z27	2.00	5	2	3	3	3	.	.	1	1	1
12Z29	1.67	5	2	1	3	3	.	.	1	1	1
12Z31	1.67	5	2	1	1	3	.	.	1	3	1

Table 4. Random Stations of the Elizabeth River sampled in 2005. Dominant tax by abundance. Taxon code: B = bivalve, C = cumacean, G = gastropod, I = isopod, N = nemertean, O = oligochaete, P = polychaete, PH = phoronid.

Rank	Taxon	Abundance per m^2
1	Mediomastus ambiseta (P)	3,891
2	Streblospio benedicti (P)	896
3	Monopylephorus rubroniveus (O)	881
4	Tubificoides spp. Group I (O)	200
5	Laeonereis culveri (P)	157
6	Tubificoides heterochaetus (O)	138
7	Glycinde solitaria (P)	118
8	Leitoscoloplos spp. (P)	101
9	Heteromastus filiformis (P)	93
10	Paraprionospio pinnata (P)	77
11	Phoronis spp. (PH)	52
12	Edotea triloba (I)	40
13	Synidotea spp. (I)	39
14	Neanthes succinea (P)	33
15	Polydora cornuta (P)	32

Table 5. Fixed Stations of the Elizabeth River sampled in 2005. Summary of physical-chemical parameters.

STATION	Date collected	LATITUDE	LONGITUDE	Water depth (m)	Temperature (ºC)	Salinity (psu)	Dissolved oxygen (ppm)	Silt_clay content (%)	Volatile organics (%)
EBB1	7/21/2005	36.8378	-76.2422	2.5	28.2	17.7	3.5	75.7	6.3
ELC1	7/21/2005	36.8796	-76.3476	3.0	29.0	19.8	6.7	44.4	1.4
ELD1	7/21/2005	36.8614	-76.3357	2.0	28.2	19.9	6.3	2.6	0.3
ELF1	7/21/2005	36.8486	-76.2967	11.5	27.2	20.6	4.2	87.3	6.3
LFA1	7/21/2005	36.9092	-76.3138	2.5	30.3	19.7	5.3	82.3	3.5
LFB1	7/21/2005	36.8896	-76.2830	3.0	31.7	17.2	6.7	97.8	6.6
SBA1	7/19/2005	36.8255	-76.2907	12.0	25.1	22.5	1.7	96.4	8.1
SBB1	7/19/2005	36.8117	-76.2886	1.1	30.3	18.1	7.2	67.5	6.0
SBC1	7/19/2005	36.7994	-76.2944	11.5	24.7	22.8	1.5	89.6	8.0
SBD1	7/19/2005	36.7796	-76.3106	12.0	25.2	22.1	1.5	59.0	6.8
SBD2	7/19/2005	36.7668	-76.2969	1.8	31.1	17.6	4.5	71.9	11.1
SBD4	7/19/2005	36.7402	-76.2990	2.0	30.4	17.2	3.7	57.9	5.9
WBB1	7/21/2005	36.8462	-76.3576	2.5	29.5	19.4	5.4	92.9	6.2
WBB5	7/21/2005	36.8293	-76.3932	1.8	30.9	17.7	6.8	78.5	5.3

Table 6. Fixed Point Stations of the Elizabeth River sampled in 2004. 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
Mainstem										
ELC1	2.56	2,971	0.847	2.44	28.3	52.0	17.6	36.8	11.3	57.1
ELD1	2.67	3,515	0.824	2.50	46.7	43.0	36.3	47.1	5.1	35.7
ELF1	1.56	14,372	2.124	1.56	32.5	60.6	59.7	32.4	1.0	67.7
Southern Branch										
SBA1	2.00	21,879	1.724	1.05	18.6	78.4	29.9	65.2	1.0	80.6
SBB1	1.67	11,416	0.975	1.57	23.6	69.2	29.8	36.5	4.4	73.0
SBC1	2.22	8,565	1.542	1.69	34.7	59.2	24.4	62.3	3.9	57.9
SBD1	2.33	1,610	0.476	2.54	45.2	35.2	19.4	37.2	22.9	17.4
SBD2	1.89	20,034	0.922	1.24	29.5	69.3	21.3	40.9	4.0	67.9
SBD4	2.78	4,226	0.529	2.37	27.4	66.1	11.8	69.0	20.4	27.1
Western Branch										
WBB1	2.22	11,053	1.300	0.96	12.4	86.2	16.9	68.4	2.8	84.5
WBB5	2.44	9,654	1.784	1.12	5.7	87.4	6.4	54.4	5.0	87.4
Eastern Branch										
EBB1	2.56	6,418	2.767	1.34	11.0	86.0	10.1	71.2	4.0	83.3
Lafayette River										
LFA1	2.11	4,521	1.315	1.56	26.2	71.3	40.9	48.4	4.0	73.5
LFB1	2.22	9,601	0.960	1.14	8.7	77.2	18.9	70.3	0.6	90.1

Table 7. Status in benthic community condition based on the Benthic IBI at the Elizabeth River Project monitoring stations for the period of 2003 through 2005.

Station	Mean IBI	Status
Mainstem		
ELC1	2.6	Degraded
ELD1	2.7	Marginal
ELF1	1.7	Severely degraded
Southern Branch		
SBA1	1.7	Severely degraded
SBB1	2.0	Severely degraded
SBC1	2.2	Degraded
SBD1	2.0	Severely degraded
SBD2	2.3	Degraded
SBD4	2.6	Degraded
Western Branch		
WBB1	2.3	Degraded
WBB5	2.4	Degraded
Eastern Branch		
EBB1	2.4	Degraded
Lafayette River		
LFA1	2.2	Degraded
LFB1	2.6	Degraded

Table 8. Significant long term trends in the B-IBI and associated bioindicators for the Elizabeth River Project monitoring stations for the period of 1999 through 2004. All trends shown were significant at p ≤ 010.

Station	CBP	Variable	p value	Baseline	Slope	% Change
Mainstem						
ELC1	ELIPH	Pollution Sensitive Species Biomass	0.0275	47.51	-5.19	-54.60
ELD1	ELIPH	Benthic Index of Biotic Integrity	0.0275	3.22	0.22	34.82
ELF1	ELIPH	Pollution Sensitive Species Abundance	0.0275	24.27	13.67	281.58
ELF1	ELIPH	Pollution Indicative Species Abundance	0.0864	41.44	-9.53	-115.01
Southern Branch						
SBA1	SBEMH	Total Abundance per square meter	0.0275	3863.16	3916.08	506.85
SBA1	SBEMH	Shannon-Weiner Diversity Index	0.0864	2.44	-0.31	-64.16
SBB1	SBEMH	Total Biomass per square meter	0.0864	0.40	0.06	80.00
SBB1	SBEMH	Pollution Sensitive Species Abundance	0.0275	31.75	14.01	220.58
SBB1	SBEMH	Pollution Sensitive Species Biomass	0.0864	19.53	4.90	125.37
SBC1	SBEMH	Total Abundance per square meter	0.0864	2143.26	4007.10	934.81
SBC1	SBEMH	Shannon-Weiner Diversity Index	0.0275	2.46	-0.40	-81.36
SBC1	SBEMH	Pollution Sensitive Species Abundance	0.0864	39.87	16.45	206.27
SBD2	SBEMH	Pollution Sensitive Species Abundance	0.0864	36.18	14.29	197.55
SBD2	SBEMH	Pollution Indicative Species Abundance	0.0864	40.83	-6.83	-83.68
SBD2	SBEMH	Pollution Sensitive Species Biomass	0.0864	26.14	12.92	247.09
SBD4	SBEMH	Shannon-Weiner Diversity Index	0.0864	2.41	-0.28	-57.49
Western Branch						
WBB1	WBEMH	Benthic Index of Biotic Integrity	0.0770	2.23	-0.17	-38.31
WBB1	WBEMH	Total Abundance per square meter	0.0864	2536.38	1706.67	336.44
WBB1	WBEMH	Shannon-Weiner Diversity Index	0.0864	2.09	-0.43	-102.28
WBB1	WBEMH	Pollution Sensitive Species Abundance	0.0071	52.08	9.65	92.66
WBB1	WBEMH	Pollution Indicative Species Abundance	0.0275	35.74	-9.30	-130.15
WBB1	WBEMH	Pollution Sensitive Species Biomass	0.0275	13.60	11.90	437.41
WBB5	WBEMH	Shannon-Weiner Diversity Index	0.0864	2.80	-0.59	-105.05
WBB5	WBEMH	Pollution Sensitive Species Abundance	0.0275	24.58	23.16	471.10
Eastern Branch						
EBB1	EBEMH	Benthic Index of Biotic Integrity	0.0275	3.03	-0.30	-49.23
EBB1	EBEMH	Shannon-Weiner Diversity Index	0.0864	2.60	-0.40	-77.45
EBB1	EBEMH	Pollution Sensitive Species Abundance	0.0275	16.07	15.55	483.79
Lafayette River						
LFB1	LAFMH	Benthic Index of Biotic Integrity	0.0462	1.97	0.11	26.69
LFB1	LAFMH	Total Abundance per square meter	0.0462	3738.42	1522.33	203.61
LFB1	LAFMH	Total Biomass per square meter	0.0462	0.49	0.31	314.73
LFB1	LAFMH	Shannon-Weiner Diversity Index	0.0462	2.08	-0.19	-46.58
LFB1	LAFMH	Pollution Sensitive Species Abundance	0.0104	6.36	21.25	1670.92
LFB1	LAFMH	Pollution Sensitive Species Biomass	0.0462	22.21	17.93	403.79

Table 9. Comparison of nutrient concentrations in the Elizabeth River compare to the lower polyhaline section of the James River (JMSPH see Appendix B, Fig. B1). All values are in mg/l except chlorophyl *a* (CHLA) which is in µg/l and are the median values for the last three years of collection. Data for JMSPH from Dauer et al. 2005.					
Parameter	James River (JMSPH)	Elizabeth River Mainstem	Western Branch	Eastern Branch	Southern Branch
STN	0.46	0.65	0.70	0.84	1.12
SDIN	0.06	0.28	0.20	0.40	0.58
STP	0.04	0.05	0.06	0.05	0.06
SDIP	0.01	0.02	0.02	0.02	0.03
CHLA	7.57	10.23	11.64	6.09	3.62

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 ≥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)	≥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 (#/m²)	≥1500-3000	1000-1500 or ≥3000-8000	<1000 or ≥8000
Biomass (g/m²)	≥3-10	0.5-3 or ≥10-30	<0.5 or ≥30
Biomass of pollution-indicative taxa (%)	≤5	5-20	>20
Biomass of pollution-sensitive taxa (%)	≥60	30-60	<30
Abundance of carnivores and omnivores	≥40	25-40	<25
Number of taxa >5 cm below the sediment-water interface (%)	≥40	10-40	<10

Appendix B: Summary of water quality status and trends for the Elizabeth River

Preface:

In this appendix water quality status and trends for the Elizabeth River are summarized. These data are collected by the Virginia Water Quality Monitoring Program as part of the Chesapeake Bay Restoration Program. Details of collection and laboratory methodology can be found in Dauer et al. 2005 which can be downloaded in pdf format from the Old Dominion University Chesapeake Bay Program website <www.chesapeakebay.odu.edu> under "Reports." The James River Report includes the Elizabeth River, the Chickahominy River and the Appomattox River. The York River Report includes the tidal Pamunkey River and Mattaponi River. The Rappahannock River Report includes the Corrotoman River. Also available at this website are appendices that include (1) tables of status for all parameters measured at all stations sampled by each program, (2) tables of all parameters and metrics for which there was a significant trend, and (3) scatter plots of all parameters over time. There are five appendices: water quality, phytoplankton, primary productivity, zooplankton and benthos.

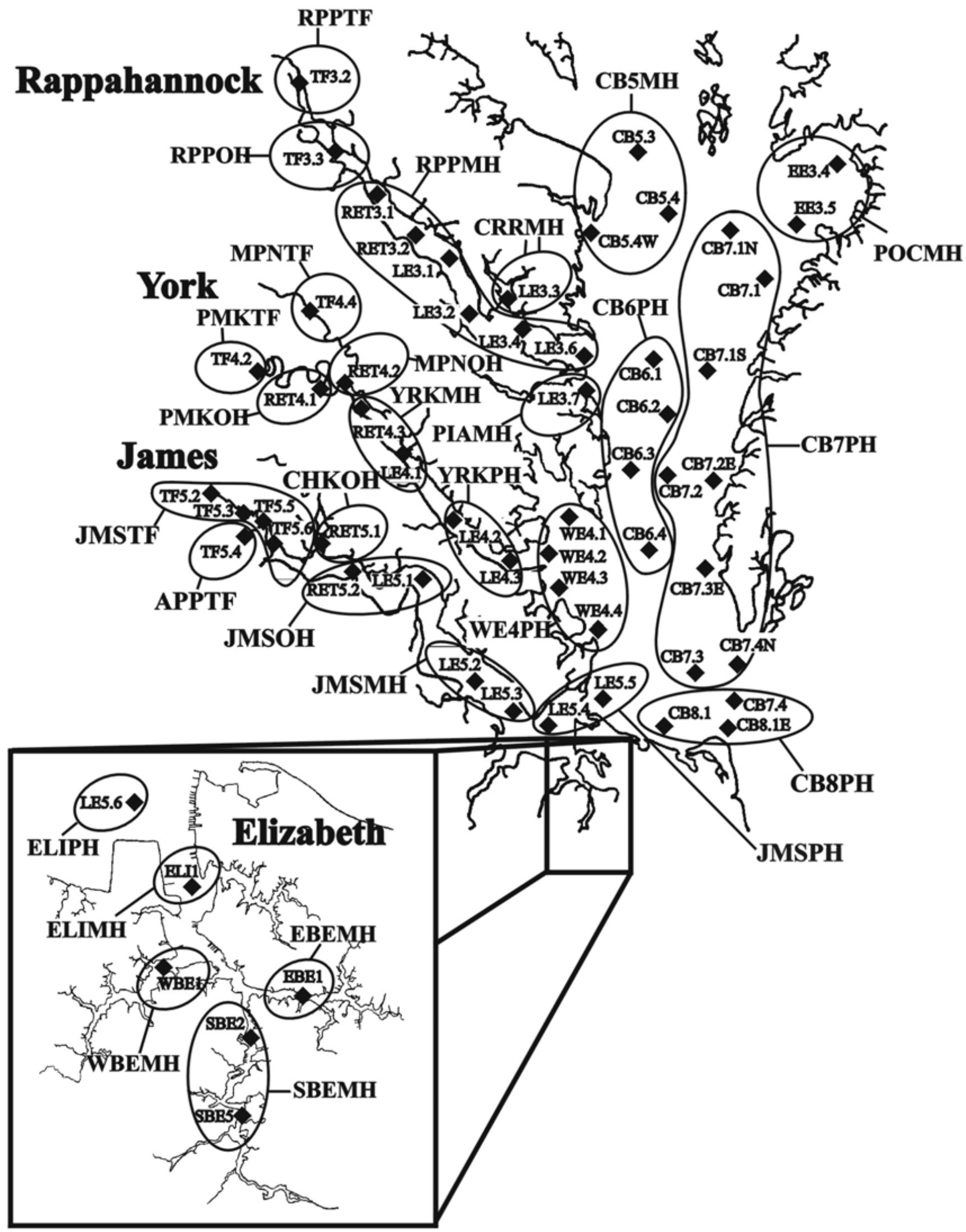

Figure B1. Map showing the locations of the water quality monitoring stations in the Virginia tributaries and the Lower Chesapeake Bay Mainstem (Dauer et al 2005). Insert shows location of Elizabeth River monitoring stations. Also shown are ellipses that delineate the Chesapeake Bay Program segmentation scheme.

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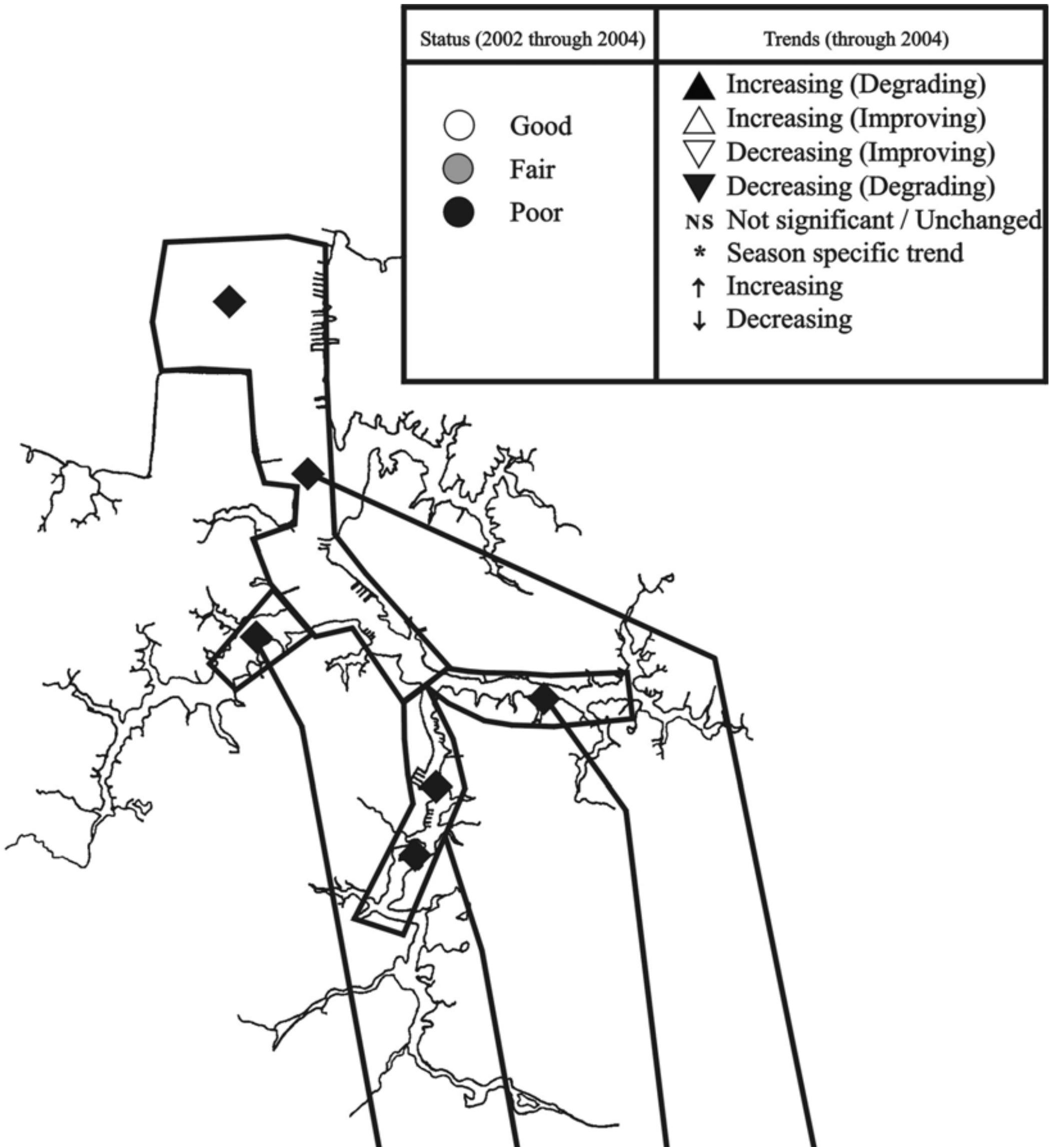
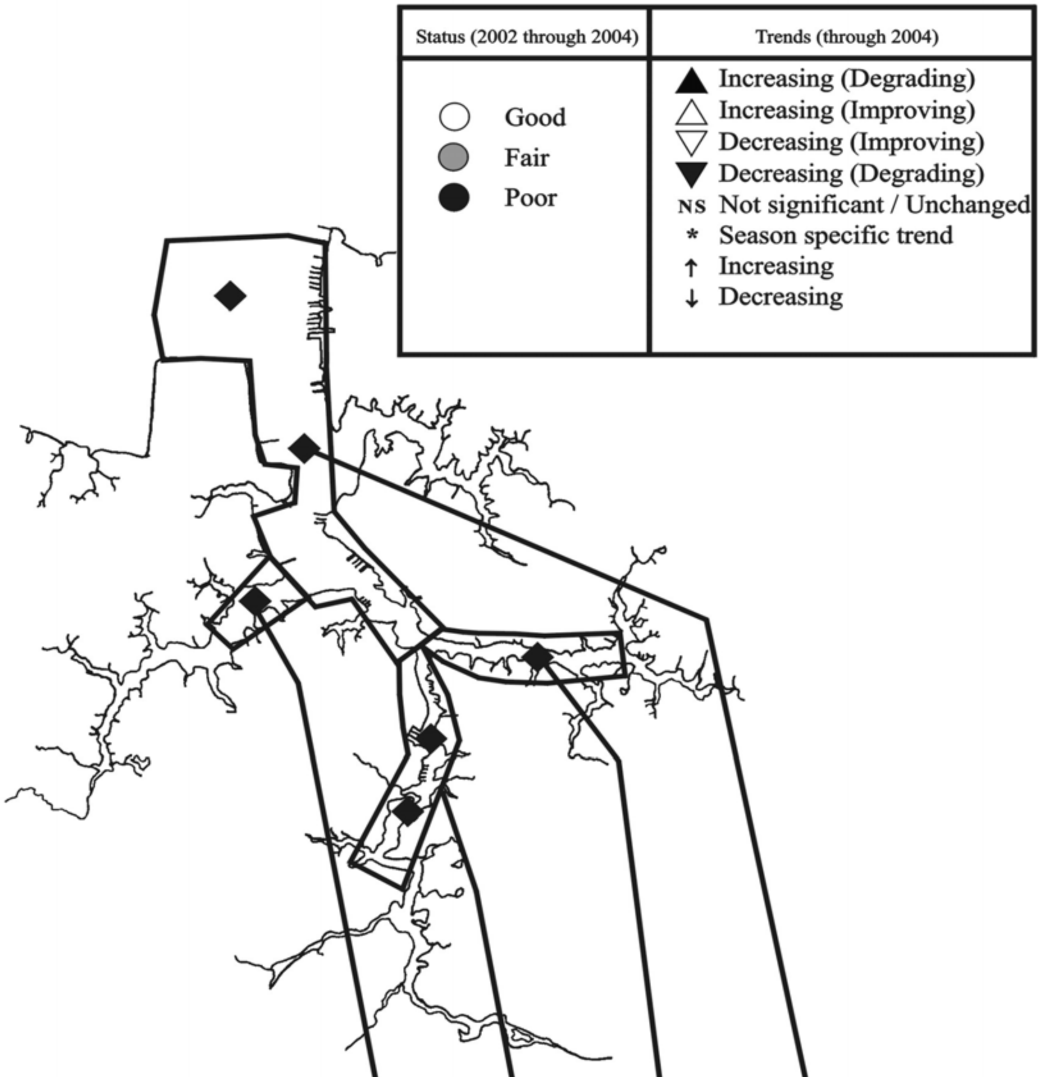


Parameter	Western Branch		Southern Branch		Eastern Branch		Elizabeth River Mainstem	
STN	◍	▽	●	▽	●	NS	◍	NS
BTN	●	▽	●	NS	●	▽	◍	NS
SDIN	◍	NS	●	▽	●	NS	●	NS
BDIN	●	NS	●	NS	●	▽	●	NS
STP	●	▽	◍	▽	●	▽	◍	NS
BTP	◍	▽	●	▽	◍	▽	●	NS
SDIP	●	▽	●	▽	●	▽	●	NS
BDIP	●	▽	●	▽	●	▽	●	NS

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



Parameter	Western Branch		Southern Branch		Eastern Branch		Elizabeth River Mainstem	
SCHLA	◐	▽	○	NS	○	NS	◐	NS
STSS	●	▽	○	▽	◐	▽	◐	▽
BTSS	●	▽	○	▽	○	▽	◐	NS
SECCHI	●	NS	●	NS	●	NS	●	▼
BDO	○	NS	◐	NS	◐	NS	◐	NS
SSALIN		NS		NS		NS		NS
BSALIN		NS		NS		NS		↓
SWTEMP		NS		↑		NS		NS
BWTEMP		NS		↑		NS		NS

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

Table B-1. Status in water quality environmental indicators in the Elizabeth River. Status designations determined by the Chesapeake Bay Program for the three year period 2002 through 2004. For information about field collection, laboratory analyses and status determination see Dauer et al. 2005. Secchi depth in meters, chlorophyll *a* in µg/l, all others in mg/l. S is surface and B is bottom layer. WBEMH - Western Branch, SBEMH - Southern Branch, EBEMH - Eastern Branch, ELIPH - Elizabeth River Mainstem.

Segment	Season	Parameter	Median	Score	Status
EBEMH	STN	Annual	0.845	80.5	Poor
EBEMH	BTN	Annual	0.768	76.0	Poor
EBEMH	SDIN	Annual	0.395	88.4	Poor
EBEMH	BDIN	Annual	0.346	93.8	Poor
EBEMH	STP	Annual	0.053	72.3	Poor
EBEMH	BTP	Annual	0.052	52.6	Fair
EBEMH	SPO4F	Annual	0.021	84.7	Poor
EBEMH	BPO4F	Annual	0.028	84.2	Poor
EBEMH	SCHLA	Annual	6.09	29.2	Good
EBEMH	STSS	Annual	8.31	42.5	Fair
EBEMH	BTSS	Annual	11.36	29.2	Good
EBEMH	SECCHI	Annual	1.00	25.3	Poor
WBEMH	STN	Annual	0.698	57.4	Fair
WBEMH	BTN	Annual	0.691	68.1	Poor
WBEMH	SDIN	Annual	0.199	59.4	Fair
WBEMH	BDIN	Annual	0.214	68.8	Poor
WBEMH	STP	Annual	0.059	70.0	Poor
WBEMH	BTP	Annual	0.058	54.3	Fair
WBEMH	SPO4F	Annual	0.017	74.8	Poor
WBEMH	BPO4F	Annual	0.019	63.5	Poor
WBEMH	SCHLA	Annual	11.64	56.8	Fair
WBEMH	STSS	Annual	15.93	79.1	Poor
WBEMH	BTSS	Annual	20.21	65.1	Poor
WBEMH	SECCHI	Annual	0.70	9.8	Poor
SBEMH	STN	Annual	1.115	95.6	Poor
SBEMH	BTN	Annual	0.989	91.6	Poor
SBEMH	SDIN	Annual	0.584	96.1	Poor
SBEMH	BDIN	Annual	0.497	98.2	Poor
SBEMH	STP	Annual	0.060	65.0	Fair
SBEMH	BTP	Annual	0.062	64.6	Poor
SBEMH	SPO4F	Annual	0.031	96.2	Poor
SBEMH	BPO4F	Annual	0.035	92.4	Poor
SBEMH	SCHLA	Annual	3.62	7.9	Good
SBEMH	STSS	Annual	7.75	35.6	Good
SBEMH	BTSS	Annual	9.28	24.3	Good
SBEMH	SECCHI	Annual	0.90	16.0	Poor
ELIPH	STN	Annual	0.645	55.2	Fair
ELIPH	BTN	Annual	0.603	64.0	Fair
ELIPH	SDIN	Annual	0.277	72.6	Poor
ELIPH	BDIN	Annual	0.225	87.5	Poor
ELIPH	STP	Annual	0.054	59.2	Fair
ELIPH	BTP	Annual	0.063	72.6	Poor
ELIPH	SPO4F	Annual	0.021	85.2	Poor
ELIPH	BPO4F	Annual	0.024	77.1	Poor
ELIPH	SCHLA	Annual	10.23	58.4	Fair
ELIPH	STSS	Annual	10.31	54.3	Fair
ELIPH	BTSS	Annual	18.02	48.0	Fair
ELIPH	SECCHI	Annual	0.95	19.1	Poor

Table B-2. Blocked seasonal Kendall Long-term trends in water quality for the segment ELIPH in the Elizabeth River (1985-2004). Parameters are as follows: STN=Surface total nitrogen, BTN=Bottom total nitrogen, SDIN=Surface dissolved inorganic nitrogen, BDIN=Bottom dissolved inorganic nitrogen, STP=Surface total phosphorus, BTP=Bottom total phosphorus, SPO4F=Surface dissolved inorganic phosphorus, BPO4F=Bottom dissolved inorganic phosphorus.

Segment	Parameter	'85-'93 Trend p value	'85-93 Trend slope	'85-'93 Trend Direction	'95-'02 Trend p value	'95-'02 Trend Slope	'95-'02 Trend Direction	Trend Comparison p value	Trend Comparison Significance	Combined Trend p value	Combined Trend Direction
ELIPH	STN	1.0000	0.000	No Trend	0.1000	0.006	No Trend	0.1761	Same	0.1900	No Trend
ELIPH	BTN	1.0000	0.000	No Trend	0.0201	0.007	No Trend	0.0570	Same	0.0570	No Trend
ELIPH	SDIN	0.9426	0.000	No Trend	0.0072	0.009	Degrading	0.0341	Same	0.0248	No Trend
ELIPH	BDIN	0.8504	0.000	No Trend	0.0389	0.005	No Trend	0.1149	Same	0.0669	No Trend
ELIPH	STP	0.8184	0.000	No Trend	0.0663	-0.001	No Trend	0.1087	Same	0.2008	No Trend
ELIPH	BTP	0.1060	0.001	No Trend	0.0707	-0.001	No Trend	0.0146	Same	0.7015	No Trend
ELIPH	SPO4F	0.7632	0.000	No Trend	0.8765	0.000	No Trend	0.7431	Same	0.9347	No Trend
ELIPH	SPO4F	0.5036	0.000	No Trend	0.7564	0.000	No Trend	0.8540	Same	0.4998	No Trend

Appendix C. Scatterplots of the B-IBI component metrics

Figure 1. Plot of the benthic IBI at station ELC1 from 1999 through 2005. 60

Figure 2. Plot of total benthic community abundance at station ELC1 for 1999 through 2005. 61

Figure 3. Plot of total benthic community biomass at station ELC1for 1999 through 2005. 62

Figure 4. Plot of the Shannon-Weiner diversity index at station ELC1 for 1999 through 2005. 63

Figure 5. Plot of pollution sensitive species abundance at station ELC1 for 1999 through 2005. 64

Figure 6. Plot of pollution indicative species abundance at station ELC1 for 1999 through 2005. 65

Figure 7. Plot of pollution sensitive species biomass at station ELC1 for 1999 through 2005. 66

Figure 8. Plot of pollution indicative species biomass at station ELC1 for 1999 through 2005. 67

Figure 9. Plot of the benthic IBI at station ELD1 from 1999 through 2005. 68

Figure 10. Plot of total benthic community abundance at station ELD1 for 1999 through

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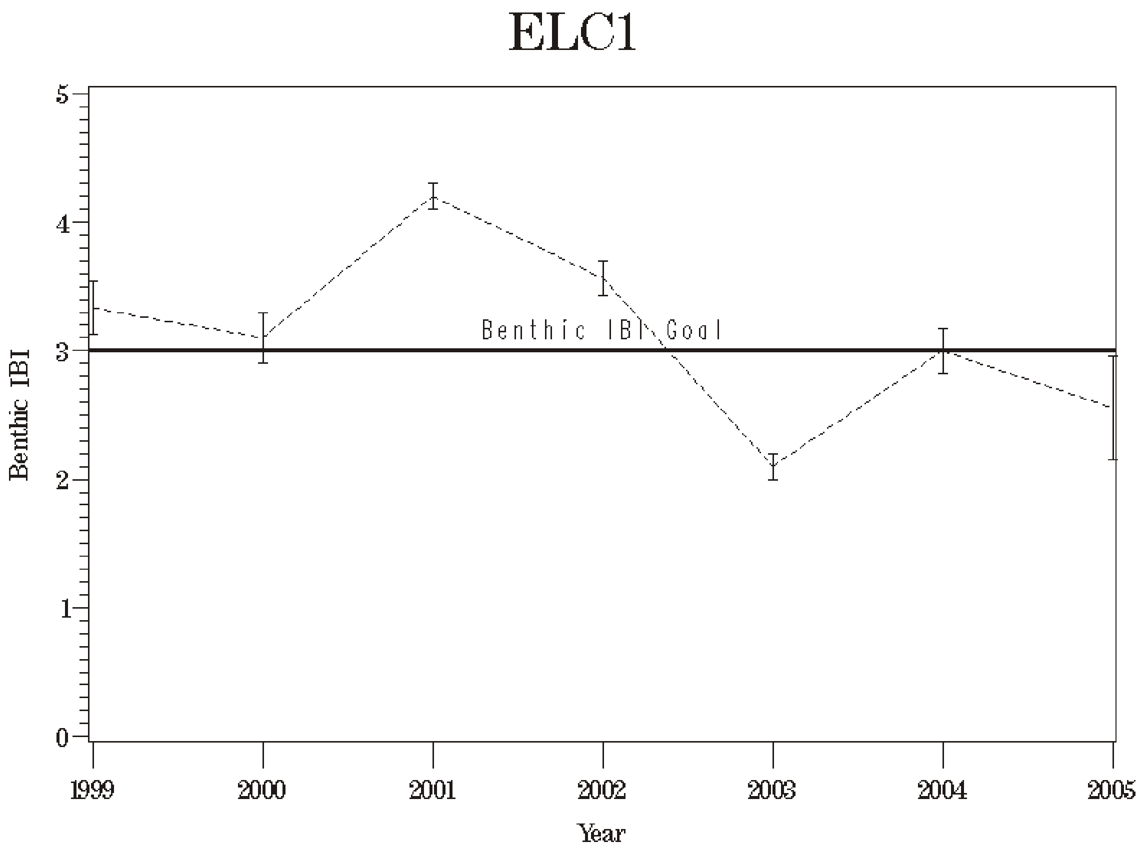
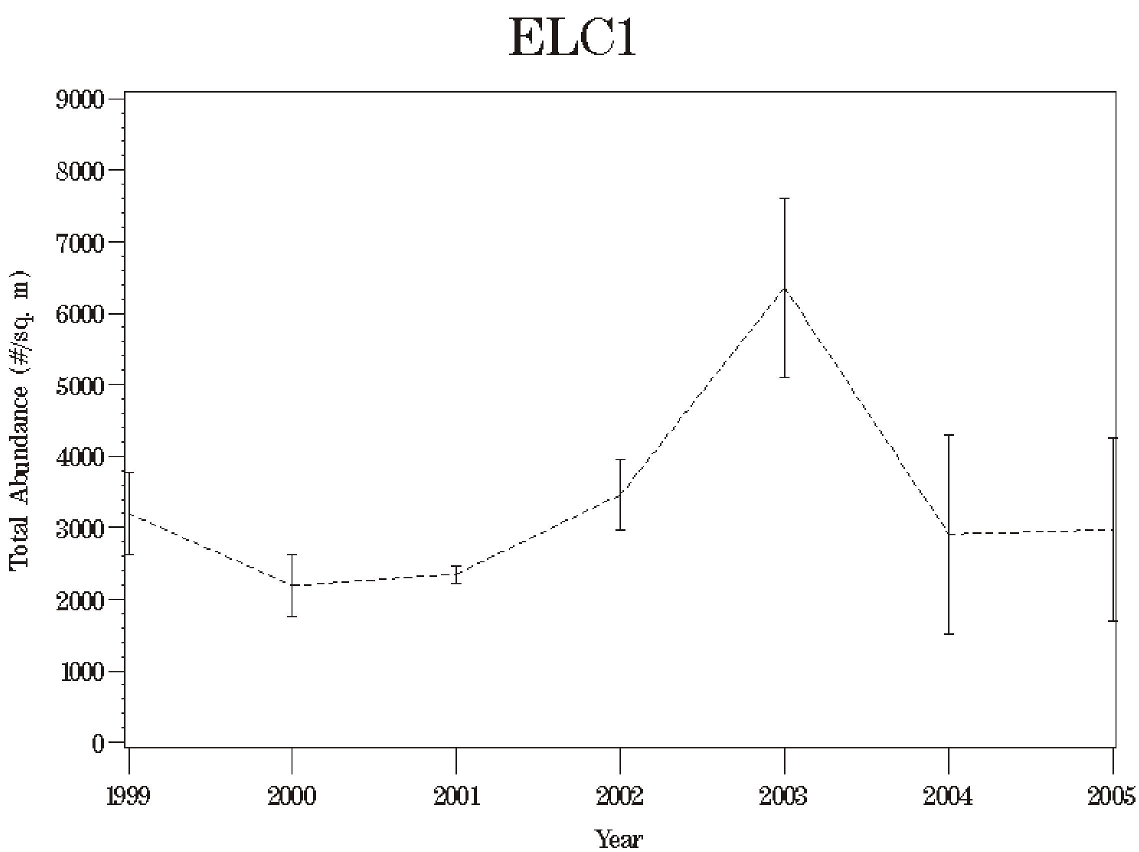


Figure 1. Plot of the benthic IBI at station ELC1 from 1999 through 2005.



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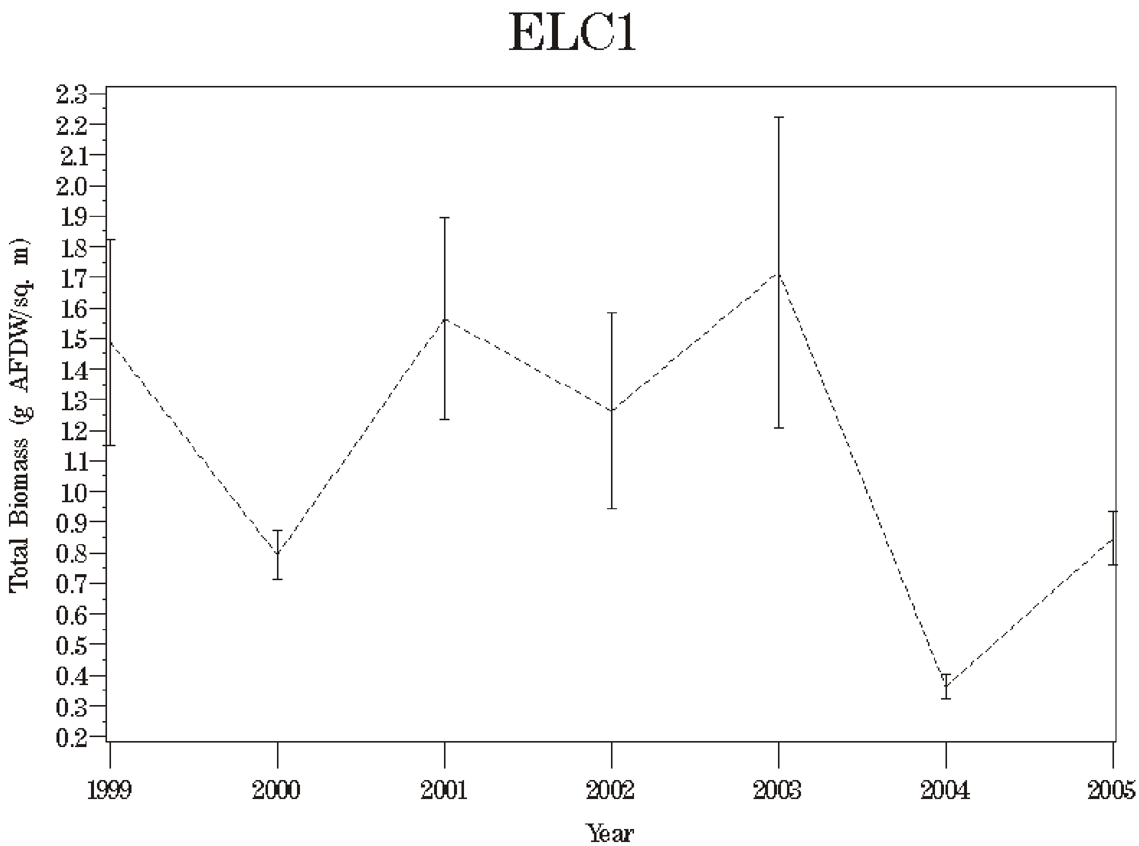

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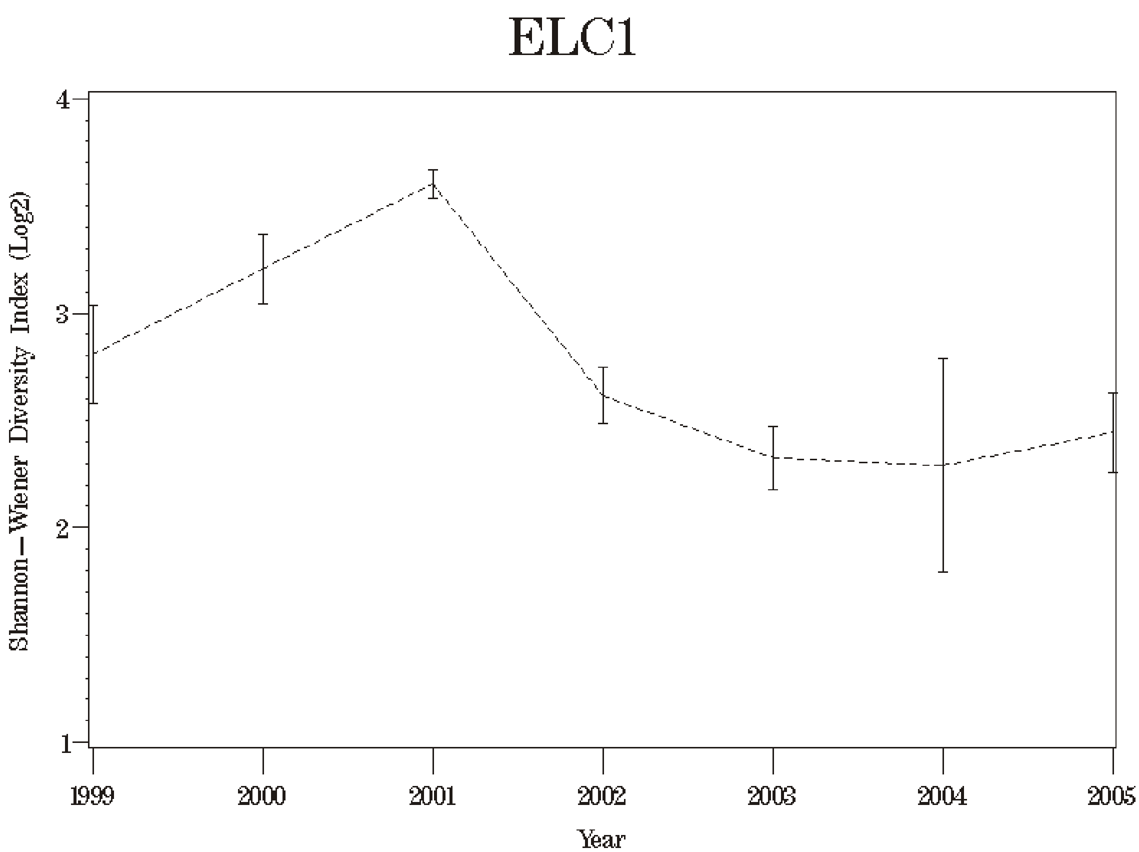

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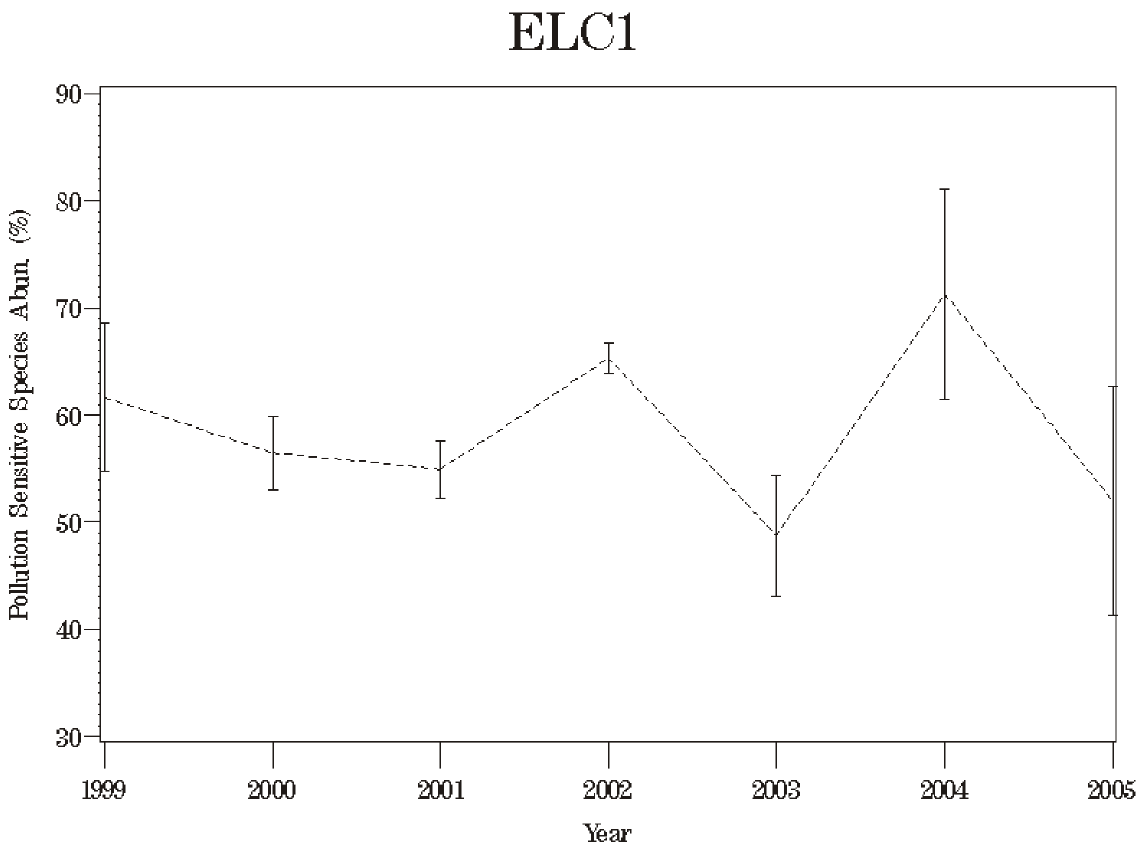

