OLD DOMINION UNIVERSITY

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

BENTHIC BIOLOGICAL MONITORING OF THE LYNNHAVEN RIVER (2006)

Prepared by

Principal Investigator:

Dr. Daniel M. Dauer

Submitted to:

Mr. David Schulte
U.S. Army Corps of Engineers l
Norfolk District
803 Front Street
Norfolk, VA 23510

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EXECUTIVE SUMMARY

Macrobenthic communities of the Lynnhaven River watershed were quantitatively sampled during the summer of 2006. The objectives of benthic biological monitoring of the Lynnhaven River watershed were: (1) To characterize the condition of regional areas of the tidal waters of the Lynnhaven River watershed as indicated by the structure of the benthic communities. (2) To produce an historical data base that will allow future evaluations of biotic impacts and/or restoration efforts by comparing changes in status within probability-based strata.

The condition of the benthic communities of the Lynnhaven River watershed was characterized by combining the Benthic Index of Biotic Integrity (B-IBI) developed for the Chesapeake Bay and probability-based sampling. A probability-based (random) 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 watershed was divided into seven strata: Inlet-Mouth, Lower Reach of the Western Branch, Upper Reach of the Western Branch, Lower Reach of the Eastern Branch, Upper Reach of the Eastern Branch, Broad Bay, and Linkhorn Bay/Crystal Lake. Consistent with the sampling design for macrobenthic community analyses for the Chesapeake Bay Monitoring Program, each sampling stratum was characterized by allocating 25 sites in a random (probability-based) design, resulting in 175 locations sampling in 2006. At each sampling site quantitative samples were collected to characterize the macrobenthic community, sedimentary parameters and field measurements of water depth, salinity, and bottom dissolved oxygen.

Analyses of the data resulted in three groups of strata based upon an Ecological Integrity Gradient of increasing levels of degradation along an upstream direction. The three groups were (1) the Inlet Group, (2) the Lower Reach Group (Lower Western Branch, Lower Eastern Branch, Broad Bay), and the Upper Reach Group(Upper western Branch, Upper Eastern Branch, Linkhorn Bay). The upstream gradient is characterized by (1) increased areal estimates of degradation, (2) decreasing mean values for the Benthic Index of Biotic Integrity, (3) decreasing levels of species diversity, and (4) increasing levels of dominance by pollution indicative species. This pattern of increasing degradation in an upstream direction is characterized by decreasing flushing rates and decreasing sediment grain size (i.e. increasing levels of silt-clay sized particles).

The Ecological Integrity Gradient of increasing levels of degradation in an upstream direction is typically representative of a pattern of (1) decreasing current velocity and flushing rates and (2) increasing amounts of non-point source runoff. Non-point source runoff typically contains levels of nutrients, contaminants and fine-sized sediments that are not conducive to supporting healthy, diverse, productive and ecologically valuable benthic communities.

The areal estimate of benthic degradation of the Lynnhaven River watershed was among the highest reported for the Chesapeake Bay. The level of degradation based upon the 2006 data of the Lynnhaven River watershed was 81.1 ± 5.8%, compared to 64.4 ± 5.9% for the Chesapeake Bay, and 59.0 ± 9.6% for all Virginia tidal waters. Comparable levels of data from polyhaline regions of Virginia were 36.0 ± 18.8% for the Virginia Mainstem, 70.0 ± 28.4% for the James River, 75.0 ± 21.2% for the of the York River and 80.0 ± 15.7% for the Elizabeth River.

INTRODUCTION

Macrobenthic communities of the Lynnhaven River watershed were quantitatively sampled during the summer of 2006. The watershed is located entirely within the City of Virginia Beach and the watershed land use is primarily suburban residential development with some commercial development in the far headwaters of the of the Western Branch and Eastern Branch. Main stressors to the watershed are (1) nutrient enrichment from stormwater runoff, (2) contaminants (organic and metal) from impervious surface runoff and stormwater runoff and (3) siltation from land runoff that has altered bottom sediment types and represents a challenge for the restoration and development of shellfish species. Although oyster beds are no longer productive, this watershed is economically important for its real estate value, recreational fishing, boating, swimming and commercial crabbing.

The two primary objectives of the study were: 1.To characterize the condition of regional areas of the tidal waters of the Lynnhaven River watershed as indicated by the structure of the benthic communities. 2. To produce an historical data base that will allow future evaluations of biotic impacts and/or restoration efforts by comparing changes in status within probability-based strata.

These characterizations were be based upon application of the benthic restoration goals and the Benthic Index of Biotic Integrity (BIBI) developed for the Chesapeake Bay (Weisberg et al 1997; Alden et al. 2002) as applied to seven sampling strata. The Lynnhaven River was sampled in 2006 using a probability-based (random) approach applied to the following seven strata: Inlet-Mouth, Lower Reach of the Western Branch, Upper Reach of the Western Branch, Lower Reach of the Eastern Branch, Upper Reach of the Eastern Branch, Broad Bay, and Linkhorn Bay/Crystal Lake. A probability-based sampling design allows calculation of confidence intervals around estimates of condition of the benthic communities. Confidence intervals provide managers with full knowledge of the strength or weakness of the data upon which their decisions will be based. In addition, probability-based data allows managers to estimate the actual area throughout the system in which ecological conditions differ from reference conditions.

The macrobenthic communities of the Lynnhaven River watershed were previously studied by Dauer et al. (1979) and Tourtellotte and Dauer (1983). Dauer et al. (1979) collected intertidal benthos from 10 stations located from the inlet through the Eastern and Western branches and compared the results to four stations collected from Old Plantation Creek on the Virginia Eastern Shore. Data were collected bimonthly from August 1976 though June 1977. Tourtellotte and Dauer (1983) collected subtidal samples from Lynnhaven Roads, the Eastern and Western branches, Broad Bay and Linkhorn Bay in 1977 and 1978.

