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BENTHIC STATUS ASSESSMENTS USING PROBABILITY-BASED SAMPLING IN THE VIRGINIA CHESAPEAKE BAY (2003)

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I. Introduction

Fixed site monitoring provides useful information about trends in the condition of benthic biological resources at the 21 benthic biological monitoring locations in Virginia (Dauer 1993, 1997; Dauer and Rodi 1996; Dauer et al. 1998a, 1998b; Dauer et al. 2003a,b,c) but it does not provide an integrated assessment of the Bay's overall condition.

An alternative approach for quantifying status of the Bay is to use probability-based sampling to estimate the bottom area populated by benthos meeting the Chesapeake Bay Benthic Community Restoration Goals (Ranasinghe et al. 1994; Weisberg et al. 1997). The fixed site approach emphasizes quantifying change at selected locations, while the probability sampling approach emphasizes quantifying the spatial extent of problems (Dauer and Llansó 2003; Llansó et al. 2003). While both approaches are valuable, developing and assessing the effectiveness of Chesapeake Bay management strategies requires understanding the extent and distribution of problems throughout the Bay, instead of assessing only site-specific problems. The probability-based sampling element is intended to provide that information, as well as a more widespread baseline data set for assessing the effects of unanticipated future contamination (e.g., oil or hazardous waste spills).

Estimates of tidal bottom area meeting the Benthic Restoration Goals are included for the entire Chesapeake Bay. The estimates are possible because both the Virginia and Maryland benthic monitoring programs include a probability-based sampling element, which started in 1996. The Virginia sampling is compatible and complementary to the Maryland effort and is part of a joint effort by the two programs to assess the extent of "healthy" tidal bottom Baywide.
Previous characterizations of the Virginia tidal waters using probability based sampling were presented in Dauer (1999) and Dauer and Rodi (1998a, 1998b, 1999, 2001, 2002).

II. Methods

A glossary of selected terms used in this report is found on page 12.

A. Field Collection

The Virginia portion of the Chesapeake Bay was divided into four strata and the Maryland portion into six strata in 1996 (Table 1). For field and laboratory sampling procedures see Dauer et al. (1998b) for the Virginia program and Ranasinghe et al. (1998) for the Maryland program.

B. 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 habitat "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 as a site approximates, deviates slightly from, or deviates strongly from the values found at the best reference sites in similar habitats, and then averaging these scores across attributes. The criteria for assigning these scores are numeric and dependent on habitat type. Application of the index is limited to a summer index period from July 15th through September 30th.

Benthic community condition was classified into four levels based on the B-IBI. Values less than 2 were classified as **severely degraded**; values form 2.0 to 2.6 were classified as **degraded**; values greater than 2.6 but less than 3.0 were classified as **marginal**; and values of 3.0 or more were classified as **meeting the goal**. Values in the marginal category do not meet the Restoration Goals, but they differ from the goals within the range of measurement error typically recorded between replicate samples.

C. Probability-Based Estimation

To estimate the amount of area in the entire Bay that failed to meet the Chesapeake Bay Benthic Restoration Goals (P), we defined for every site *i* in stratum *h* a variable y_{hi} that had a value of 1 if the benthic community met the goals, and 0 otherwise. For each stratum, the estimated proportion of area meeting the goals, $p_{h,}$ and its variance were calculated as the mean of the y_{hi}'s and its variance, as follows:

$$p_h = \bar{y}_h = \sum_{i=1}^{n_h} \frac{y_{hi}}{n_h}, \qquad (1)$$

and

$$\mathbf{var}\ (p_h) = s_h^2 = \sum_{i=1}^{n_h} \frac{(y_{hi} - \bar{y}_h)^2}{n_h - 1}. \qquad (2)$$

Estimates for strata were combined to achieve a statewide estimate as:

were the weighting factors, W_h, = A_h/A and A_h were the total area of the *h*th stratum. The

$$\hat{\mathbf{P}}_{\mathbf{ps}} = \bar{\mathbf{y}}_{\mathbf{ps}} = \sum_{\mathbf{h=1}}^{\mathbf{10}} \mathbf{W_h \bar{y}_h}, \qquad \textbf{(3)}$$

variance of (3) was estimated as:

$$\text{var } (\hat{P}_{ps}) = V(\bar{y}_{ps}) = \sum_{h=1}^{103} W_h s_h^2 / n_h. \qquad \textbf{(4)}$$

For combined strata, the 95% confidence intervals were estimated as the proportion plus or minus twice the standard error. For individual strata, the exact confidence interval was determined from tables.

III. Results

A. Bay-wide Patterns in Community Condition

In terms of number of sites failing the goals in Chesapeake Bay, 2003 was the worst year since probability-based sampling started in 1994. Of the 250 probability samples collected in the entire Chesapeake Bay in 2003, 93 met and 157 failed the restoration goals. Of the 100 Virginia samples collected in 2003, 38 met and 62 failed the Chesapeake Bay benthic community restoration goals (Figure 1). The Maryland sampling results are presented in Figure 2. In 2003, the total percentage area of bottom failing the Chesapeake Bay Benthic Restoration Goals was 59% for the entire Chesapeake Bay watershed, 52% for Virginia tidal waters, and 65% for Maryland tidal waters. The total area failing the Benthic Restoration Goals for the entire Chesapeake Bay increased from 5,250 km^2 in 1996 to 6,743 km^2 in 1998, decreased to 5,450 km^2 in 1999 and increased thereafter reaching a maximum of 6,852 km^2 in 2003 (Figure 3A). This general pattern was reflected in both the Virginia and Maryland tidal waters of Chesapeake Bay (Figure 3B-C).