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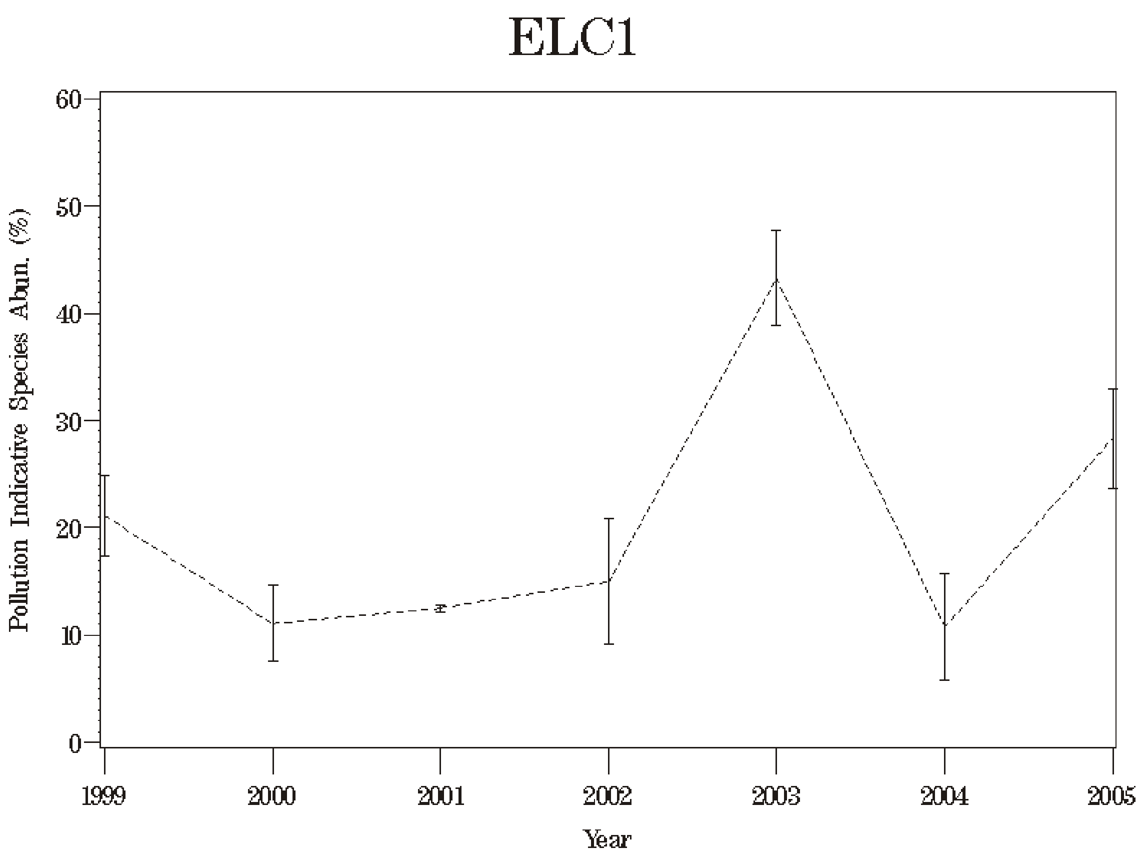

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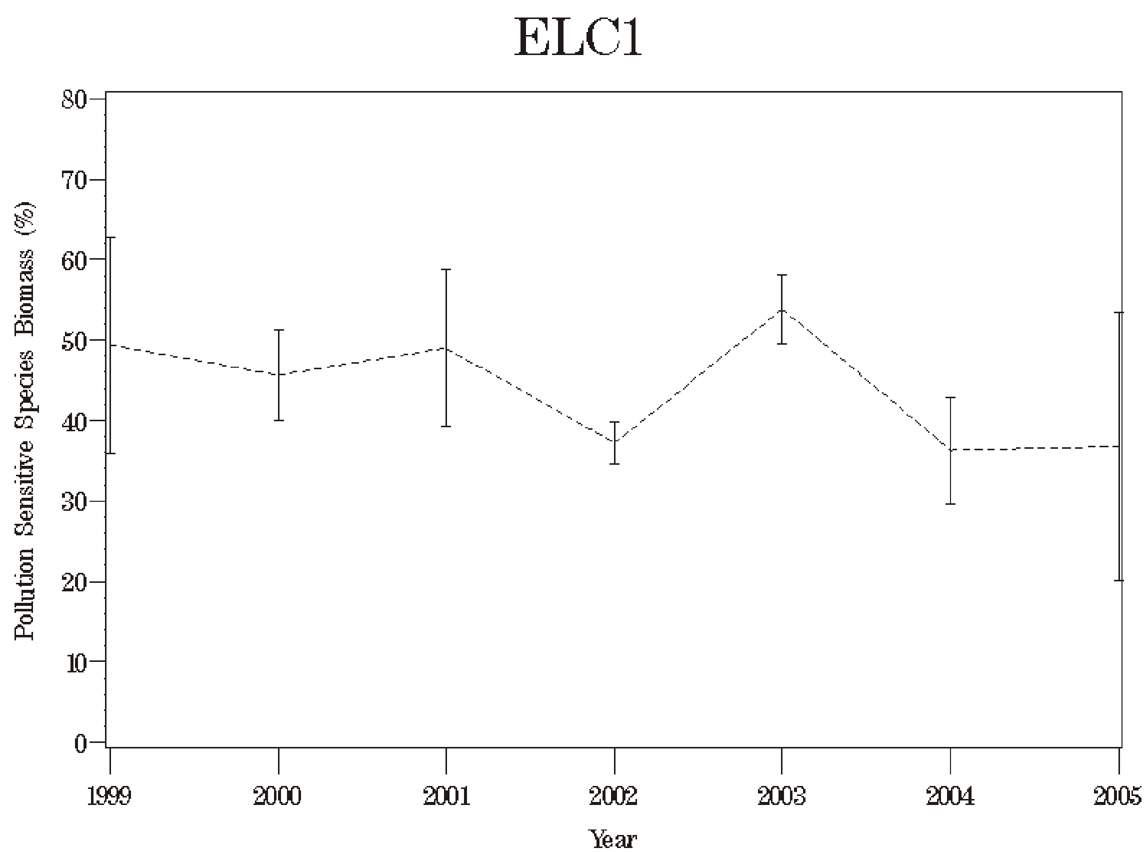

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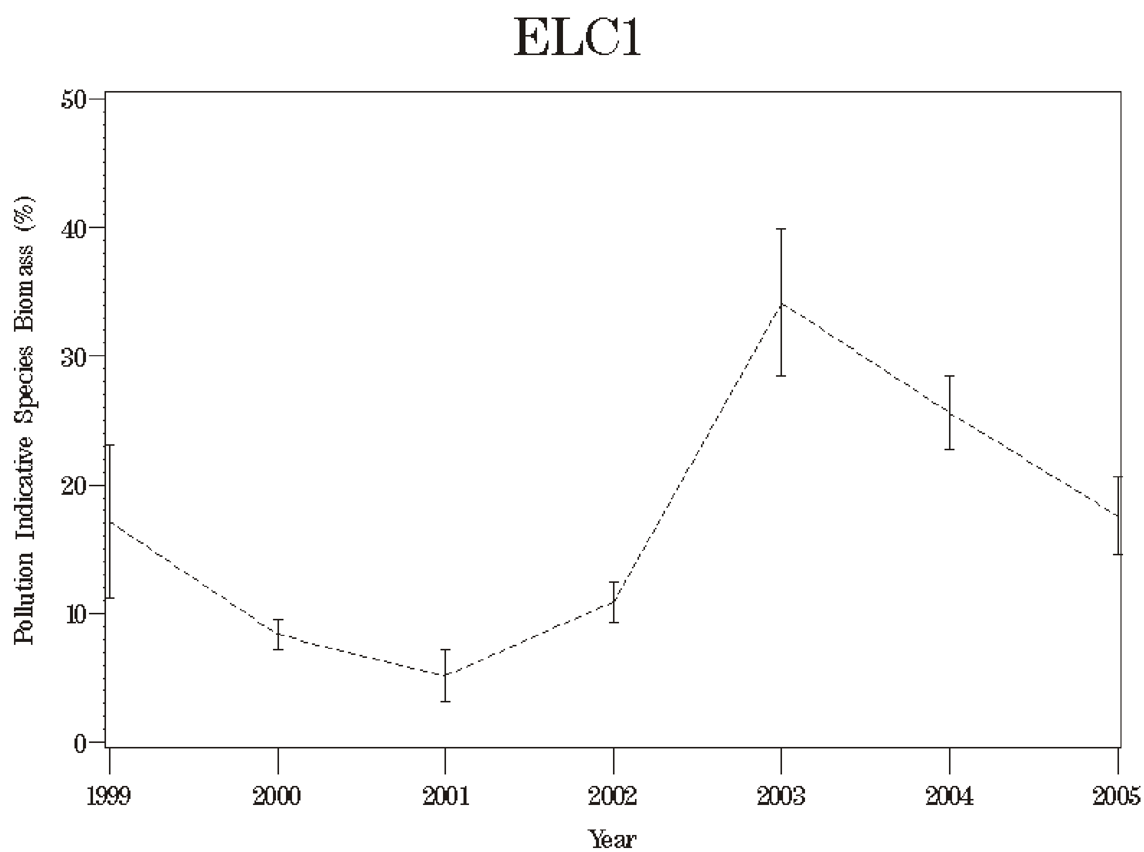


Figure 8. Plot of pollution indicative species biomass at station ELC1 for 1999 through 2005.

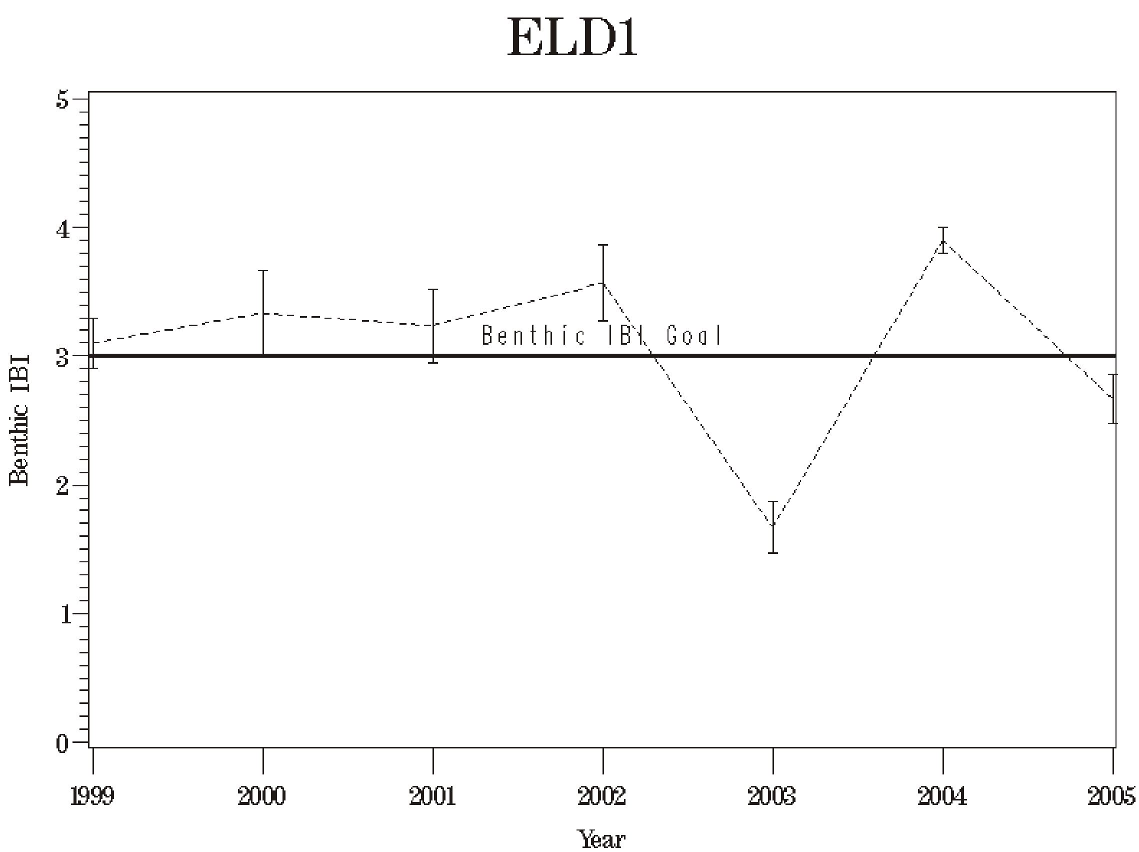
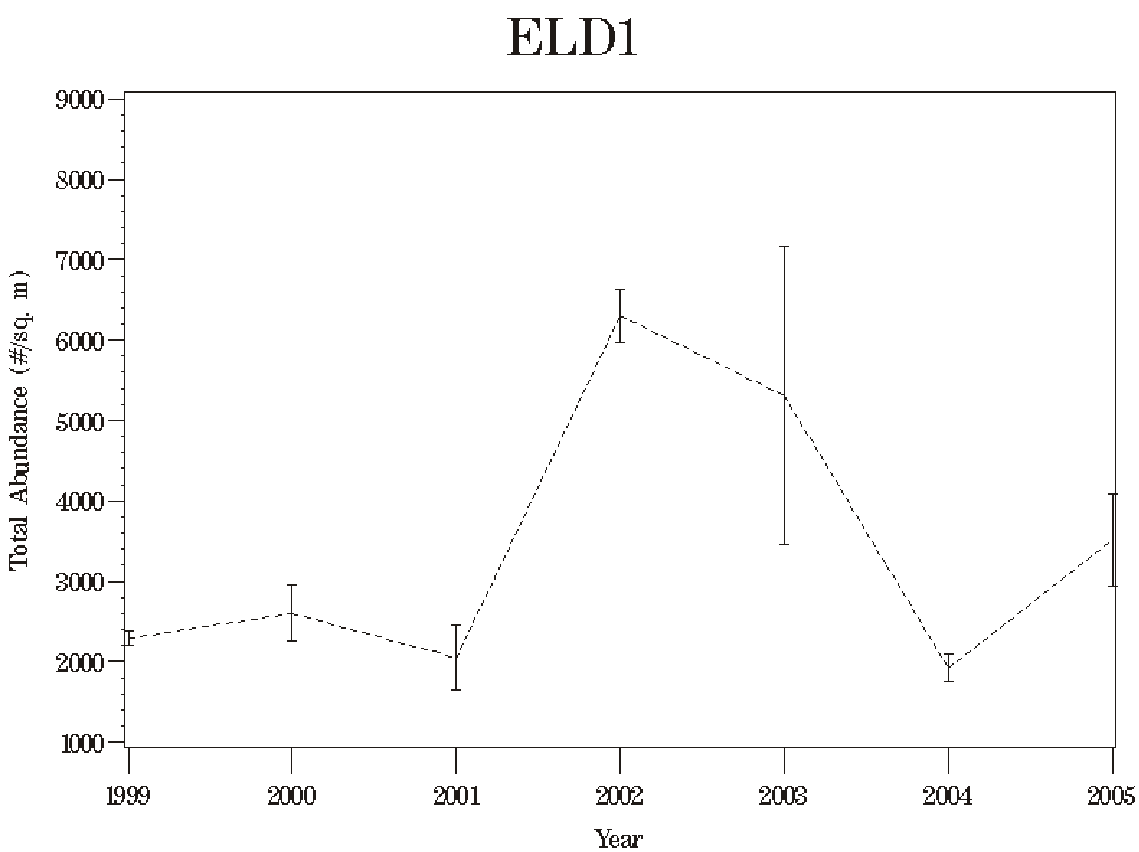


Figure 9. Plot of the benthic IBI at station ELD1 from 1999 through 2005.



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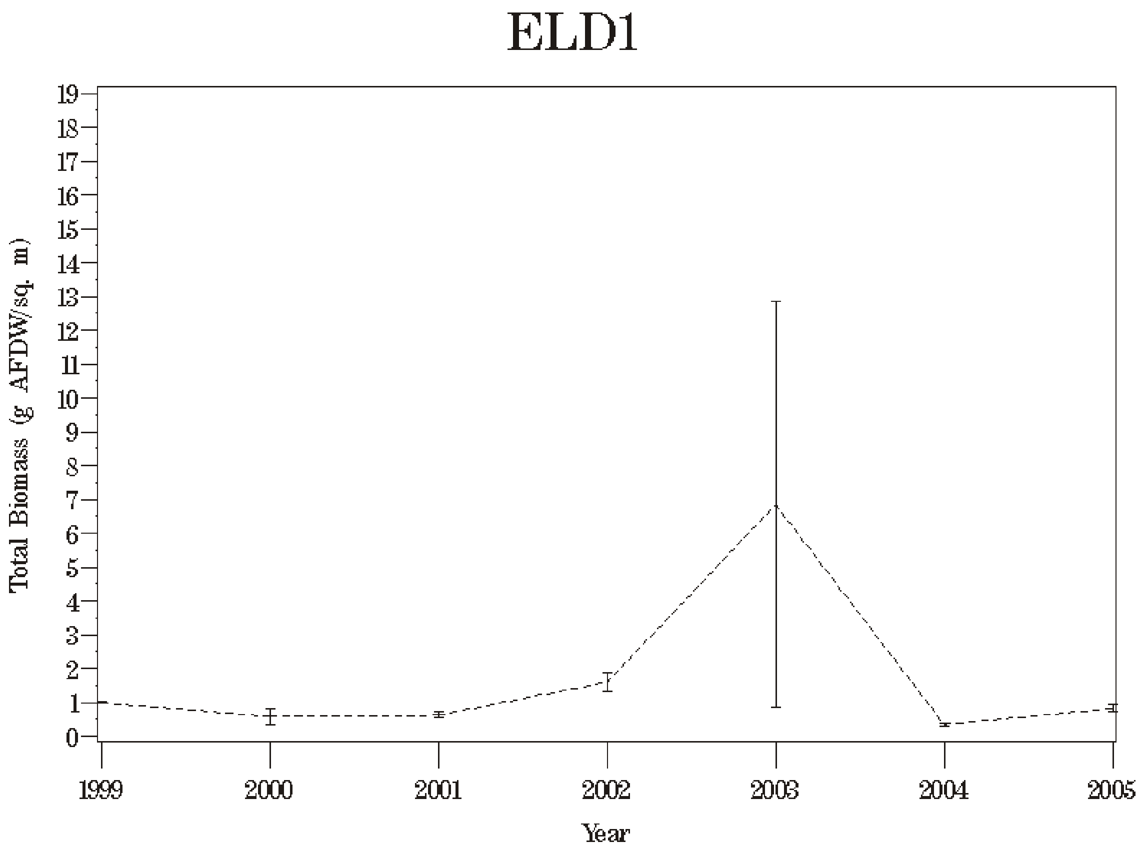

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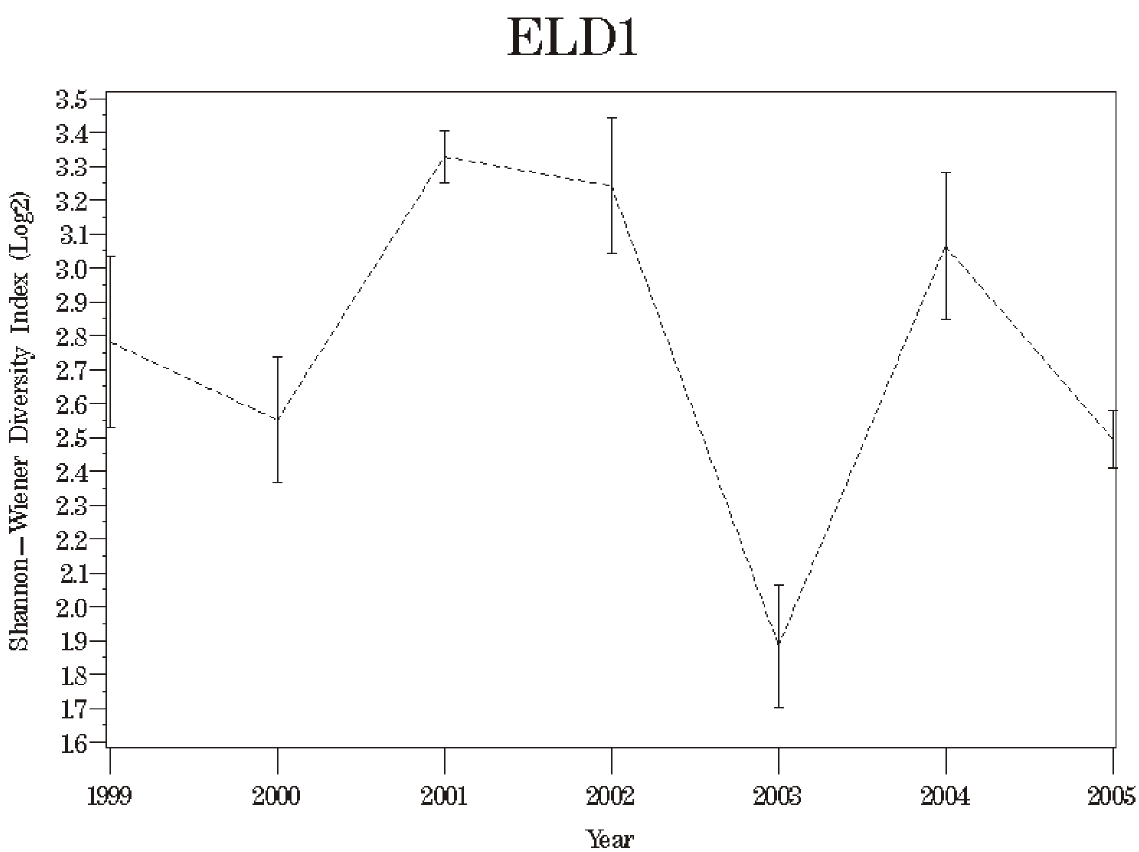

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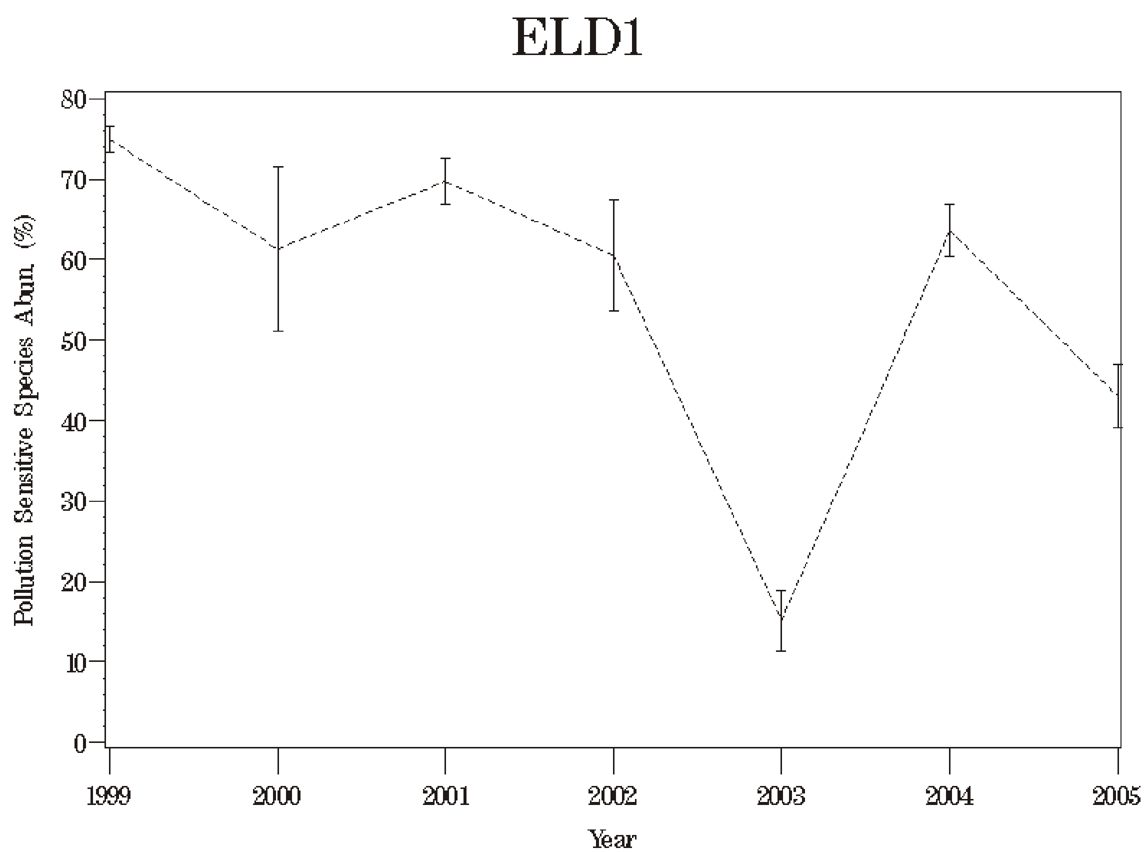

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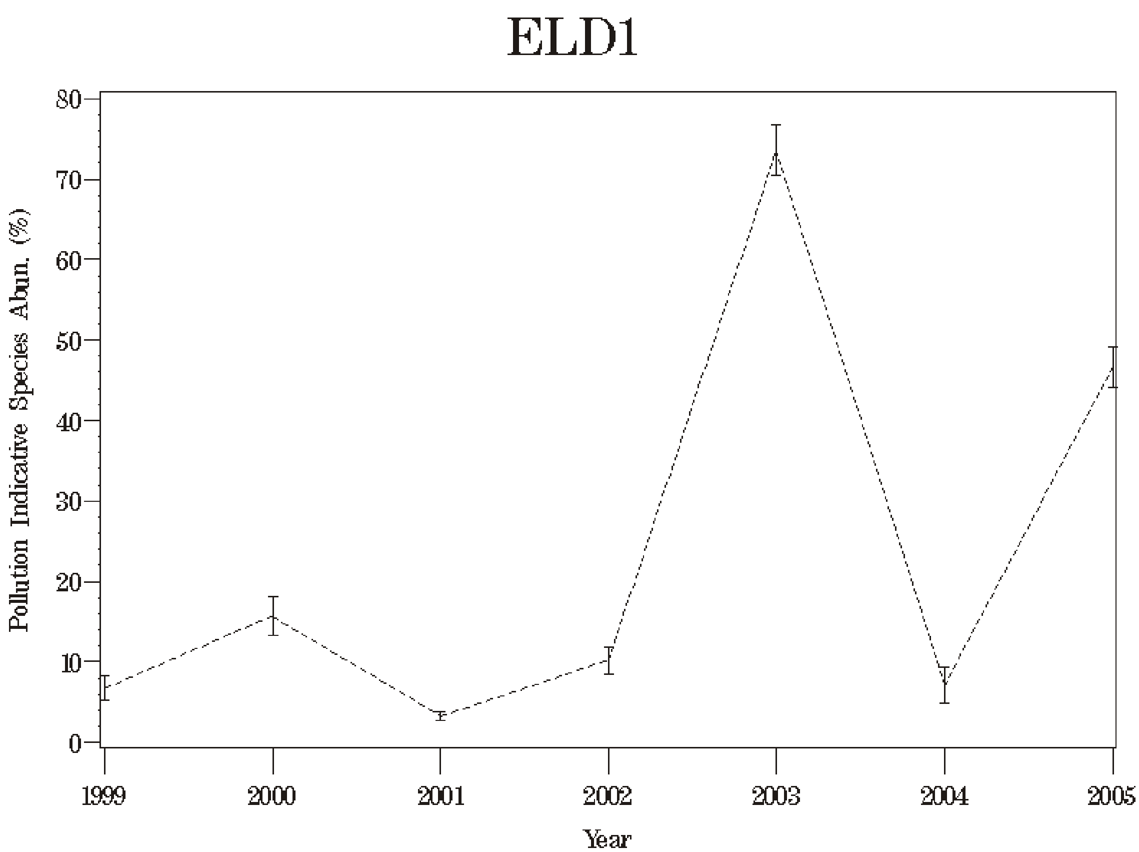

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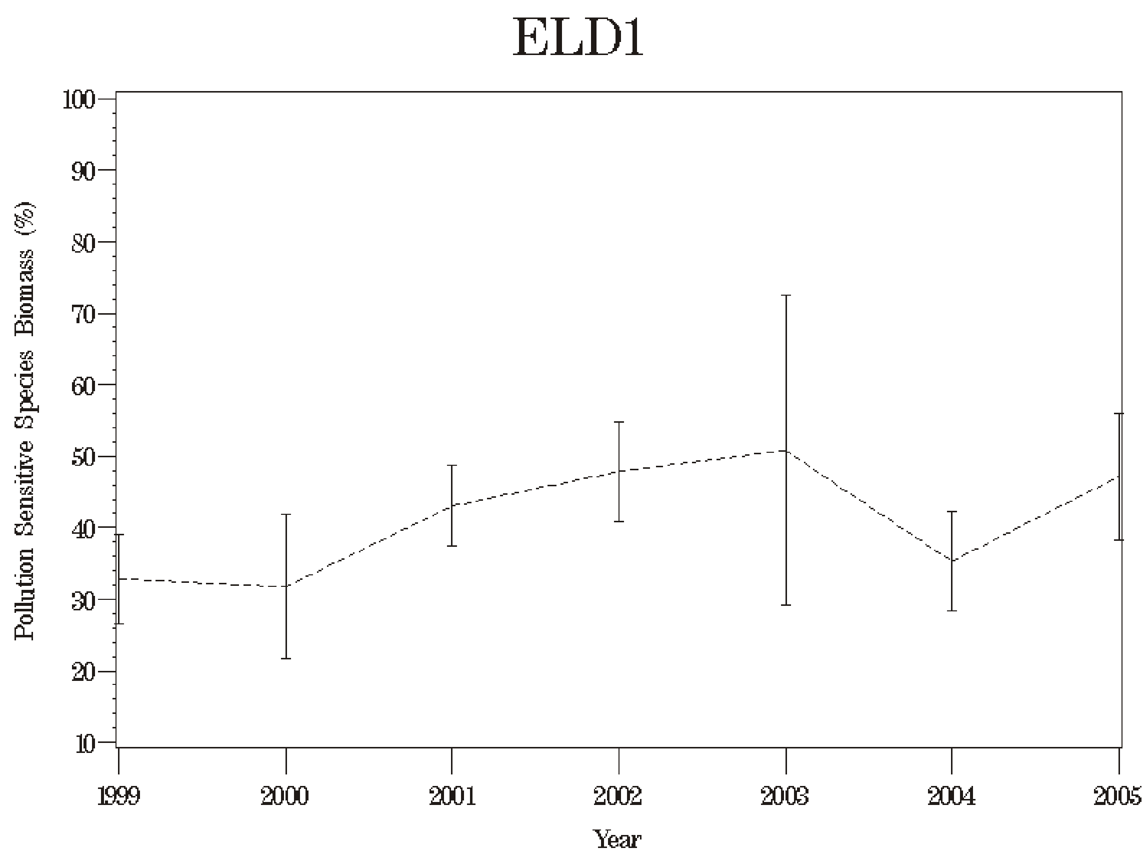

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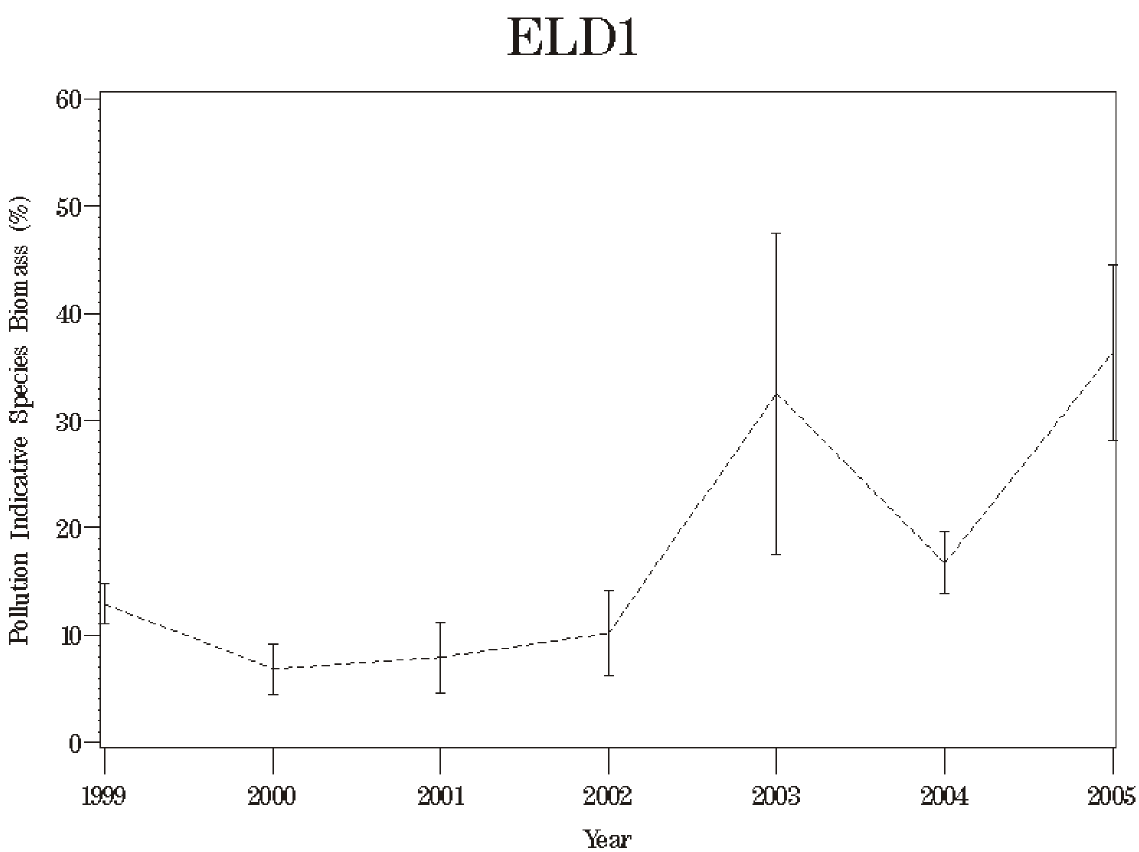

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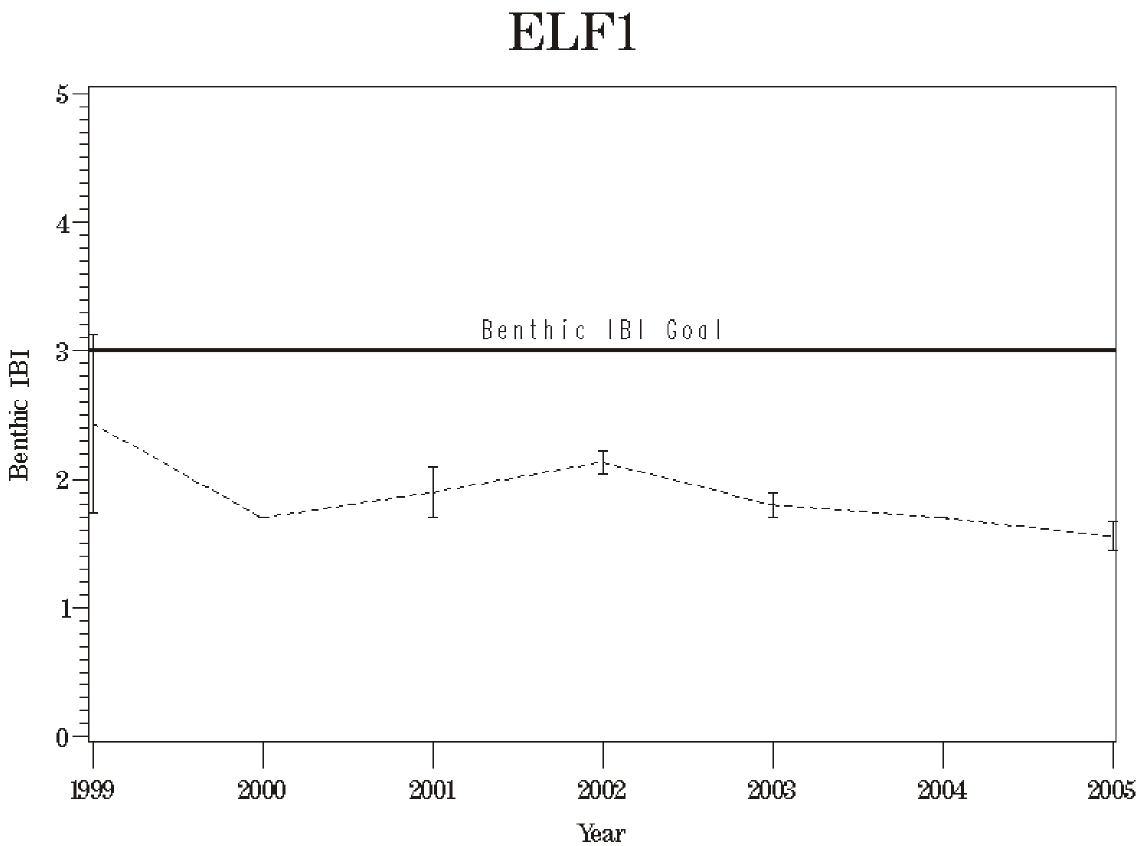


Figure 17. Plot of the benthic IBI at station ELF1 from 1999 through 2005.

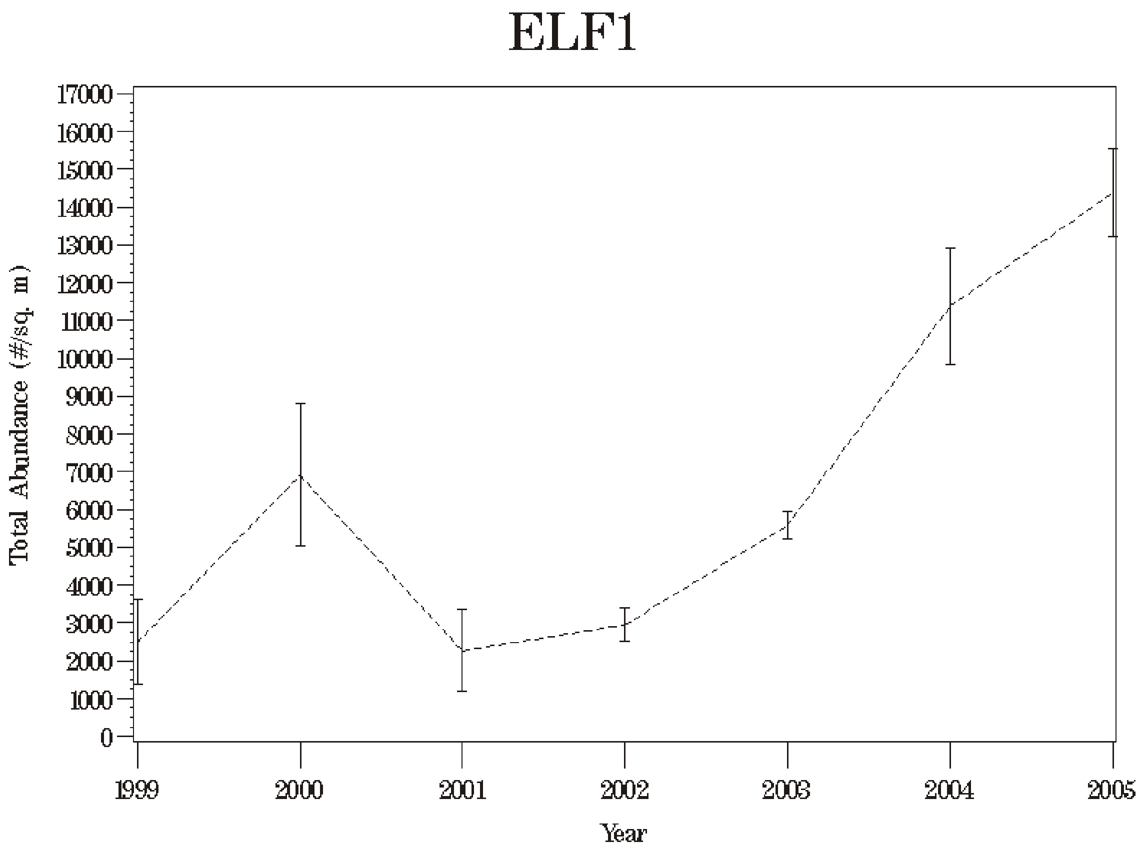
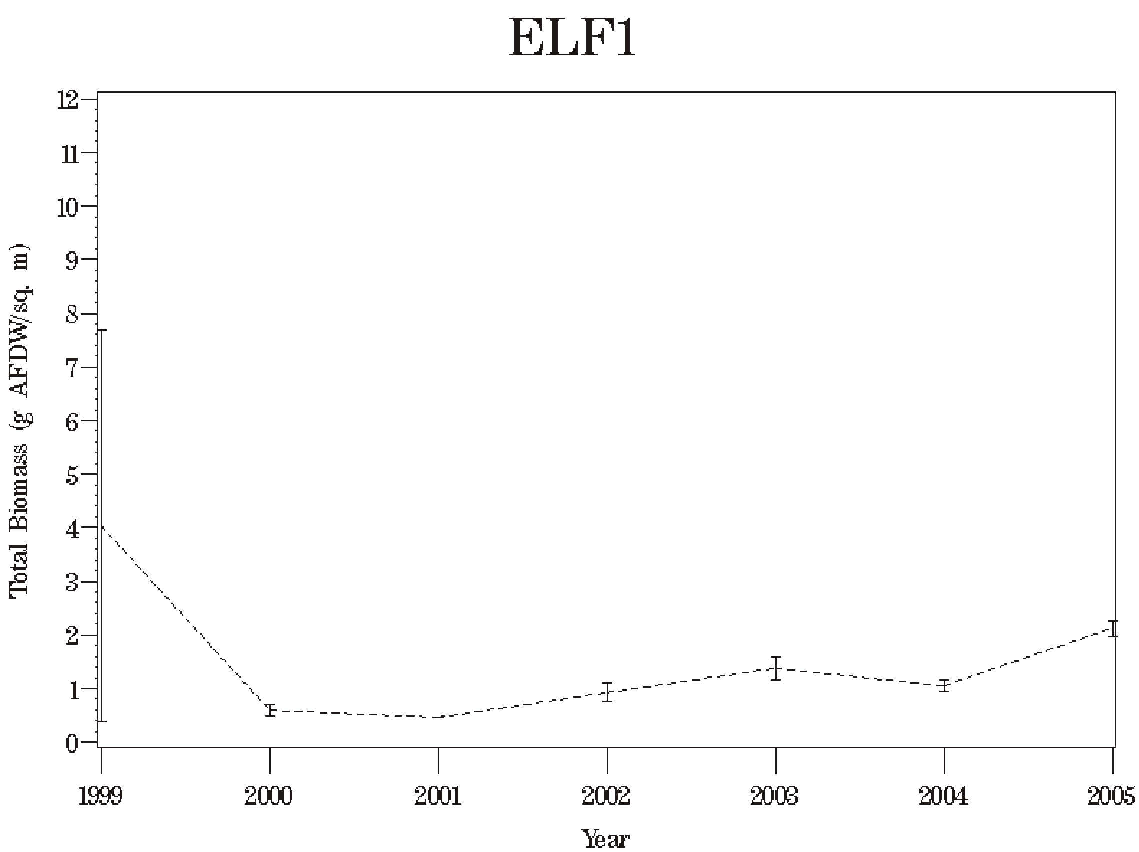


Figure 18. Plot of total benthic community abundance at station ELF1 for 1999 through 2005.



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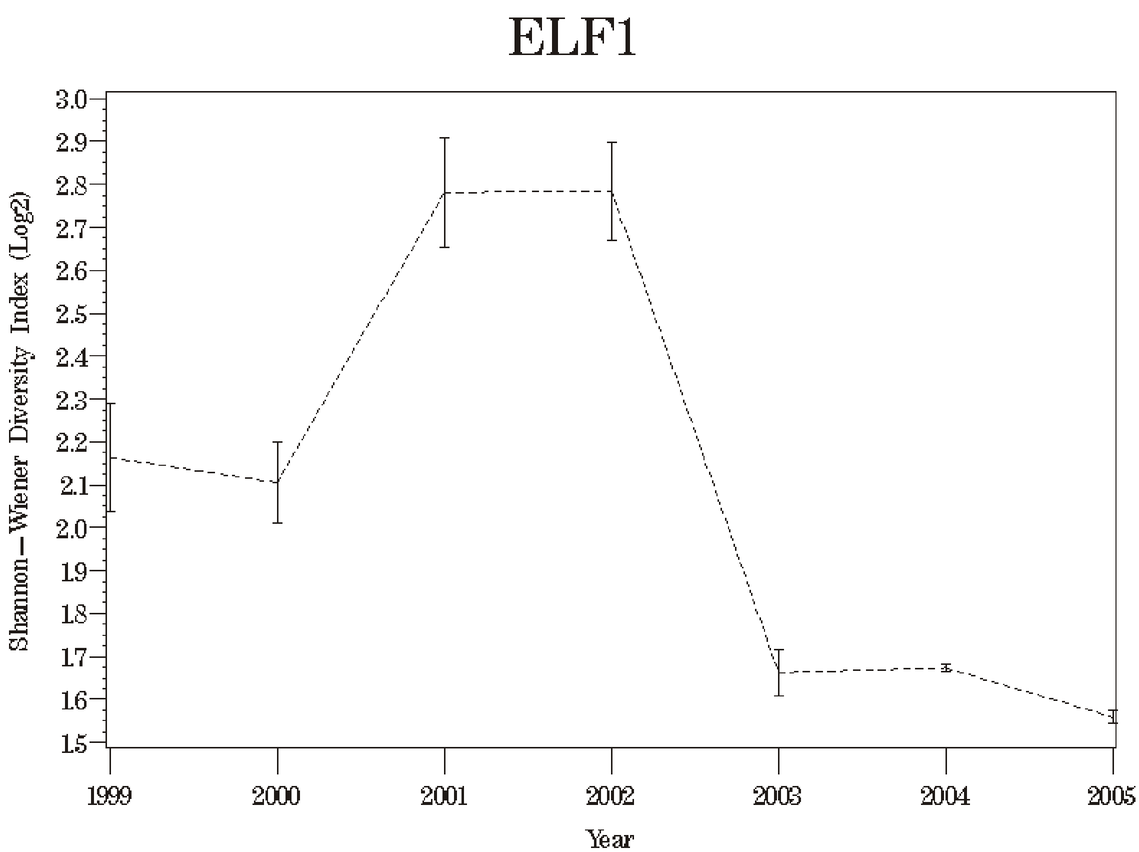


Figure 20. Plot of the Shannon-Weiner diversity index at station ELF1 for 1999 through 2005.