RATIONALE

Characterizing Benthic Community Condition

Coastal seas, bays, lagoons and estuaries have become increasingly degraded due to anthropogenic stresses (Nixon 1995). Relationships between land use, levels of nutrients and contaminants, and the condition of the biotic communities of receiving waters are well studied in freshwater ecosystems (Allan et al. 1997) with fewer studies addressing these relationships in estuarine ecosystems (Comeleo et al. 1996; Valiela et al. 1997; Dauer et. al. 2000). Smaller watersheds such as the Lynnhaven River watershed are often poorly studied ecologically, making restoration and management decisions more difficult to make with confidence.

Land use patterns in a watershed influence the delivery of nutrients, sediments and contaminants into receiving waters through surface flow, groundwater flow, and atmospheric deposition (Correll 1983; Correll et al. 1987; Hinga et al. 1991; Correll et al. 1992; Lajtha et al. 1995; Jordan et al. 1997c). Increased nutrient loads are associated with high levels of agricultural and urban land use in both freshwater and coastal watersheds compared to forested watersheds (Klein 1979; Ostry 1982; Duda 1982; Novotny et al. 1985; Ustach et al. 1986; Valiela and Costa 1988; Benzie et al. 1991; Fisher and Oppenheimer 1991; Turner and Rabalais 1991; Correll et al. 1992; Hall et al. 1994; Jaworski et al. 1992; Lowrance 1992; Weiskel and Howes 1992; Balls 1994; Hopkinson and Vallino 1995; Nelson et al. 1995; Hall et al. 1996; Hill 1996; Allan et al. 1997; Correll 1997; Correl et al. 1997; Valiela et al. 1997; Verchot et al. 1997a, 1997b; Gold et al. 1998). At smaller spatial scales, riparian forests and wetlands may ameliorate the effects of agricultural and urban land use (Johnston et al 1990; Correll et al. 1992; Osborne and Kovacic 1993).

Aquatic biotic communities associated with watersheds with high agricultural and urban land use are generally characterized by lower species diversity, less trophic complexity, altered food webs, altered community composition and reduced habitat diversity (Fisher and Likens 1973; Boynton et al. 1982; Conners and Naiman 1984; Malone et al. 1986, 1988, 1996; Mangum 1989; Howarth et al. 1991; Fisher et al. 1992; Grubaugh and Wallace 1995; Lamberti and Berg 1995; Roth et al 1996; Correll 1997). High nutrient loads in coastal ecosystems result in increased algal blooms (Boynton et al. 1982; Malone et al. 1986, 1988; Fisher et al. 1992), increased low dissolved oxygen events (Taft et al. 1980; Officer et al. 1984; Malone et al. 1996), alterations in the food web (Malone 1992) and declines in valued fisheries species (Kemp et al. 1983; USEPA 1983). Sediment and contaminant loads are also increased in watersheds dominated by agricultural and urban development mainly due to storm-water runoff (Wilber and Hunter 1979; Hoffman et al. 1983; Medeiros et al. 1983; Schmidt and Spencer 1986; Beasley and Granillo 1988; Howarth et al. 1991; Vernberg et al. 1992; Lenat and Crawford 1994; Corbett et al. 1997).

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; Tapp et al. 1993; Wilson and Jeffrey 1994; Dauer et al. 2000). Many characteristics of benthic assemblages make them useful indicators (Bilyard 1987; Dauer 1993), 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).

Benthic Community Studies of the Lynnhaven River Watershed

There are few studies of the benthic communities of the Lynnhaven River watershed. Dauer et al. (1979) studied intertidal benthic communities of the Eastern Branch and Western Branch and compared the benthic communities to those of Old Plantation Creek located on the bayside of the Virginia Eastern Shore. Tourtellotte and Dauer (1983) studied the subtidal benthic communities including stations located in Lynnhaven Roads, the Eastern Branch, the Western Branch, the Narrows, Broad Bay and Linkhorn Bay. The Narrows and Lynnhaven Roads had the highest species diversity and all other locations had low species diversity (compared to the later developed Chesapeake Bay Restoration Goals of Weisberg et al. 1997). Linkhorn Bay had the lowest species diversity indicative of extreme stress (see Table 2 in Tourtellotte and Dauer 1983). Additional studies include Hawthorne and Dauer's (1983) comparison of the muddy bottom benthic communities of the Lynnhaven River, the Southern Branch of the Elizabeth River and Old Plantation Creek of the Eastern Shore (Ewing and Dauer 1982). The Lynnhaven River benthic communities had intermediate values of species diversity and community abundance. Finally Dauer et al. (1982a,b) conducted field experiments in Broad Bay of the Lynnhaven River watershed concerning the relative importance of predation, resource limitation and physical refugia in affecting benthic community structure.

The Chesapeake Bay Index of Biotic Integrity

The Benthic Index of Biotic Integrity (B-IBI) was developed for macrobenthic communities of the Chesapeake Bay (Weisberg et al. 1997). The index defines expected conditions based upon the distribution of metrics from reference samples. Reference samples were collected from locations relatively free of anthropogenic stress. In calculating the index, categorical values are assigned for various descriptive metrics by comparison with thresholds of the distribution of metrics from reference samples. The result is a multi-metric index of biotic condition, frequently referred to as an index of biotic integrity (IBI). The analytical approach is 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 are possible.

A six-step procedure was used to develop the index: acquire and standardize data sets from a number of monitoring programs; temporally and spatially stratify data sets to identify seasons and habitat types; identify reference sites; select benthic community metrics; select metric thresholds for scoring; and validate 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 as part of the monitoring program 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 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 and, and polyhaline mud habitats (see Table 5 in Weisberg et al. 1997).

Metrics to include in the index were selected from a candidate list proposed by benthic experts of the Chesapeake Bay. Selected metrics had to (1) differ significantly between reference and all other sites in the data set and (2) differ in an ecologically meaningful manner. Reference sites were selected as those sites which met all three of the following criteria: no sediment contaminant exceeded Long et al.'s (1995) effects range-median (ER-M) concentration, total organic content of the sediment was less than 2%, and bottom dissolved oxygen concentration was consistently high. A total of 11 metrics representing measures of species diversity, community abundance and biomass, species composition, depth distribution within the sediment, and trophic composition were used to create the index (see Table 2 in Weisberg et al. 1997).

The habitat-specific metrics are 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. The IBI approach involves scoring each metric as 5, 3, or 1, depending on whether its value at a site approximates, deviates slightly, or deviates greatly from conditions at reference sites (Karr et al. 1986). Threshold values are established as approximately the 5th and 50th (median) percentile values for reference sites in each habitat. For each metric, values below the 5th percentile are scored as 1; values between the 5th and 50th percentiles are scored as 3, and values above the 50th percentile are scored as 5. Metric scores are combined into an index by computing the mean score across all metrics for which thresholds were developed. Assemblages with an average score less than three are considered stressed, as they have metric values that on average are less than values at the poorest reference sites. Two of the metrics, abundance and biomass, respond bimodally; that is, the response can be greater than at reference sites with moderate degrees of stress and less than at reference sites with higher degrees of stress (Pearson and Rosenberg 1978; Dauer and Conner 1980; Ferraro et al. 1991). For these metrics, the scoring is modified so that both exceptionally high (those exceeding the 95th percentile at reference sites) and low (<5th percentile) responses are scored as a 1. Values between the 5th and 25th percentiles or between the 75th and 95th percentiles are scored as 3, and values between the 25th and 75th percentiles of the values at reference sites are scored as 5. The index was validated by examining its response at a new set of reference sites and a new set of sites with known environmental stress. Data used for validation were collected between 1992 and 1994 and were independent of data used to calibrate the index. The B-IBI classified 93% of the validation sites correctly (Weisberg et al. 1997).

Values for the B-IBI range from 1.0 to 5.0. Benthic community condition was classified into four levels based on the B-IBI. Values ≥ 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 (Dauer et al. 2006a,b,c).

METHODS

A glossary of selected terms used in this report is found on page 21.

Strata Sampled

In the summer of 2006, the Lynnhaven River watershed was divided into seven strata (Fig. 1). The seven strata were (1) Inlet-Mouth (Lynn_1), (2) Lower Reach of the Western Branch (Lynn_2), (3) Upper Reach of the Western Branch (Lynn_3), (4) Lower Reach of the Eastern Branch (Lynn_4), (5) Upper Reach of the Eastern Branch (Lynn_5), (6) Broad Bay (Lynn_6), and (7) Linkhorn Bay/Crystal Lake (Lynn_7).

Probability-based Sampling

A wide variety of sampling designs have been used in marine and estuarine environmental monitoring programs (e.g., see case studies reviewed recently in Kramer, 1994; Kennish, 1998; Livingston, 2001). Allocation of samples in space and time varies depending on the environmental problems and issues addressed (Kingsford and Battershill, 1998) and the type of variables measured (e.g., water chemistry, phytoplankton, zooplankton, benthos, nekton). In the Chesapeake Bay, the benthic monitoring program consists of both fixed-point stations and probability-based samples. The fixed-point stations are used primarily for the determination of long-term trends (e.g., Dauer and Alden, 1995; Dauer, 1997; Dauer et al. 2006a,b,c) and the probability-based samples for the determination of the areal extent of degraded benthic community condition (Llansó et al. 2003; Dauer and Llansó 2003). The probability-based sampling design consists of equal replication of random samples among strata and is, therefore, a stratified simple random design (Kingsford, 1998). 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 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:

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

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).

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. 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 ≥ 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 (e.g. 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.

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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).

RESULTS AND SUMMARY

Benthic Community Condition using Probability-Based Sampling

Environmental Parameters

Physical-chemical parameters for the seven strata are summarized in Table 1. Mean water depths were less than 2 m for all strata except Broad Bay (Lynn_6) and Linkhorn Bay (Lynn_7). Salinity was in the polyhaline range (18-32) for all strata except the Upper Reach of the Western Branch (16.8). Sediments were on average coarsest in the Inlet stratum (Lynn_1) and were the finest in the upper reaches of both the Western Branch and Eastern Branch. In Table 1B the strata are organized into three groups based upon the biological results (see below). Proceeding in an upstream direction the silt-clay content increases as well as the volatile solid content.

For each of the 175 sampling sites all data measurements are presented in Appendix A. Data in Appendix A includes station coordinates (Table A-1); date of collection and all field measured physical and chemical parameters - sampling data, water depth, salinity, dissolved oxygen and temperature (Table A-2); and sedimentary parameters - percent sand, percent silt-clay and sediment volatile solids (Table A-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 all 175 random sites was 2.1 and ranged from 2.9 at the Inlet Stratum (Lynn_1) to 1.6 in the

Linkhorn Bay - Crystal Lake Stratum (Lynn_7). In Table 2B the seven strata are presented in three groups - the Inlet, the Lower Reaches and the Upper Reaches. These three groups represent an Ecological Integrity Gradient of increasing levels of degradation along an upstream direction. The three groups were (1) the Inlet Group, (2) the Lower Reach Group (Lower Western Branch, Lower Eastern Branch, Broad Bay), and the Upper Reach Group(Upper western Branch, Upper Eastern Branch, Linkhorn Bay). The upstream gradient is characterized by (1) increased areal estimates of degradation, (2) decreasing mean values for the Benthic Index of Biotic Integrity, (3) decreasing levels of species diversity, and (4) increasing levels of dominance by pollution indicative species. This pattern of increasing degradation in an upstream direction is characterized by decreasing flushing rates and decreasing sediment grain size (i.e. increasing levels of silt-clay sized particles). The Ecological Integrity Gradient of increasing levels of degradation in an upstream direction is typically representative of a pattern of (1) decreasing current velocity and flushing rates and (2) increasing amounts of non-point source runoff.. Non-point source runoff typically contains levels of nutrients, contaminants and fine-sized sediments that are not conducive to supporting healthy, diverse, productive and ecologically valuable benthic communities.