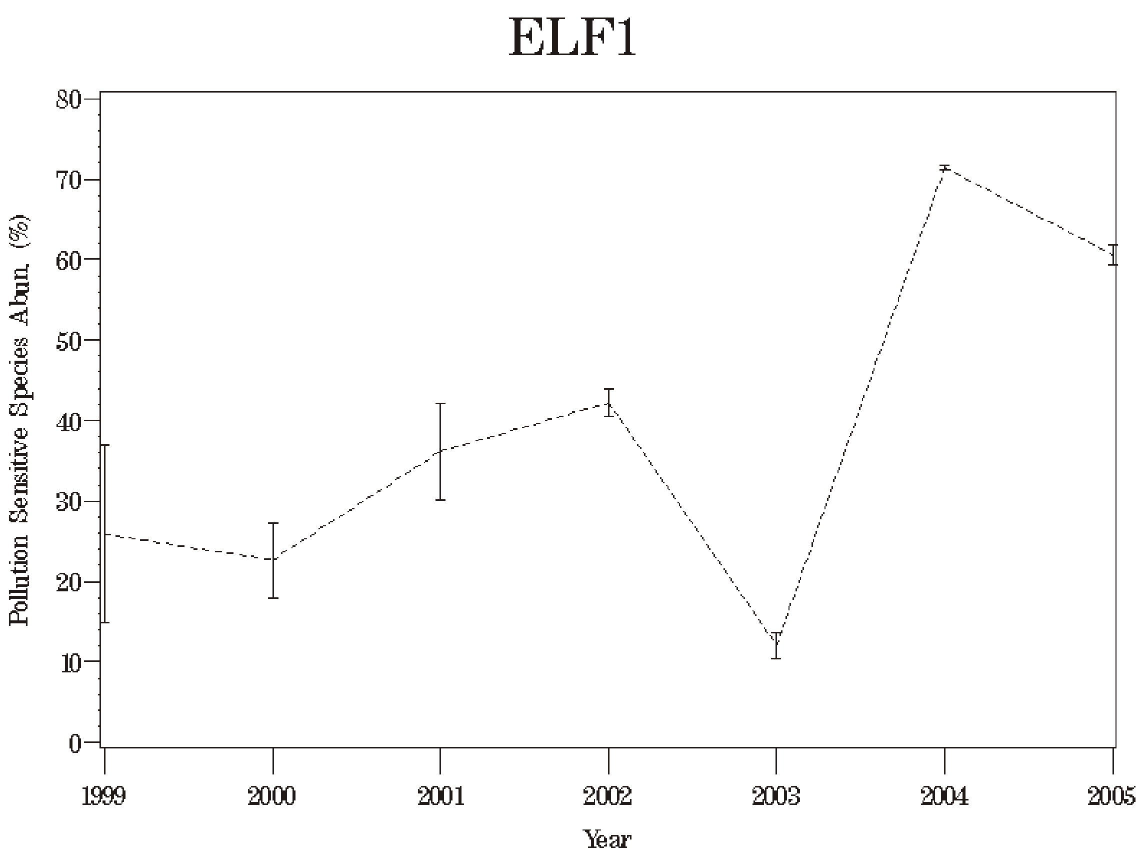
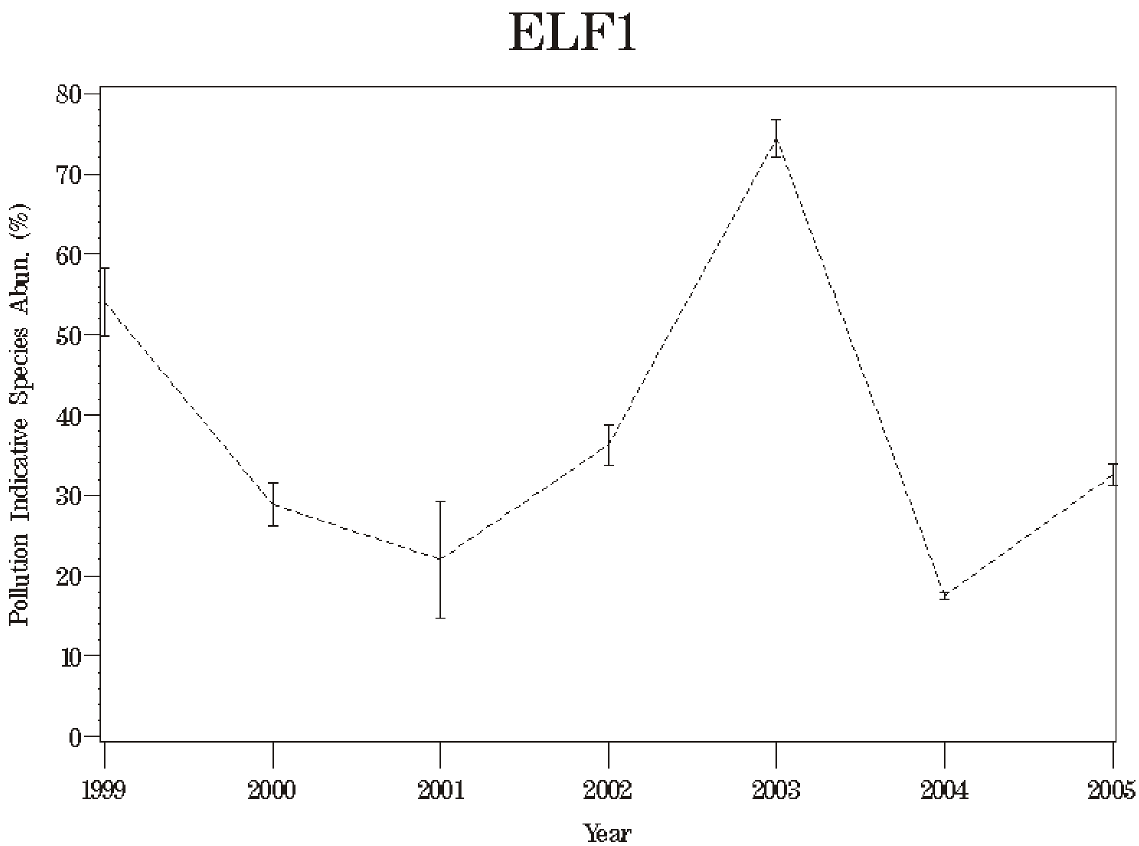


Figure 21. Plot of pollution sensitive species abundance at station ELF1for 1999 through 2005.



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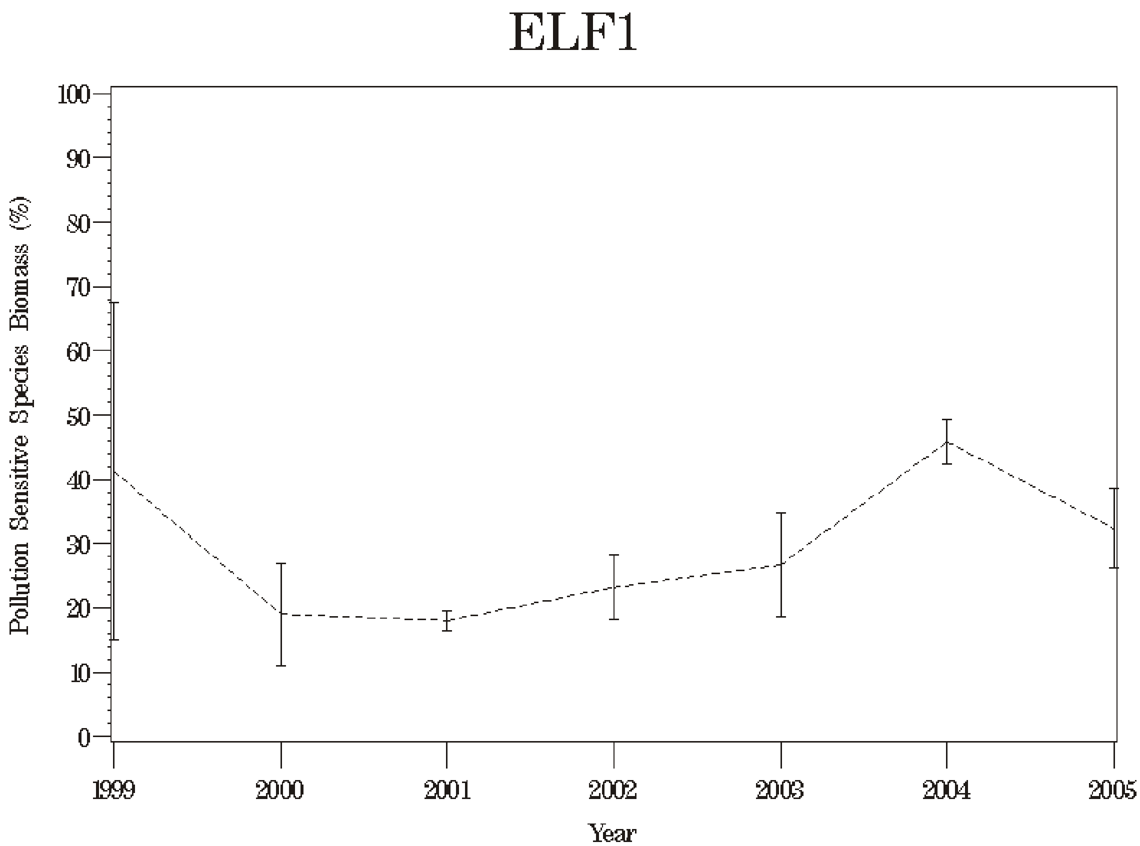

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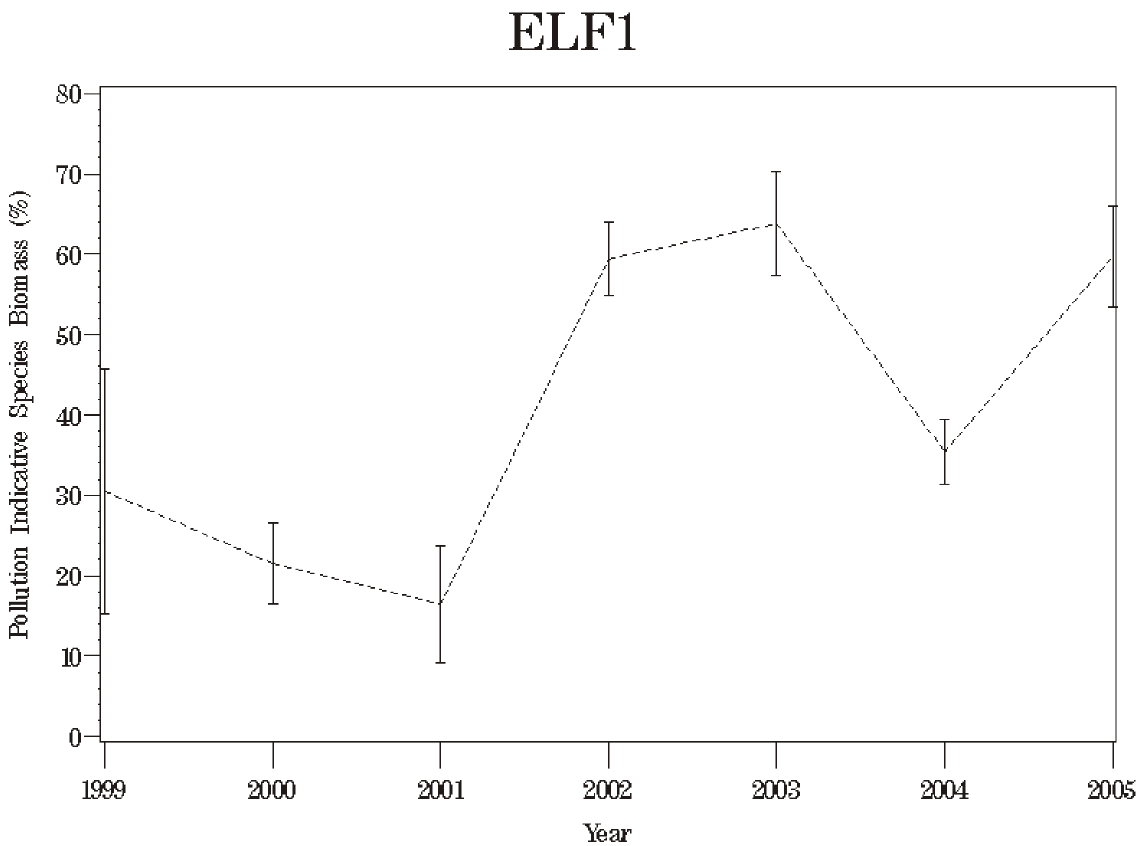

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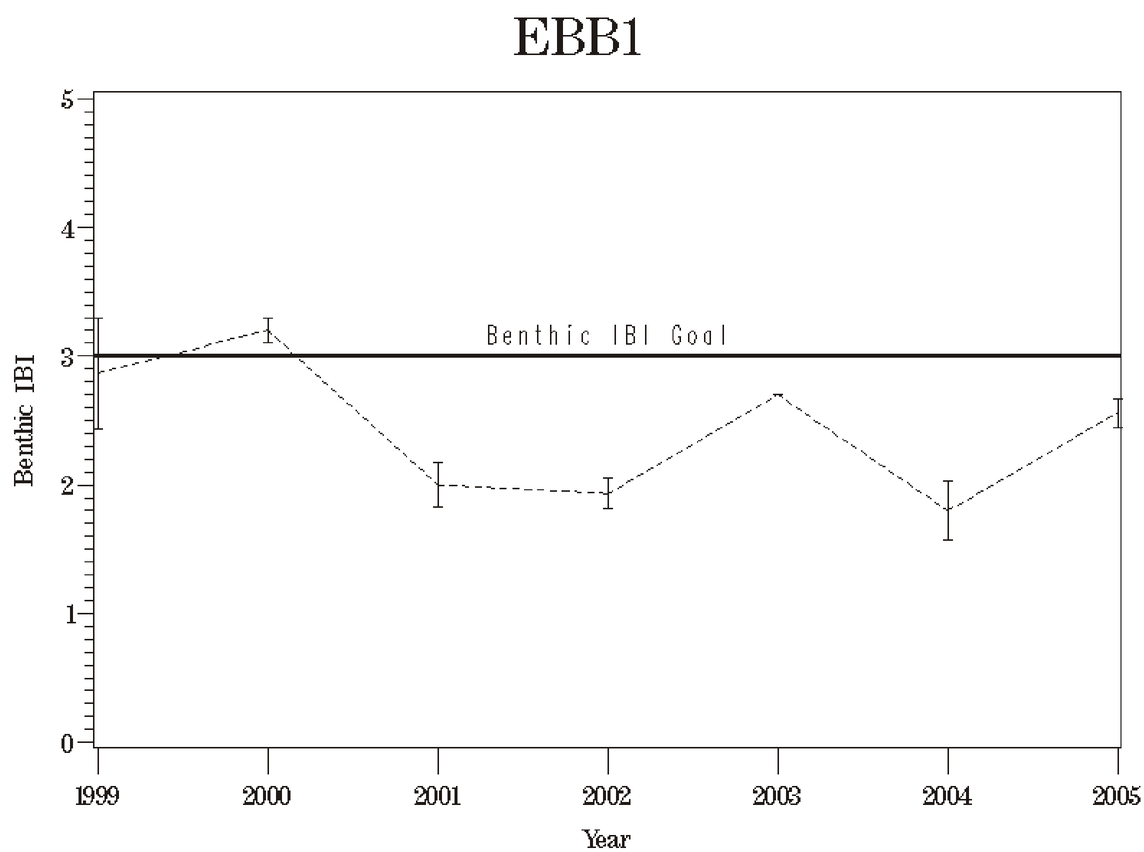


Figure 25. Plot of the benthic IBI at station EBB1 from 1999 through 2005.

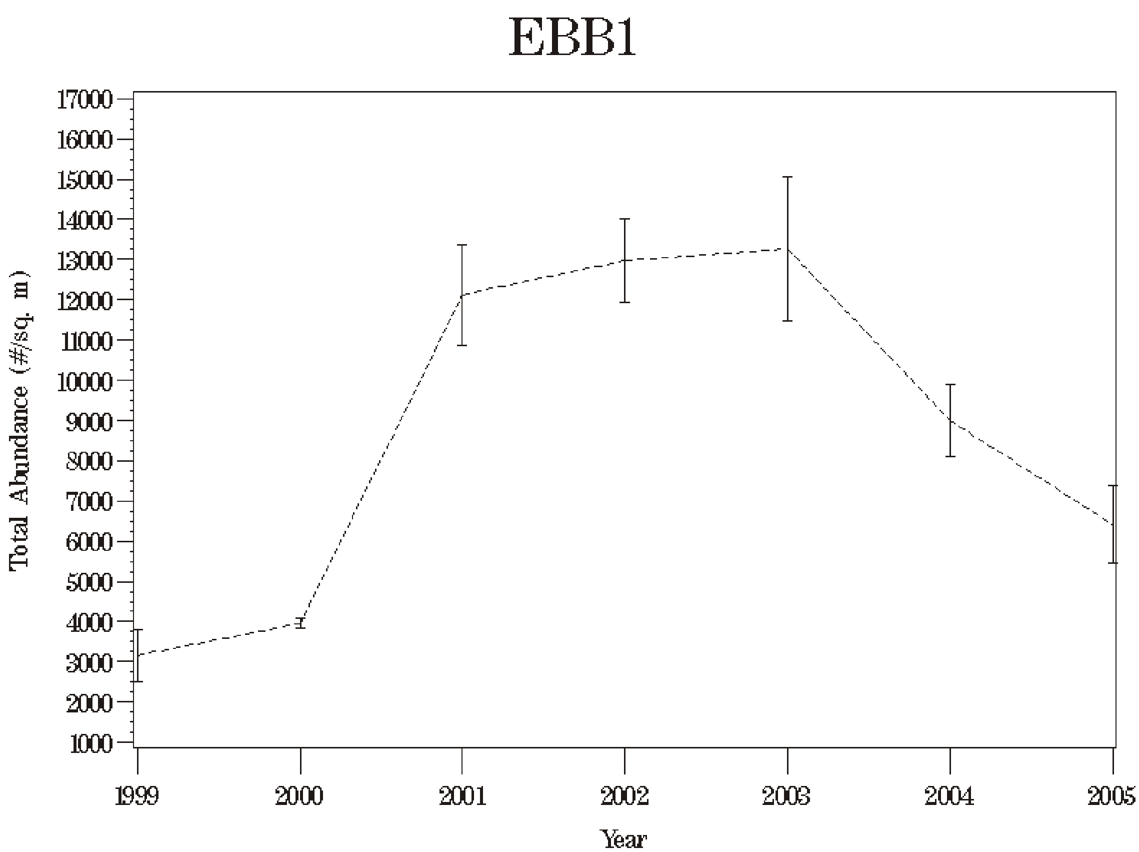


Figure 26. Plot of total benthic community abundance at station EBB1 for 1999 through 2005.

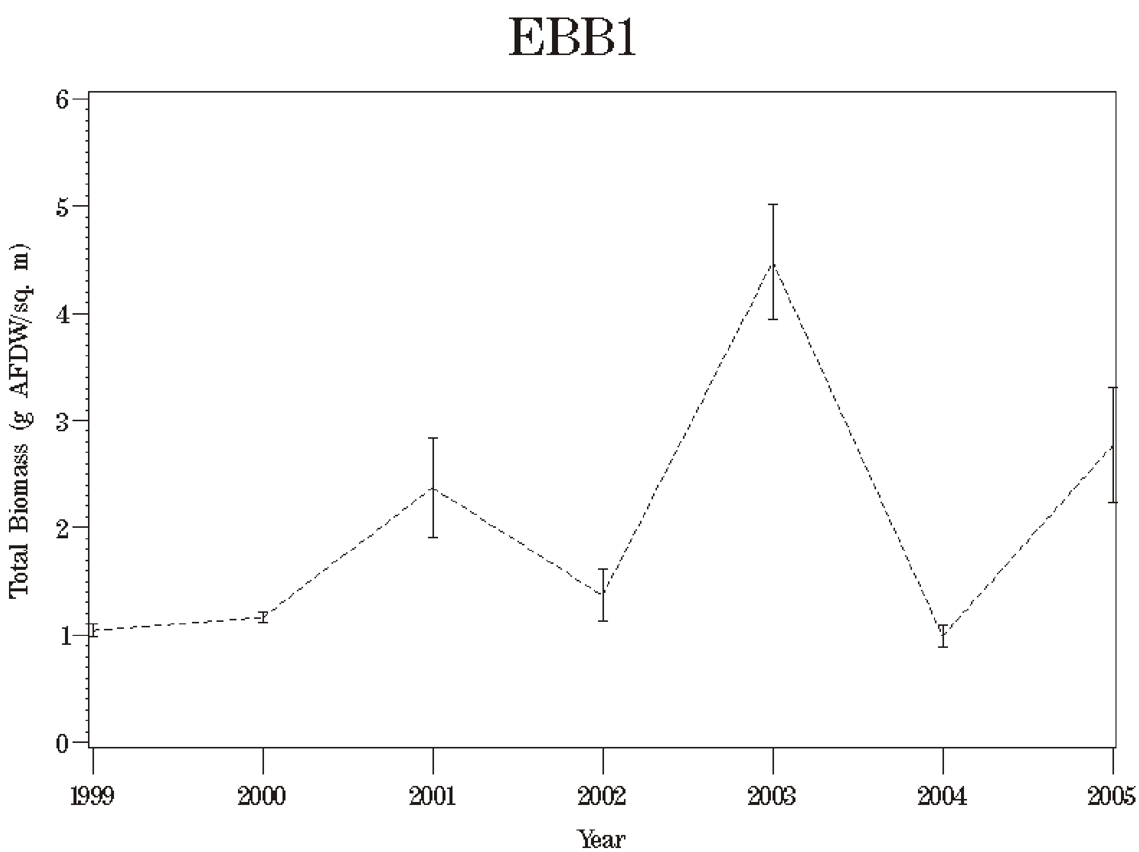


Figure 27. Plot of total benthic community biomass at station EBB1 for 1999 through 2005.

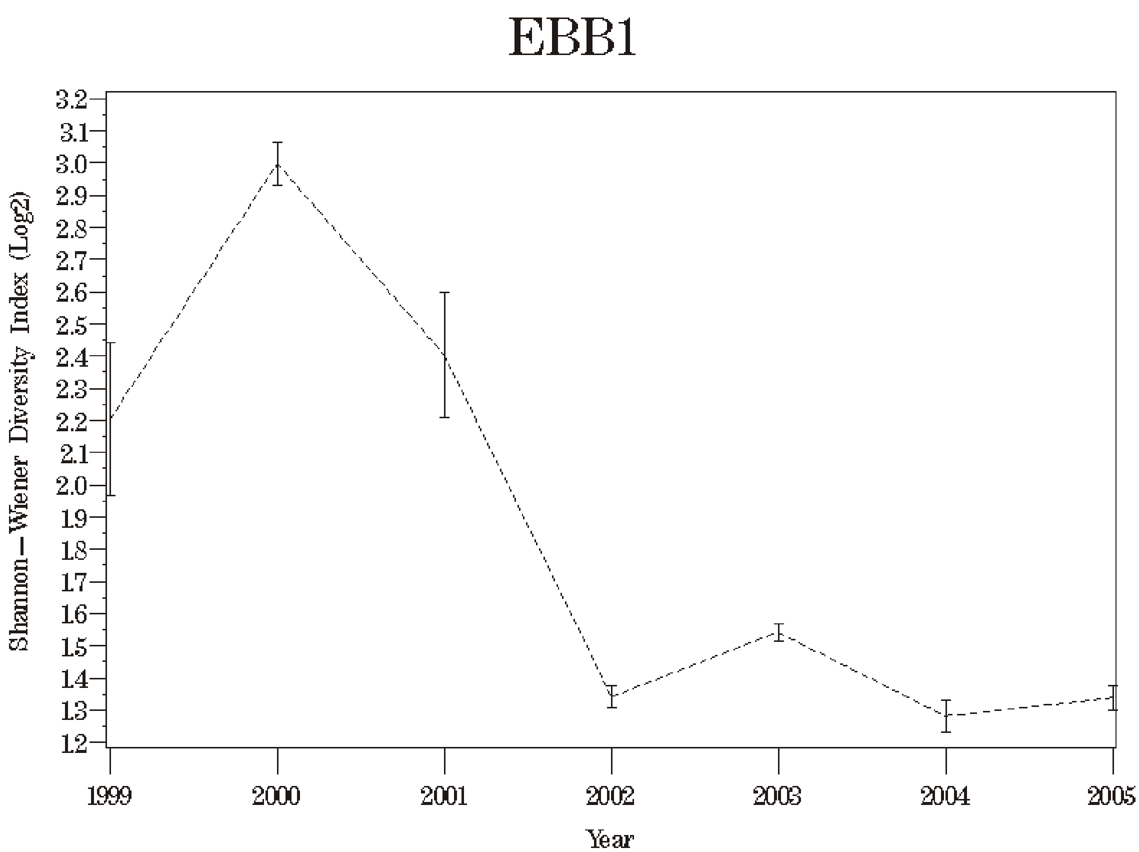


Figure 28. Plot of the Shannon-Weiner diversity index at station EBB1 for 1999 through 2005.

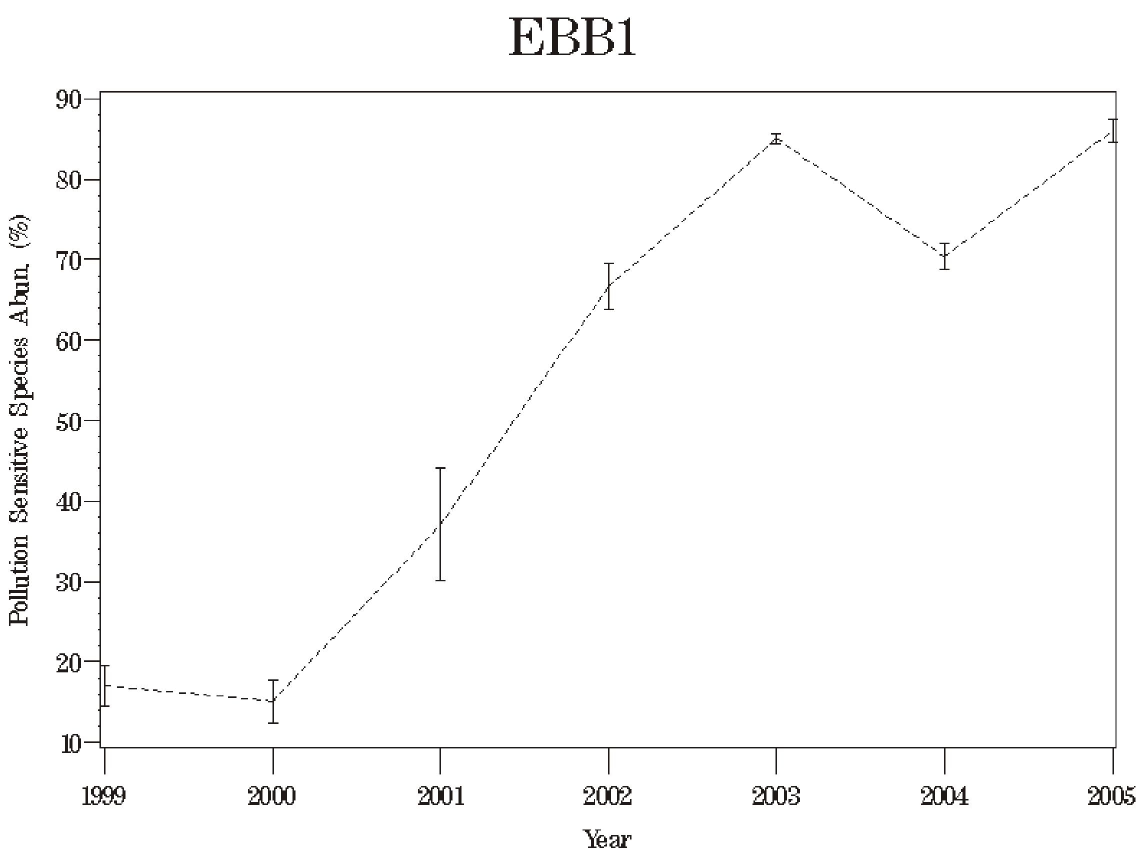


Figure 29. Plot of pollution sensitive species abundance at station EBB1for 1999 through 2005.

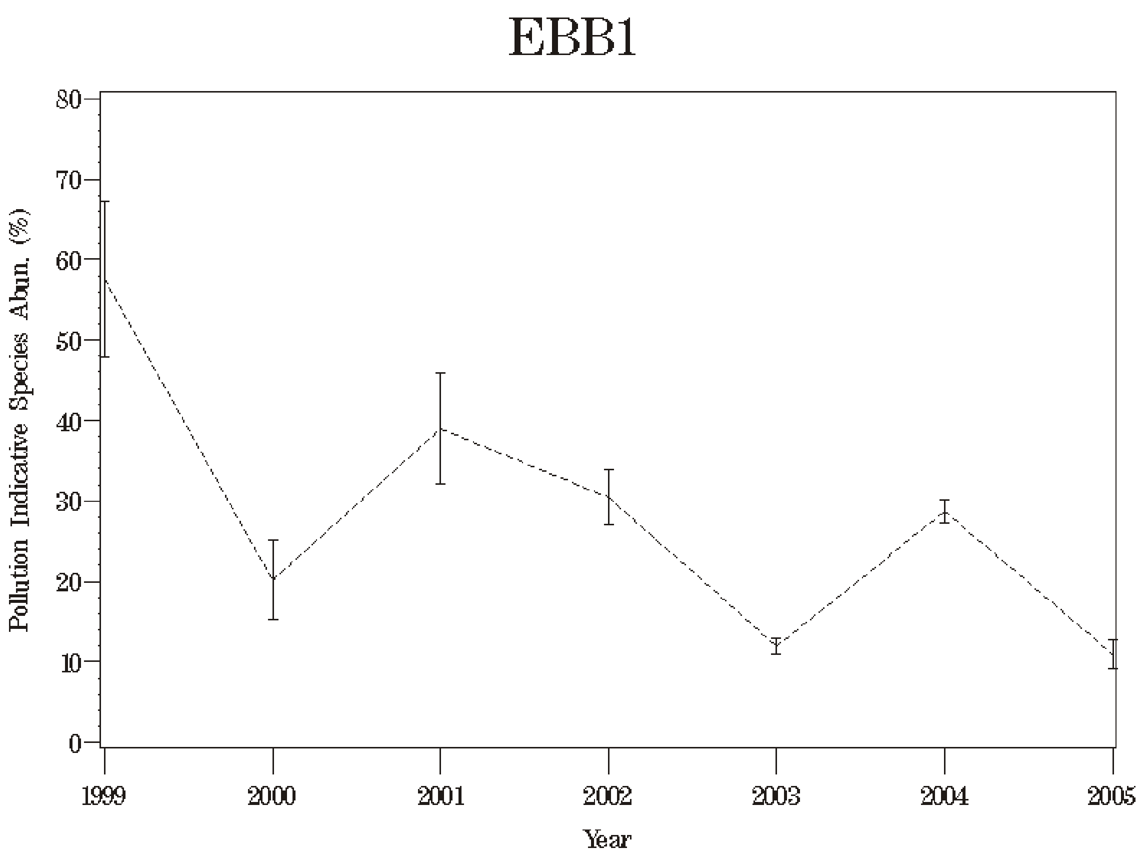


Figure 30. Plot of pollution indicative species abundance at station EBB1 for 1999 through 2005.

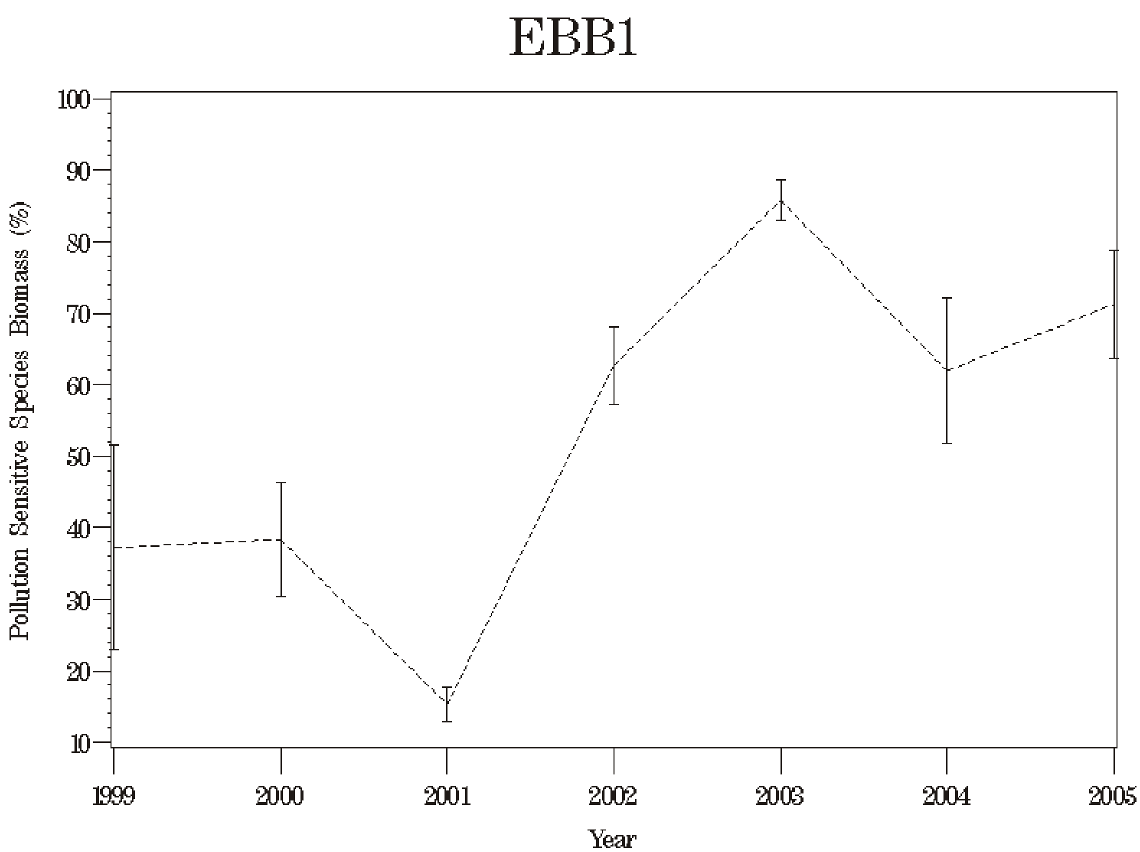


Figure 31. Plot of pollution sensitive species biomass at station EBB1 for 1999 through 2005.

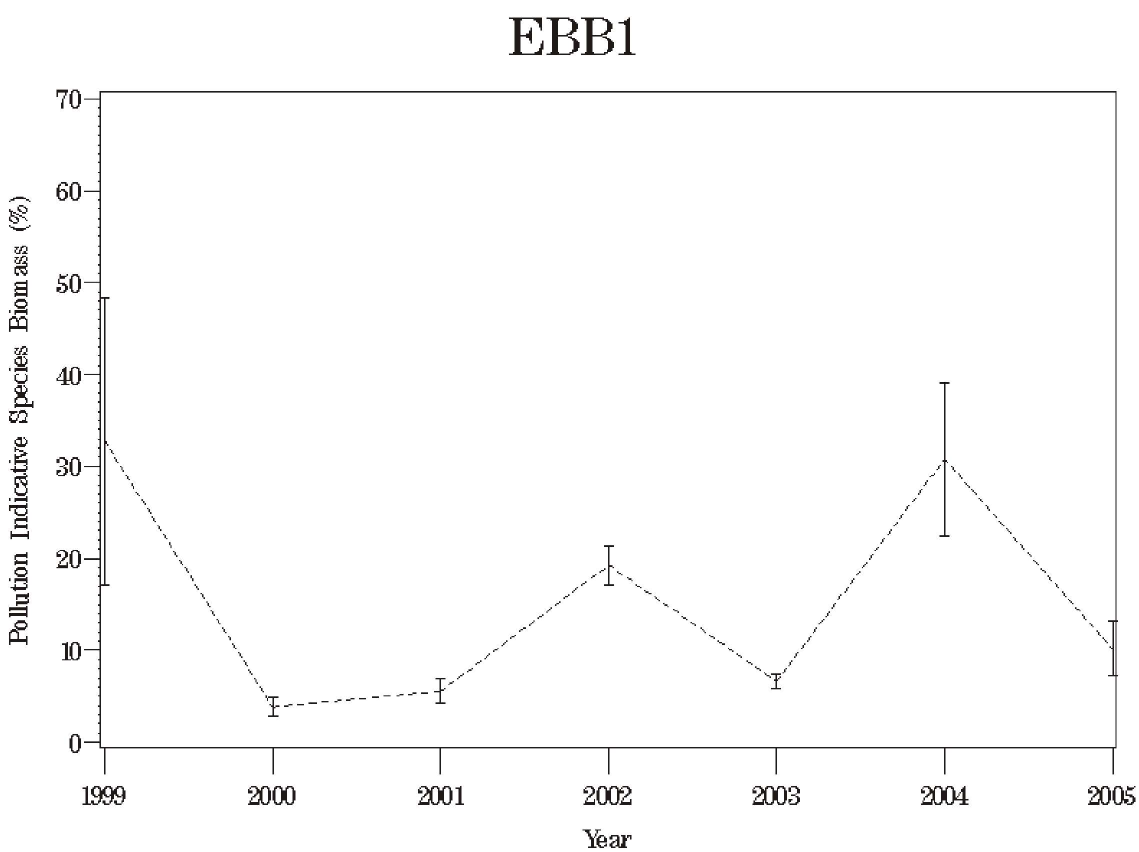


Figure 32. Plot of pollution indicative species biomass at station EBB1 for 1999 through 2005.

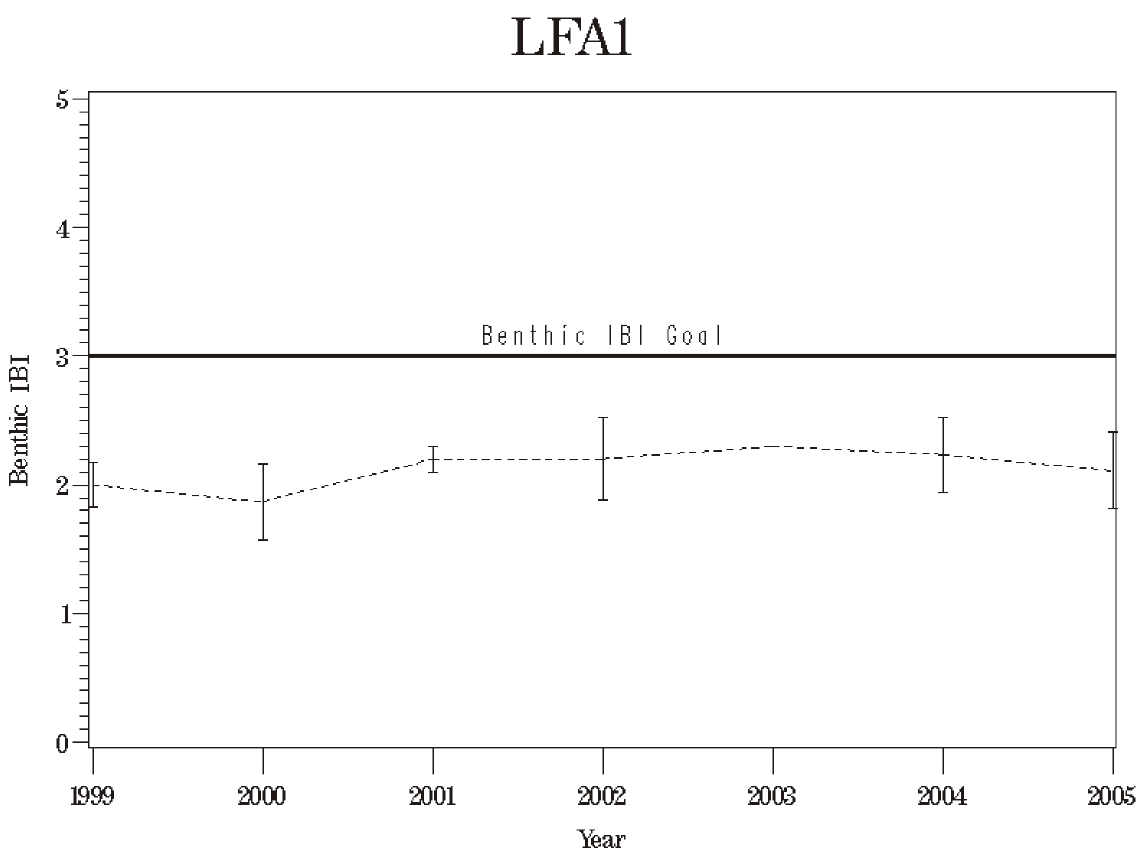


Figure 33. Plot of the benthic IBI at station LFA1 from 1999 through 2005.

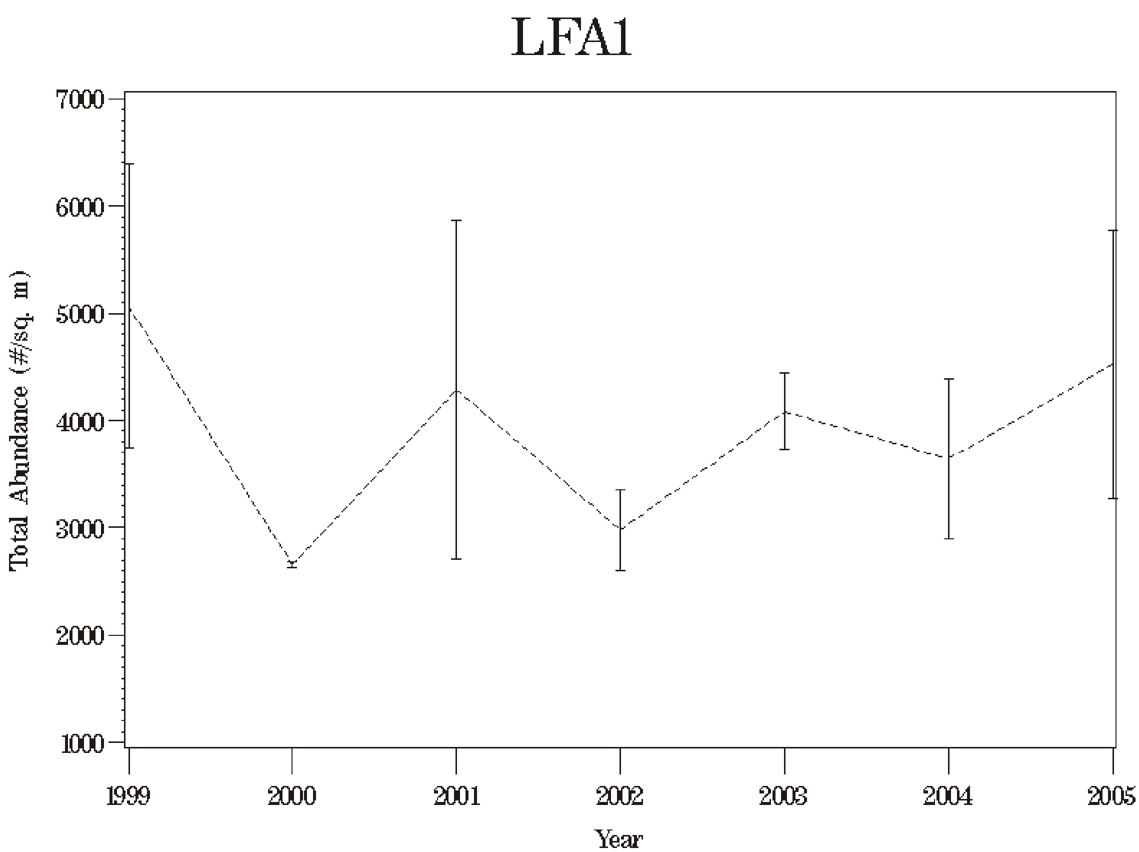


Figure 34. Plot of total benthic community abundance at station LFA1 for 1999 through 2005.

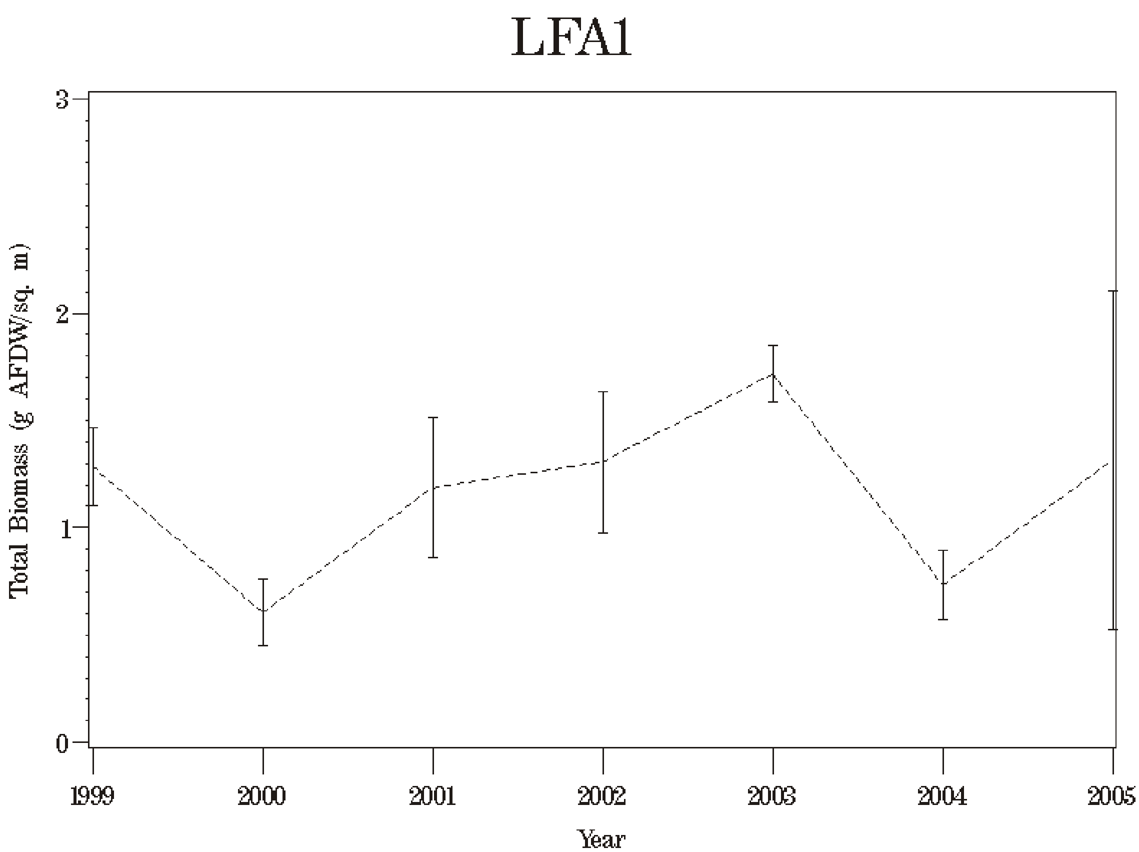


Figure 35. Plot of total benthic community biomass at station LFA1 for 1999 through 2005.

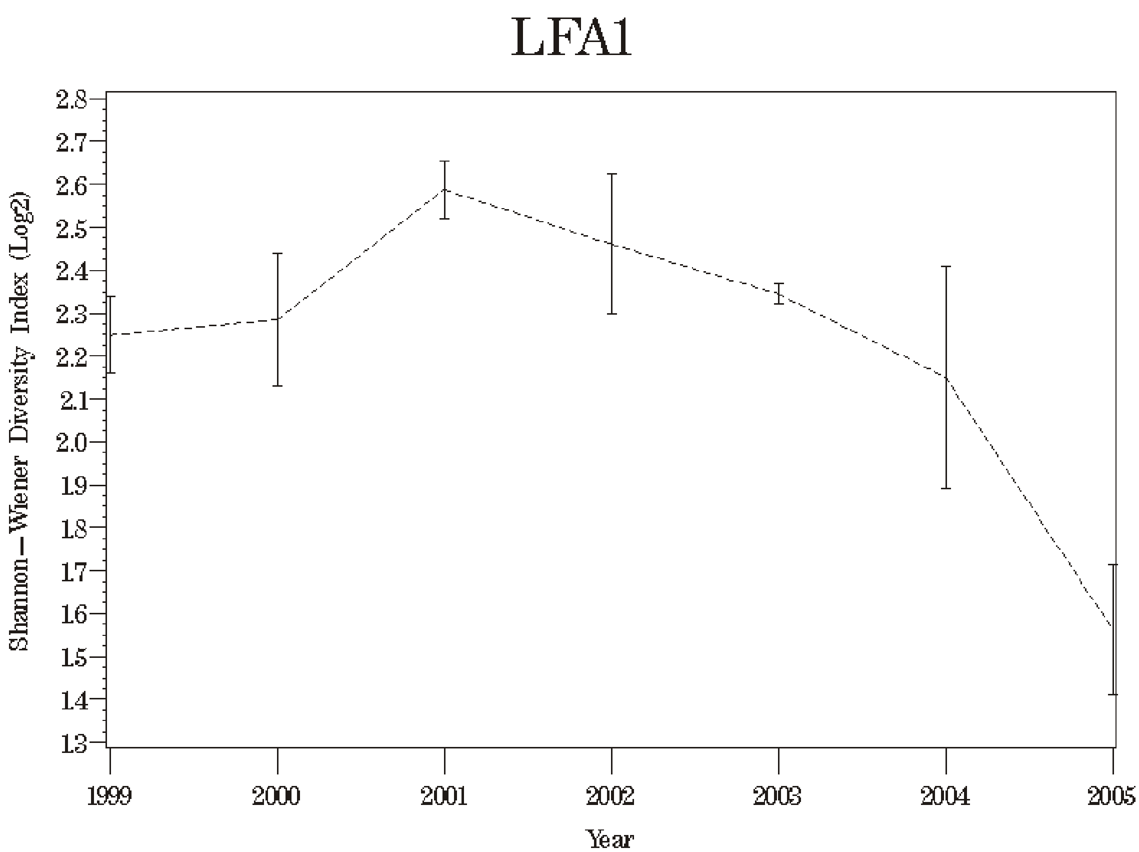


Figure 36. Plot of the Shannon-Weiner diversity index at station LFA1 for 1999 through 2005.