The dominant taxa of the random sites are summarized in Table 3. Th Lynnhaven River system is dominated by annelid species including the polychaete species *Mediomastus ambiseta*, *Streblospio benedicti*, *Heteromastus filiformis, Paraprionospio pinnata*, *Leitoscoloplos* spp.,,*Neanthes succinea* ans the oligochaeta taxon *Tubificoides* spp.

The areal estimate of degraded benthic bottom of the Lynnhaven River watershed was among the highest reported for the Chesapeake Bay. The level of degradation (B-IBI < 3.0) based upon the 2006 data of the Lynnhaven River watershed was 81.1 ± 5.8%, compared to 64.4 ± 5.9% for the Chesapeake Bay, and 59.0 ± 9.6% for all Virginia tidal waters. Comparable levels of data from polyhaline regions of Virginia were 36.0 ± 18.8% for the Virginia Mainstem, 70.0 ± 28.4% for the James River, 75.0 ± 21.2.8% for the of the York River and 80.0 ± 15.7% for the Elizabeth River.

Benthic biological data for each of the 175 sampling sites all data measurements are presented in Appendix B. Data include benthic community parameters - total species per site, abundance of individuals per m^2, AFDW biomass m^2, and AFDW biomass m^2 less the bivalve biomass (Table B-1); for each sample the complete list of taxa, raw abundance counts and raw biomass measurements (Table B-2); and the complete taxon list for the entire study (Table B-3). Plots of the ecological status of the B-IBI at each station in each stratum are presented in Appendix C.

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Glossary of 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.

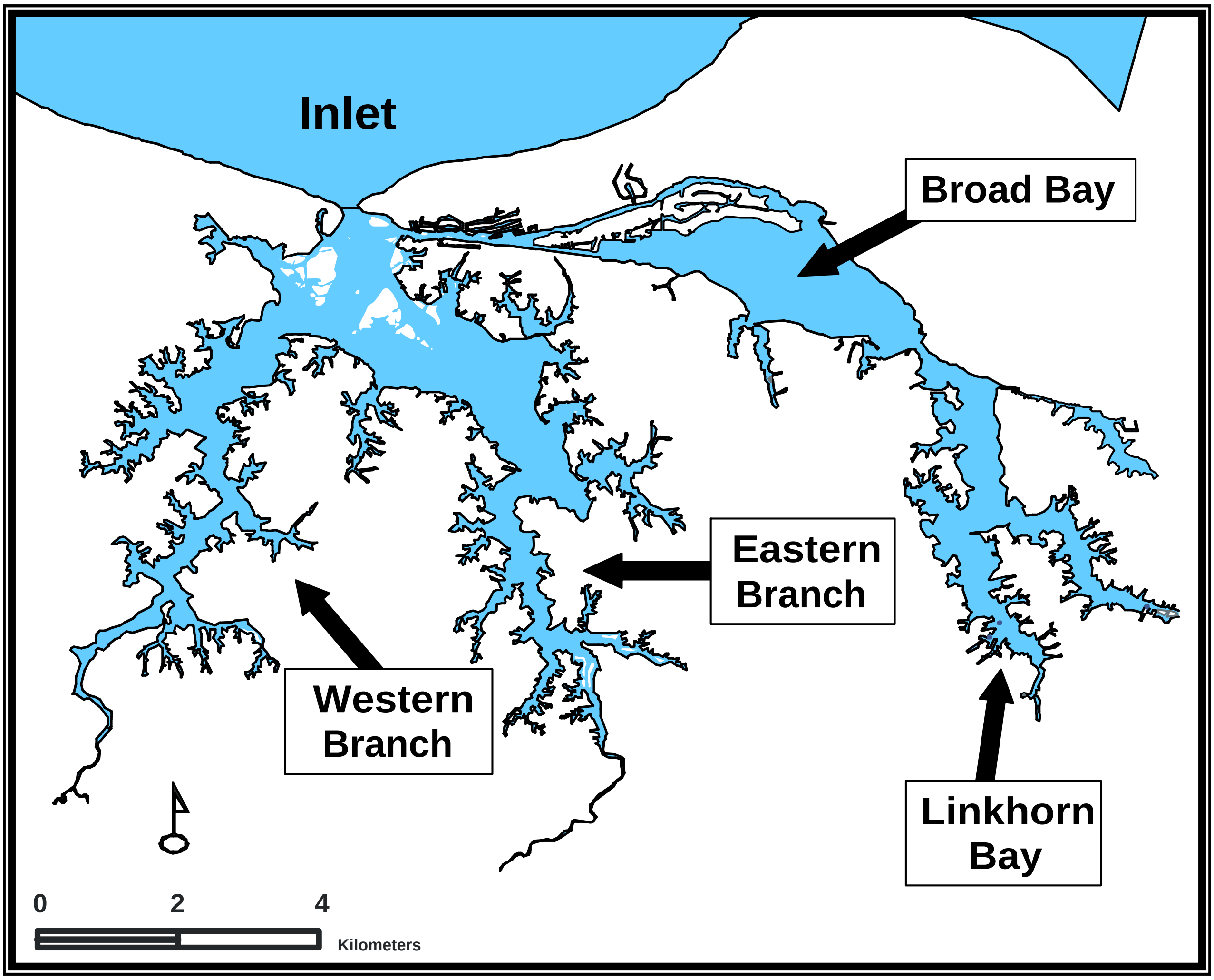

Figure 1. Lynnhaven River watershed.