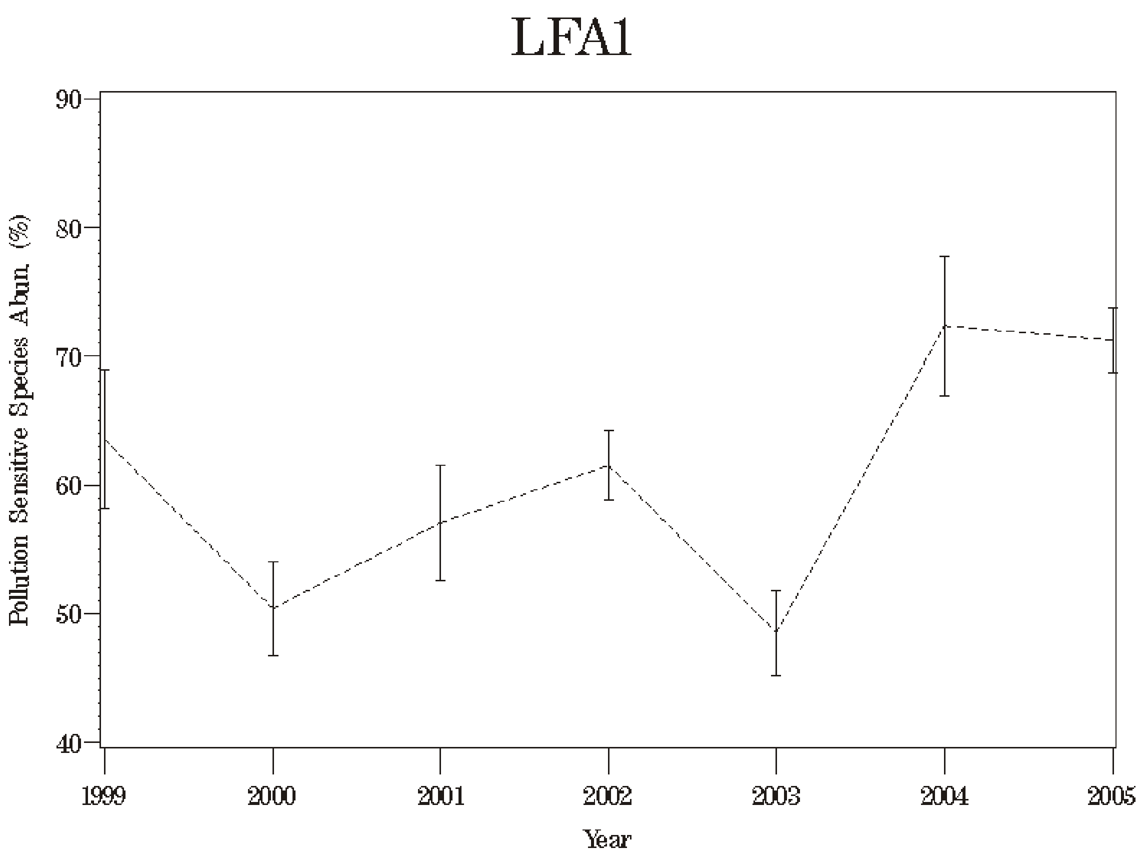
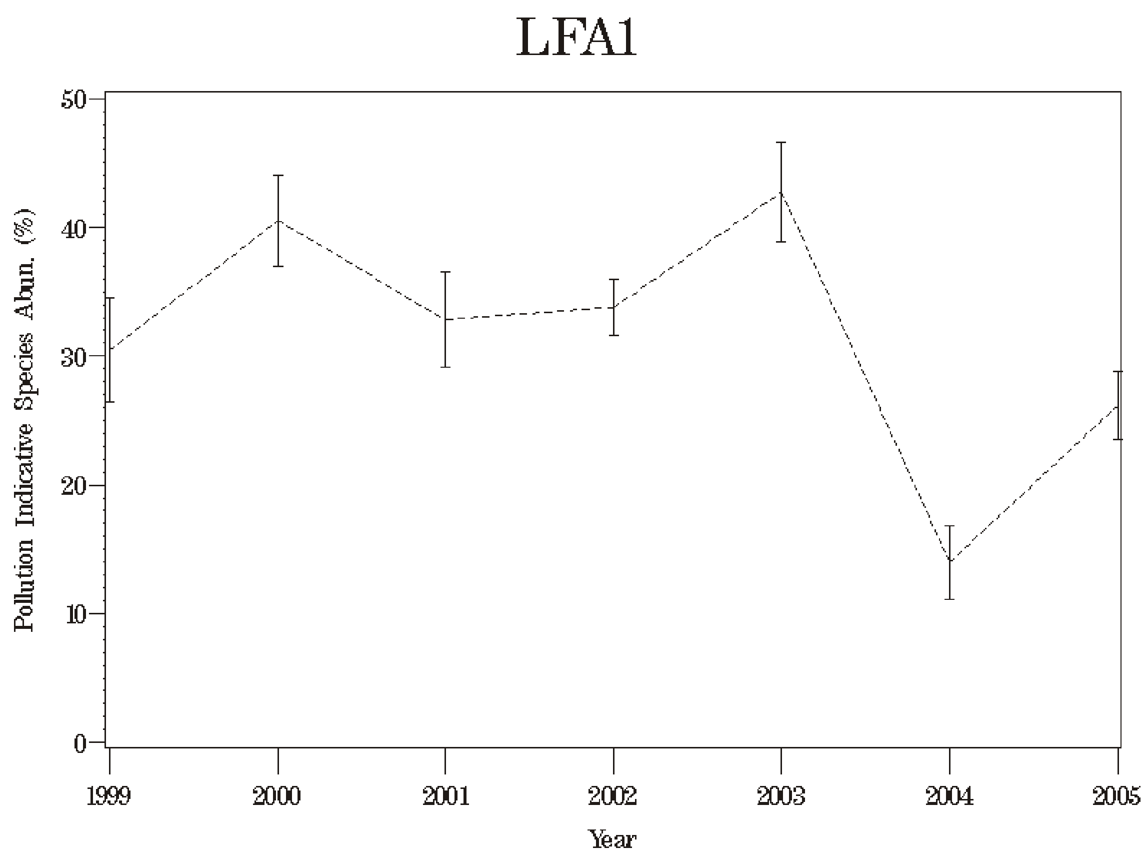


Figure 37. Plot of pollution sensitive species abundance at station LFA1for 1999 through 2005.



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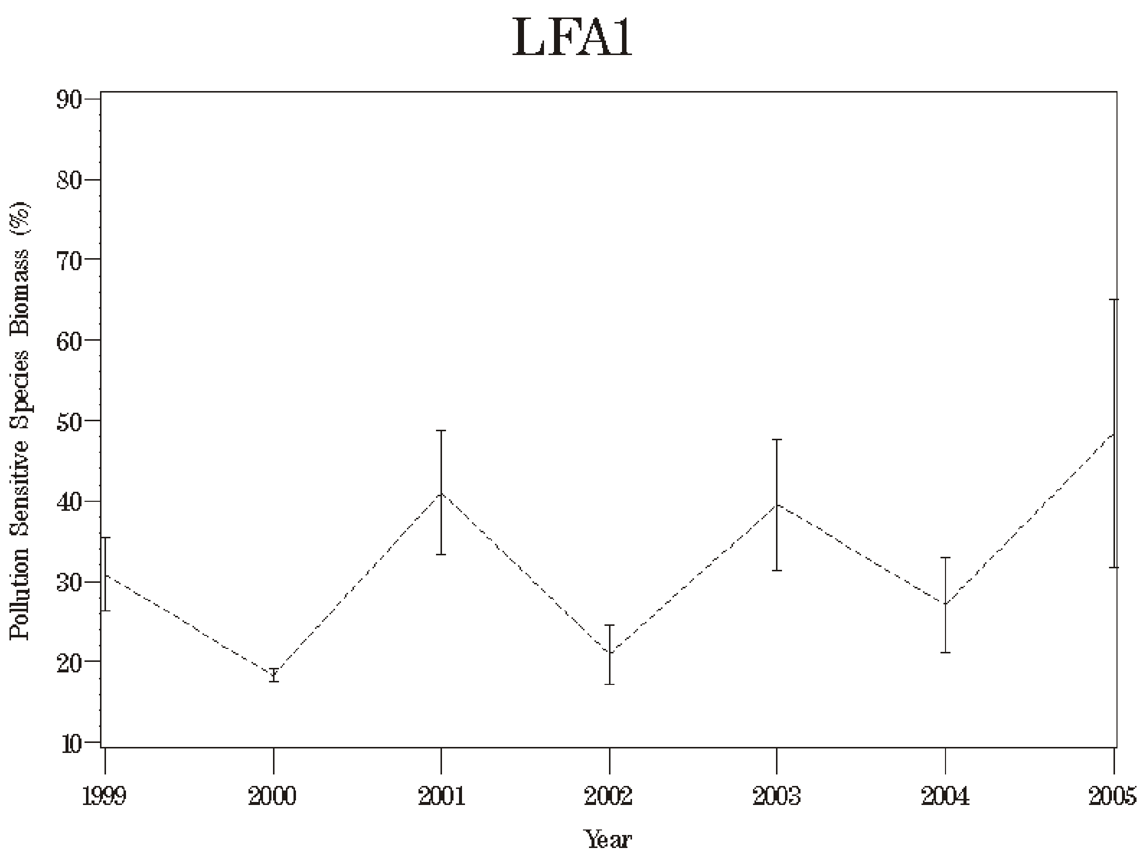
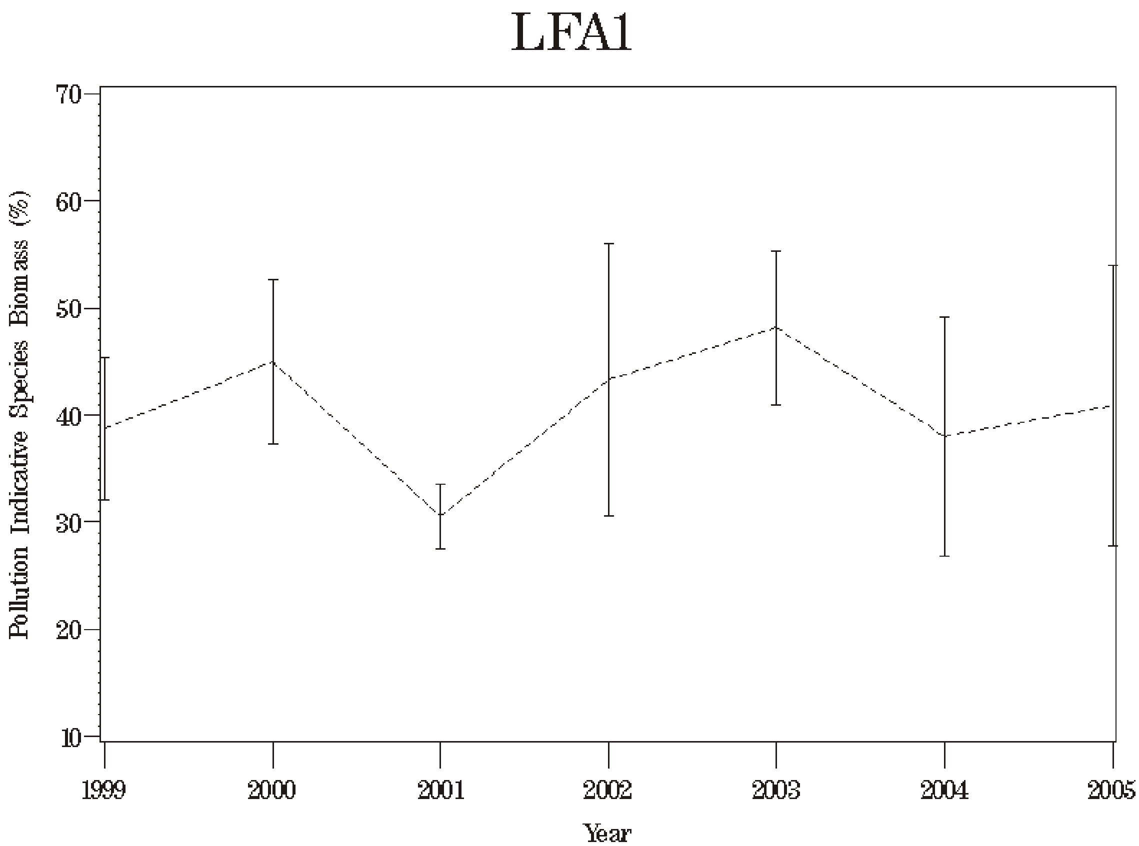


Figure 39. Plot of pollution sensitive species biomass at station LFA1 for 1999 through 2005.



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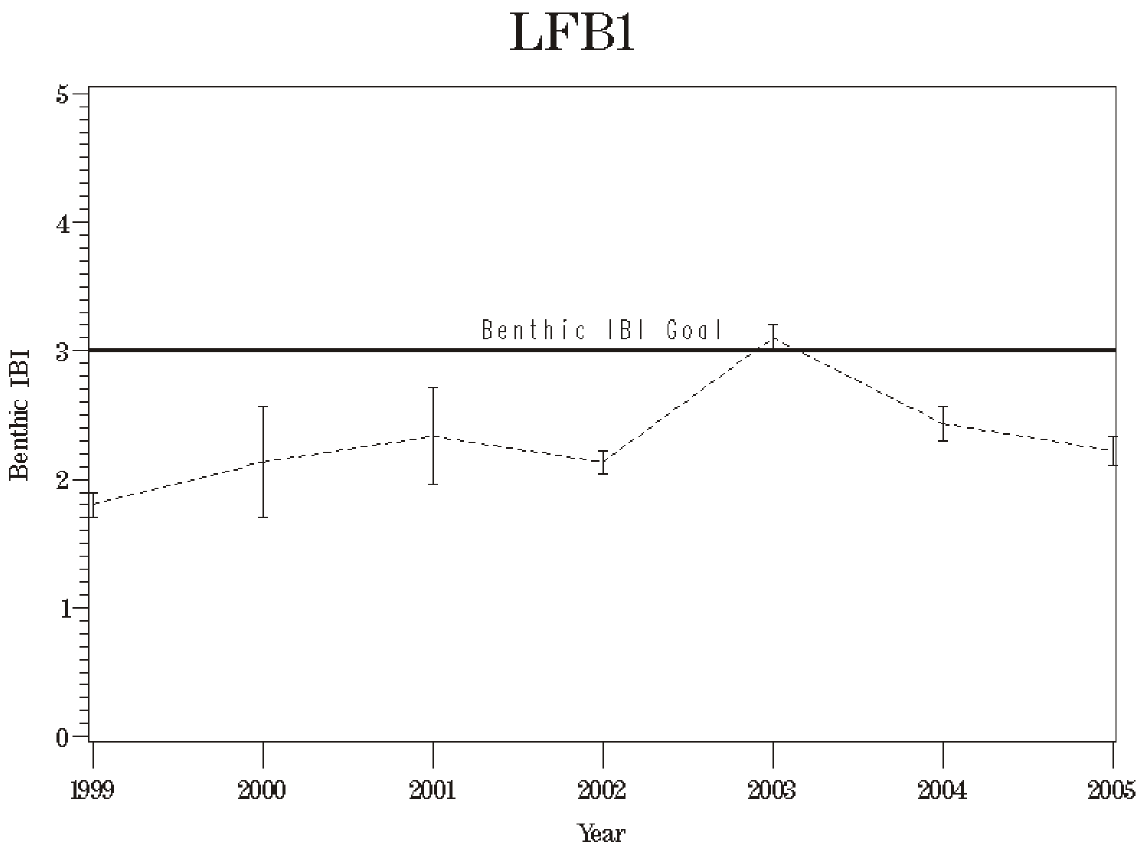


Figure 41. Plot of the benthic IBI at station LFB1 from 1999 through 2005.

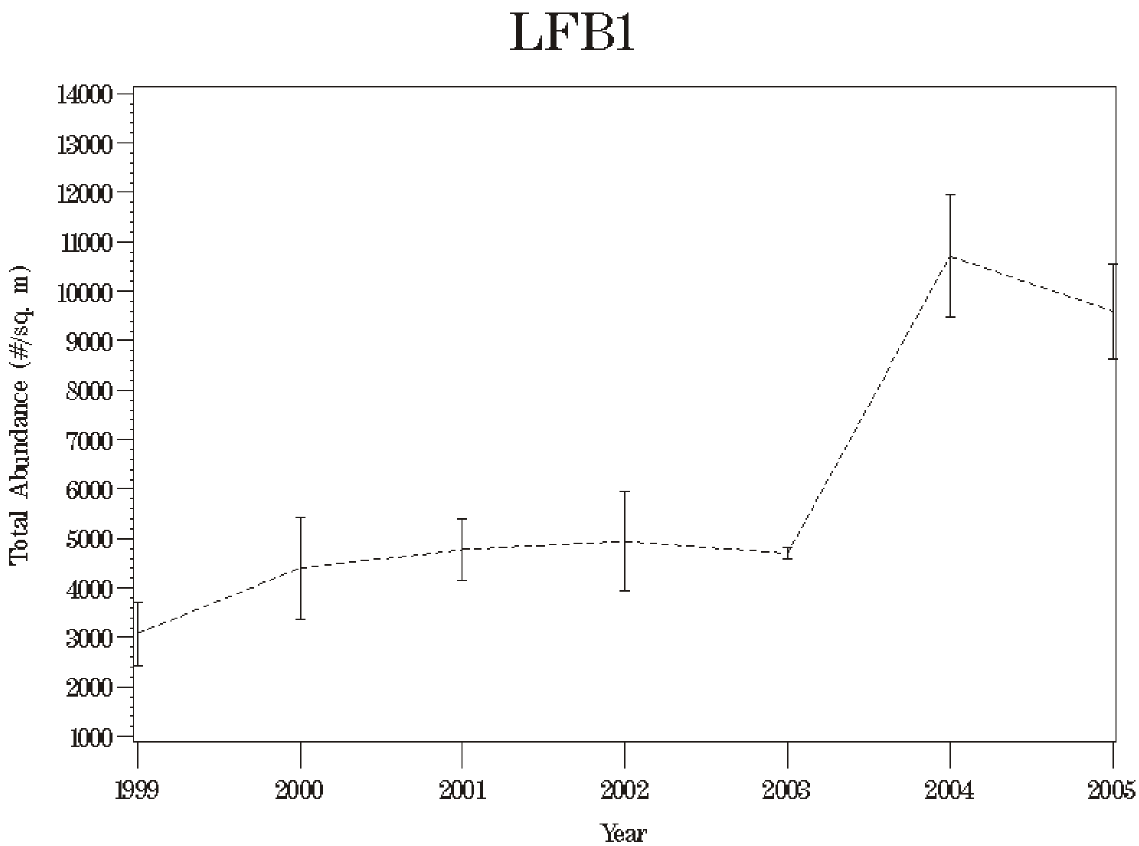


Figure4 2. Plot of total benthic community abundance at station LFB1 for 1999 through 2005.

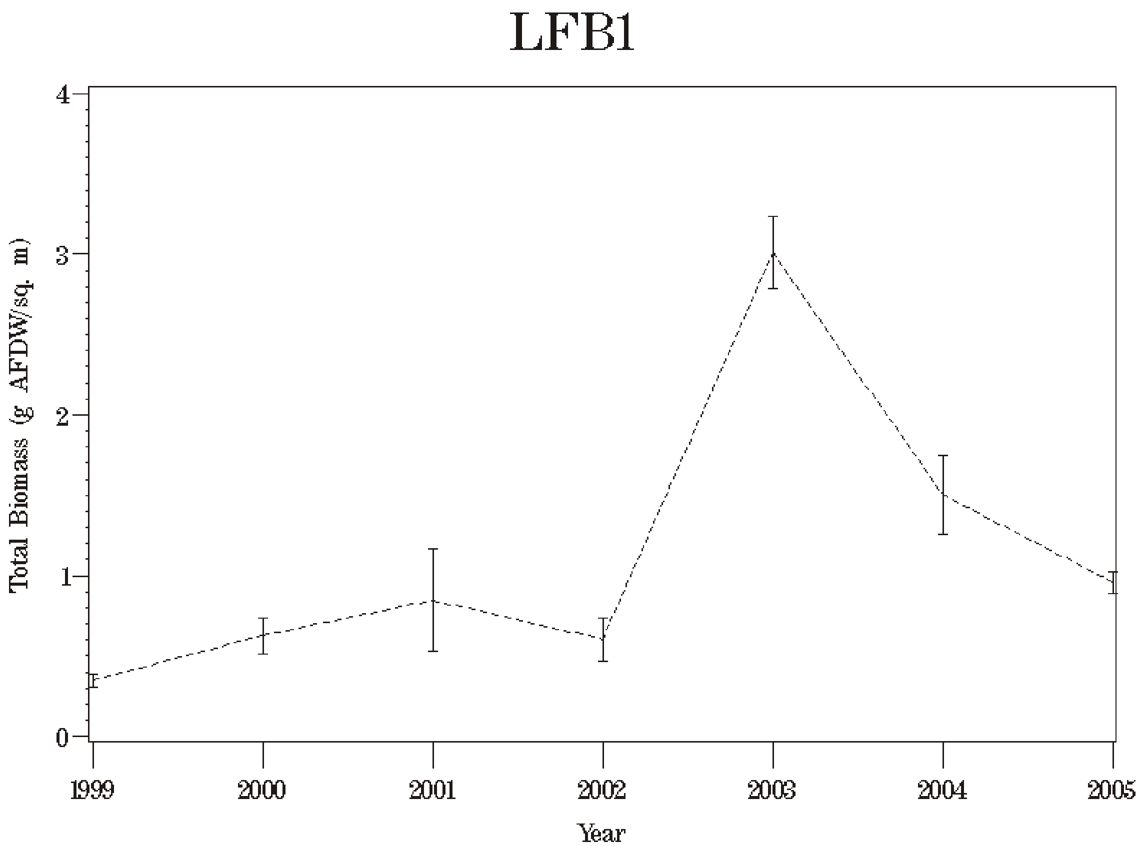


Figure 43. Plot of total benthic community biomass at station LFB1 for 1999 through 2005.

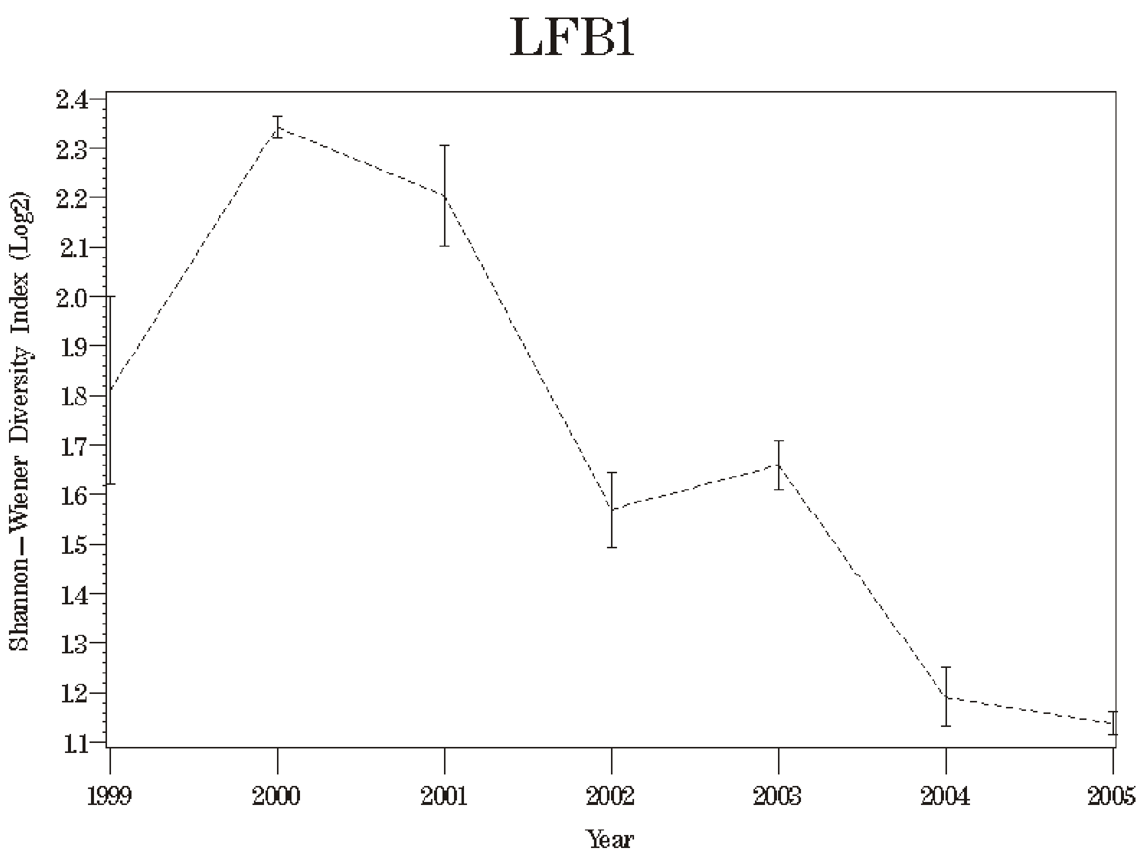
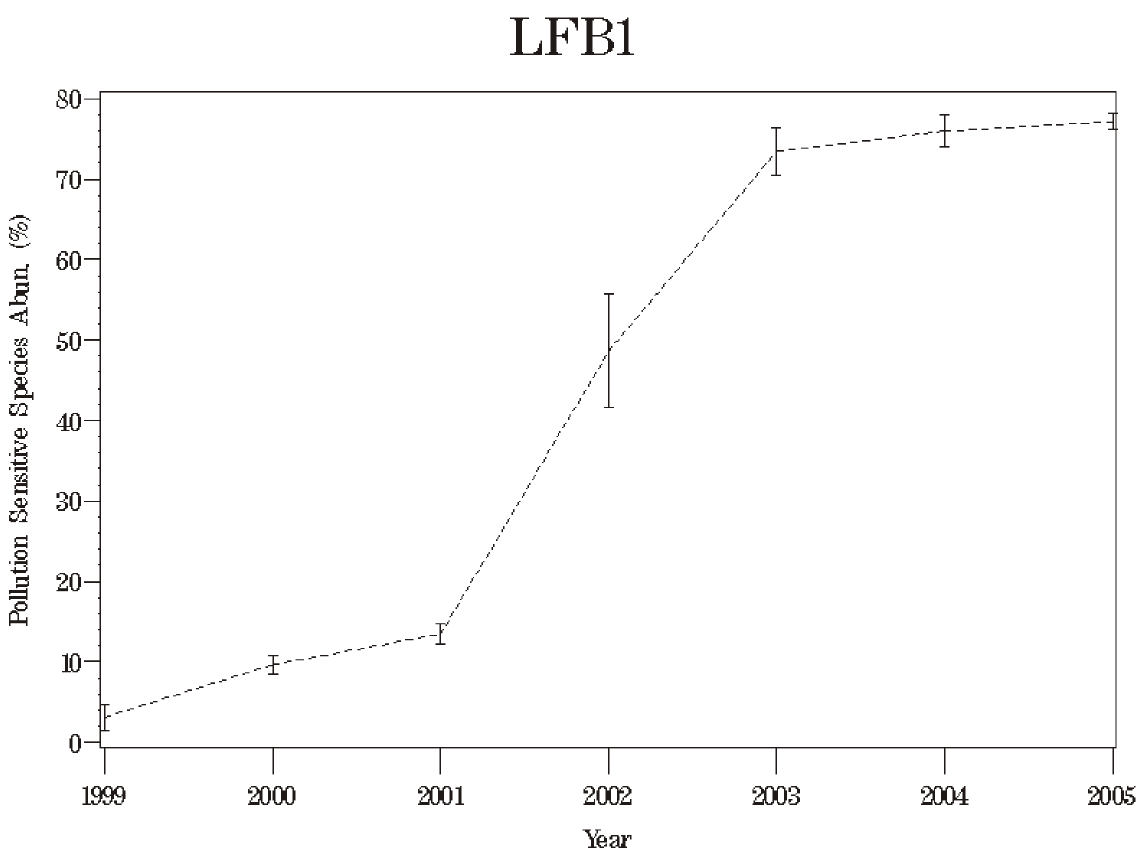


Figure 44. Plot of the Shannon-Weiner diversity index at station LFB1 for 1999 through 2005.



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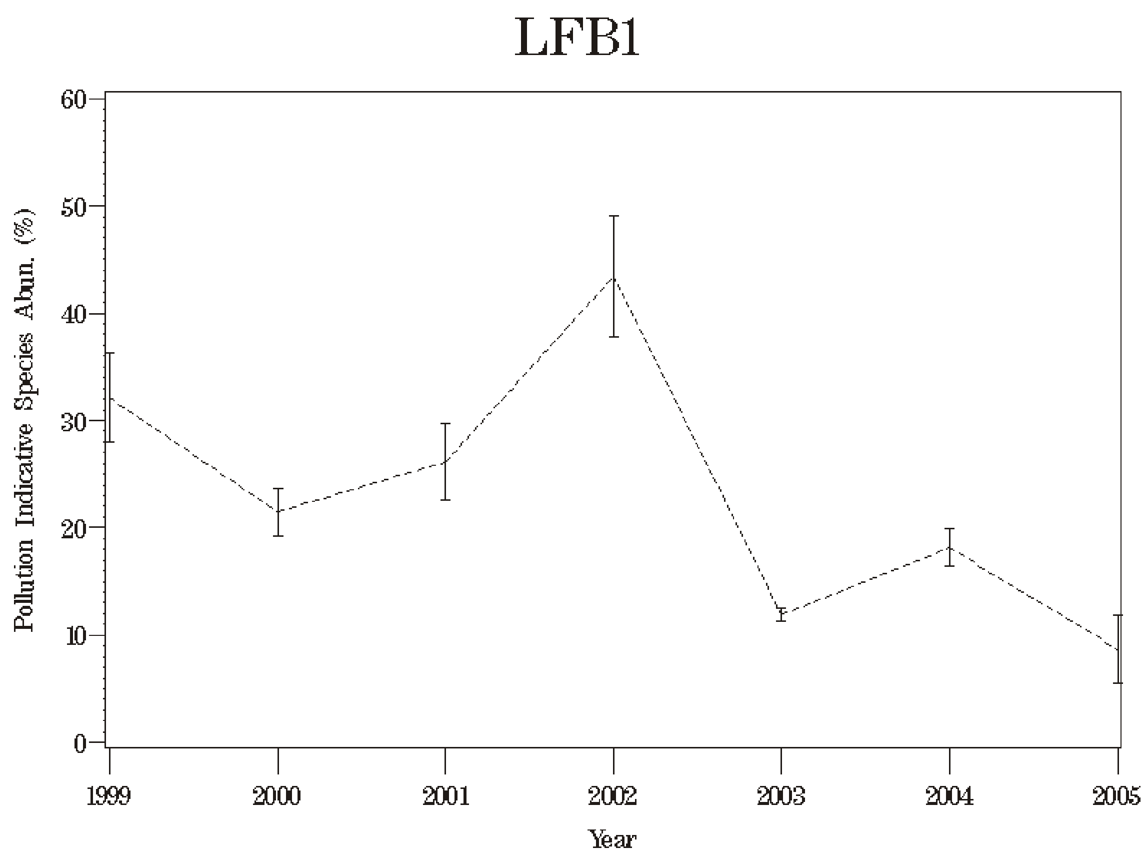

Figure 46. Plot of pollution indicative species abundance at station LFB1 for 1999 through 2005.

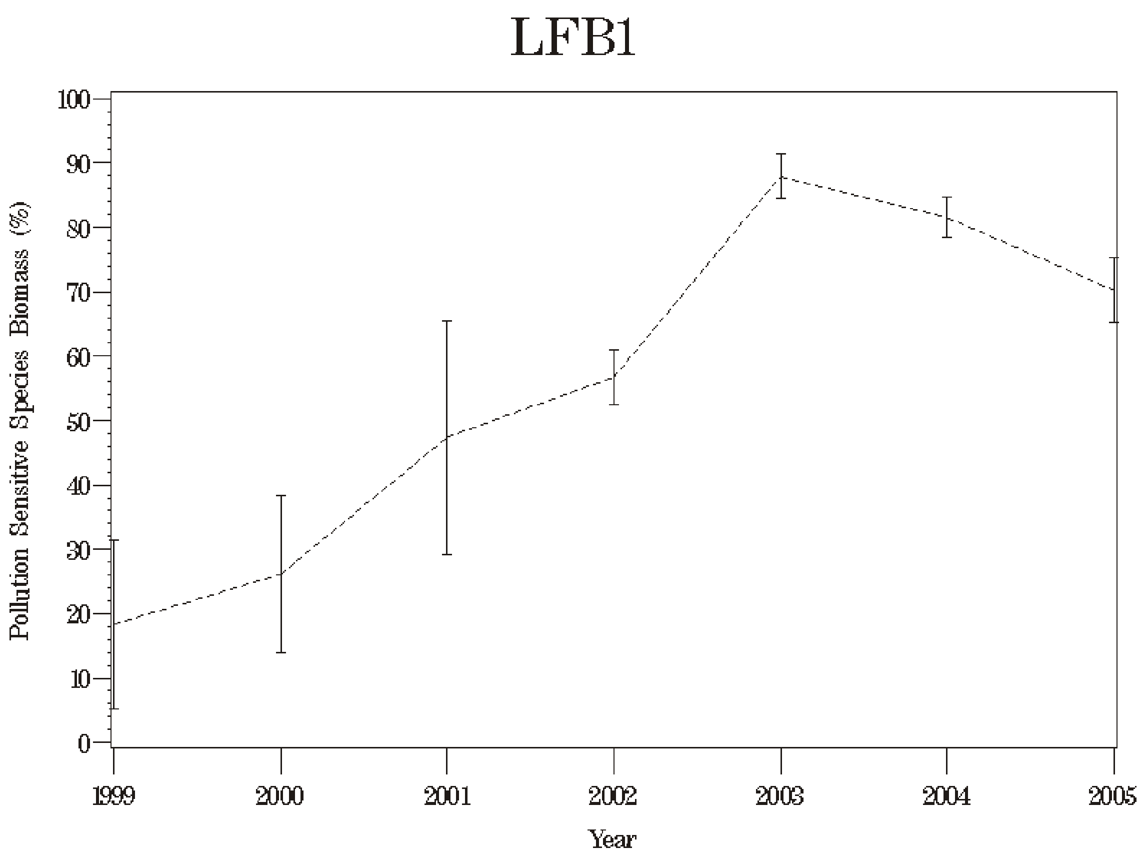

Figure 47. Plot of pollution sensitive species biomass at station LFB1 for 1999 through 2005.

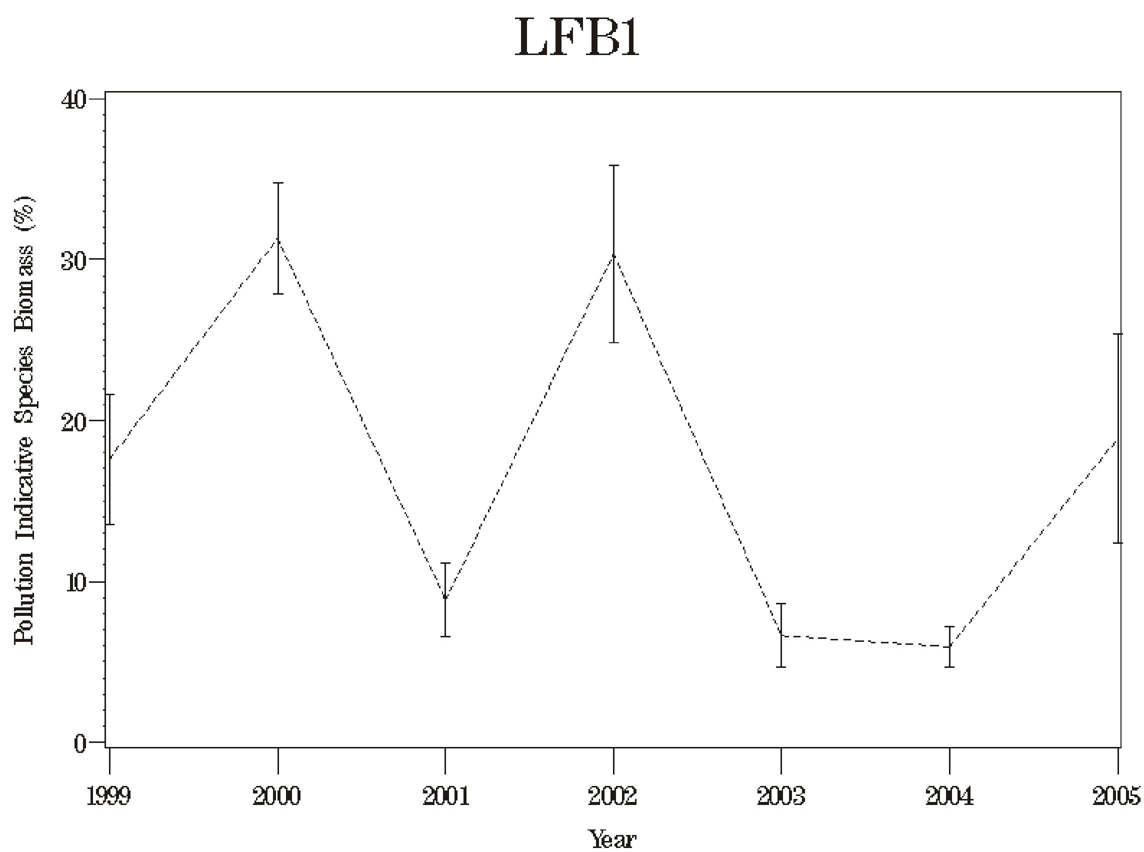

Figure 48. Plot of pollution indicative species biomass at station LFB1 for 1999 through 2005.

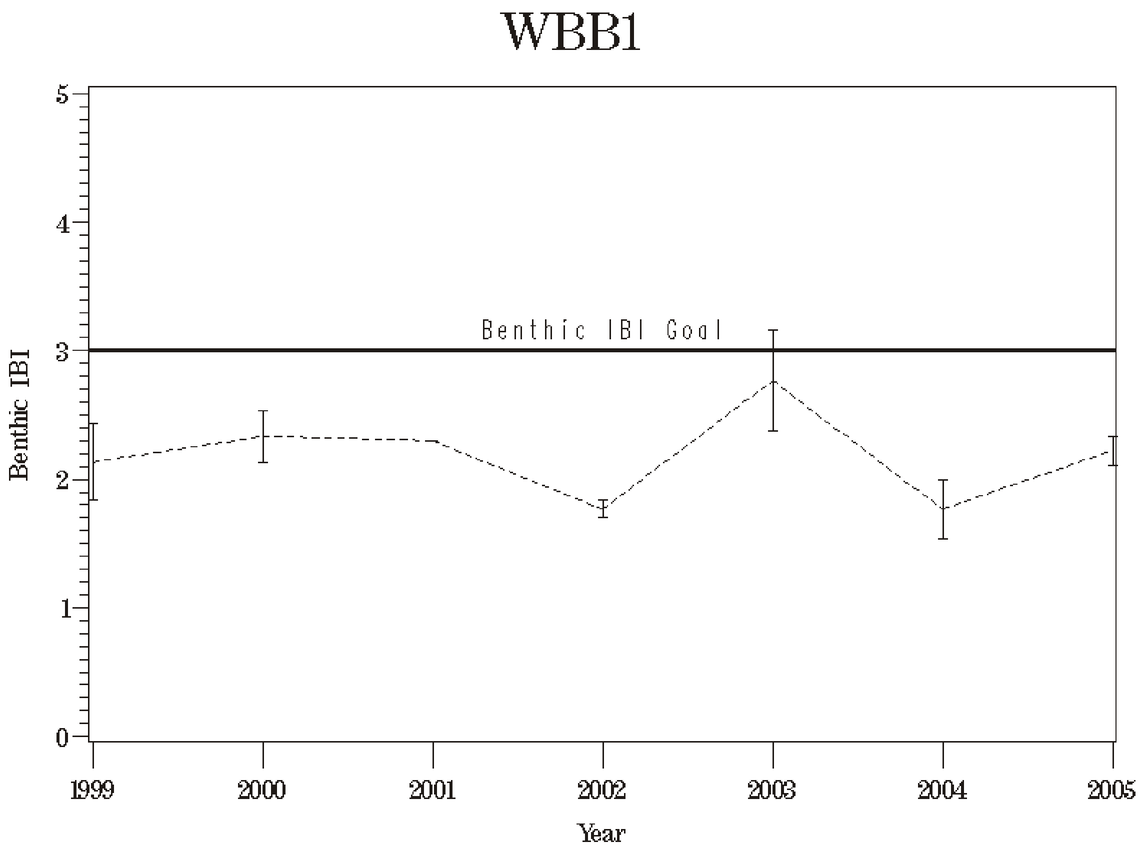

Figure 49. Plot of the benthic IBI at station WBB1 from 1999 through 2005.

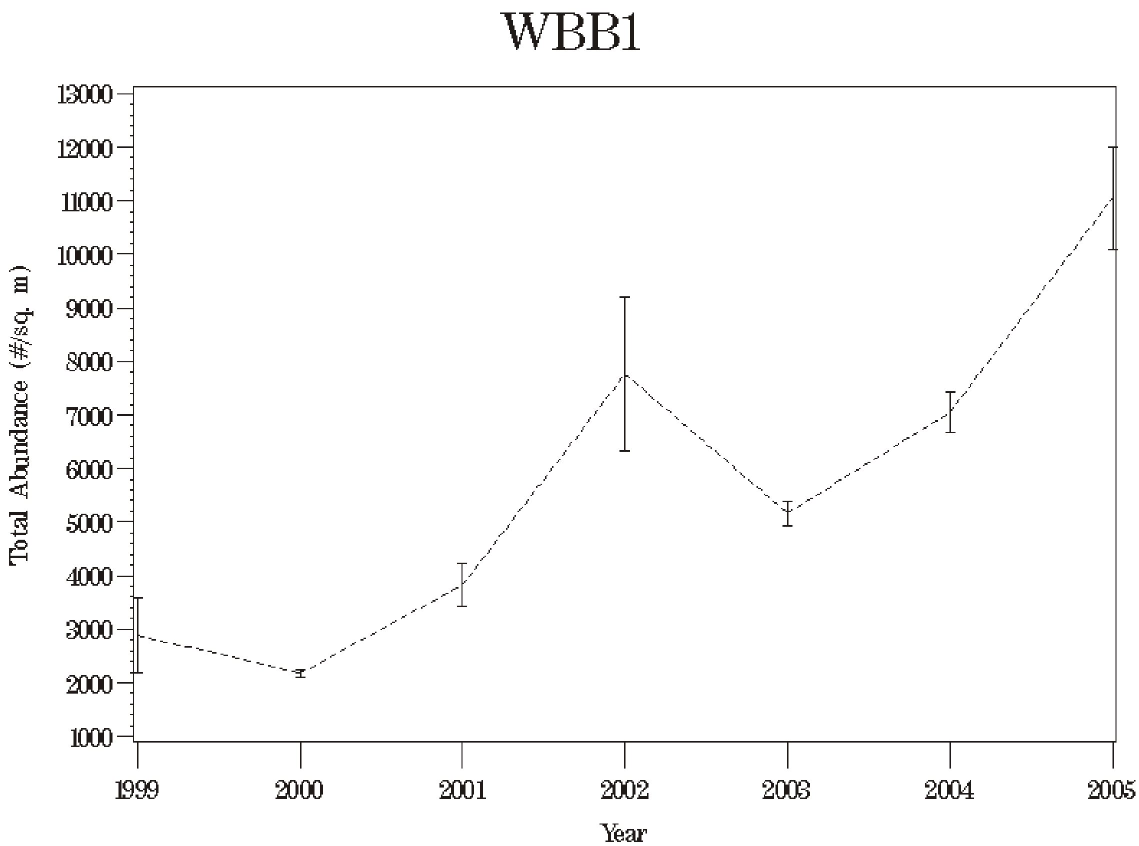

Figure 50. Plot of total benthic community abundance at station WBB1 for 1999 through 2005.

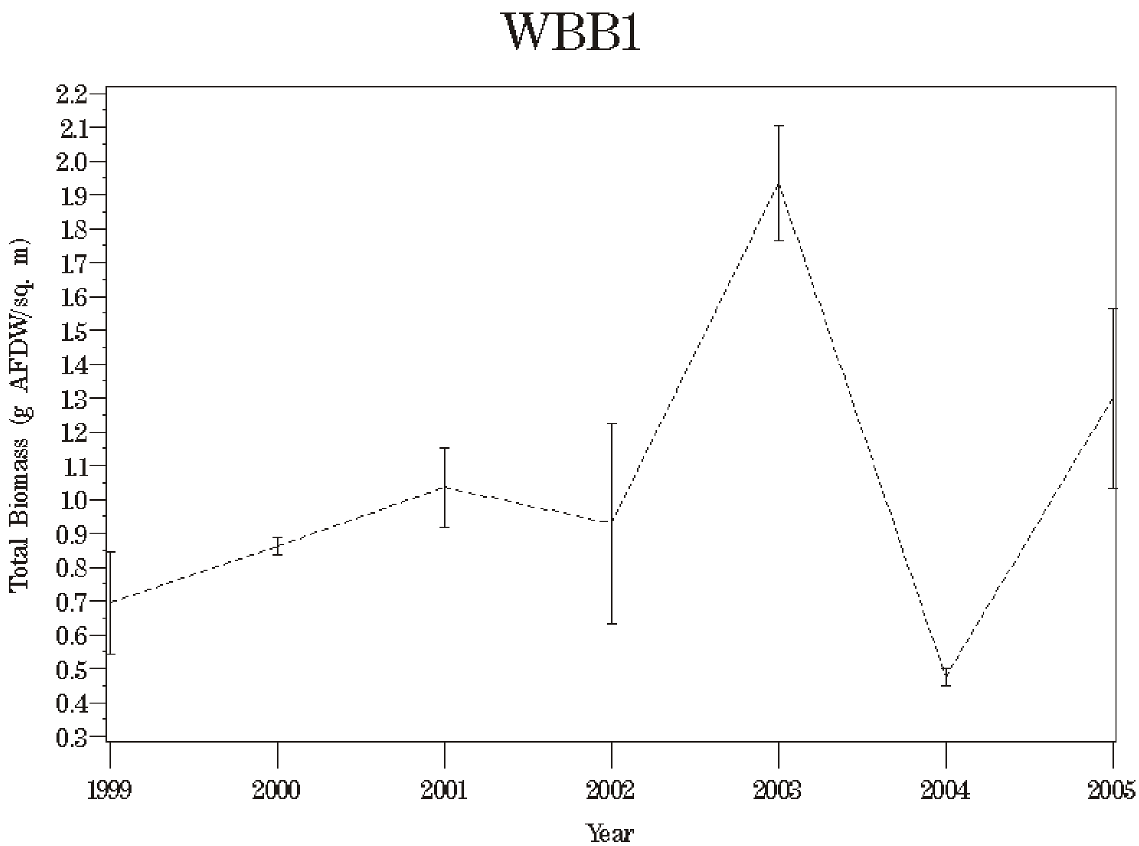

Figure 51. Plot of total benthic community biomass at station WBB1 for 1999 through 2005.