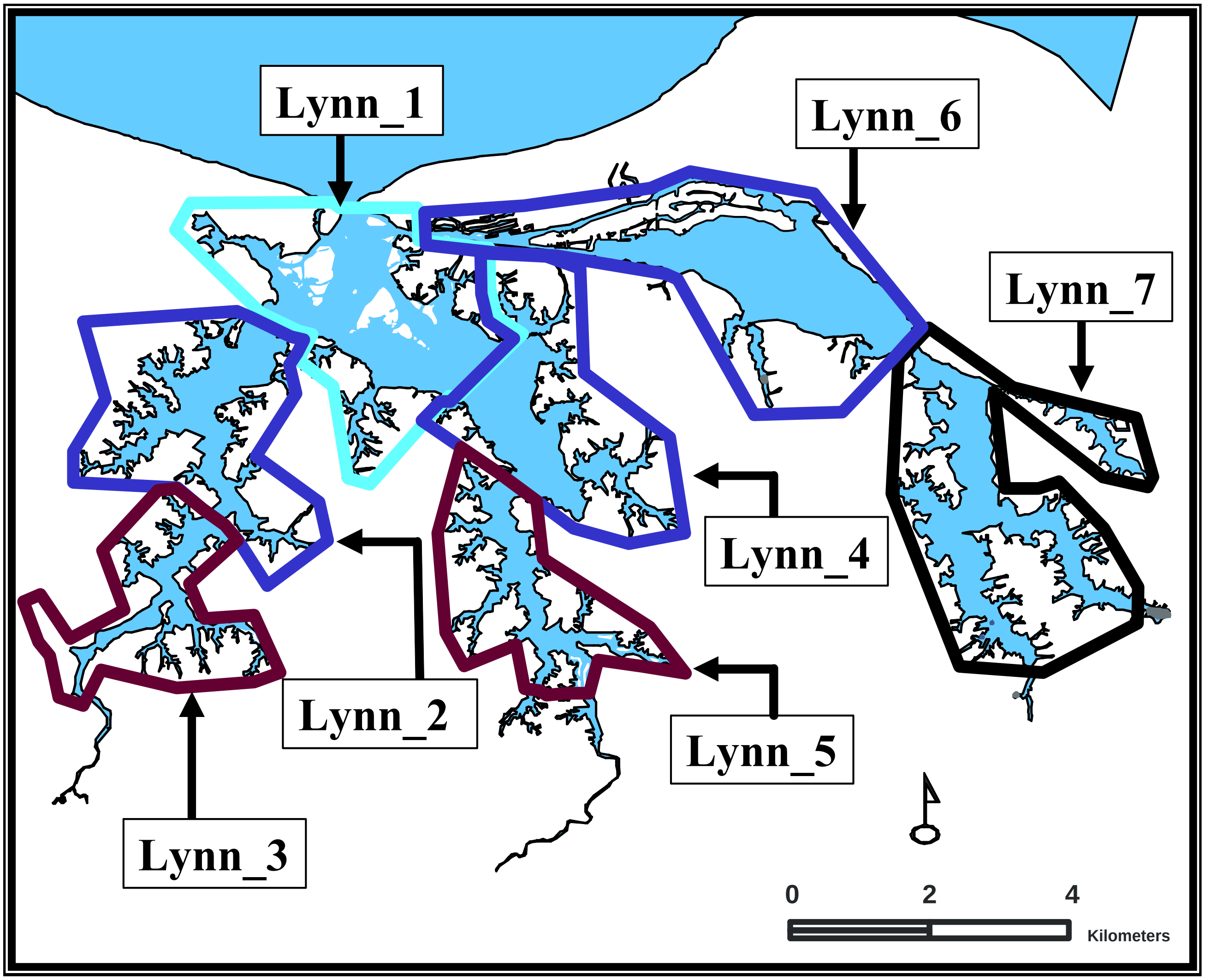

Figure 2. Lynnhaven River watershed sampling strata. The seven strata were (1) Inlet-Mouth (Lynn_1), (2) Lower Reach of the Western Branch (Lynn_2), (3) Upper Reach of the Western Branch (Lynn_3), (4) Lower Reach of the Eastern Branch (Lynn_4), (5) Upper Reach of the Eastern Branch (Lynn_5), (6) Broad Bay (Lynn_6), and (7) Linkhorn Bay/Crystal Lake (Lynn_7).

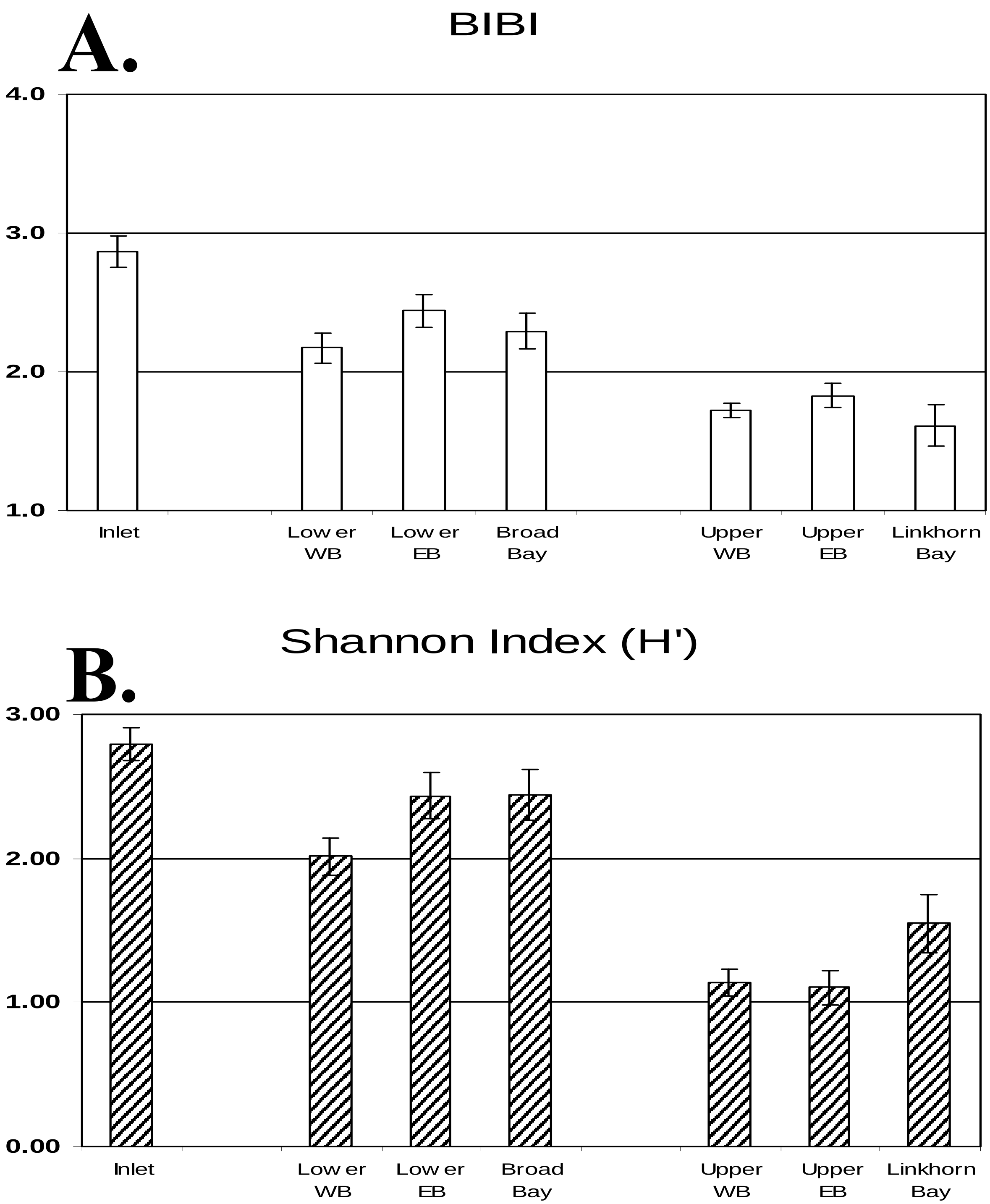

Figure 3. Lynnhaven River benthic community parameters. Seven strata organized into three groups – the Inlet Stratum, the Lower Reaches Stratum and the Upper Reaches Stratum. A. Mean values for the B-IBI showing one standard error. B. Mean values for the Shannon Index of species diversity showing one standard error.

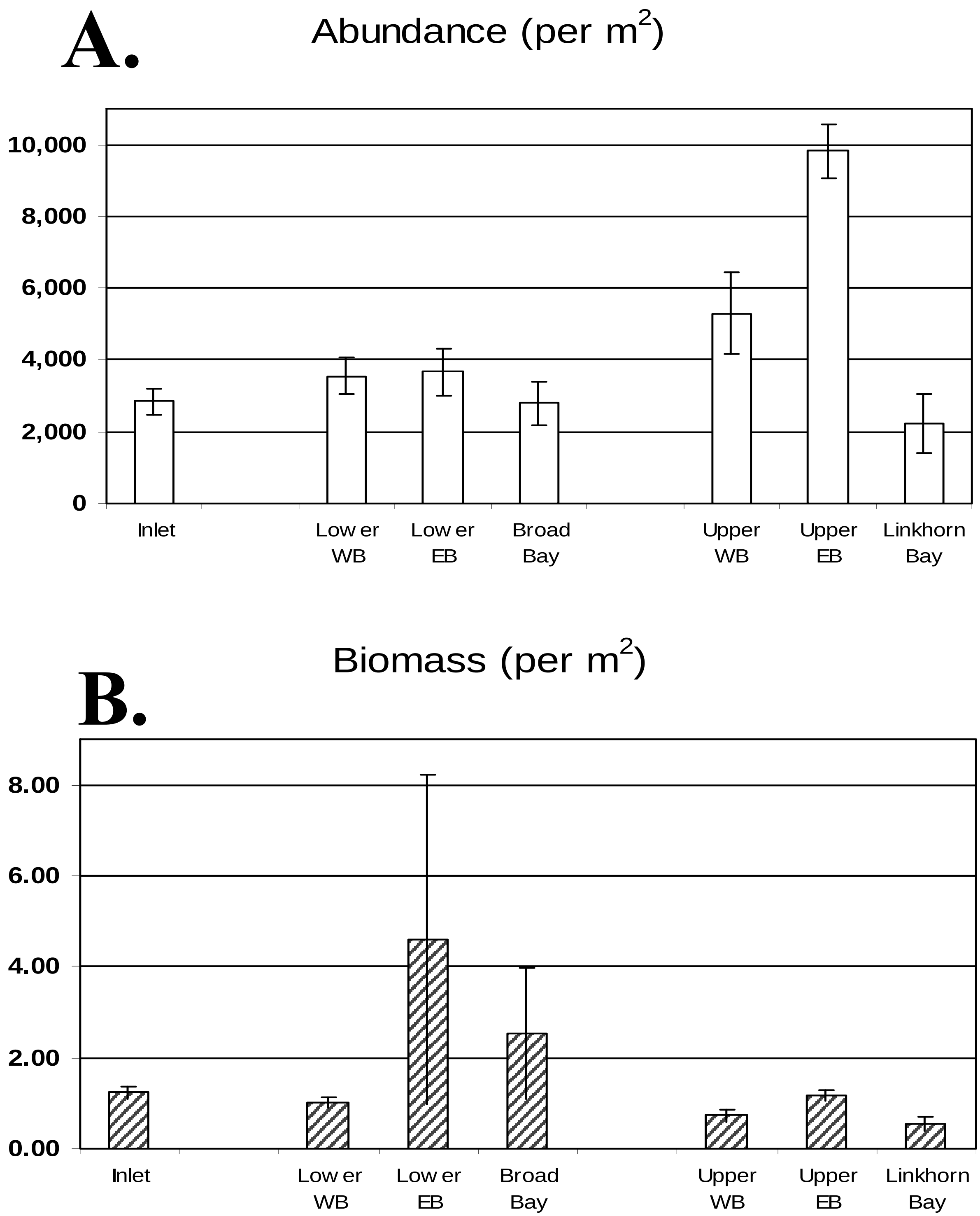

Figure 4. Lynnhaven River benthic community parameters. Seven strata organized into three groups – the Inlet Stratum, the Lower Reaches Stratum and the Upper Reaches Stratum. A. Mean values for community abundance showing one standard error. B. Mean values for the community biomass showing one standard error.