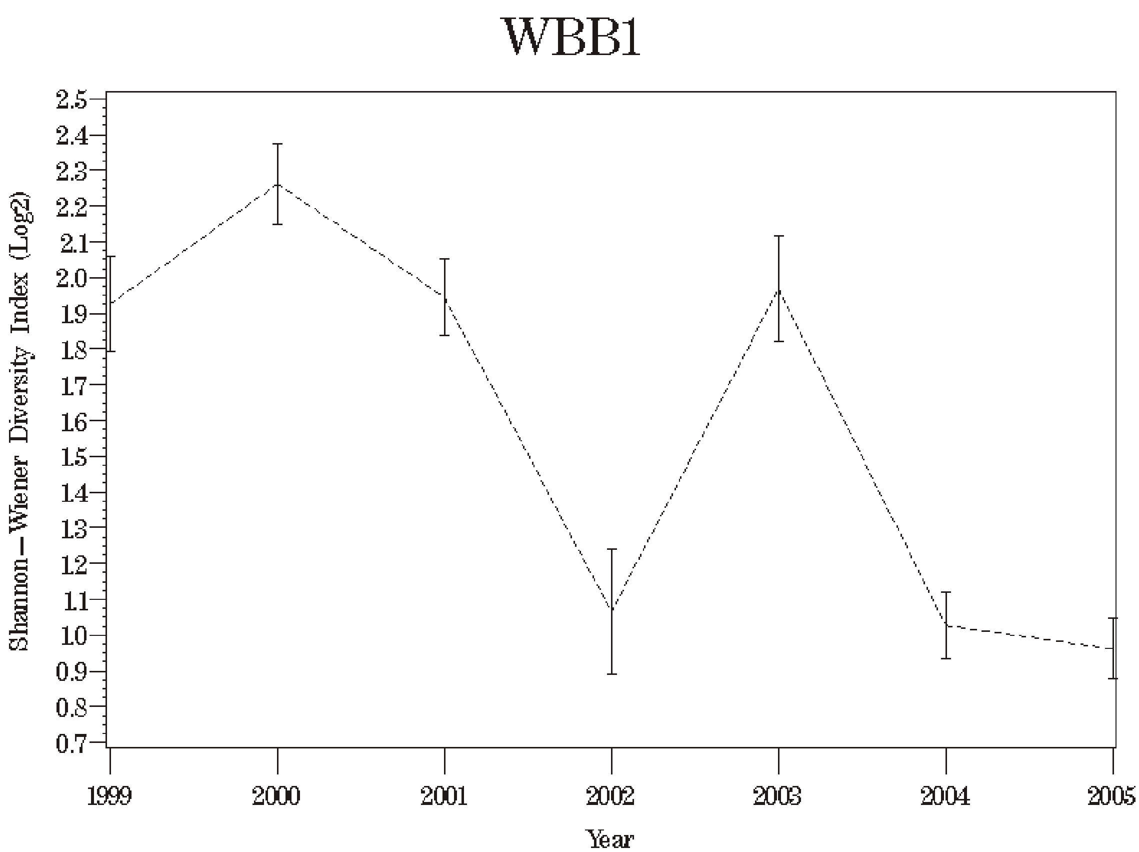

Figure 52. Plot of the Shannon-Weiner diversity index at station WBB1 for 1999 through 2005.

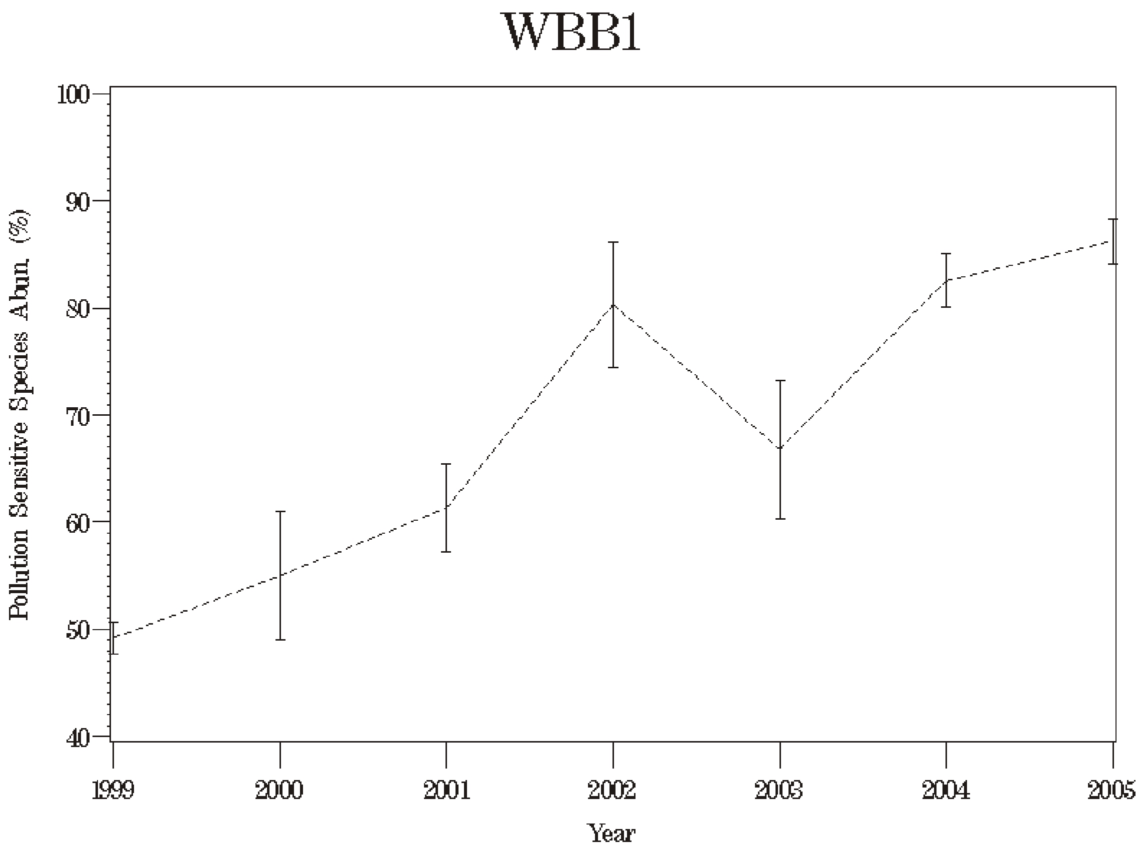

Figure 53. Plot of pollution sensitive species abundance at station WBB1for 1999 through 2005.

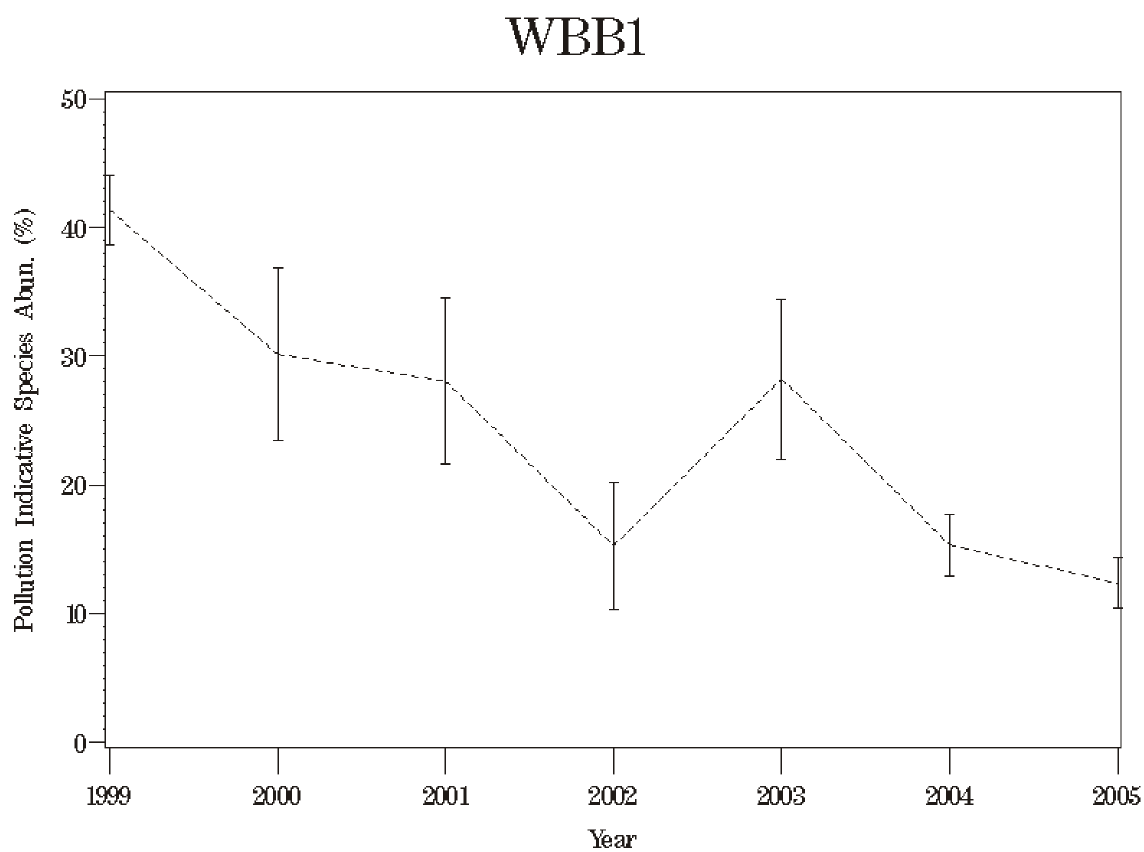

Figure 54. Plot of pollution indicative species abundance at station WBB1 for 1999 through 2005.

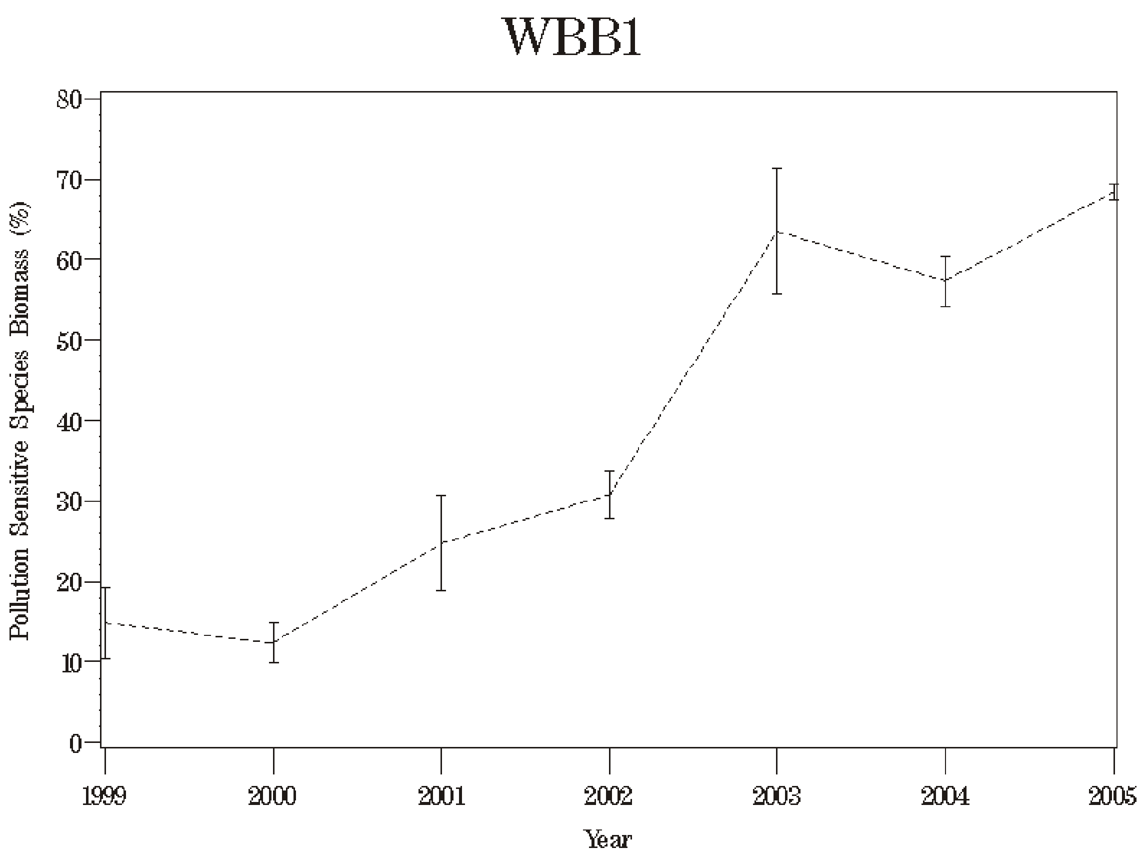

Figure 55. Plot of pollution sensitive species biomass at station WBB1 for 1999 through 2005.

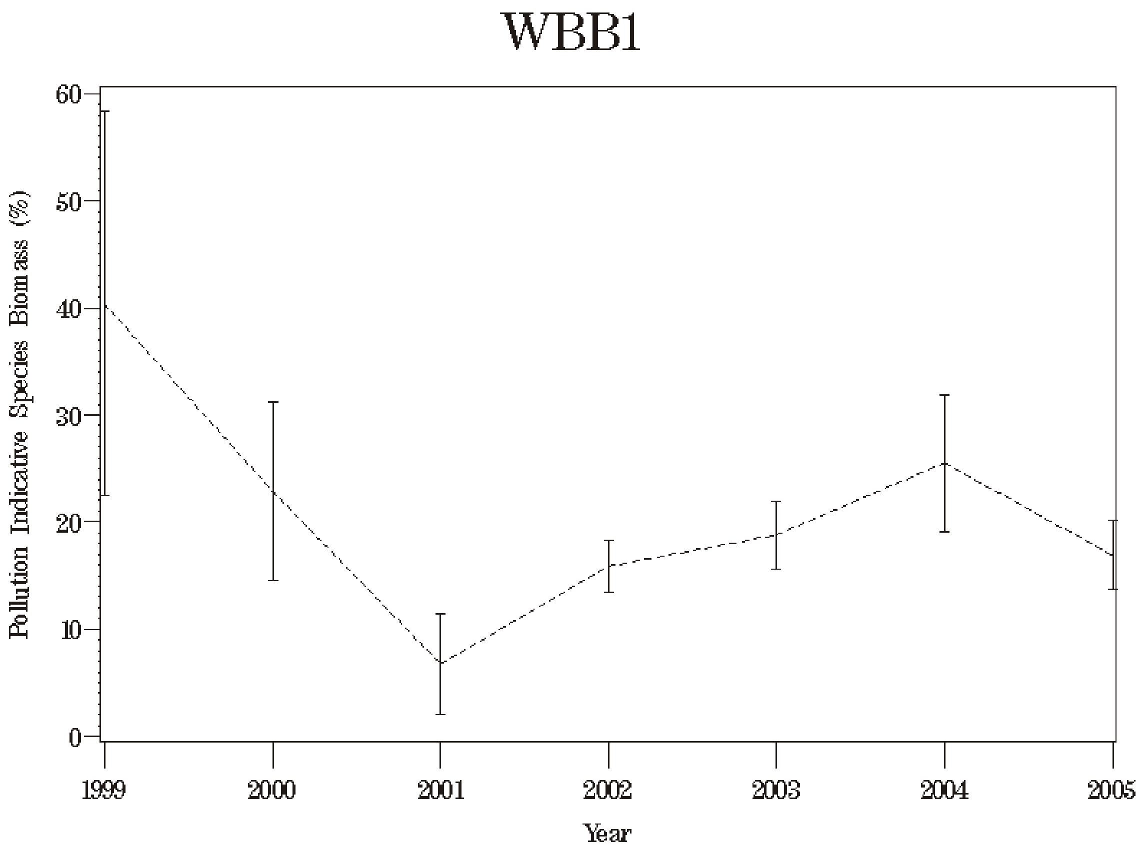

Figure 56. Plot of pollution indicative species biomass at station WBB1 for 1999 through 2005.

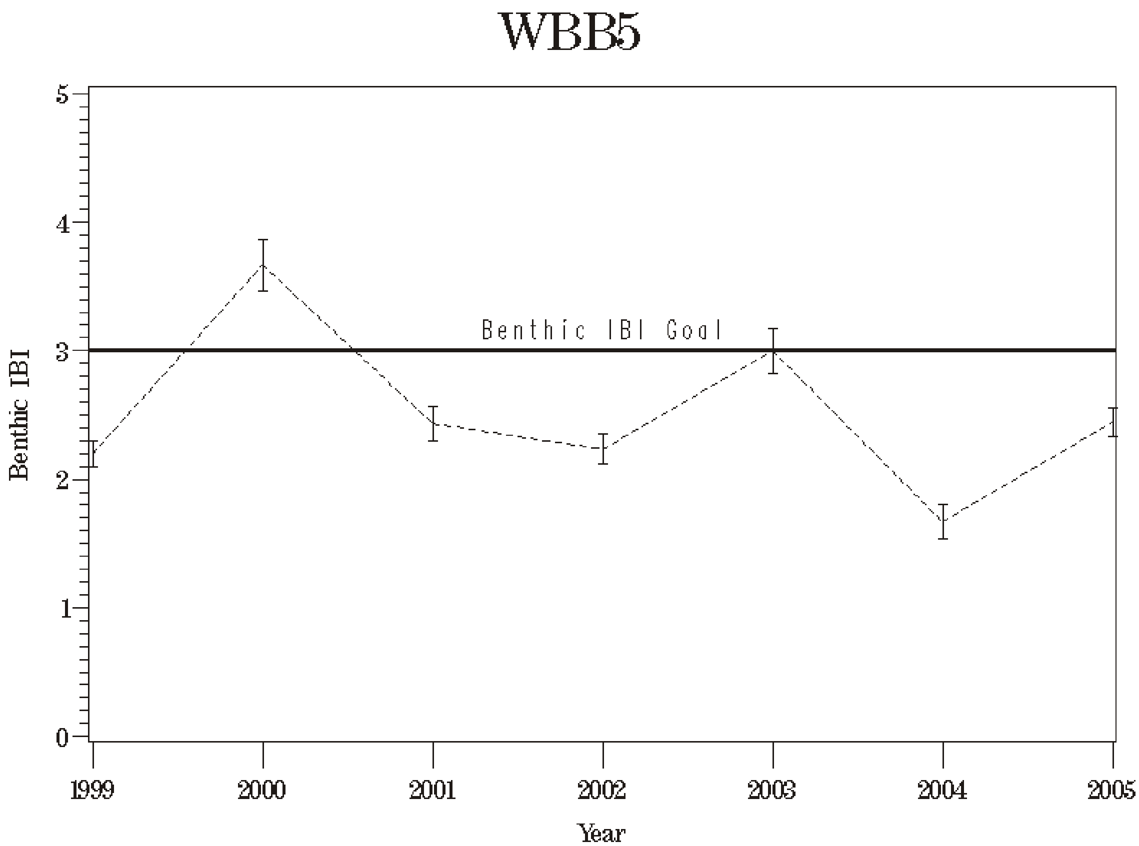

Figure 57. Plot of the benthic IBI at station WBB5 from 1999 through 2005.

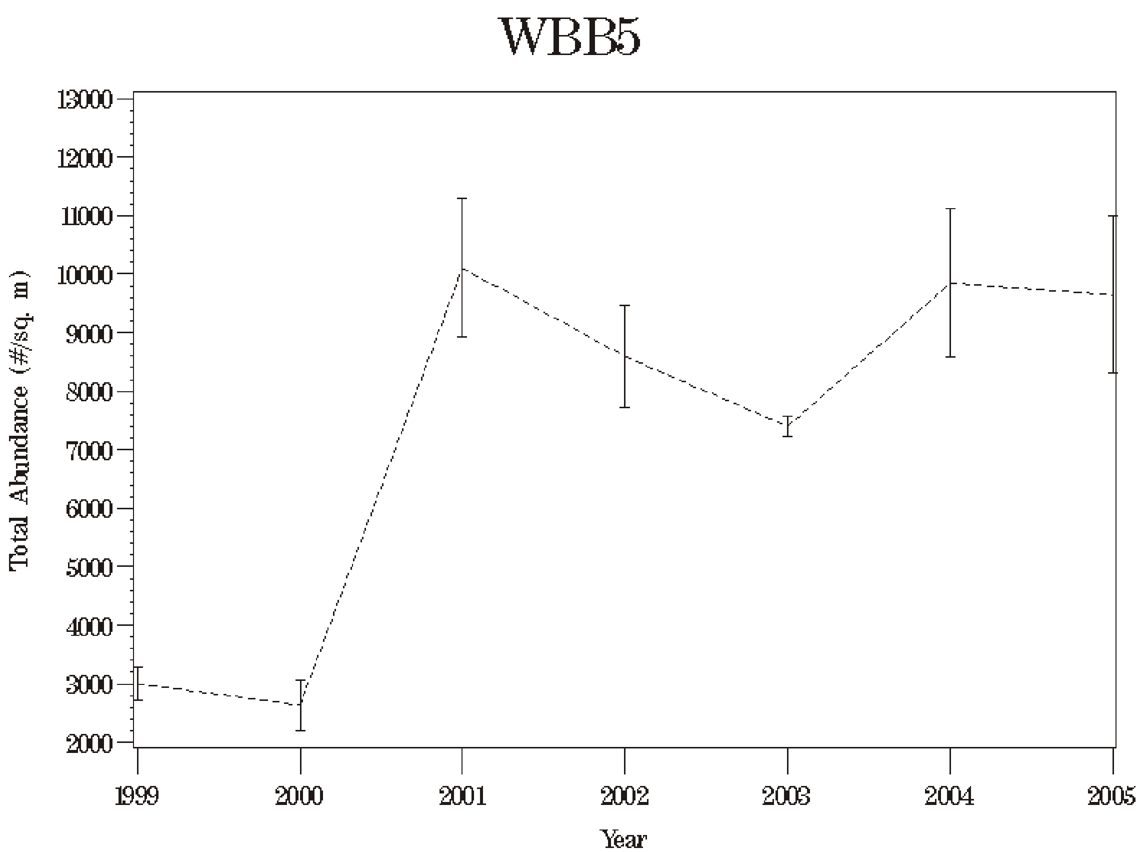

Figure 58. Plot of total benthic community abundance at station WBB5 for 1999 through 2005.

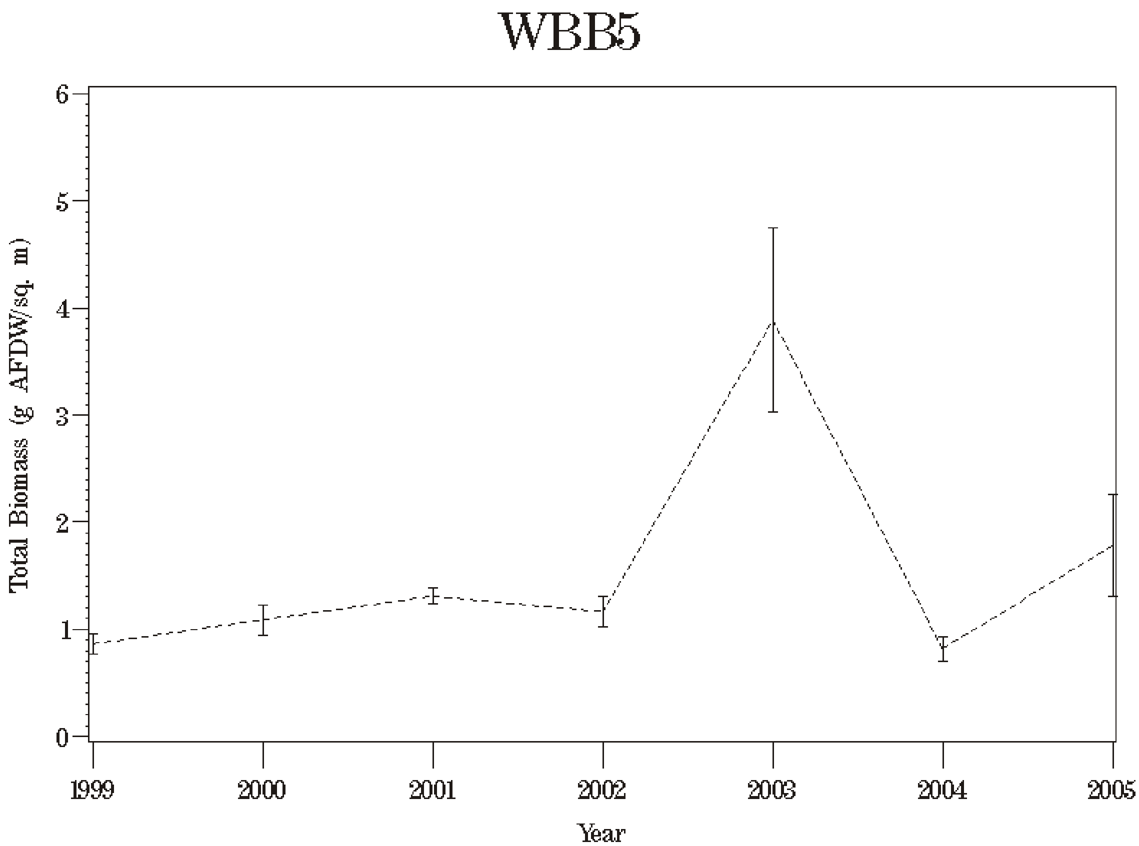

Figure 59. Plot of total benthic community biomass at station WBB5 for 1999 through 2005.

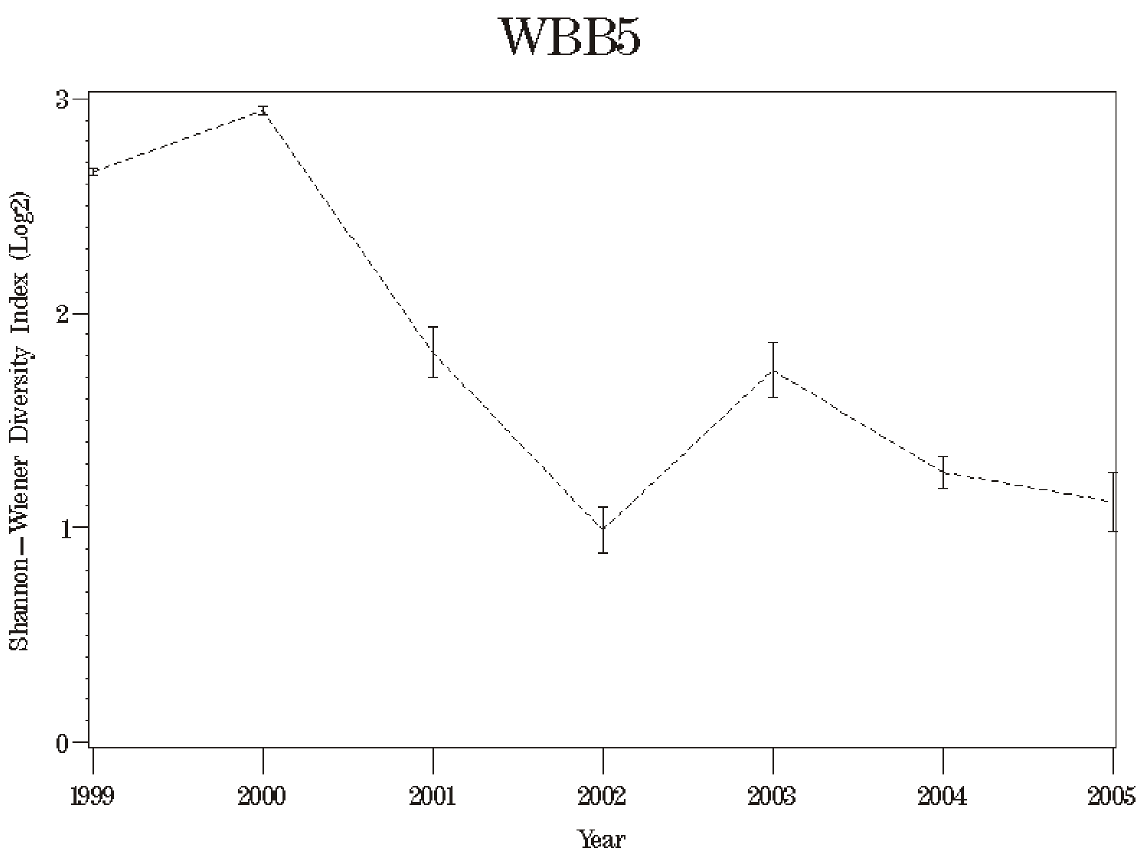

Figure 60. Plot of the Shannon-Weiner diversity index at station WBB5 for 1999 through 2005.

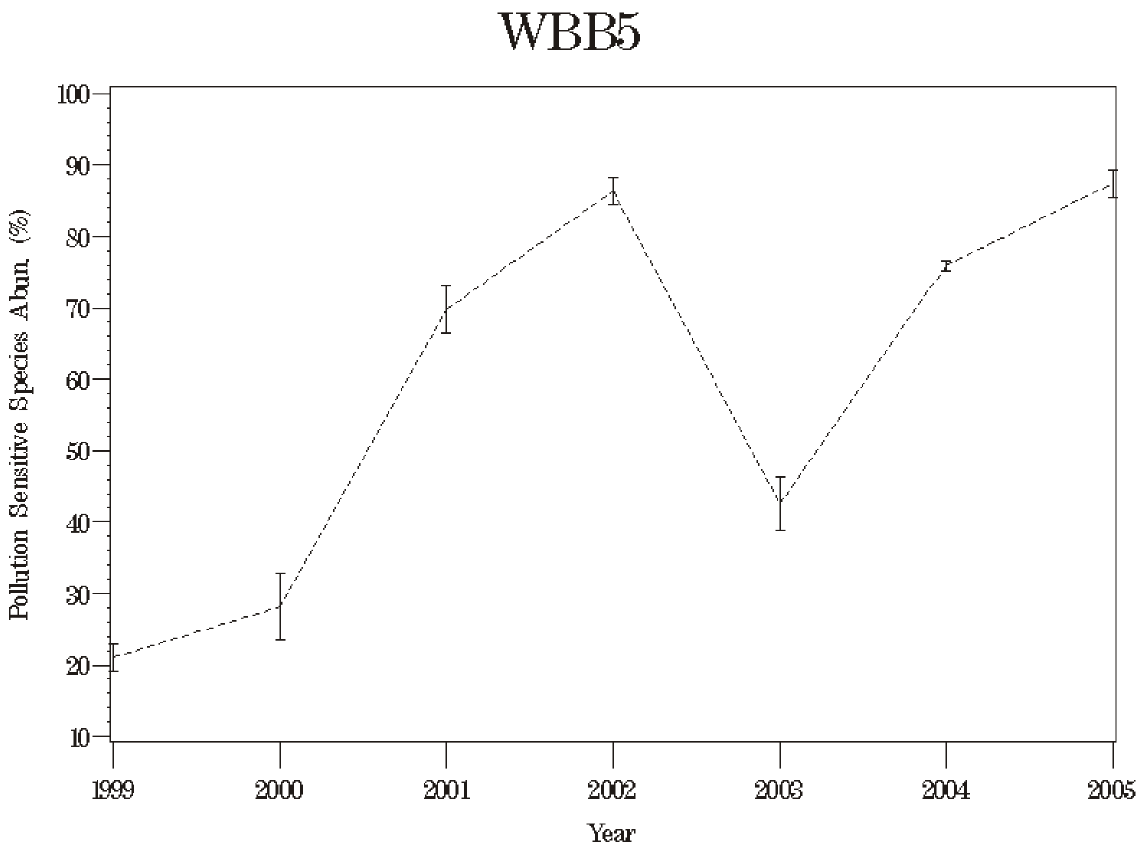

Figure 61. Plot of pollution sensitive species abundance at station WBB5for 1999 through 2005.

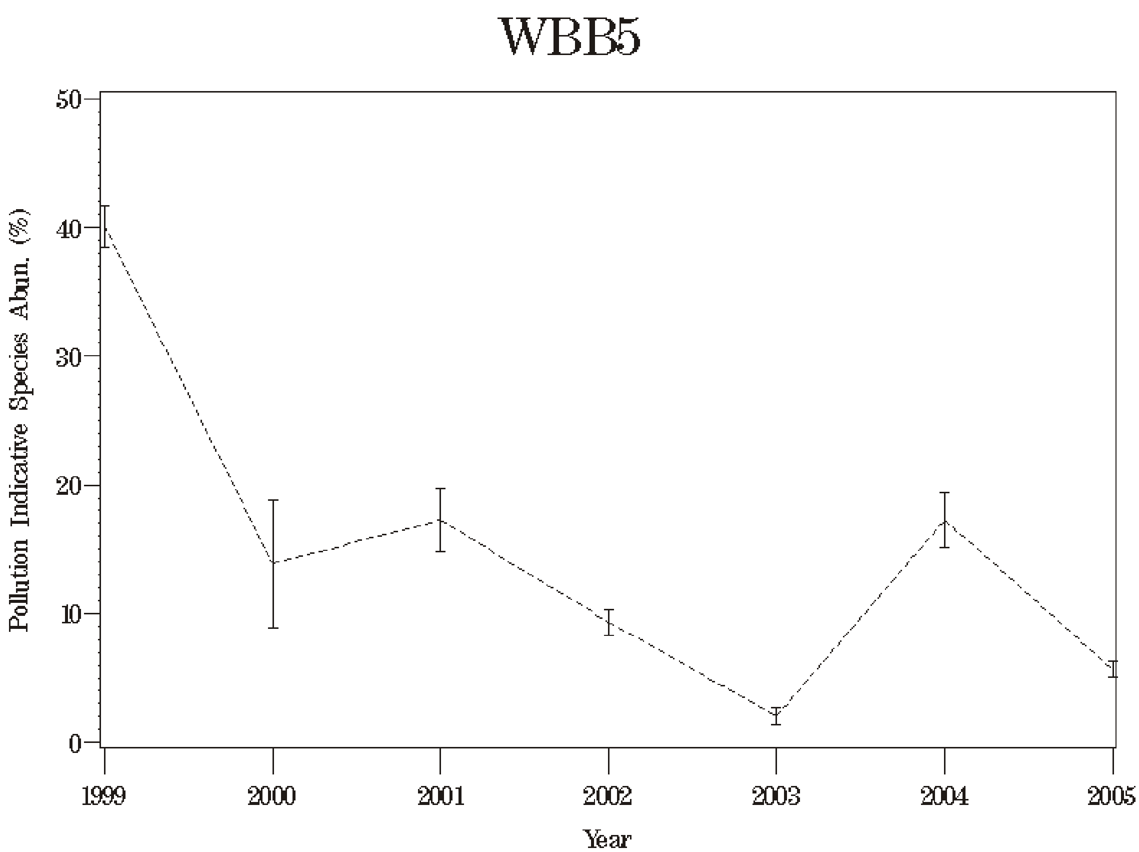

Figure 62. Plot of pollution indicative species abundance at station WBB5 for 1999 through 2005.

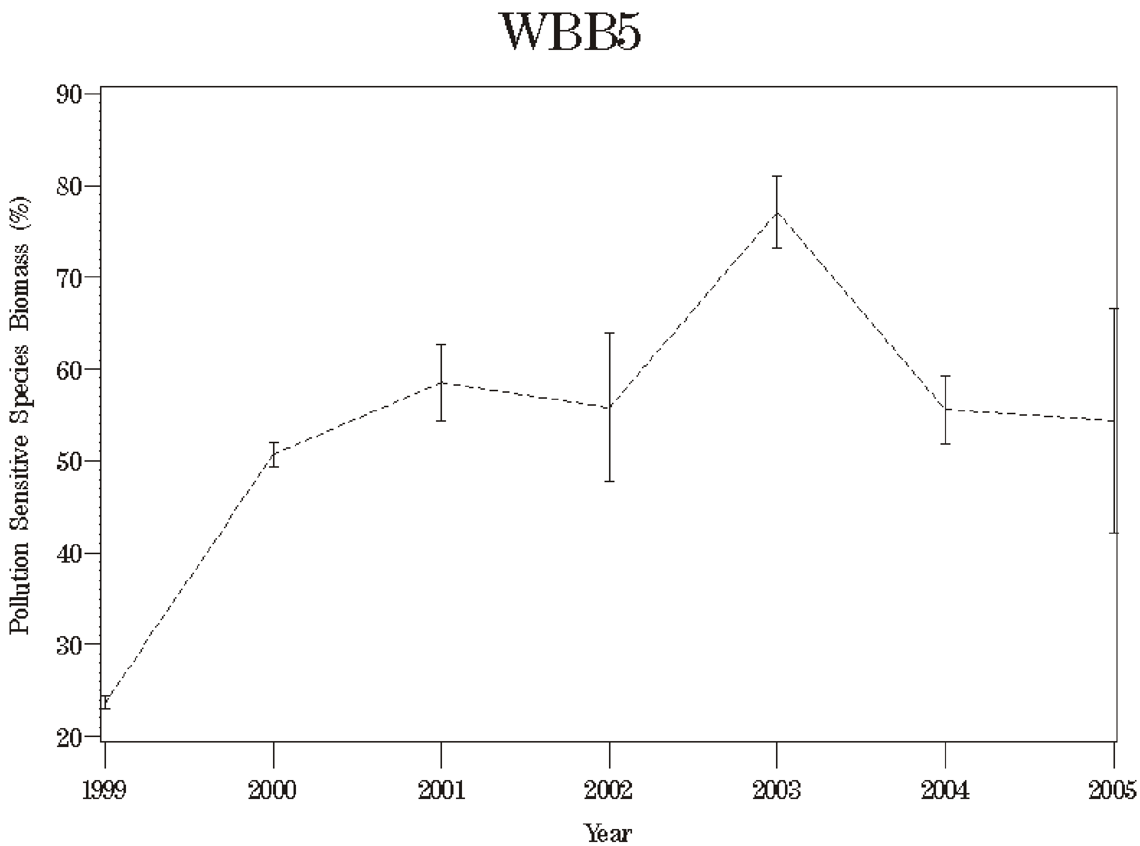

Figure 63. Plot of pollution sensitive species biomass at station WBB5 for 1999 through 2005.

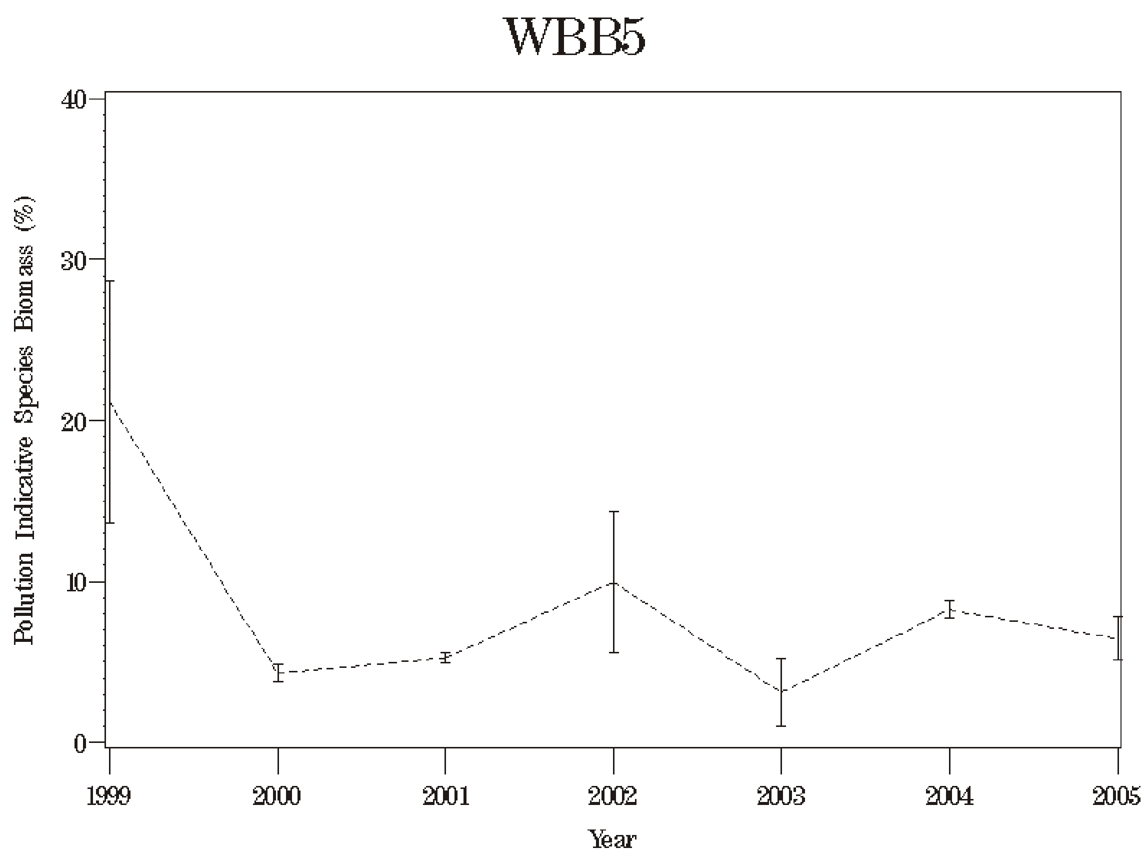

Figure 64. Plot of pollution indicative species biomass at station WBB5 for 1999 through 2005.

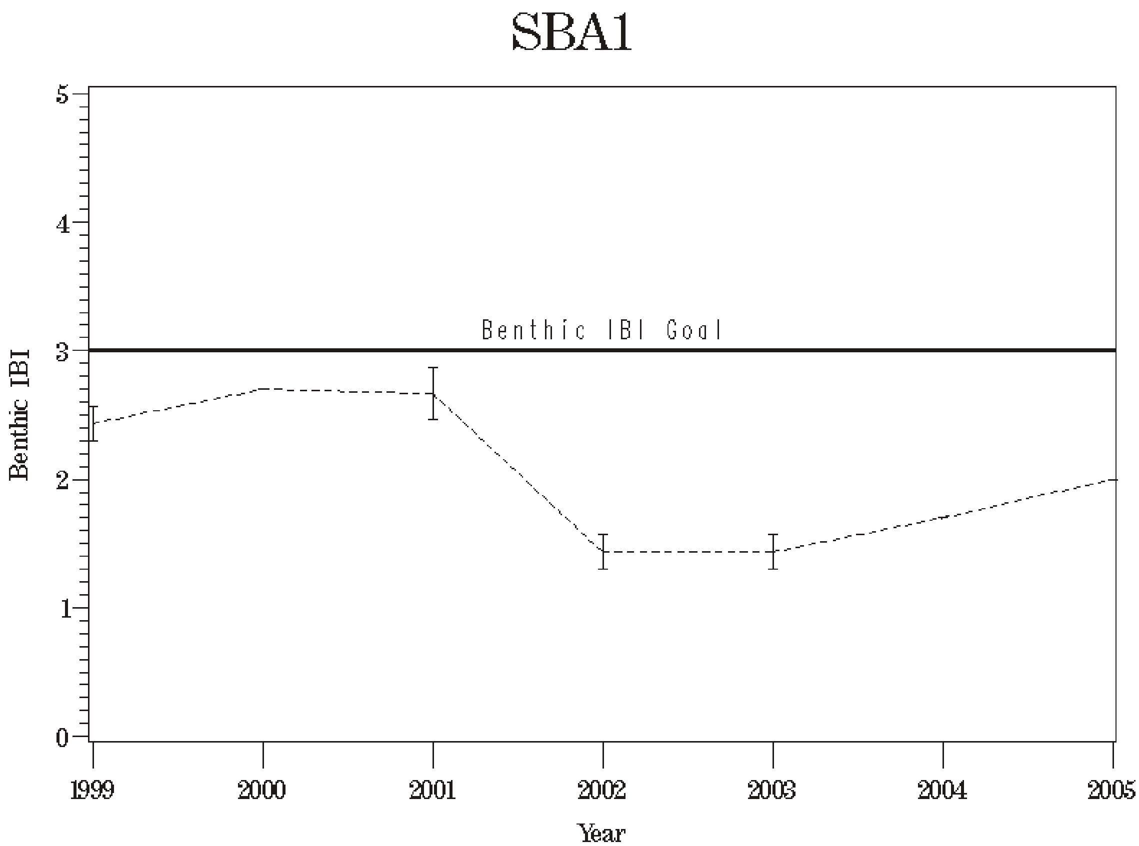

Figure 65. Plot of the benthic IBI at station SBA1 from 1999 through 2005.

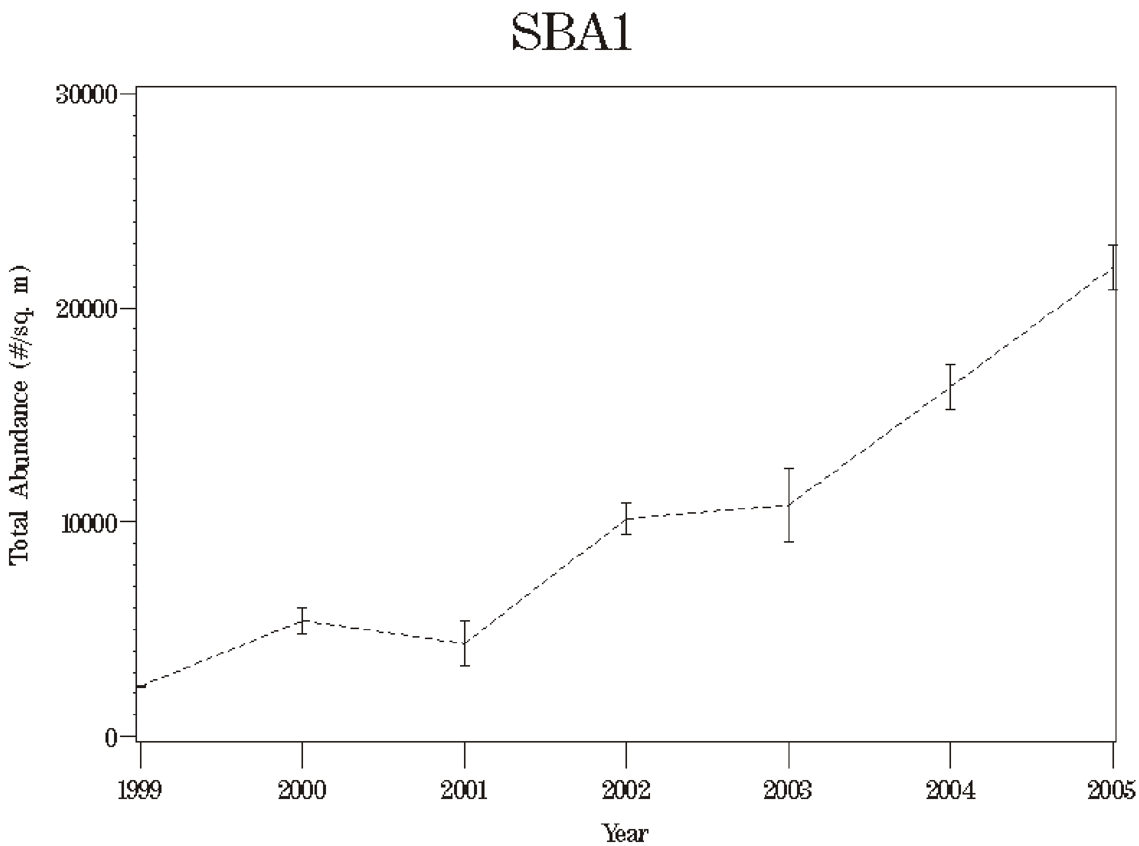

Figure 66. Plot of total benthic community abundance at station SBA1 for 1999 through 2005.