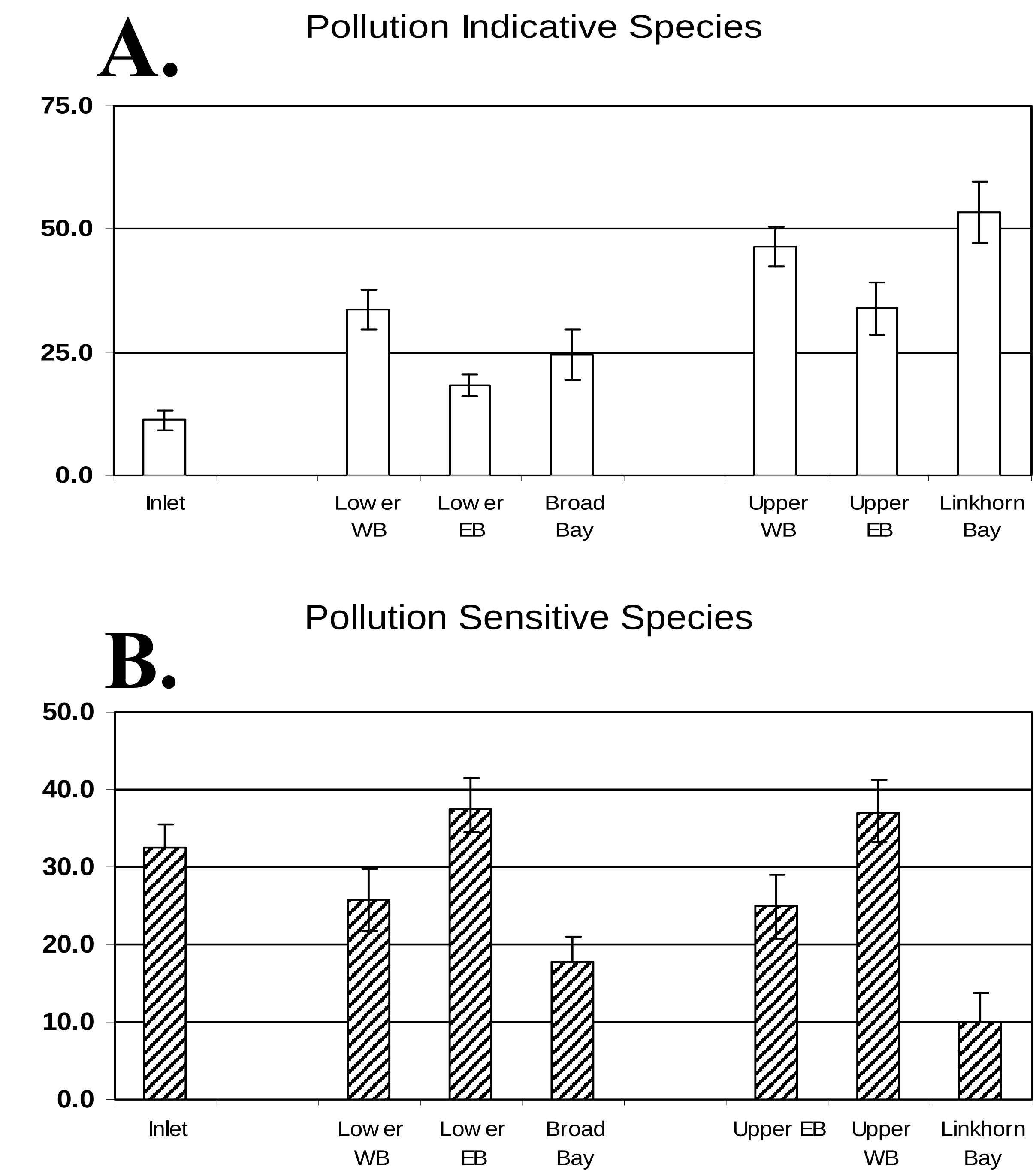

Figure 5. Lynnhaven River benthic community parameters. Seven strata organized into three groups – the Inlet Stratum, the Lower Reaches Stratum and the Upper Reaches Stratum. A. Mean values for percent pollution sensitive species abundance showing one standard error. B. Mean values for percent pollution sensitive species biomass showing one standard error.

Table 1. Summary patterns for physical-chemical collected from the seven strata sampled in the Lynnhaven River watershed in 2006. Shown are mean values with standard errors of the mean in parentheses. (n=25 for each stratum). A. Seven sampling strata. B. Strata organized into three groups based upon the Ecological Integrity Gradient of the biological data.

A. Lynnhaven Strata

Stratum	Depth (m)	DO (ppm)	Salinity	Silt-clay (%)	Volatiles (%)
Lynn_1	1.3 (0.2)	5.8 (0.1)	24.0 (0.1)	15.8 (5.5)	0.5 (0.1)
Lynn_2	1.2 (0.1)	5.3 (0.3)	24.7 (0.1)	63.5 (7.7)	1.3 (0.1)
Lynn_3	1.0 (0.1)	4.3 (0.2)	16.8 (0.7)	88.3 (3.6)	2.0 (0.1)
Lynn_4	1.1 (0.1)	6.0 (0.2)	21.0 (0.1)	63.1 (6.9)	1.3 (0.1)
Lynn_5	1.1 (0.1)	5.7 (0.2)	20.3 (0.1)	94.7 (1.5)	2.1 (0.1)
Lynn_6	2.2 (0.2)	6.3 (0.2)	22.2 (0.1)	46.6 (8.3)	1.4 (0.2)
Lynn_7	2.8 (0.2)	5.7 (0.1)	20.9 (0.1)	64.0 (7.7)	2.5 (0.3)

B. Ecological Groups

Stratum Group	Depth (m)	DO (ppm)	Salinity	Silt-clay (%)	Volatiles (%)
Inlet	1.3 (0.2)	5.8 (0.1)	24.0 (0.1)	15.8 (5.5)	0.5 (0.1)
Lower Reaches	1.5 (0.9)	5.8 (0.1)	22.6 (0.1)	57.7 (4.5)	1.3 (0.1)
Upper Reaches	1.6 (0.1)	5.3 (0.1)	19.4 (0.3)	82.3 (3.2)	2.2 (0.1)

Table 2. Sampling strata of the Lynnhaven River sampled in 2006. Summary of benthic community parameters. Abundance reported in ind/m2, biomass reported as grams/m^2, all other abundance and biomass metrics are percentages.

A. Lynnhaven strata

Stratum	BIBI	Abundance	Biomass	Shannon Index	Pollution Indicative Abundance	Pollution Sensitive Abundance	Pollution Indicative Biomass	Pollution Sensitive Biomass	Carnivore Omnivore Abundance	Deep Deposit Feeders
Lynn _1	2.9	2,840	1.23	2.80	15.6	35.6	11.3	32.4	16.2	42.3
Lynn_2	2.2	3,554	1.00	2.02	42.9	37.8	33.7	25.7	9.9	42.5
Lynn_3	1.7	5,293	0.73	1.14	53.3	38.7	46.6	25	6.7	41.1
Lynn_4	2.4	3,665	4.60	2.43	23.6	53.3	18.3	37.5	10.5	46.9
Lynn_5	1.8	9,820	1.18	1.10	33.6	60.9	33.8	37.1	4.7	62
Lynn_6	2.3	2,790	2.53	2.44	43.8	27.4	24.6	17.8	9.6	33.1
Lynn_7	1.6	2,224	0.54	1.55	67.6	12.3	53.4	10	12.9	14.8
Mean	2.1	4,312	1.69	1.93	40.1	38	31.7	26.5	10.1	40.4

B. Inlet , Lower Reaches and Upper Reaches

Inlet										
Lynn_1	2.9	2,840	1.230	2.80	15.6	35.6	11.3	32.4	16.2	42.3
Lower Reaches (Western Branch, Eastern Branch, Broad Bay)										
Lynn_2	2.2	3,554	1.000	2.02	42.9	37.8	33.7	25.7	9.9	42.5
Lynn_4	2.4	3,665	4.600	2.43	23.6	53.3	18.3	37.5	10.5	46.9
Lynn_6	2.3	2,790	2.530	2.44	43.8	27.4	24.6	17.8	9.6	33.1
Mean	2.3	3,336	2.710	2.30	36.8	39.5	25.5	27.0	10.0	40.8
Upper Reaches (Western Branch, Eastern Branch, Linkhorn Bay, Crystal Lake)										
Lynn_3	1.7	5,293	0.730	1.14	53.3	38.7	46.6	25.0	6.7	41.1
Lynn_5	1.8	9,820	1.180	1.10	33.6	60.9	33.8	37.1	4.7	62.0
Lynn_7	1.6	2,224	0.540	1.55	67.6	12.3	53.4	10.0	12.9	14.8
Mean	1.7	5,779	0.817	1.26	51.5	37.3	44.6	24.0	8.1	39.3

Table 3. Overall Random Stations of the Lynnhaven River Watershed sampled in 2006. Dominant tax by abundance. Taxon code: A = Amphipod, B = bivalve, C = cumacean, N = nemertean, O = oligochaete, P = polychaete, PH =phoronid.

Rank	Taxon	Abundance per m^2
1	Mediomastus ambiseta (P)	2142.94
2	Streblospio benedicti (P)	1244.16
3	Heteromastus filiformis (P)	132.97
4	Nemertea spp. (N)	91.76
5	Phoronis spp. (PH)	60.26
6	Paraprionospio pinnata (P)	49.64
7	Tubificoides spp. Group I (O)	45.75
8	Leitoscoloplos spp. (P)	44.32
9	Caulleriella killariensis (P)	43.80
10	Neanthes succinea (P)	31.49
11	Leucon americanus (C)	26.96
12	Listriella clymenellae (A)	26.18
13	Cyathura polita (I)	23.59
14	Podarkeopsis levifuscina (P)	22.16
15	Cyclaspis varians (C)	19.96

Table 4. Comparison of benthic community condition from data collected in 2006. Chesapeake Bay Program strata consist of four strata – James River, York River, Rappahannock River and the Mainstem. Also shown are polyhaline portions of the James River and York for comparison with the polyhaline strata of the Mainstem, Elizabeth River and Lynnhaven River. Abundance reported in ind/m2, biomass reported as grams/m^2 .

Region	B-IBI	Abundance	Biomass	Shannon Index	Species	Percent Degraded	Depth (m)	DO (ppm)	Salinity	n
Chesapeake Bay Program Strata										
All Virginia tidal waters	2.6	3,515	1.893	2.28	11.6	60.0	6.2	5.3	16.0	100
Mainstem	3.0	3,403	1.292	2.87	16.7	36.0	7.7	5.7	20.4	25
James River	2.6	3,992	1.045	2.02	9.8	56.0	5.8	5.3	12.5	25
York River	2.5	3,661	1.223	2.27	11.6	68.0	4.9	5.0	17.8	25
Rappahannock River	2.1	2,793	0.484	1.73	7.4	76.0	6.2	4.8	12.3	25
Polyhaline strata										
Mainstem	3.0	3,402	1.292	2.87	16.7	36.0	7.7	5.7	20.4	25
James River	2.5	2,480	0.957	2.50	13.2	80.0	7.5	5.6	22.0	10
York River	2.4	3,828	1.314	2.41	12.6	75.0	5.7	5.0	20.4	16
Elizabeth River	2.4	5,074	1.259	2.12	14.0	80.0	5.2	5.1	21.9	25
Lynnhaven River	2.1	4,312	1.687	1.93	11.2	81.0	1.6	5.6	21.4	175