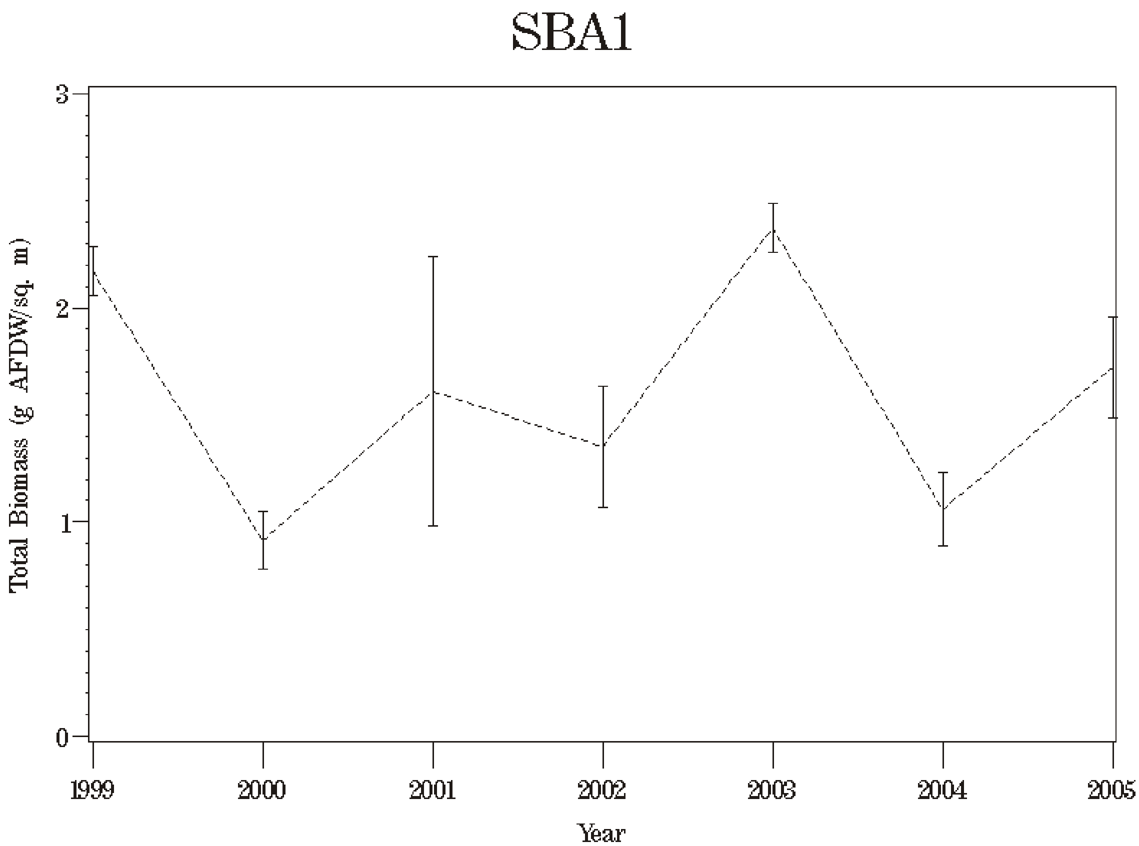

Figure 67. Plot of total benthic community biomass at station SBA1 for 1999 through 2005.

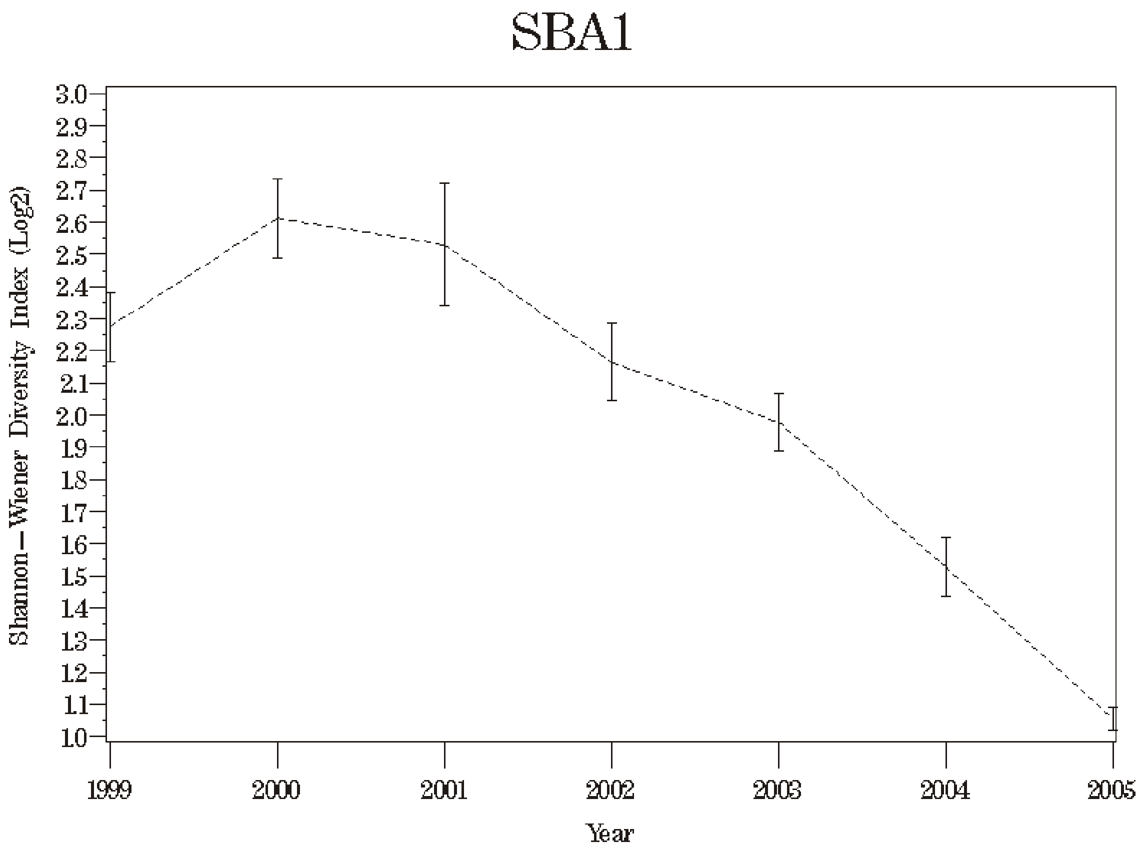

Figure 68. Plot of the Shannon-Weiner diversity index at station SBA1 for 1999 through 2005.

Figure 69. Plot of pollution sensitive species abundance at station SBA1for 1999 through 2005.

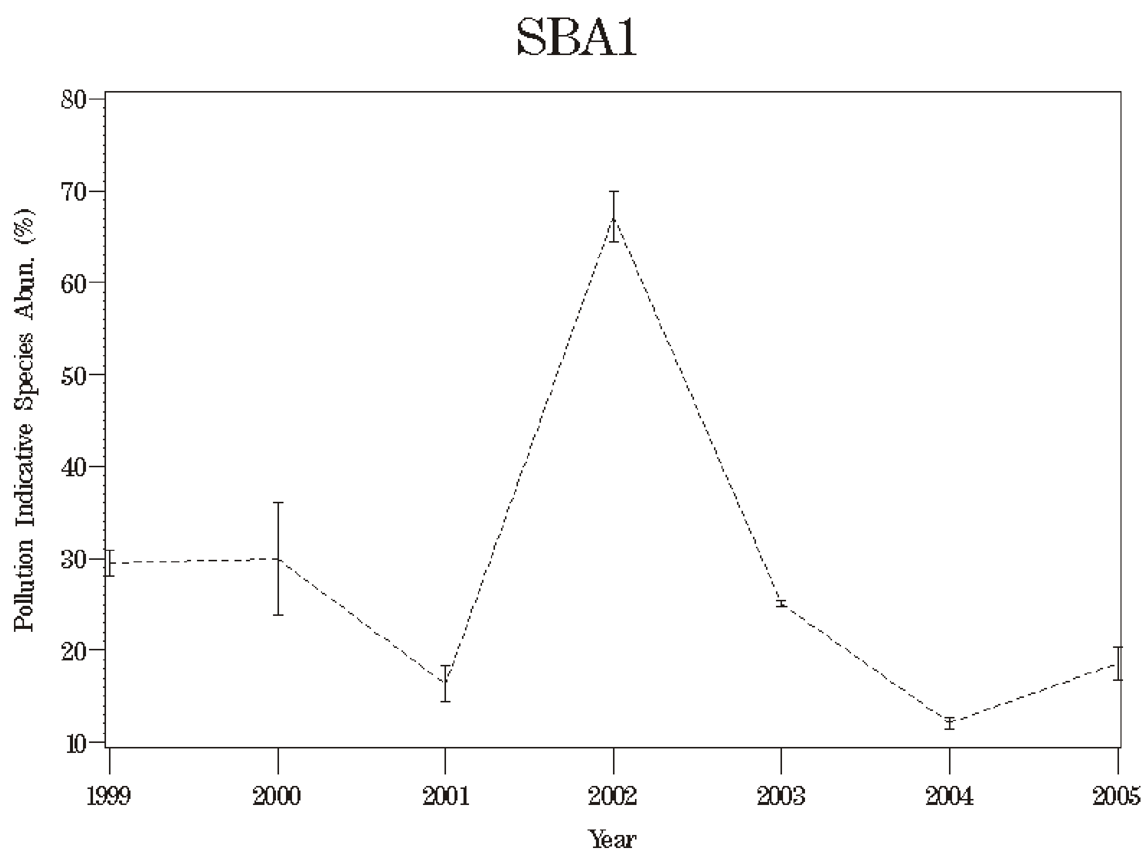

Figure 70. Plot of pollution indicative species abundance at station SBA1 for 1999 through 2005.

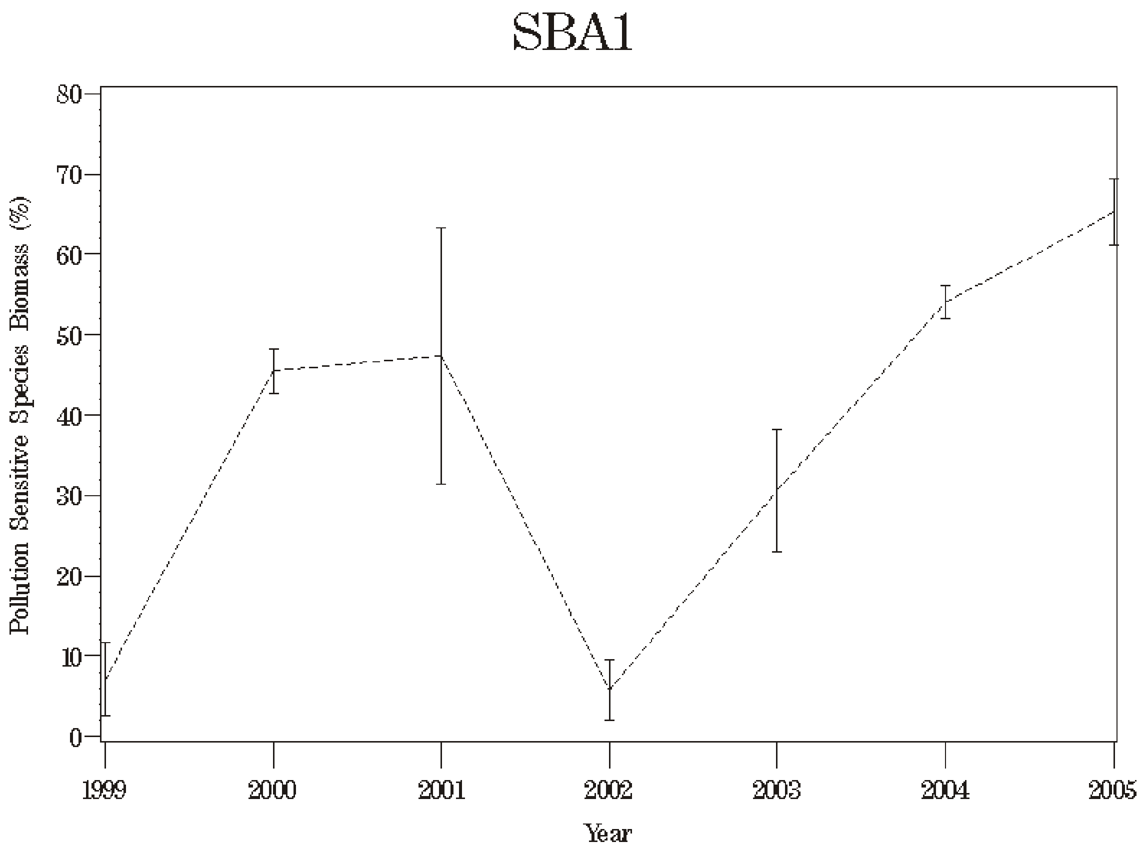

Figure 71. Plot of pollution sensitive species biomass at station SBA1 for 1999 through 2005.

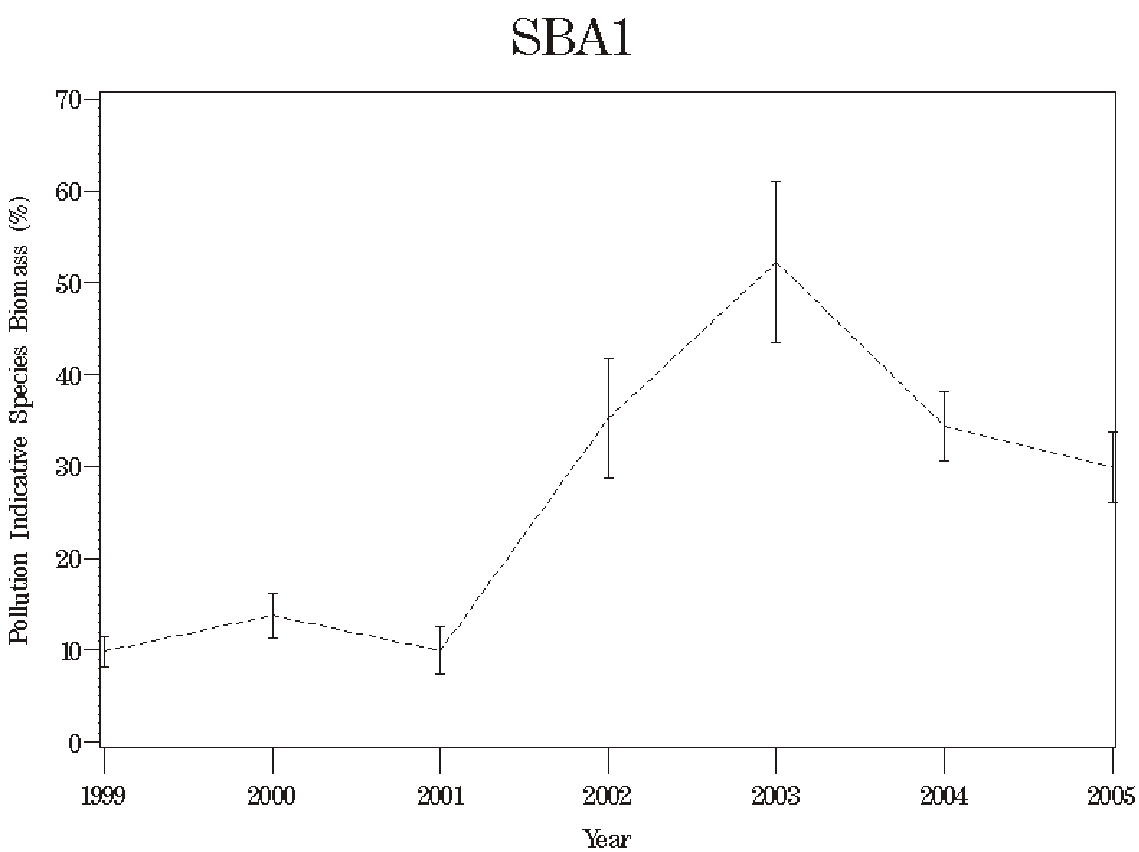

Figure 72. Plot of pollution indicative species biomass at station SBA1 for 1999 through 2005.

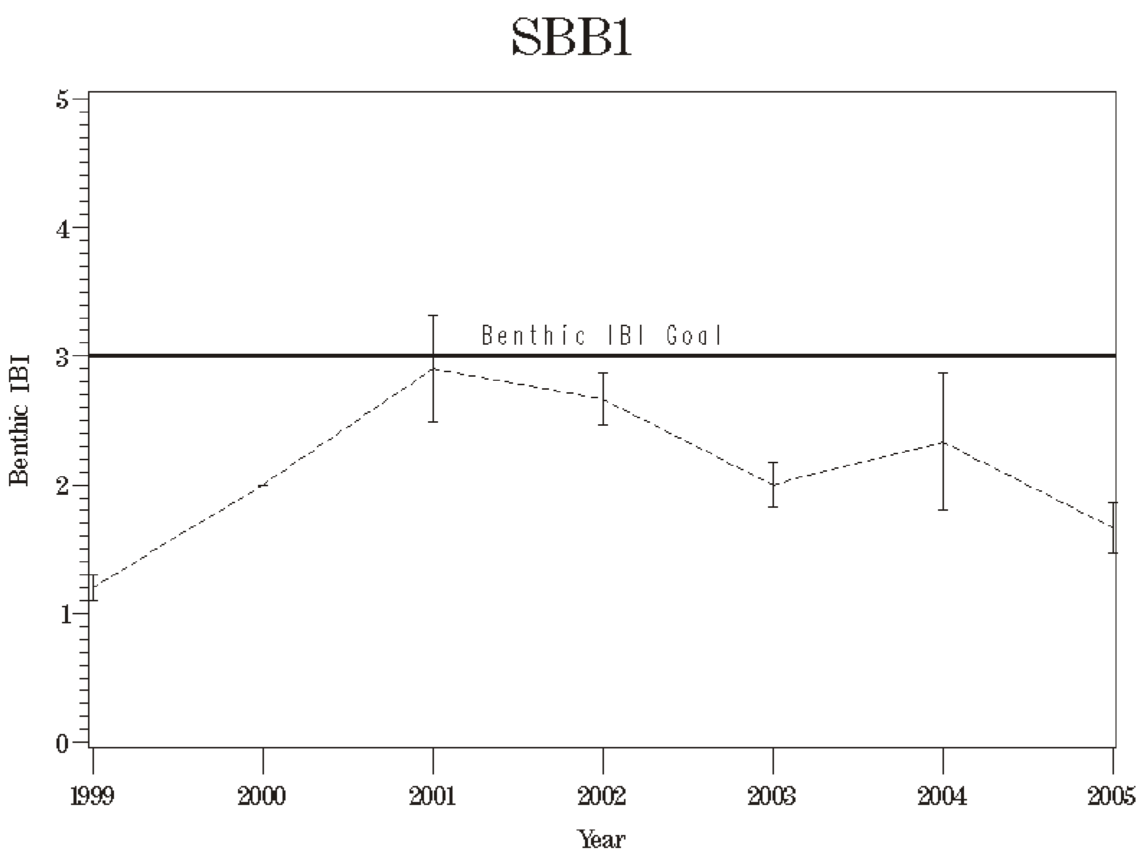

Figure 73. Plot of the benthic IBI at station SBB1 from 1999 through 2005.

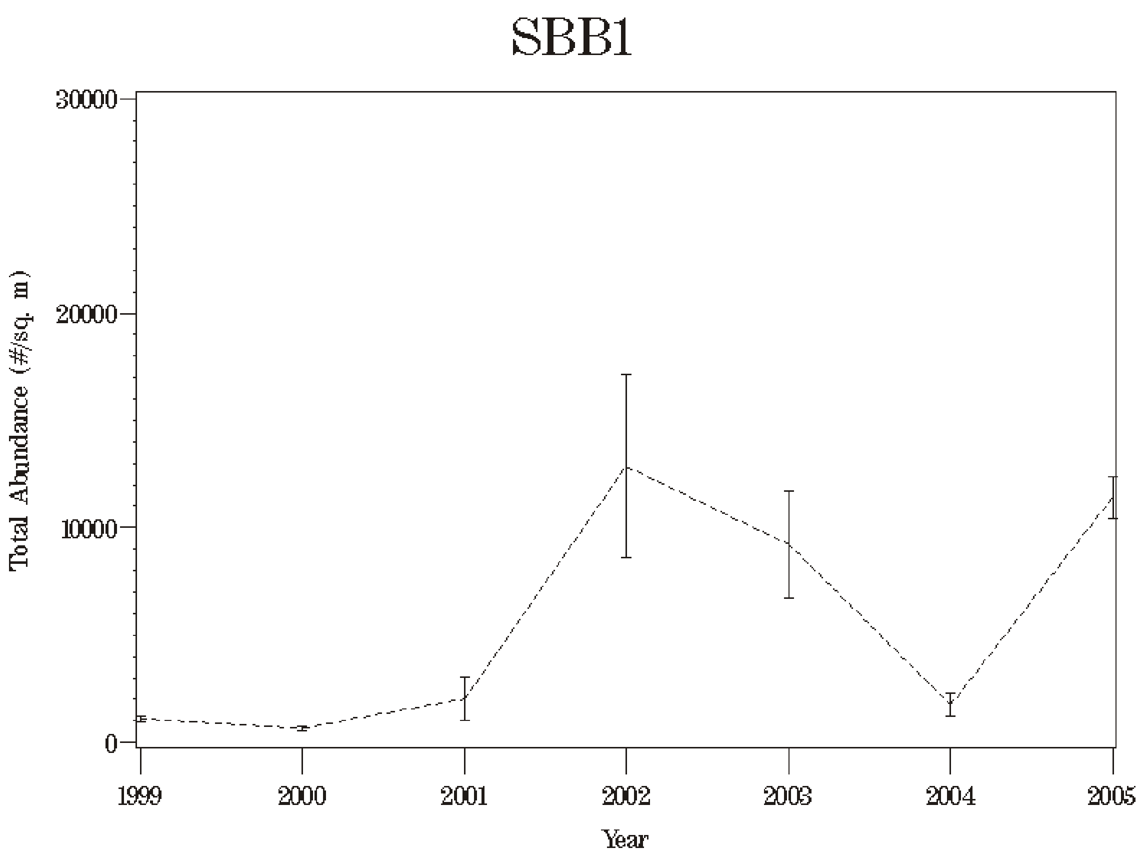

Figure 74. Plot of total benthic community abundance at station SBB1 for 1999 through 2005.

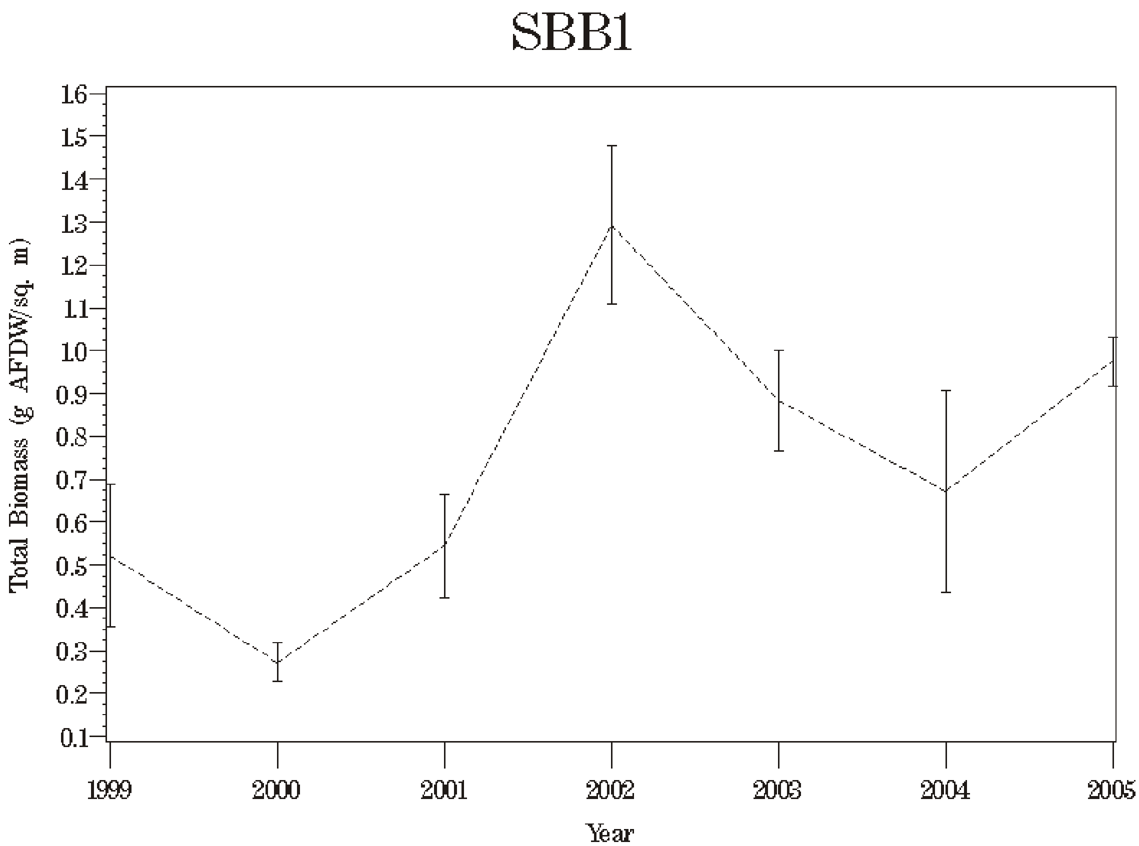

Figure 75. Plot of total benthic community biomass at station SBB1 for 1999 through 2005.

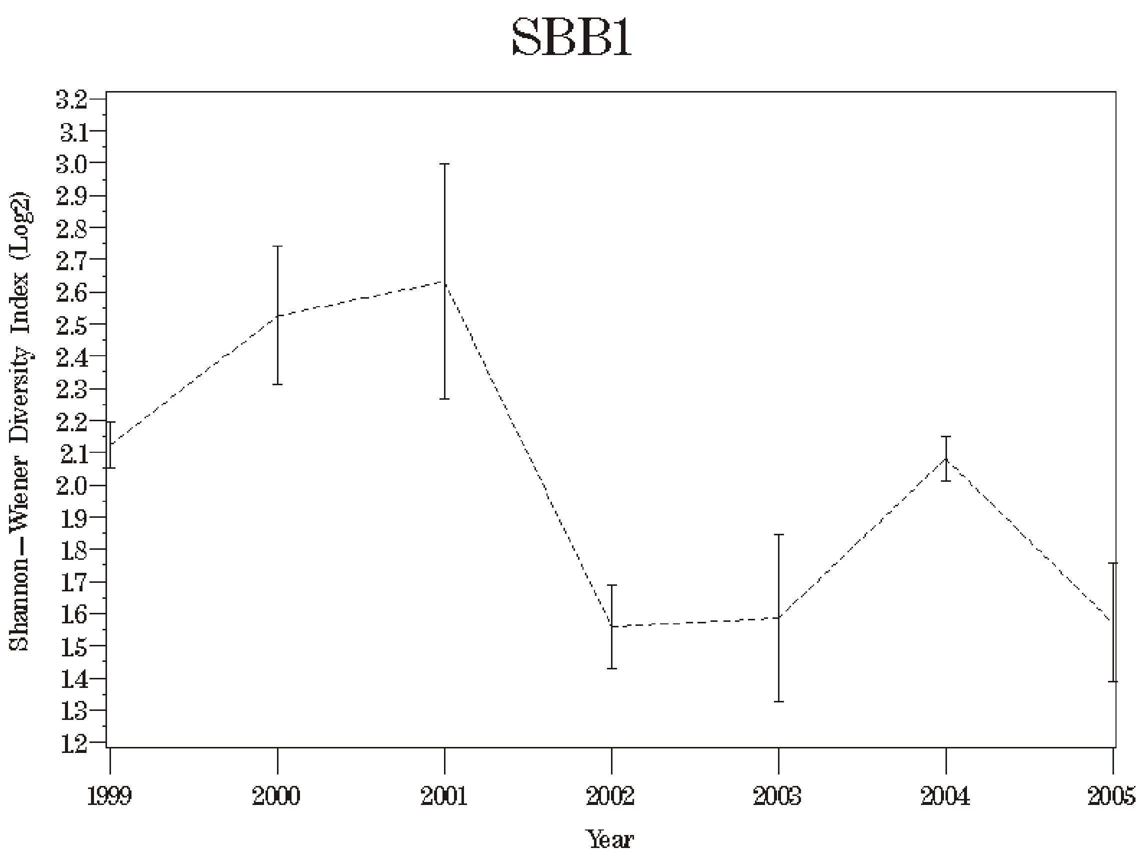

Figure 76. Plot of the Shannon-Weiner diversity index at station SBB1 for 1999 through 2005.

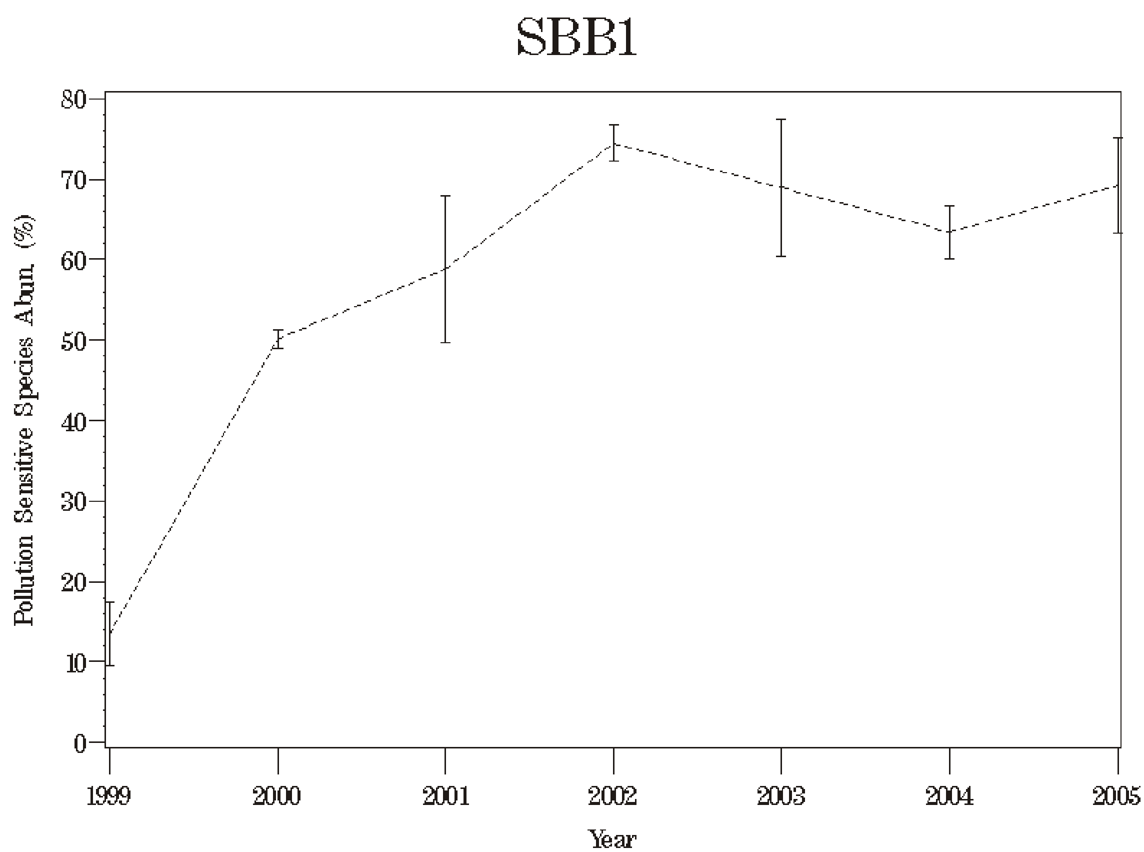

Figure 77. Plot of pollution sensitive species abundance at station SBB1for 1999 through 2005.

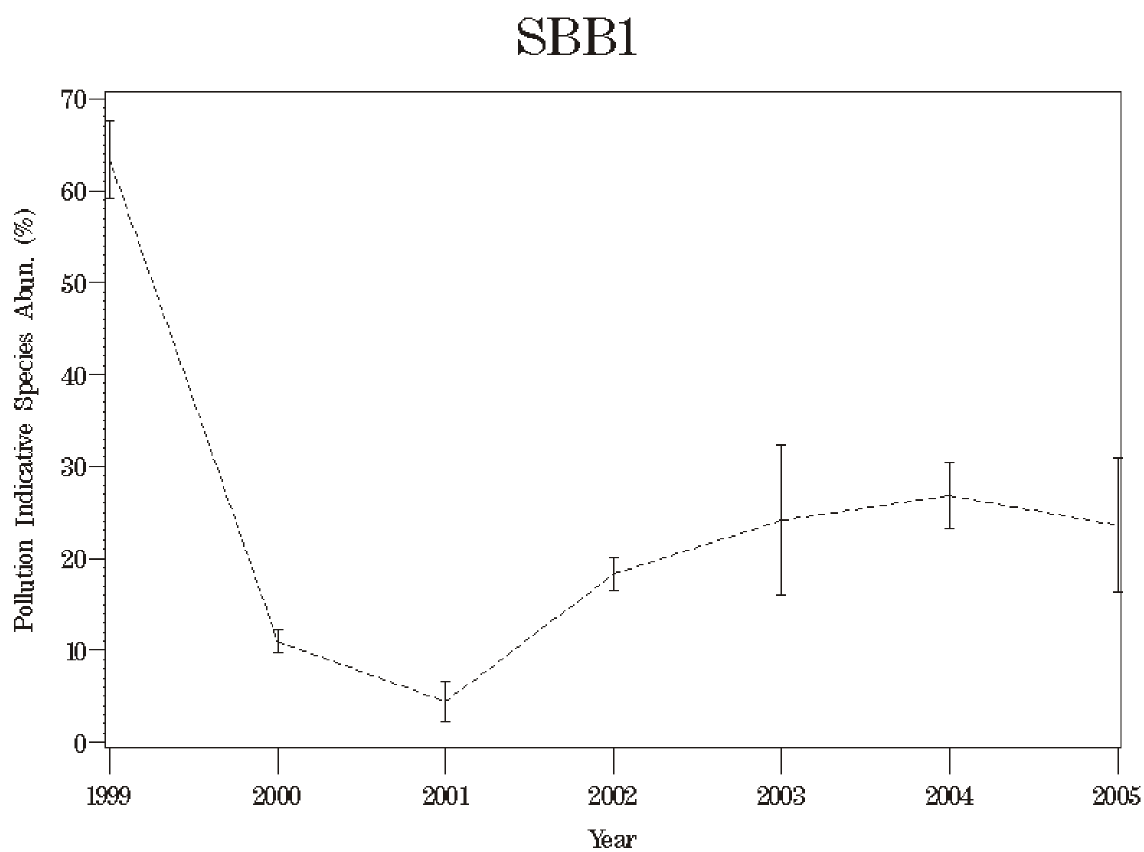

Figure 78. Plot of pollution indicative species abundance at station SBB1 for 1999 through 2005.

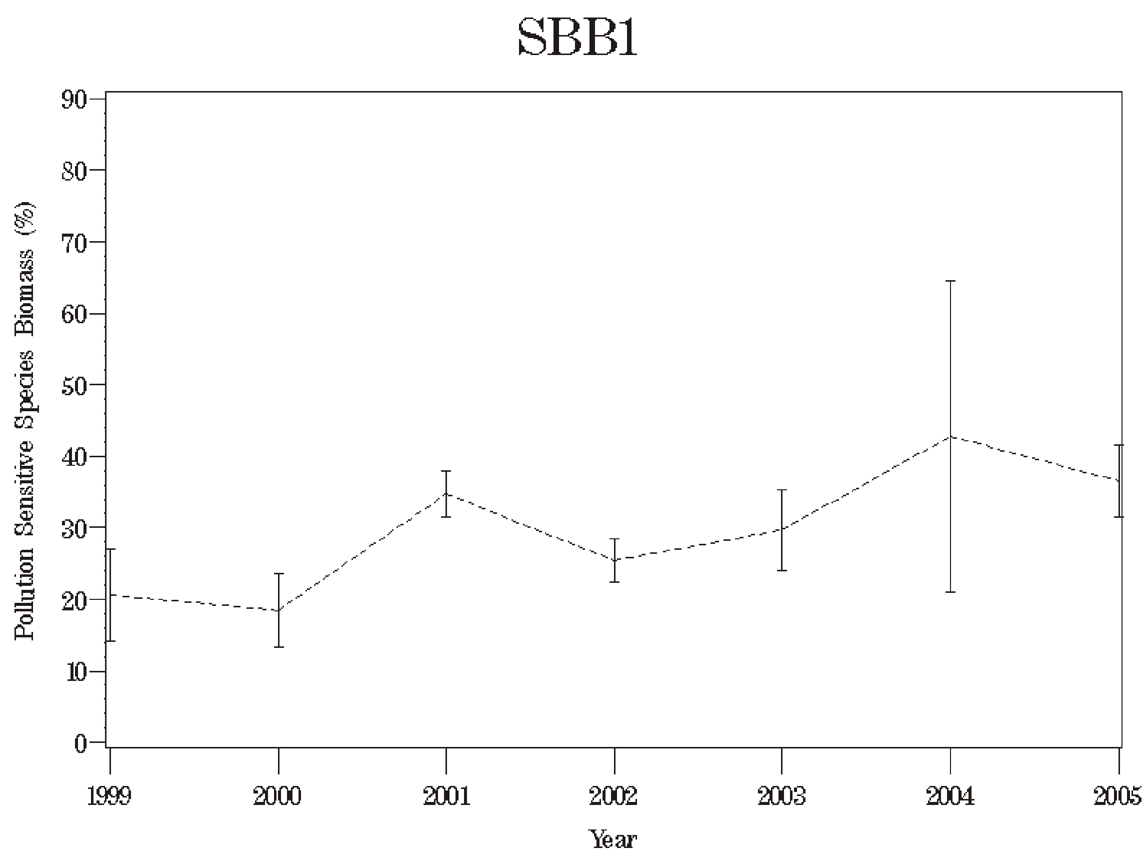

Figure 79. Plot of pollution sensitive species biomass at station SBB1 for 1999 through 2005.

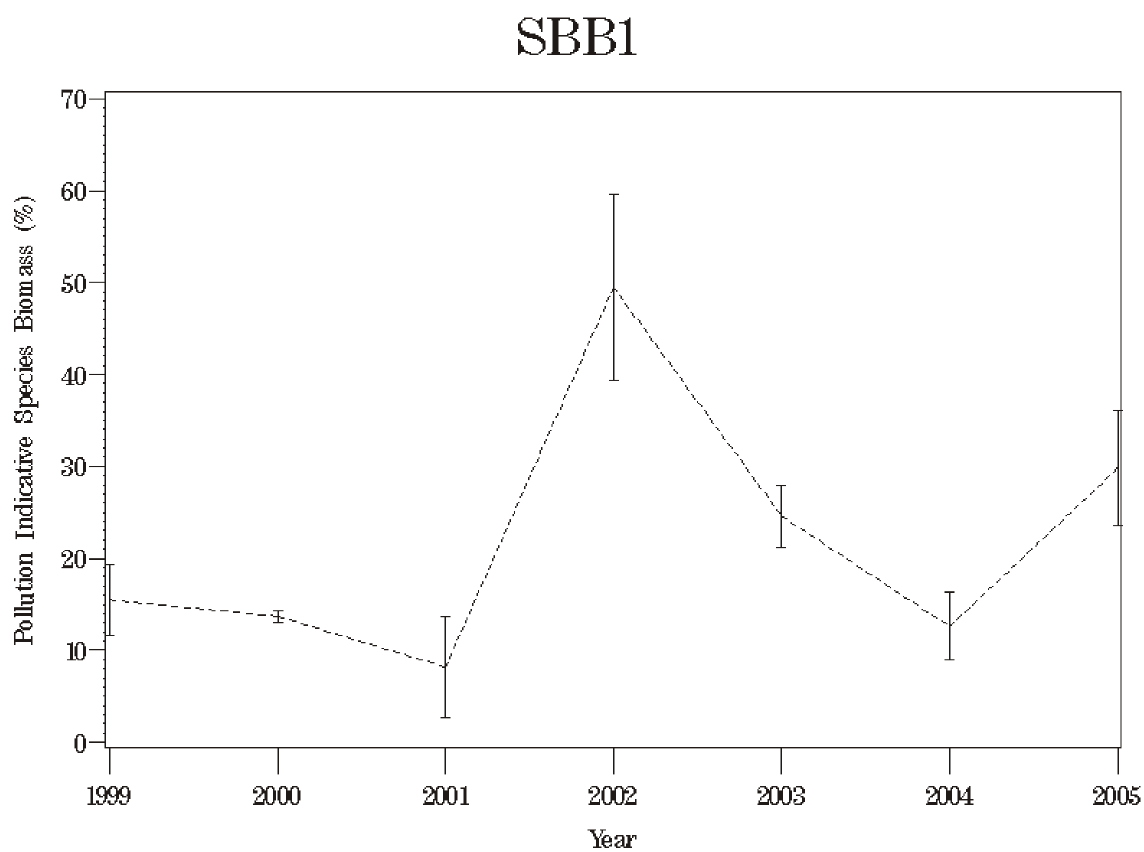

Figure 80. Plot of pollution indicative species biomass at station SBB1 for 1999 through 2005.

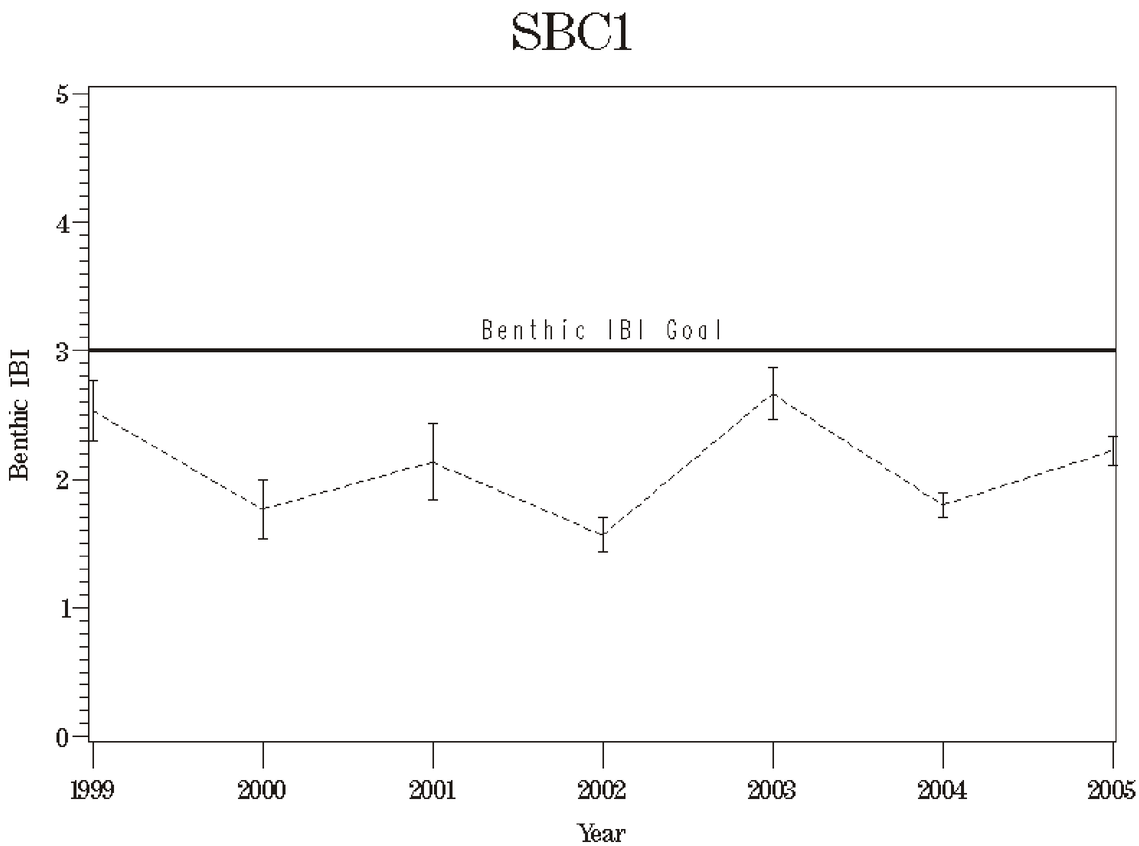

Figure 81. Plot of the benthic IBI at station SBC1 from 1999 through 2005.

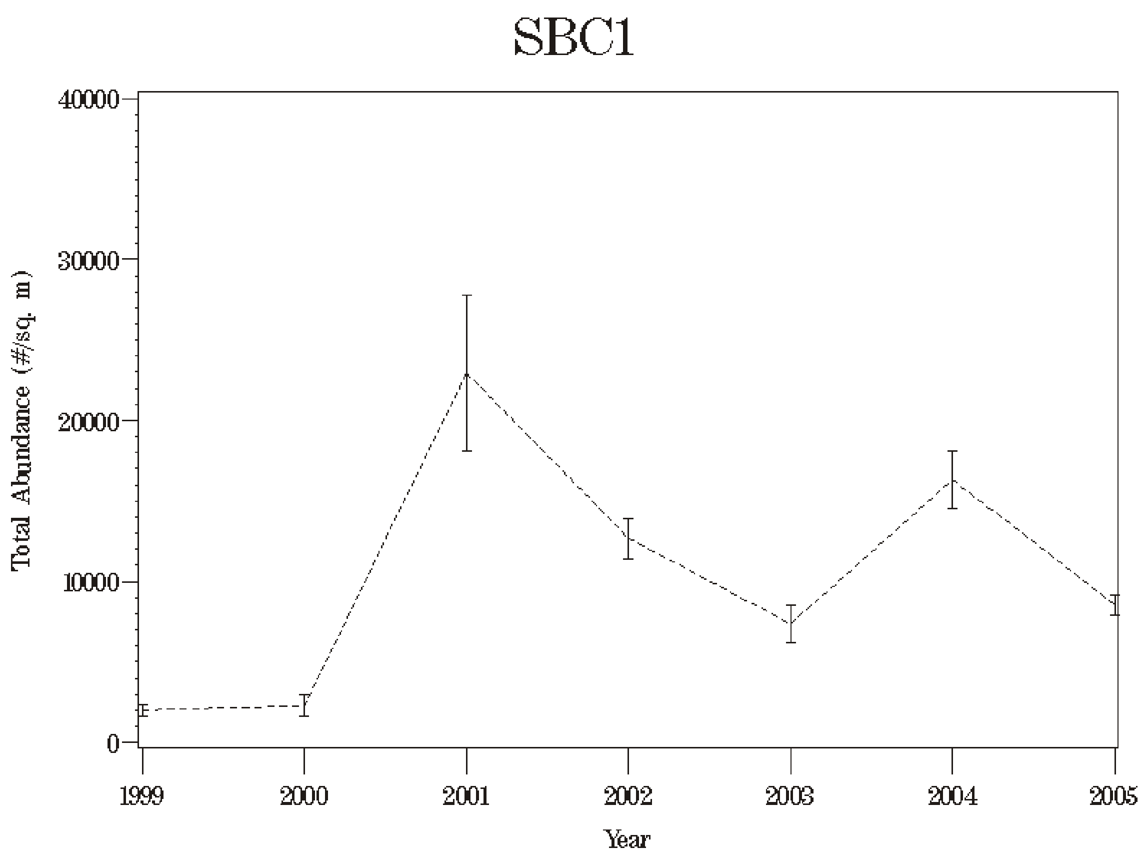

Figure 82. Plot of total benthic community abundance at station SBC1 for 1999 through 2005.

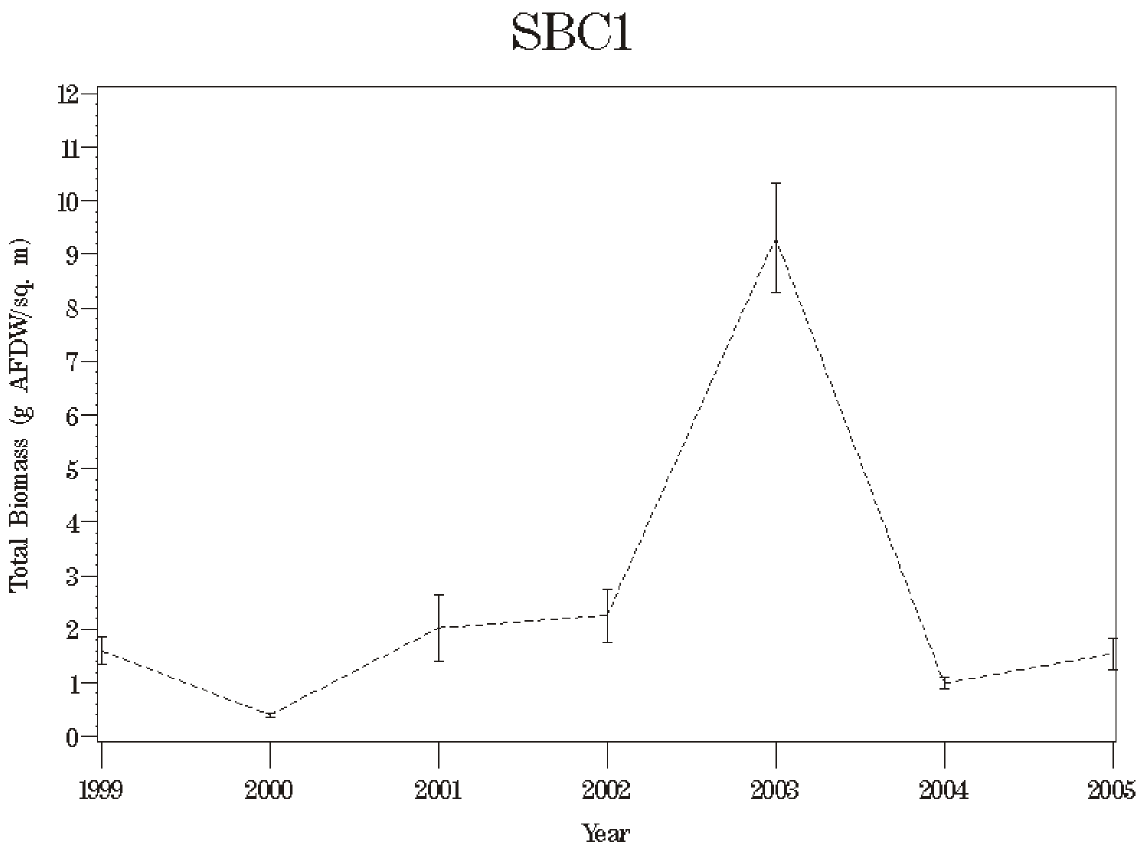

Figure 83. Plot of total benthic community biomass at station SBC1 for 1999 through 2005.

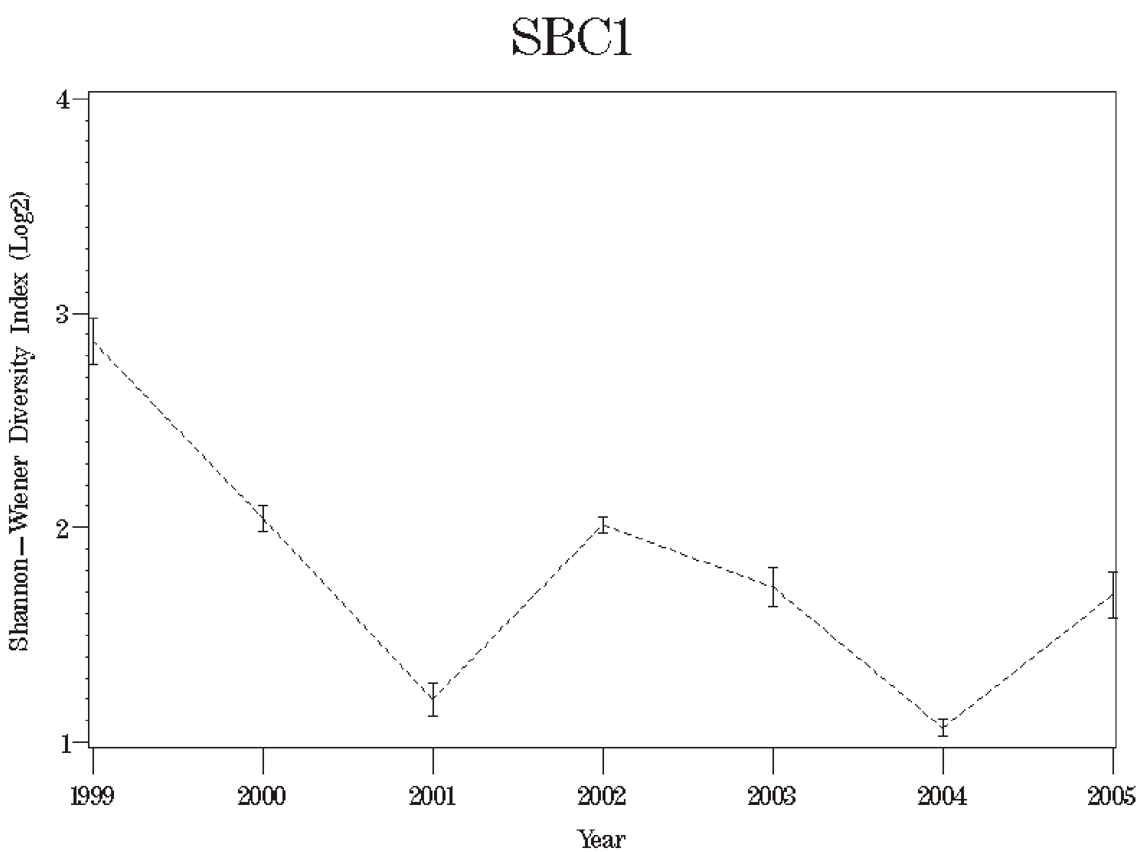

Figure 84. Plot of the Shannon-Weiner diversity index at station SBC1 for 1999 through 2005.

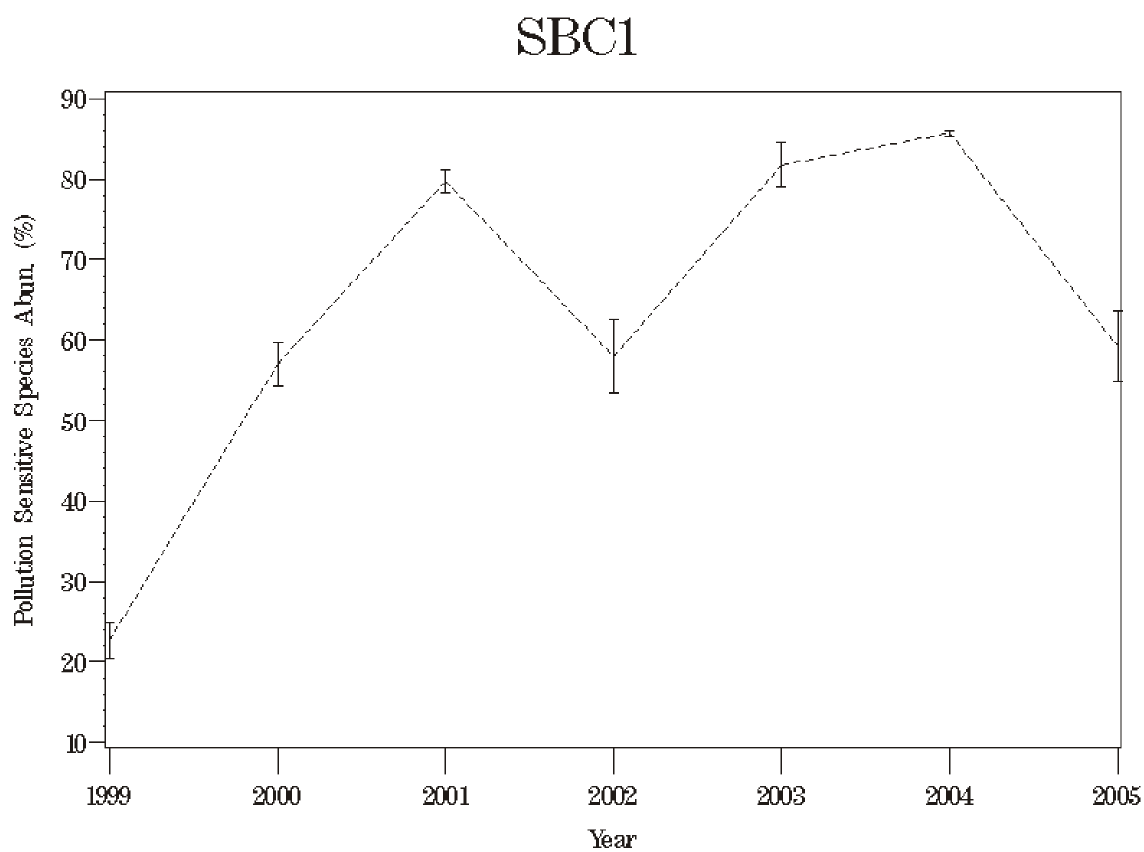

Figure 85. Plot of pollution sensitive species abundance at station SBC1for 1999 through 2005.

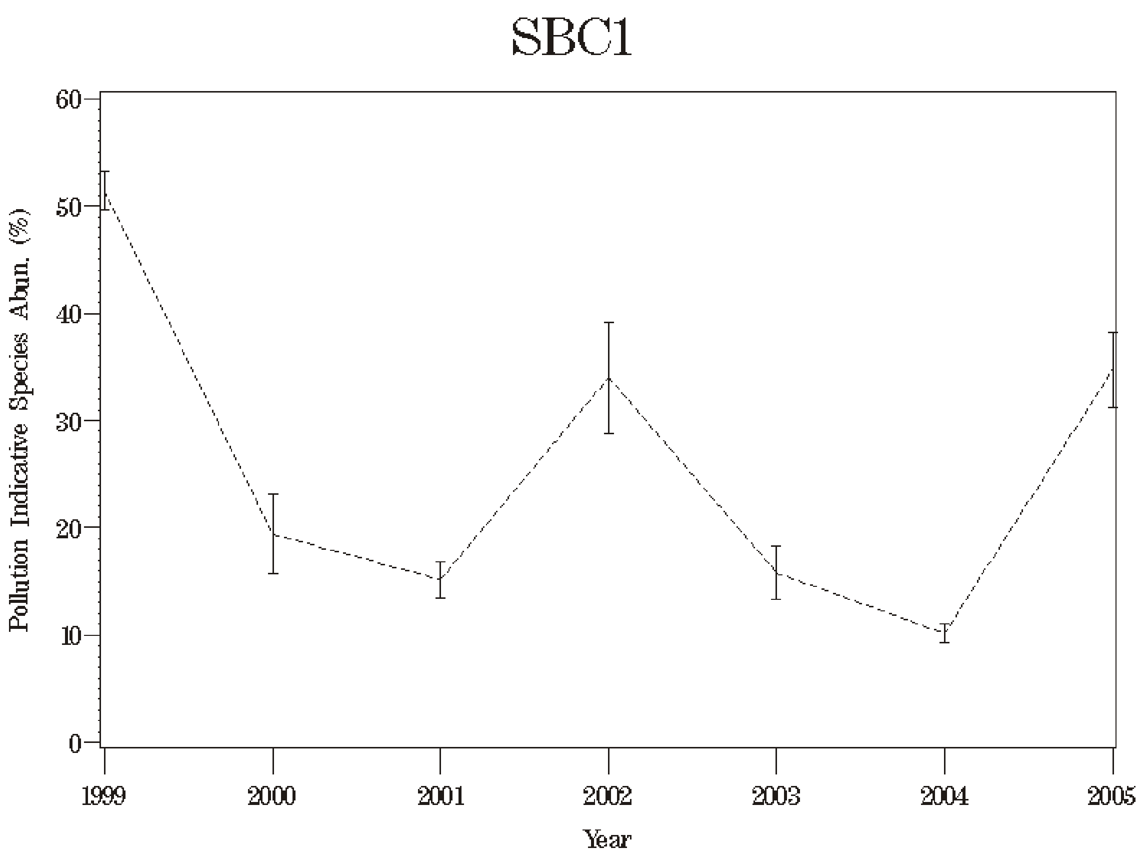

Figure 86. Plot of pollution indicative species abundance at station SBC1 for 1999 through 2005.

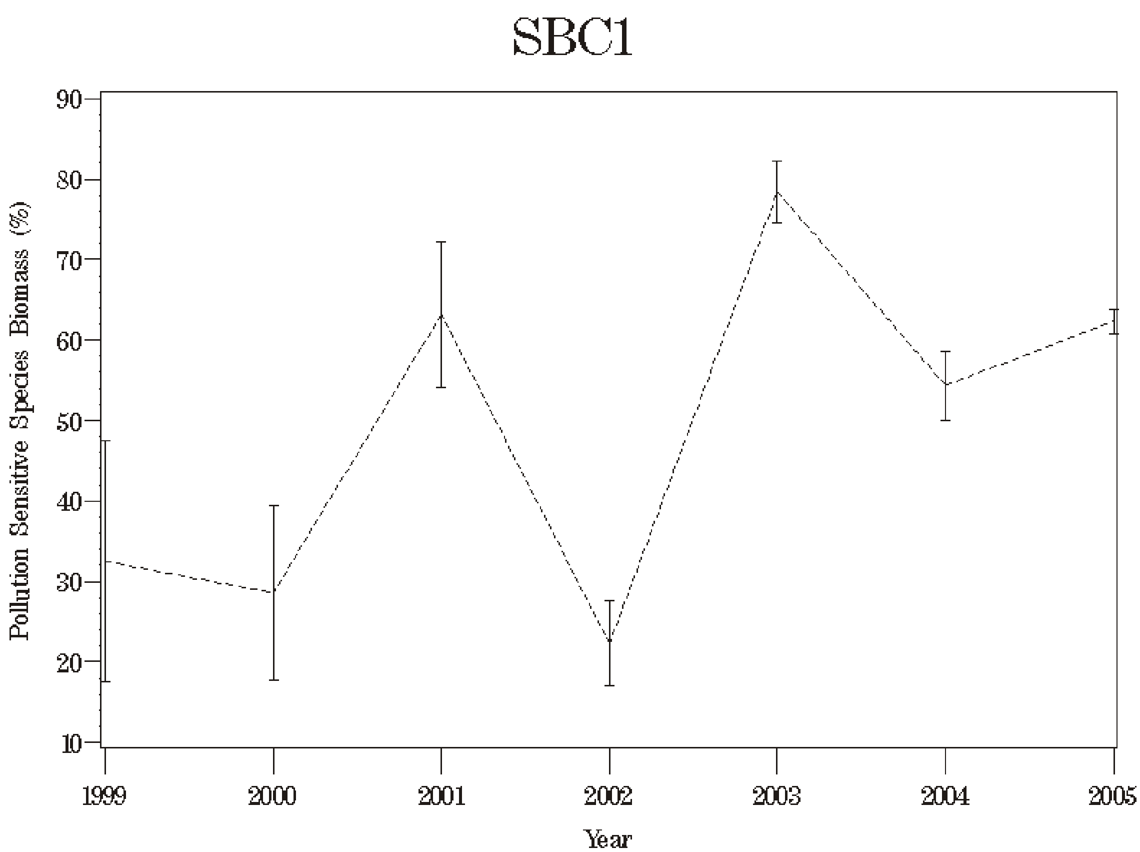

Figure 87. Plot of pollution sensitive species biomass at station SBC1 for 1999 through 2005.

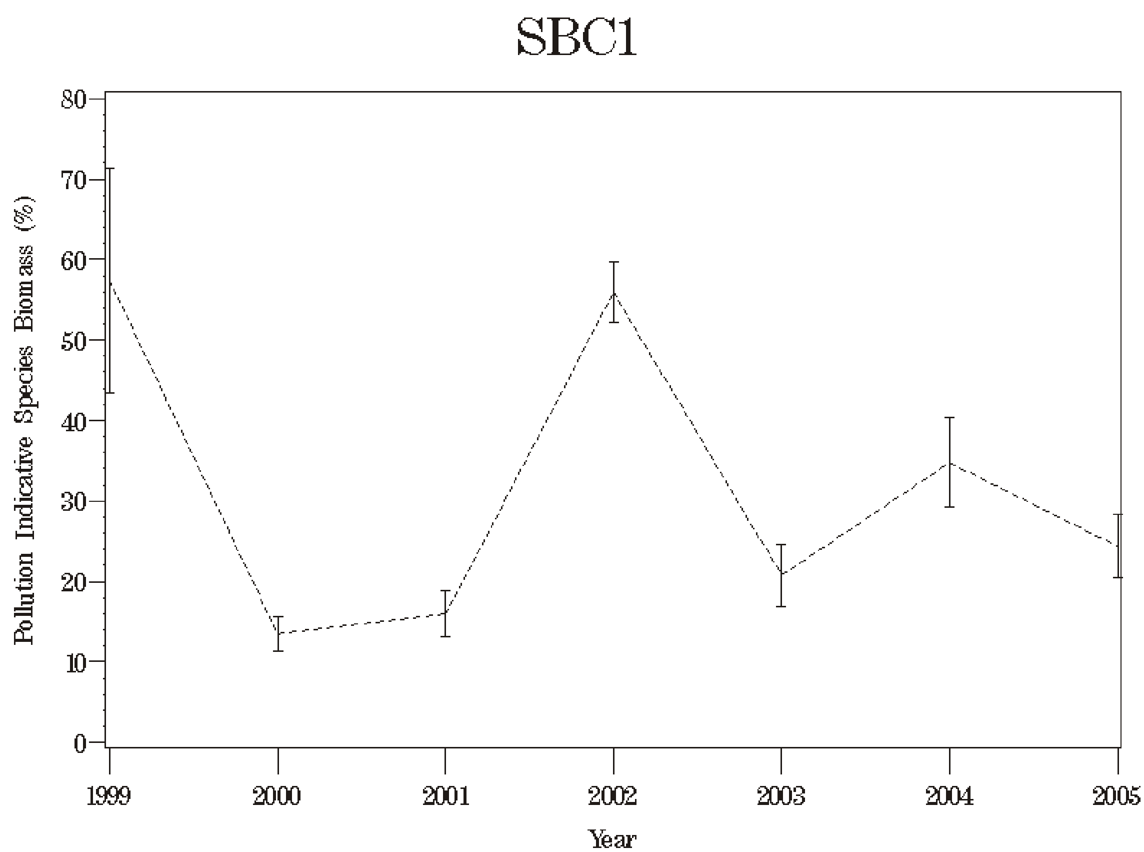

Figure 88. Plot of pollution indicative species biomass at station SBC1 for 1999 through 2005.

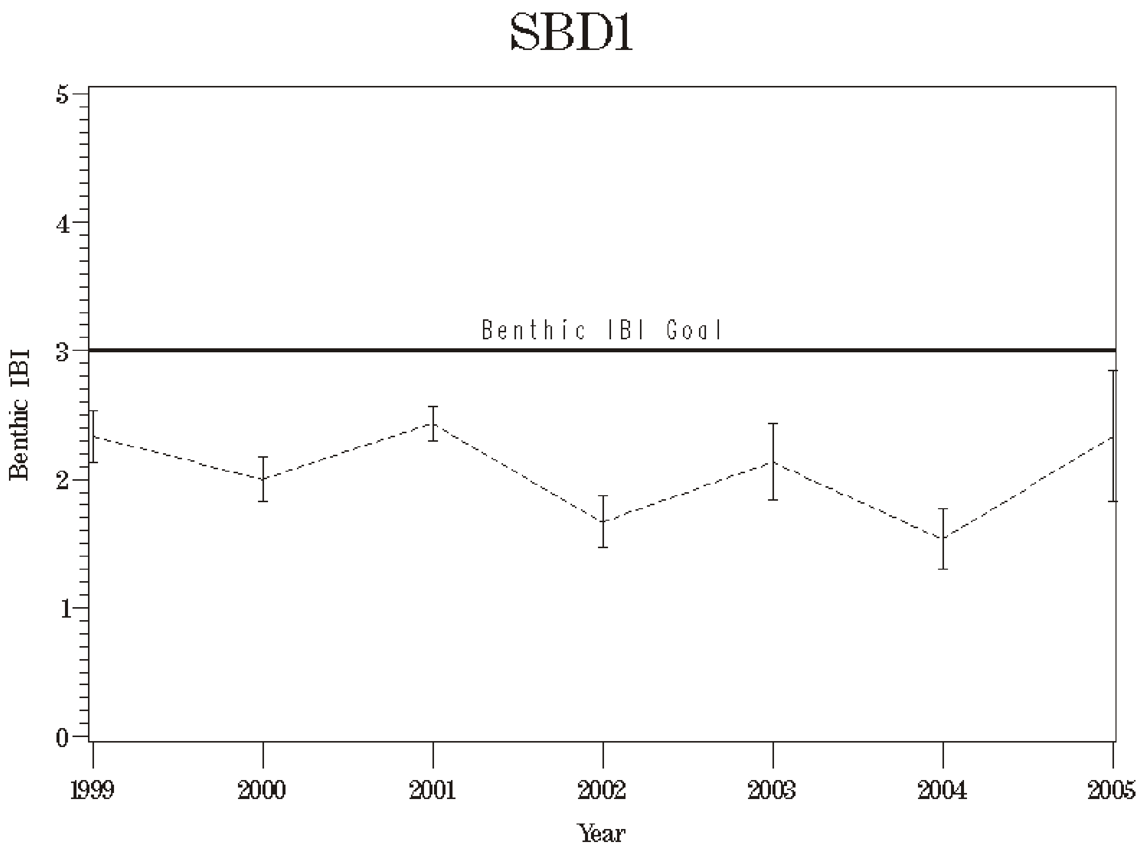

Figure 89. Plot of the benthic IBI at station SBD1 from 1999 through 2005.

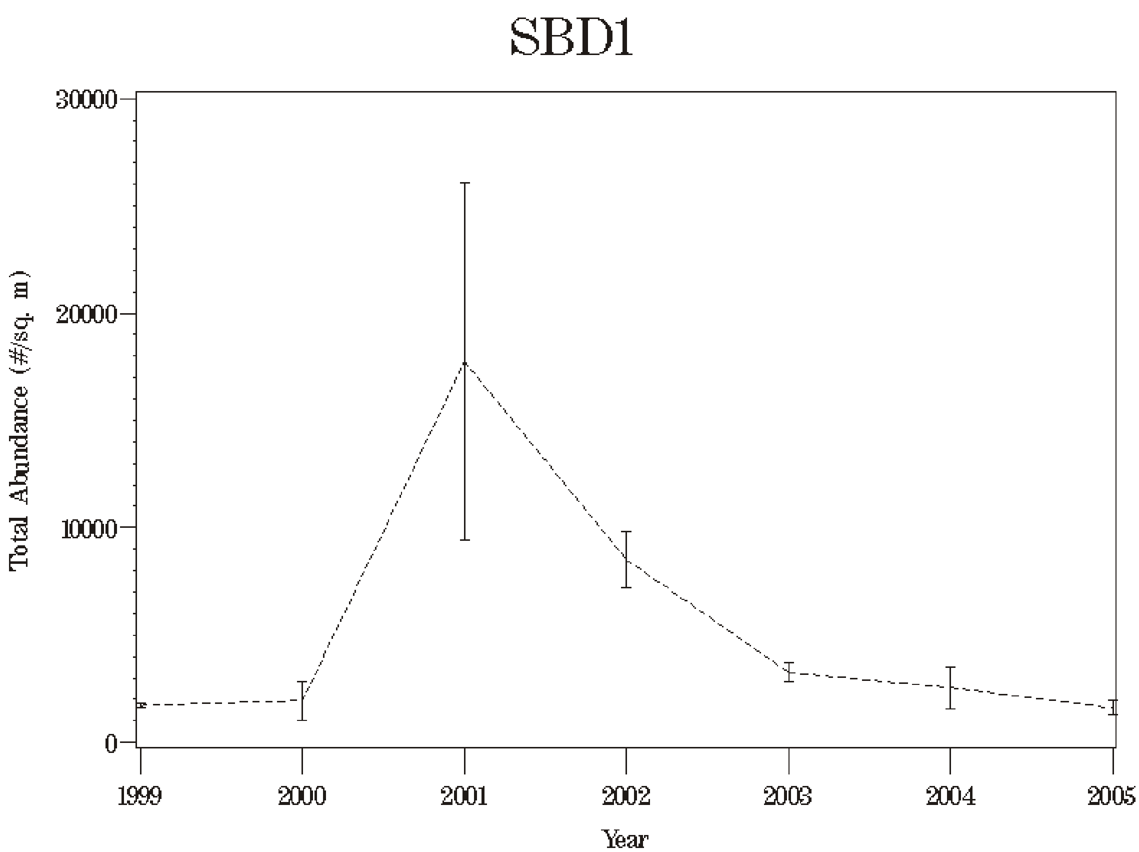

Figure 90. Plot of total benthic community abundance at station SBD1 for 1999 through 2005.

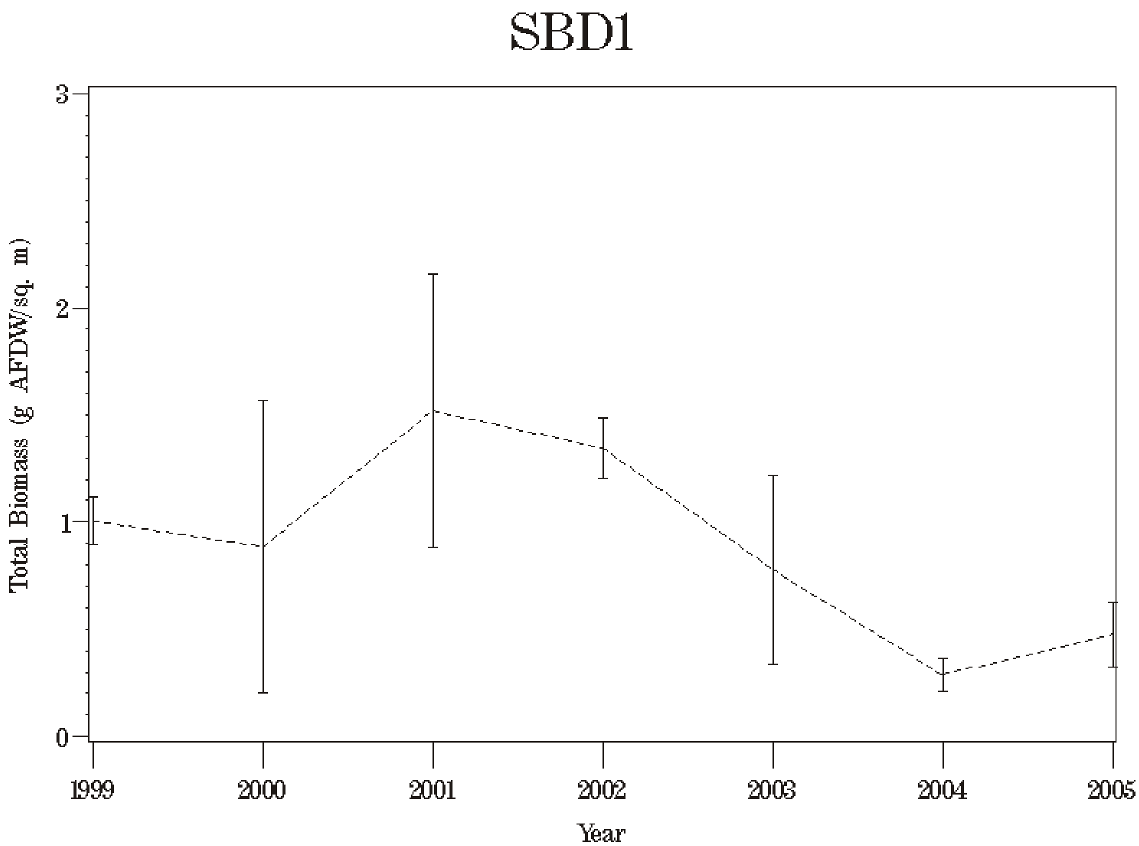

Figure 91. Plot of total benthic community biomass at station SBD1 for 1999 through 2005.

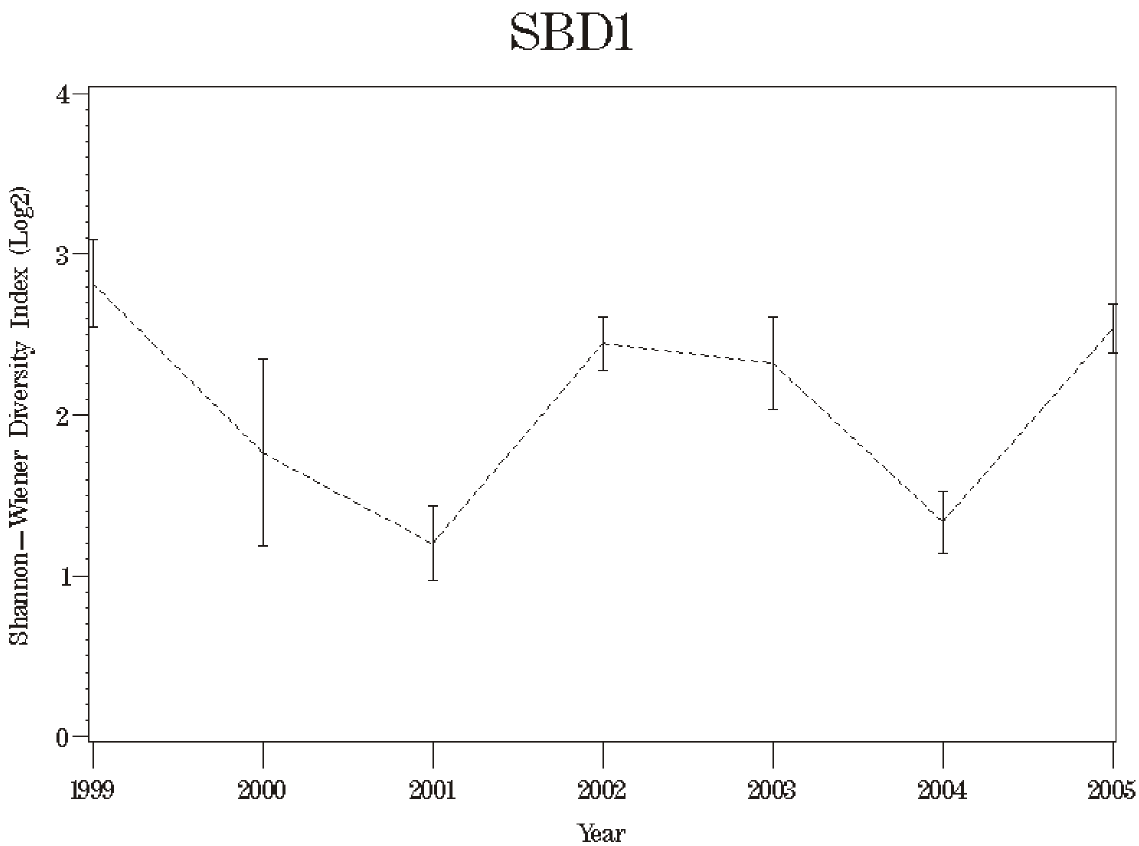

Figure 92. Plot of the Shannon-Weiner diversity index at station SBD1 for 1999 through 2005.

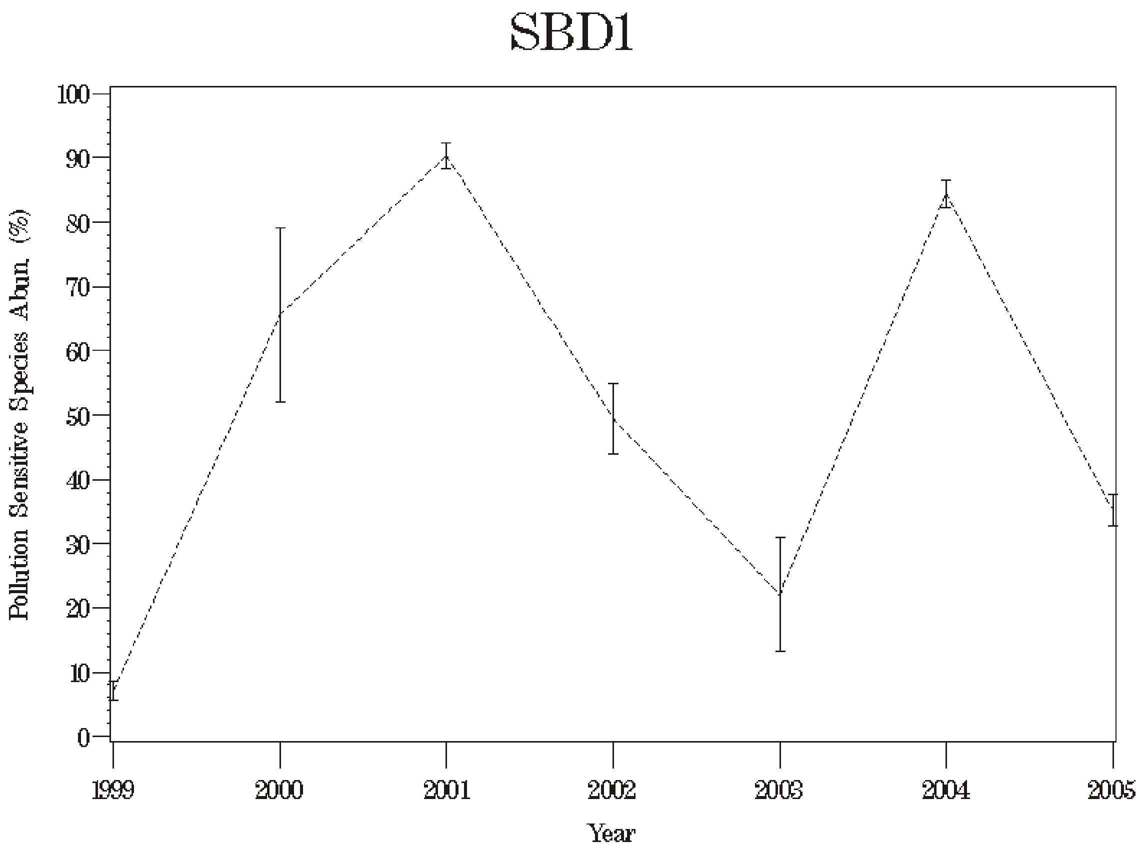

Figure 93. Plot of pollution sensitive species abundance at station SBD1 for 1999 through 2005.

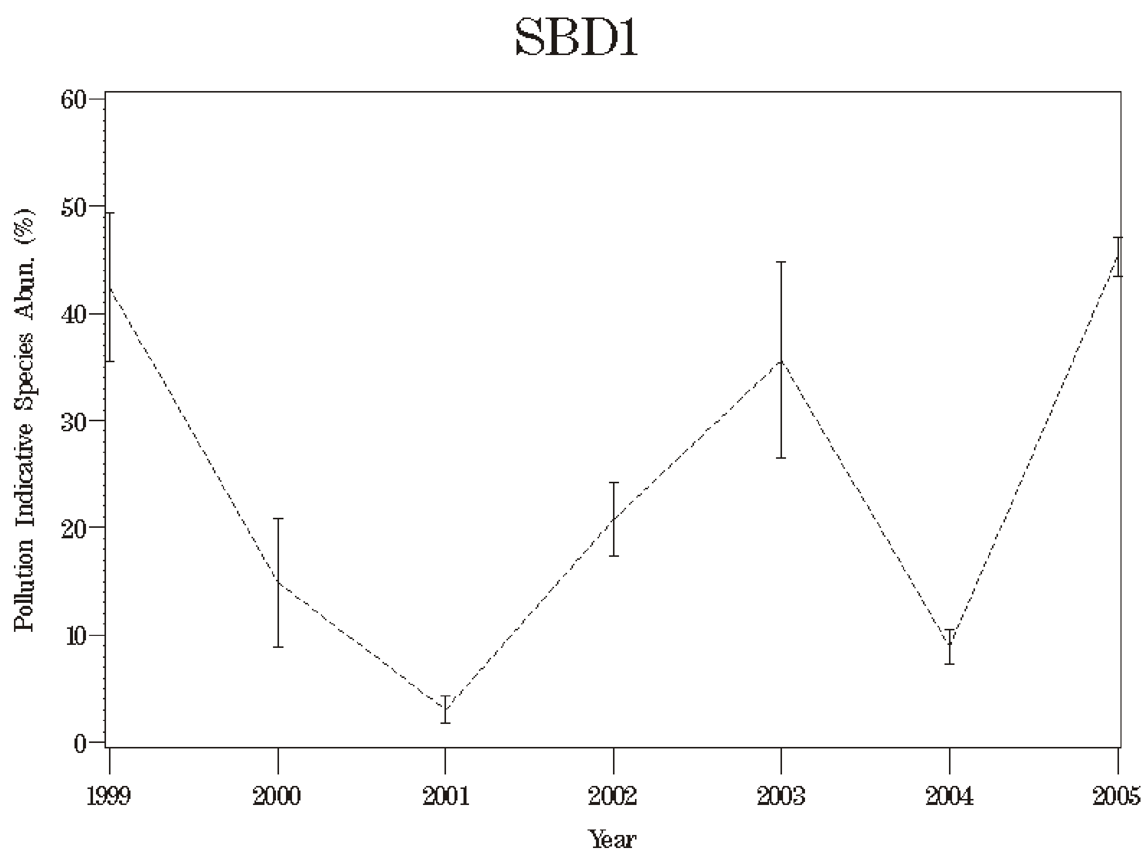

Figure 94. Plot of pollution indicative species abundance at station SBD1 for 1999 through 2005.

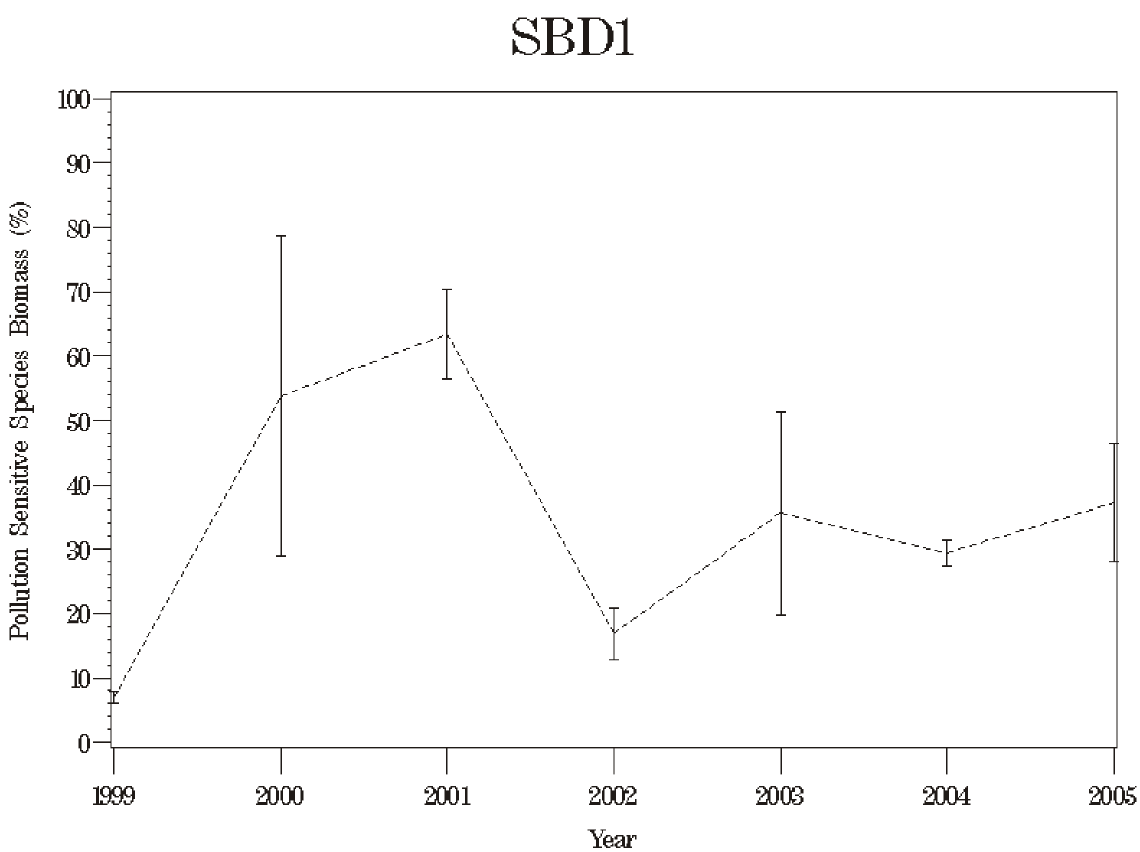

Figure 95. Plot of pollution sensitive species biomass at station SBD1 for 1999 through 2005.

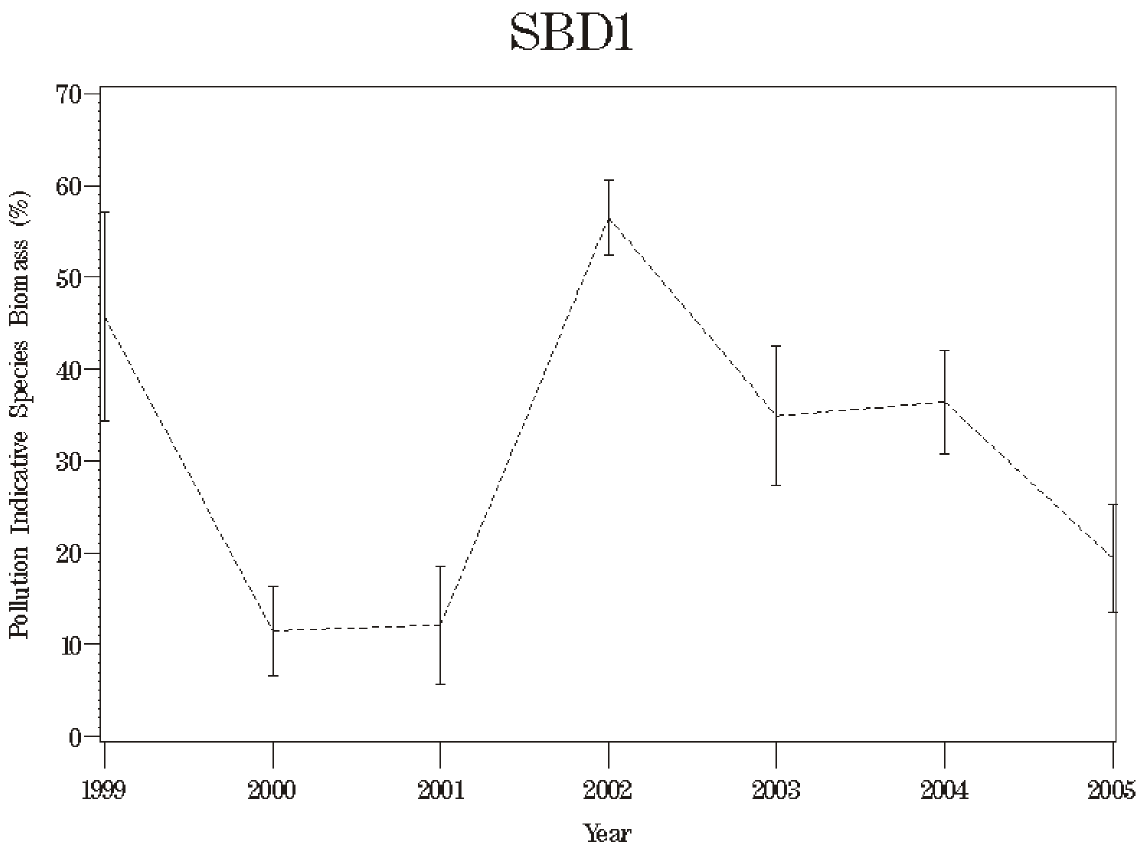

Figure 96. Plot of pollution indicative species biomass at station SBD1 for 1999 through 2005.

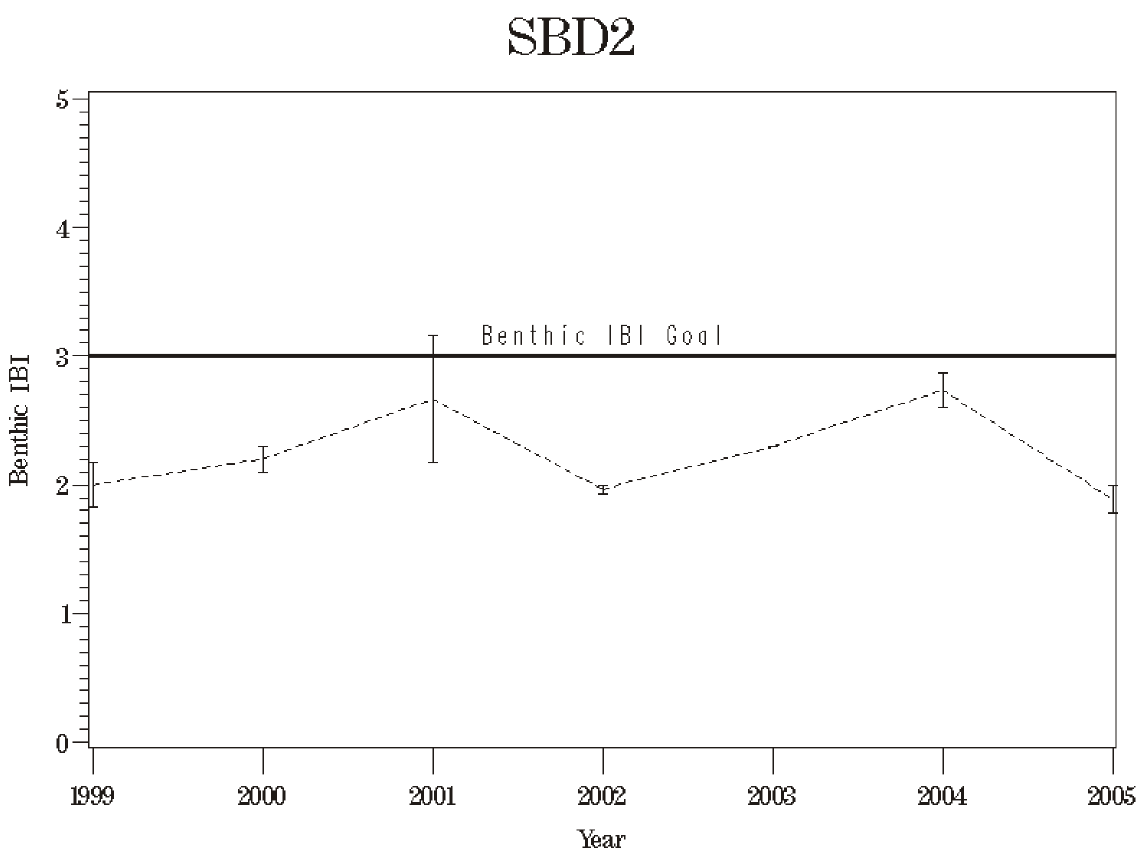

Figure 97. Plot of the benthic IBI at station SBD2 from 1999 through 2005.

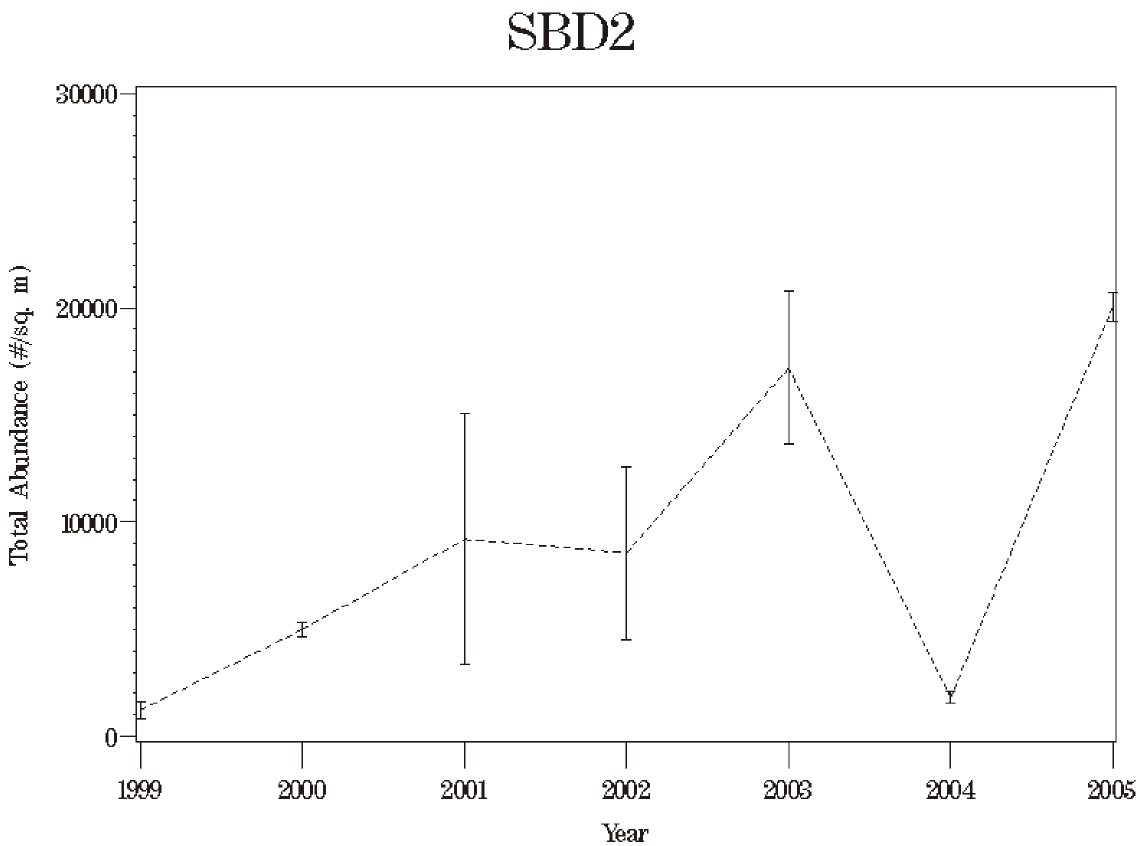

Figure 98. Plot of total benthic community abundance at station SBD2 for 1999 through 2005.

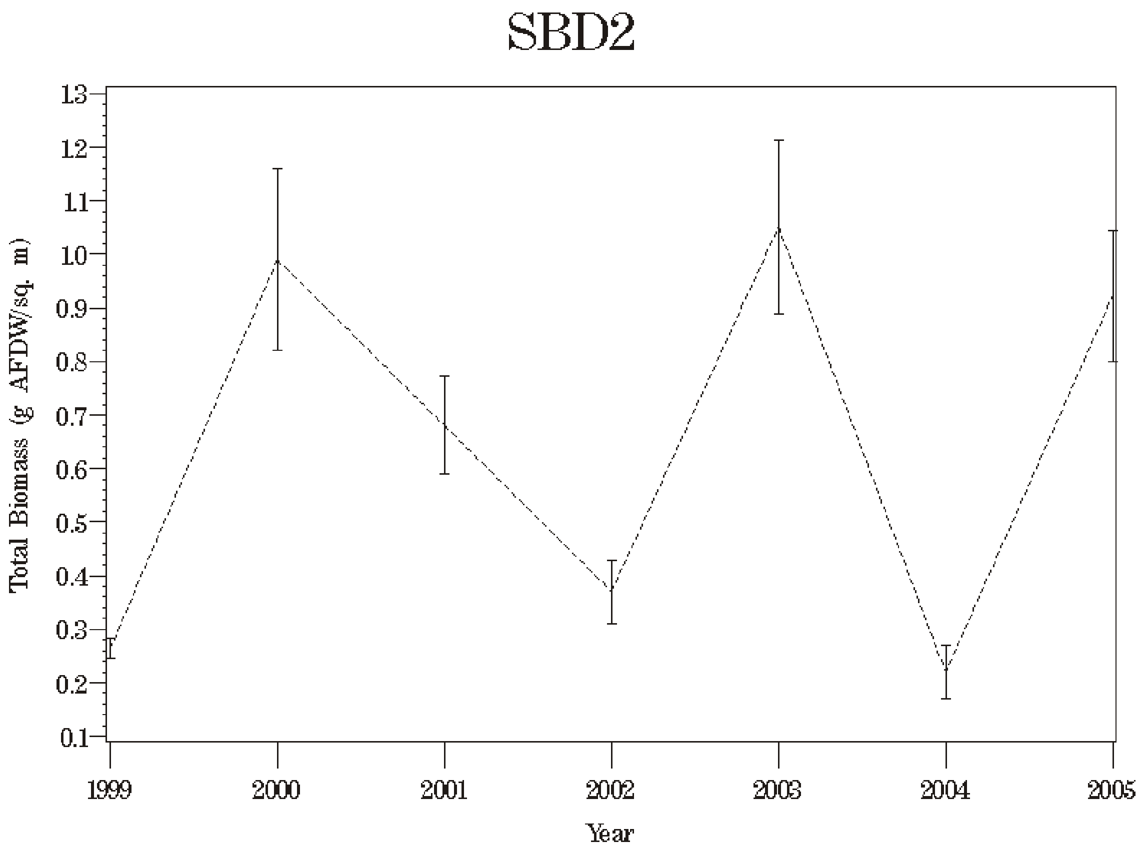

Figure 99. Plot of total benthic community biomass at station SBD2 for 1999 through 2005.

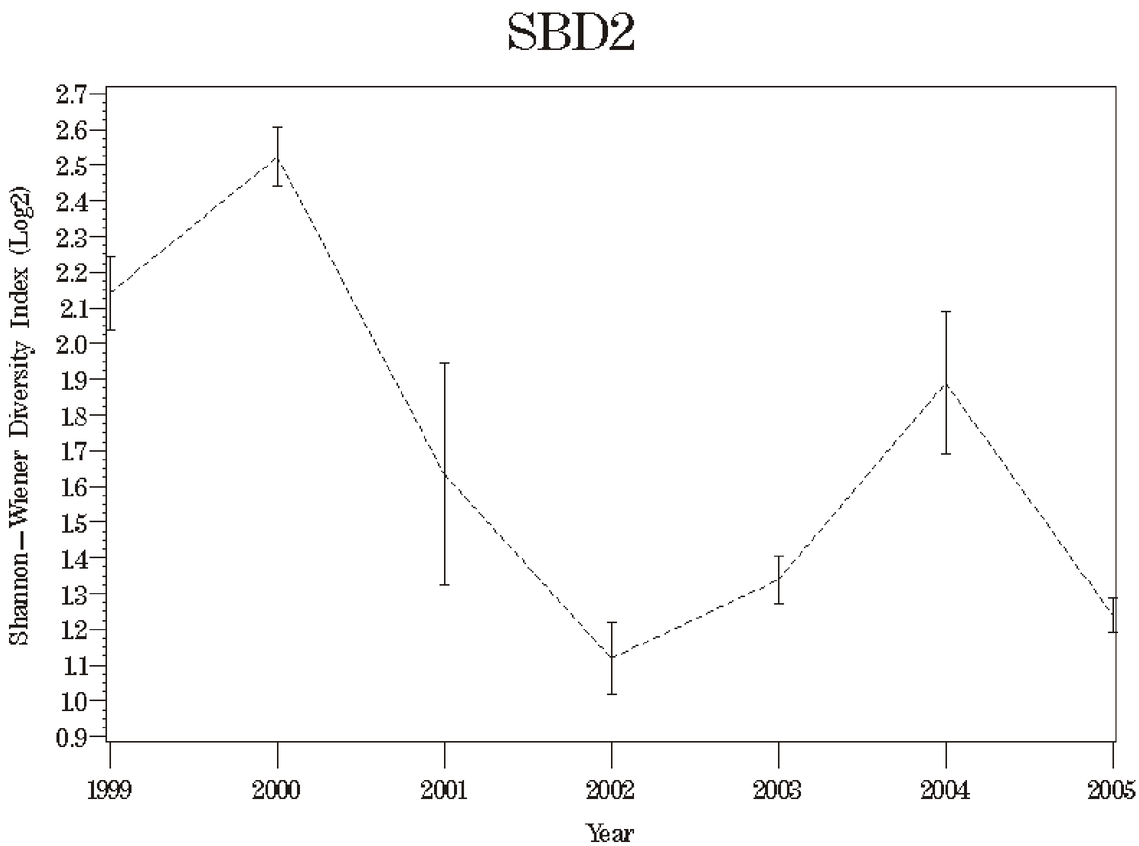

Figure 100. Plot of the Shannon-Weiner diversity index at station SBD2 for 1999 through 2005.

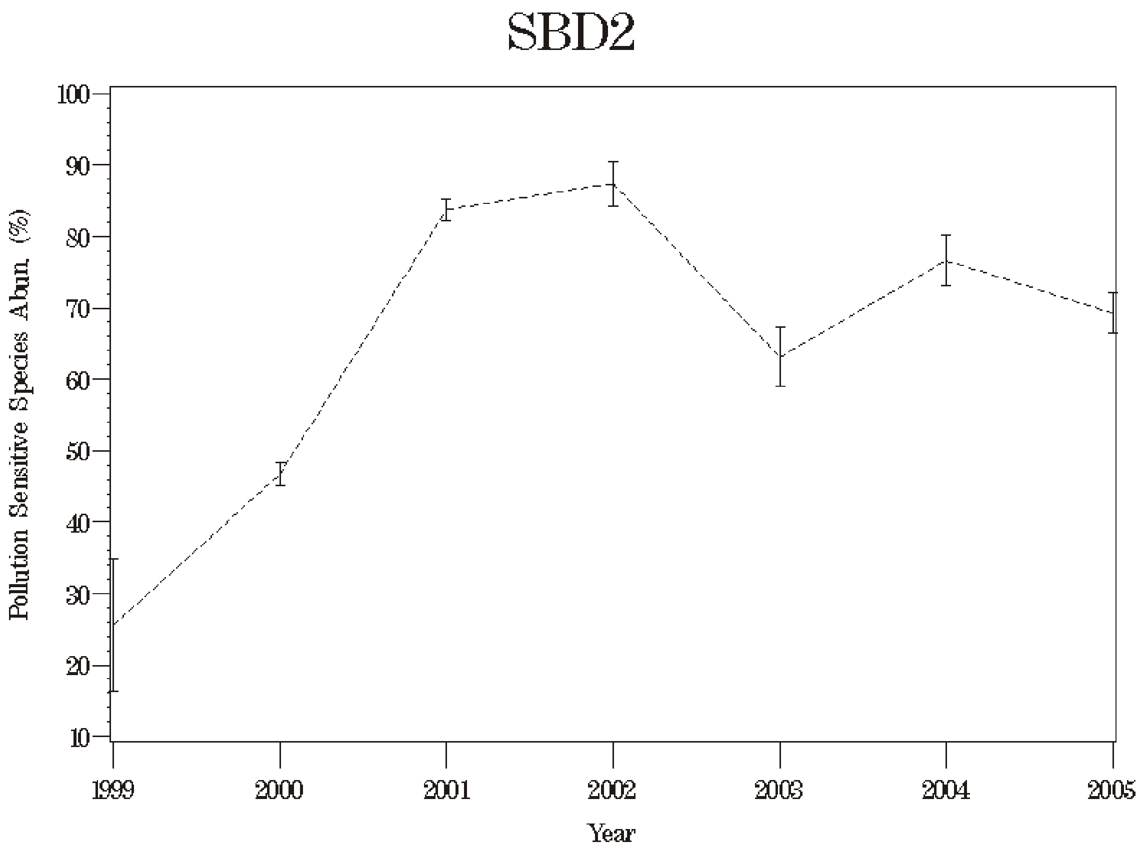

Figure 101. Plot of pollution sensitive species abundance at station SBD2for 1999 through 2005.

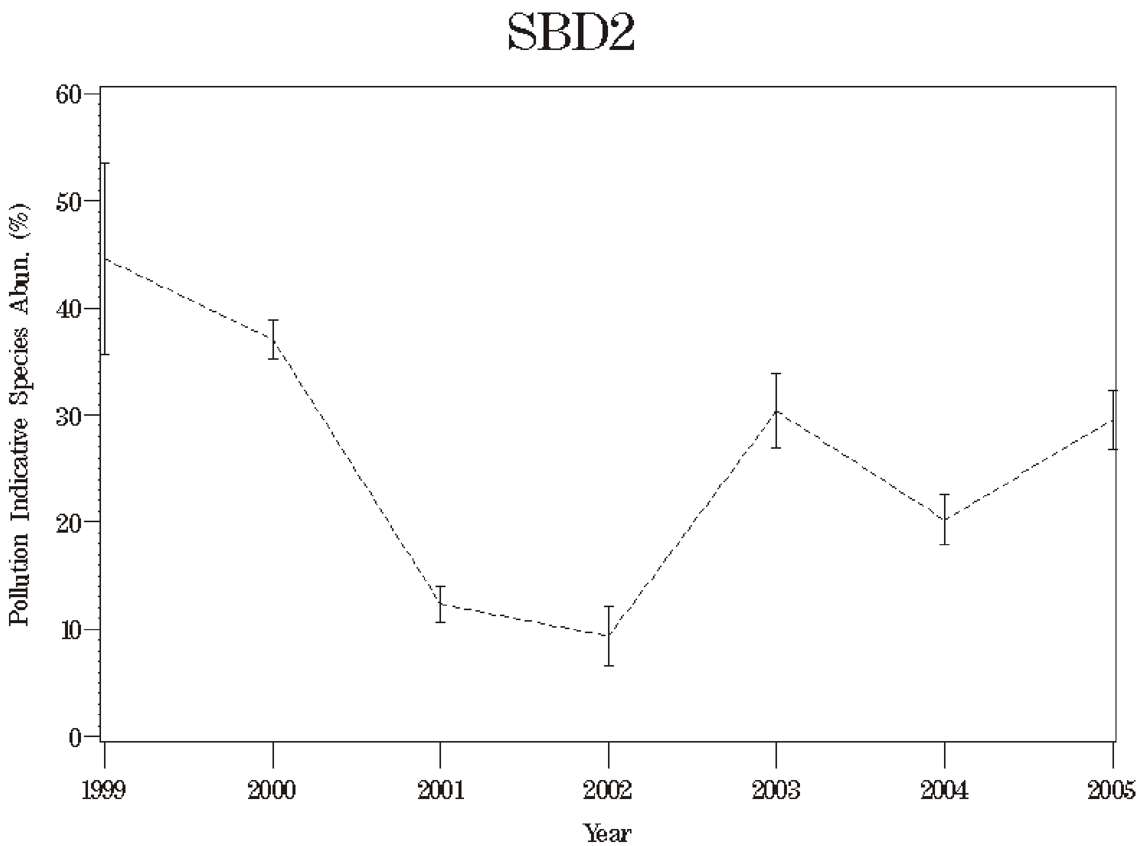

Figure 102. Plot of pollution indicative species abundance at station SBD2 for 1999 through 2005.

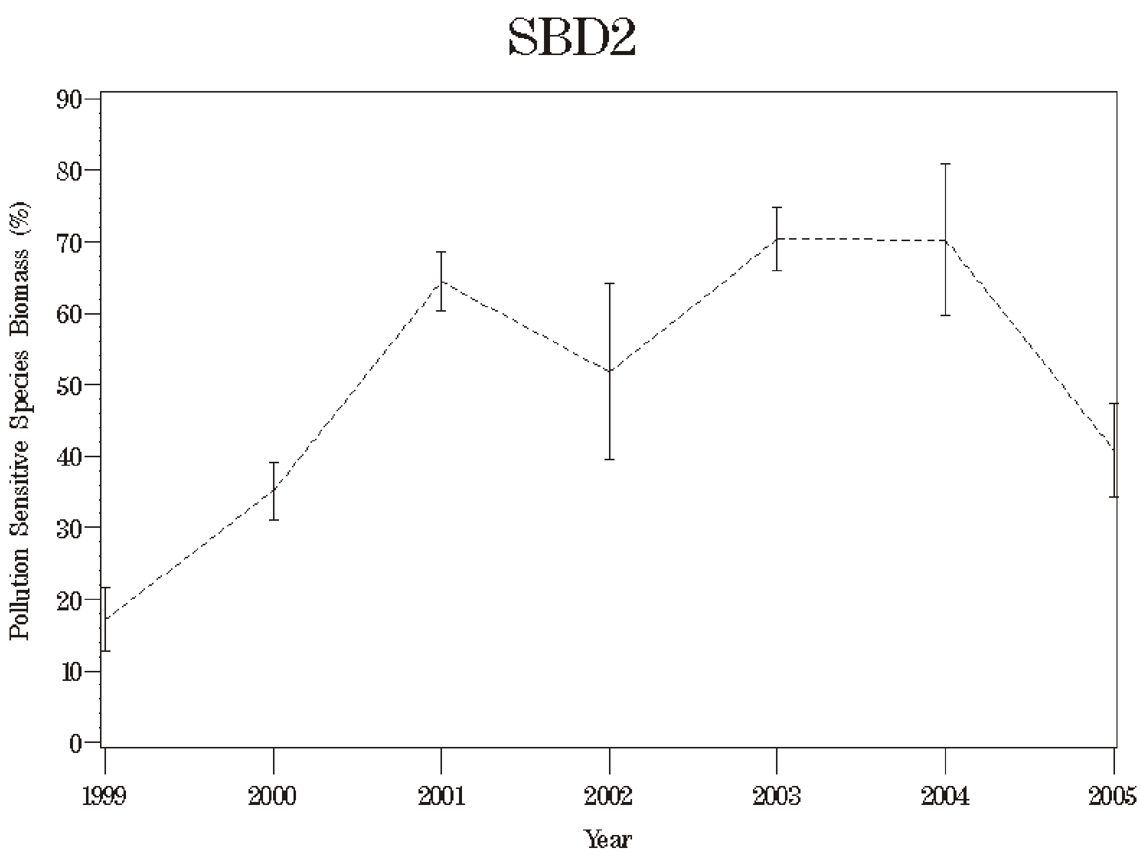

Figure 103. Plot of pollution sensitive species biomass at station SBD2 for 1999 through 2005.

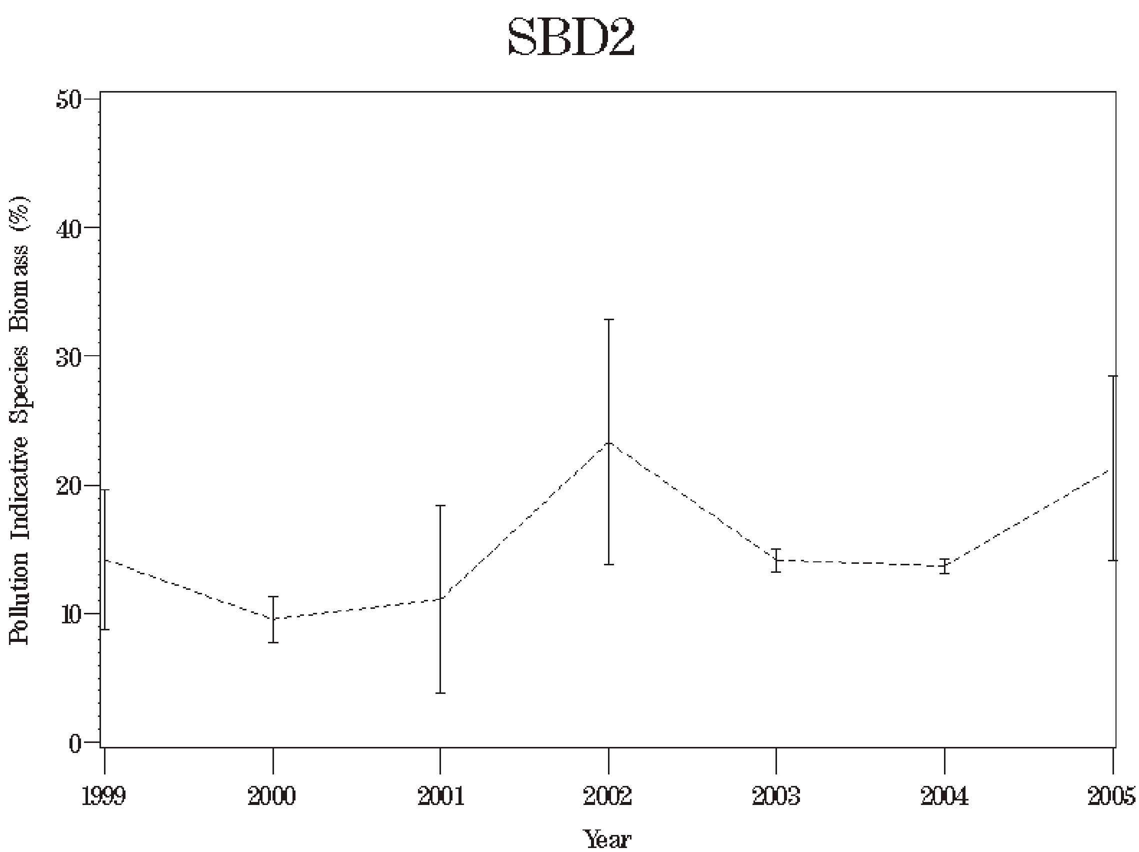

Figure 104. Plot of pollution indicative species biomass at station SBD2 for 1999 through 2005.

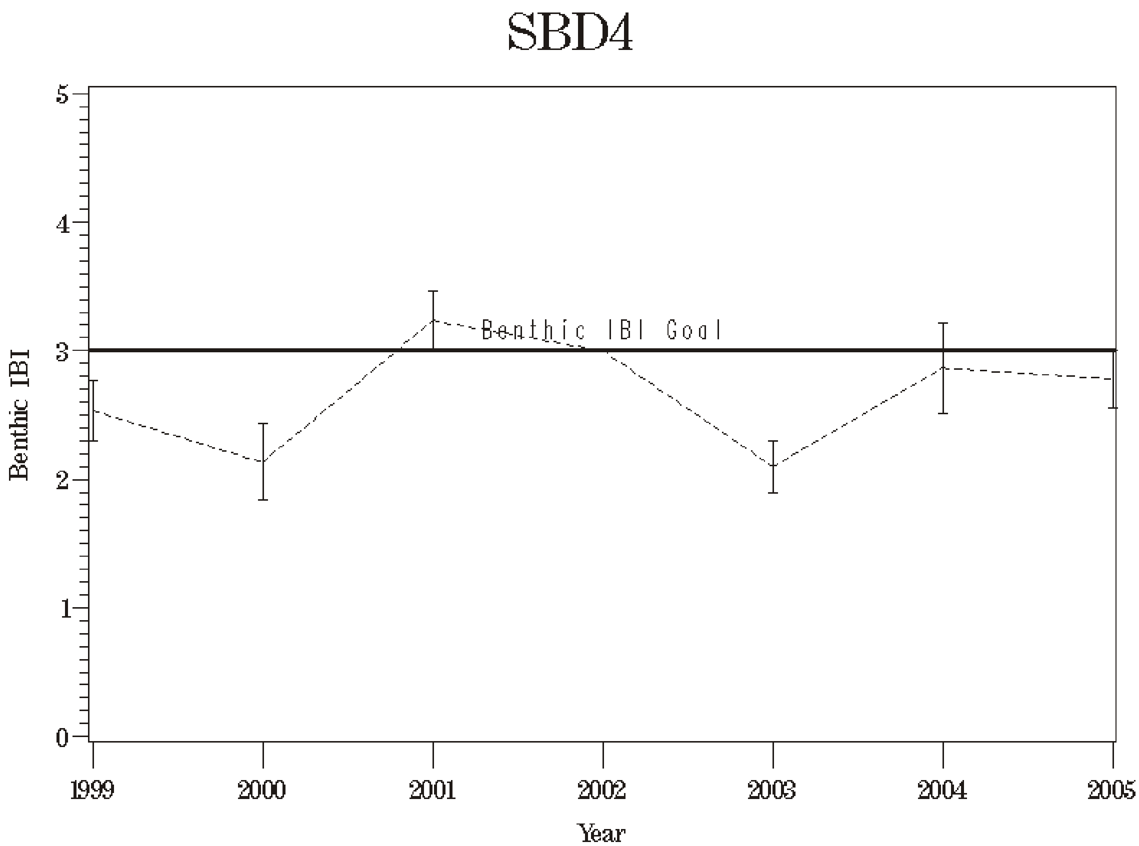

Figure 105. Plot of the benthic IBI at station SBD4 from 1999 through 2005.

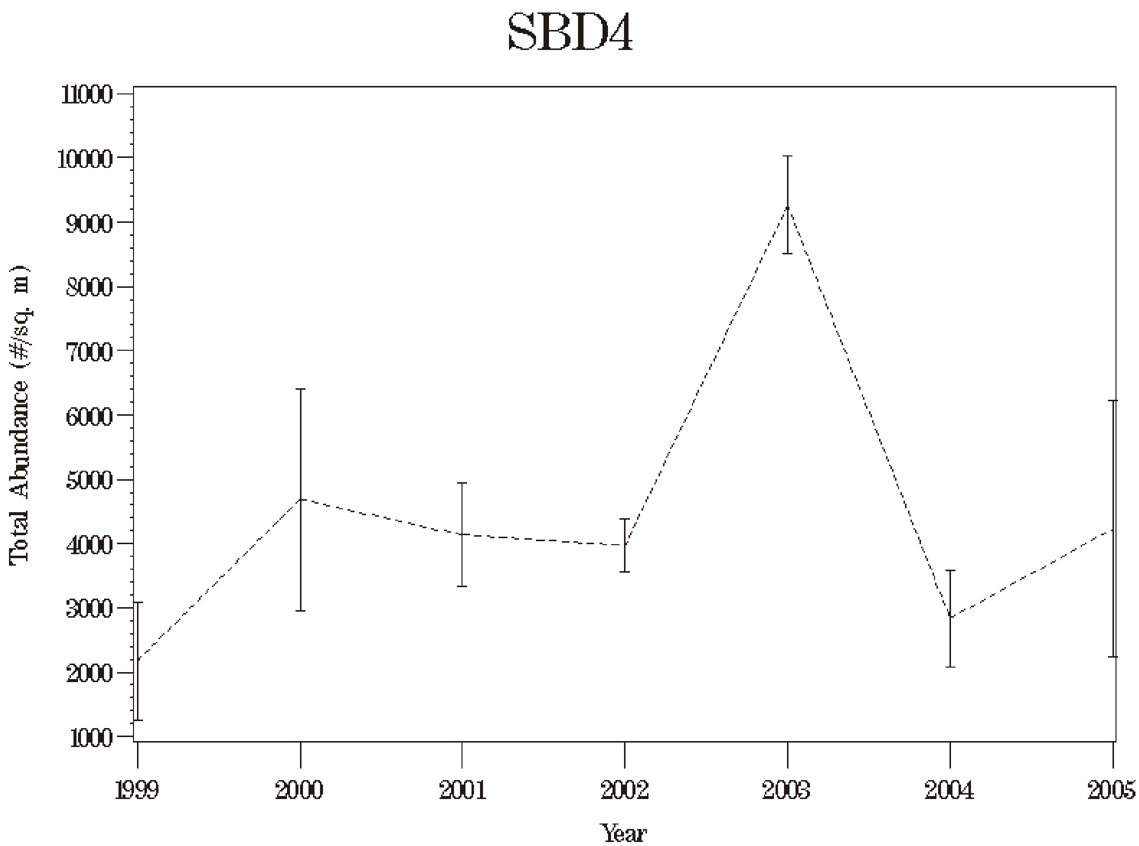

Figure 106. Plot of total benthic community abundance at station SBD4 for 1999 through 2005.

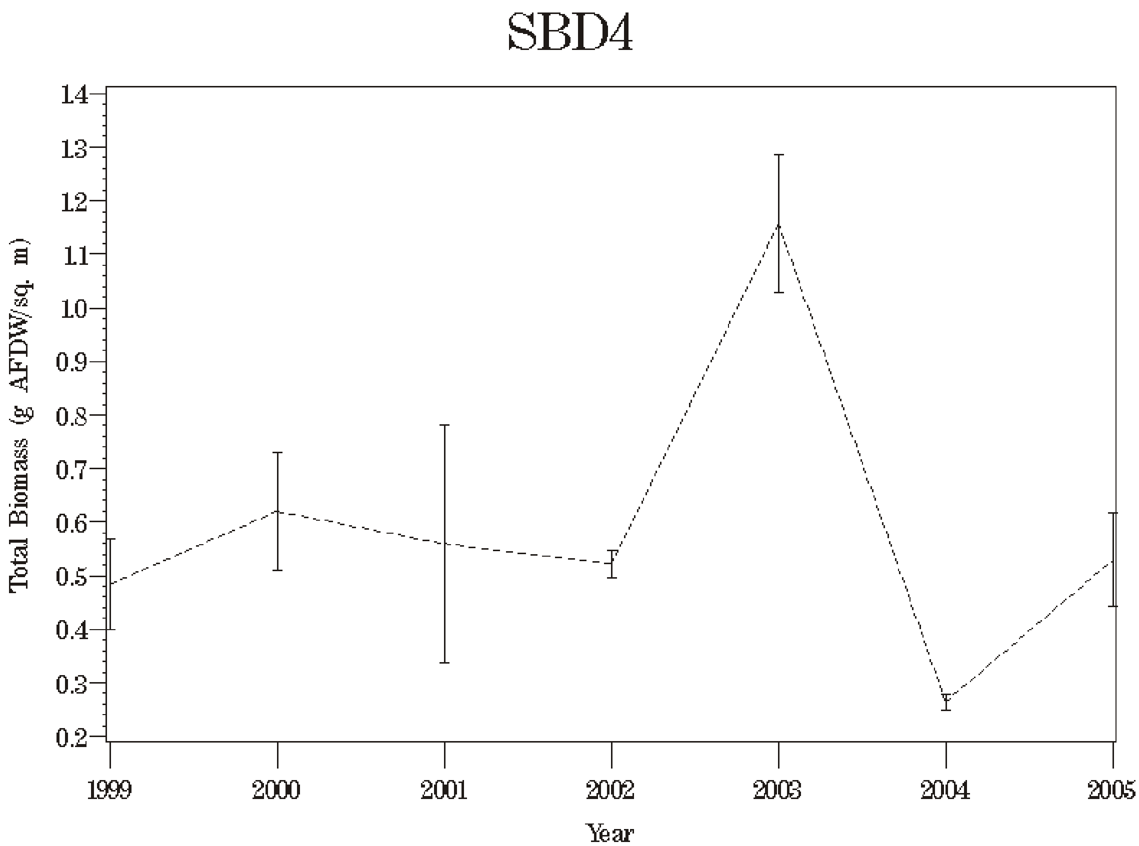

Figure 107. Plot of total benthic community biomass at station SBD4 for 1999 through 2005.

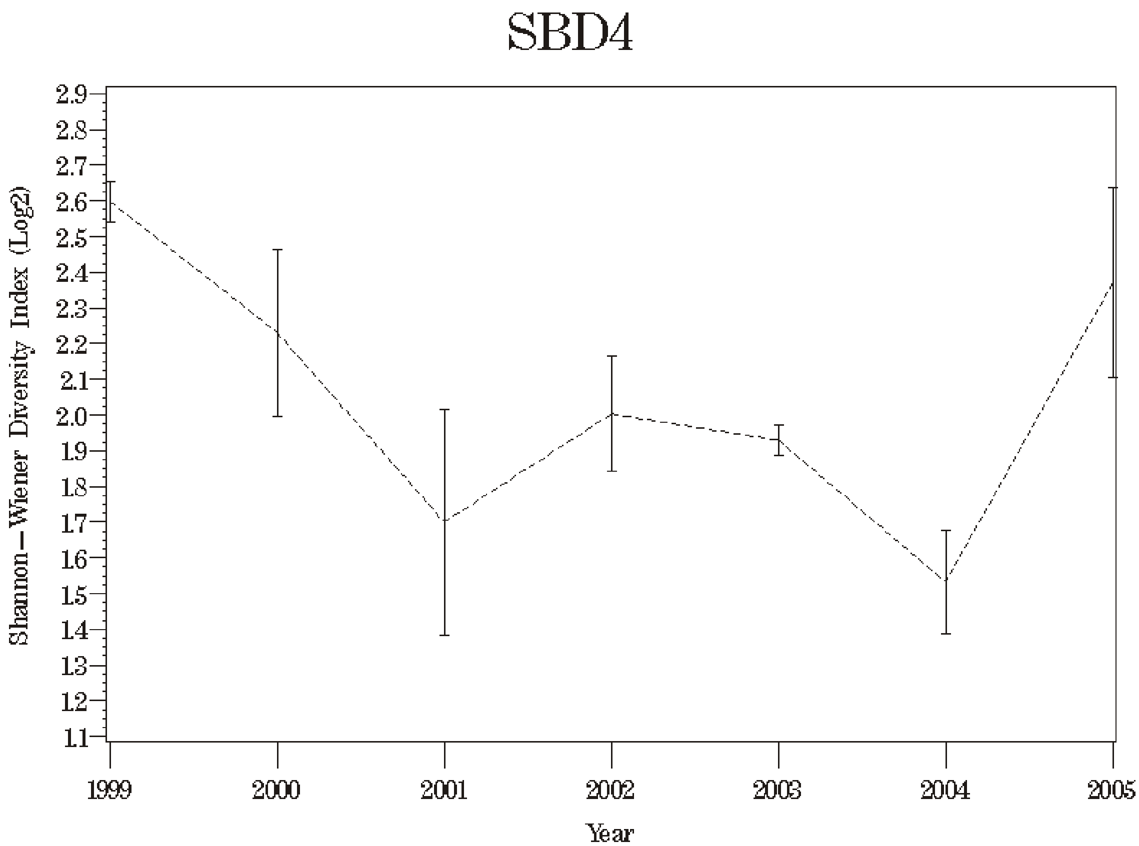

Figure 108. Plot of the Shannon-Weiner diversity index at station SBD4 for 1999 through 2005.

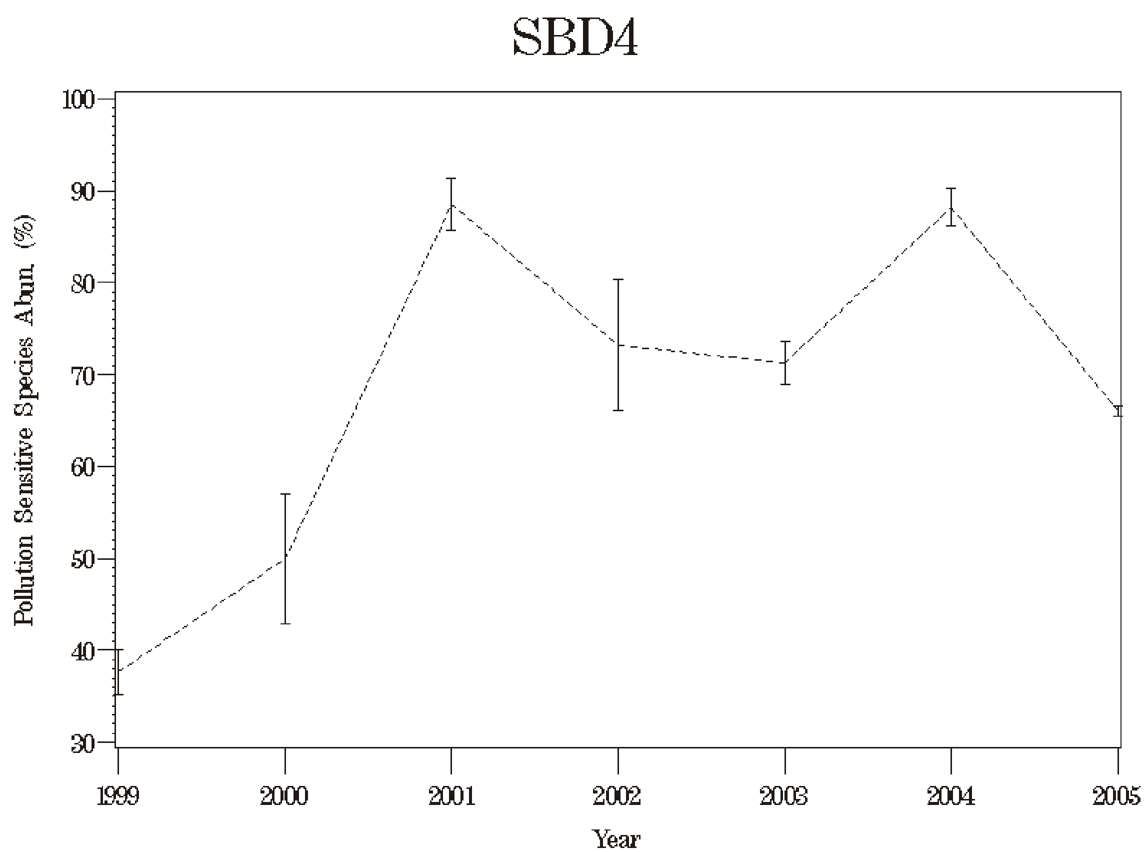

Figure 109. Plot of pollution sensitive species abundance at station SBD4for 1999 through 2005.

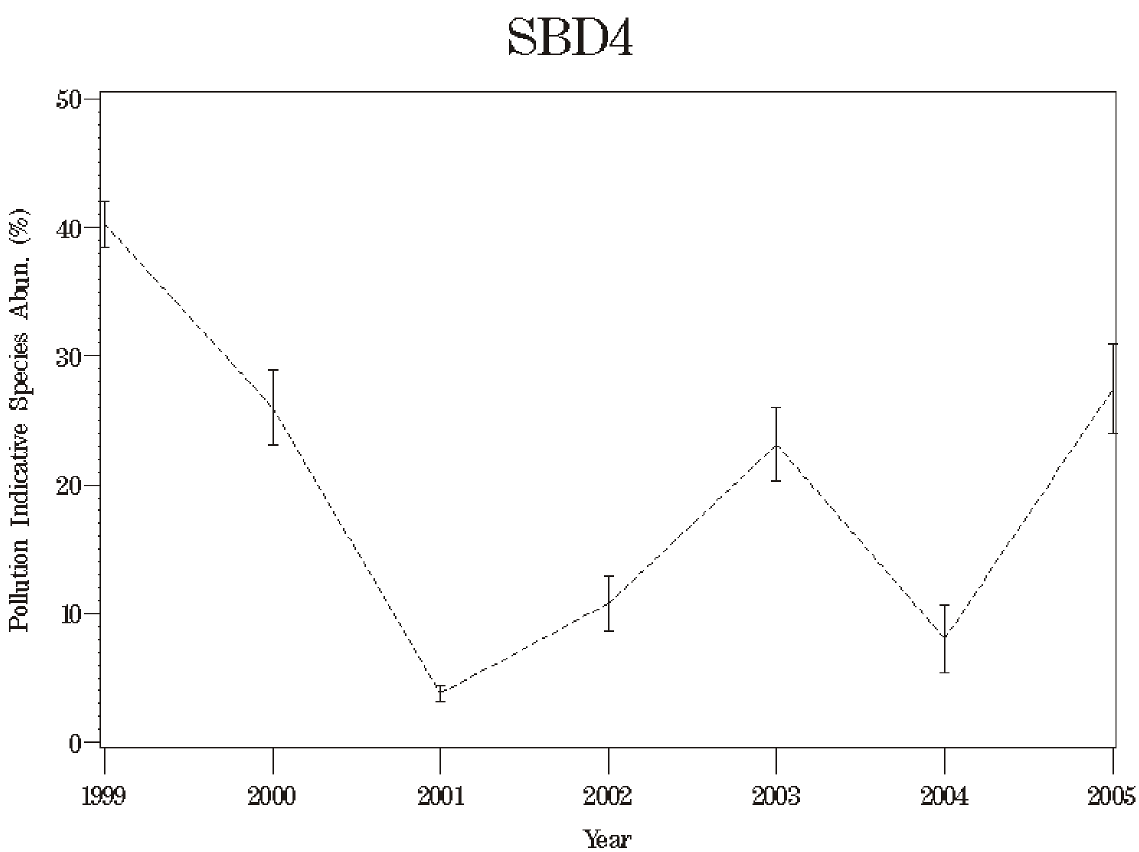

Figure 110. Plot of pollution indicative species abundance at station SBD4 for 1999 through 2005.

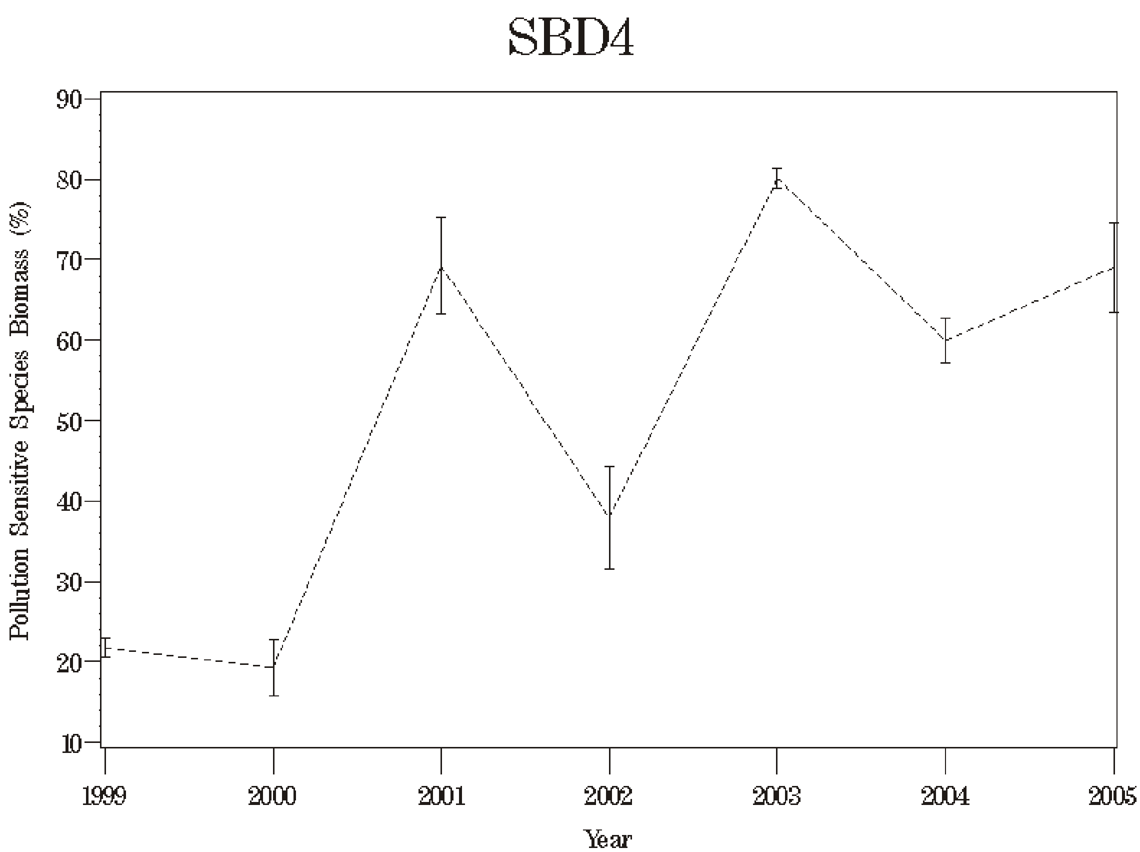

Figure 111. Plot of pollution sensitive species biomass at station SBD4 for 1999 through 2005.

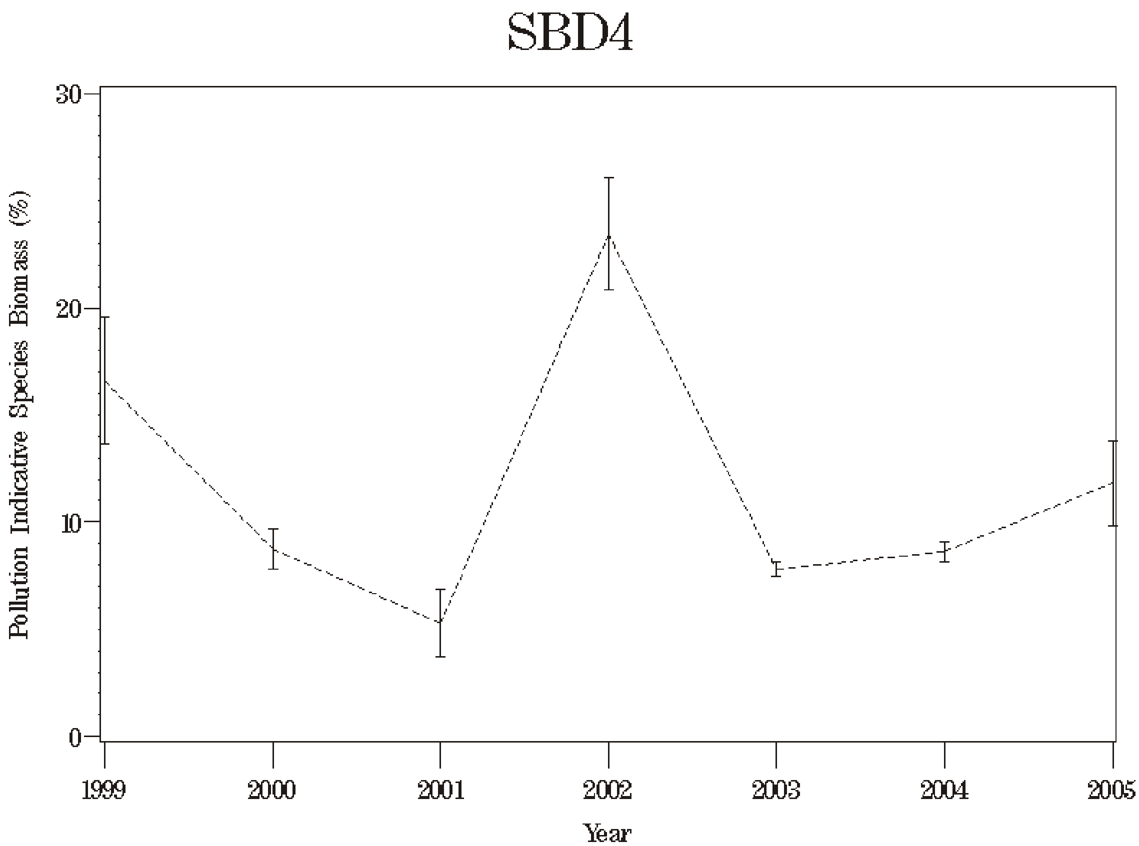

Figure 112. Plot of pollution indicative species biomass at station SBD4 for 1999 through 2005.