Based on a three-year running mean, the Potomac River had the highest percentage of area failing to meet the restoration goals with 77.3% failing to meet the criteria, however, confidence intervals for this estimate overlapped with those of the Patuxent River, the Maryland Mid-Mainstem, and the York River indicating comparable percentages of degraded area within these strata with that in the Potomac River (Figure 4). The Maryland Upper Bay had the lowest percentage of area failing the goal with 34.7% of the total area failing to meet the criteria. Confidence intervals for this estimate overlapped with those of the Rappahannock River and Virginia Mainstem indicating that the estimated percentage of degraded area was similar to that found in the Maryland Upper Bay stratum.

Based on a three-year running mean, the Maryland Mid-Bay, Virginia Mainstem and Potomac River had the highest values for total area failing to meet the benthic restoration goal with 2167 km^2, 1593 km^2 and 986 km^2, respectively. The total for the Maryland Mid-Mainstem includes 676 km^2 of a deep trench found in this stratum which is permanently anoxic and which continually fails the benthic restoration goals. For all other strata, the total areal estimates of benthic habitat failing the criteria were less than 500 km^2.

In the James River, the majority of samples (48.5%) classified as failing the restoration goals were degraded while in both the York River and Rappahannock River the majority of samples failing the criteria (44.6% and 49.5%, respectively) were severely degraded (Table 2). In the Virginia Mainstem, however, most samples that failed to meet the restoration goals were marginal (Table 2). The number of samples failing the restoration goals with insufficient abundance and/or biomass ranged from 32.0% in the James River to 65.7% in the Virginia Mainstem (Table 2). Both the James River and York River also had high percentages (>25%) of samples failing the restoration goals with excessive abundance and/or biomass (Table 2).

Percentages of samples failing the goal classified as severely degraded ranged from 27.9% in the Maryland Eastern Tributaries to 68.4% in the Maryland Mid Mainstem. For all strata in Maryland, the majority of samples failing to meet the restoration goals were classified as severely degraded except in the Maryland Eastern Tributaries where most samples were classified as degraded (Table 2). In Maryland, percentages of samples failing the goal that had insufficient abundance and/or biomass ranged from 45.3% in the Maryland Eastern Tributaries to 78.4% in the Potomac River (Table 2). Both the Maryland Eastern Tributaries and Maryland Upper Mainstem also had high percentages of samples failing the goals (>25%) with excessive abundance and/or biomass (Table 2).

B. Benthic Community Conditions in Virginia

In Virginia, levels of degradation for all tributaries in 2003 were high relative to previous years and reflected the pronounced degradation seen bay-wide (Figure 5). Benthic community condition in all Virginia tributaries declined in 2003 relative to the previous year, with the York River exhibiting the largest decline and the most extensive degradation (Figure 5) with 84% of the river characterized as having degraded benthic communities. The Virginia mainstem, which usually supports good benthos, exhibited the largest increase in degraded area of the eight-year time series, almost reaching 50% degradation. Of the sites failing the restoration goal, the majority were classified as degraded in James River, severely degraded in the York and Rappahannock rivers, and marginal in the Virginia Mainstem for the period 1996 through 2003 (Table 2). Percentages of samples failing due to insufficient or excessive abundance and/or biomass were approximately equal at around 30% for both the James and York rivers. In contrast, the majority of samples for the Rappahannock River and the Virginia Mainstem, 62% and 66% respectively, failed due to insufficient abundance and/or biomass.

Eleven of the 26 segments assessed had three-year mean B-IBI values at or above the restoration goal (Figures 7-10). Of the remaining segments, seven were classified marginal, seven were classified degraded and only one segment, located in the Southern Branch of the Elizabeth River was classified as severely degraded based on a three-year mean B-IBI.

1. James River

The percentage of area in the James River failing the restoration goal increased from 24% in 1996 to 68% in 1998, decreased to 20% in 2000 but reached levels above 50% during the last three years of monitoring and up to 64% in 2003 (Figure 5). The percentage of samples failing the restoration goal due to insufficient abundance and/or biomass declined during the last three years of monitoring from levels around 50% in previous years to a range of 20% to 30%. The percentage of samples failing the goal due to excessive abundance and/or biomass ranged from 50% in 1996 to less than 10% in 2002 (Figure 6A).

Three-year mean B-IBI values for the James River were higher at upstream segments, ranging from 2.6 in segment JMSMH to a maximum of 3.7 in the Chickahominy River (segment CHKOH). Only two segments (JMSTF and CHKOH) had three-year mean values above the benthic restoration goal (Figure 7A). Within the Elizabeth River, mean B-IBI values for the past three years were less than the benthic restoration goal in all segments although the mean at segment ELIPH was close to the goal (Figure 7B).

2. York River

In the York River, the percentage of area failing the restoration goal was at or above 55% prior to 2000 when the percentage dropped to less than 40%. This percentage rose to 80% in 2001, dropped to 40% in 2002 and reached a maximum of 84% in 2003 (Figure 5). The percentage of samples failing the restoration goal due to insufficient abundance and/or biomass although generally below 30% during most years fluctuated to levels at or above 50% during 1996, 2000 and 2003. The percentage of samples failing the goal due to excessive abundance and/or biomass generally ranged from 50% to 30% and showed a slight decline from1996 through 2003 (Figure 6B).

Three-year mean B-IBI values in the York River were highest in the tidal freshwater portion of the Pamunkey River (segment PMKTF) declined in Lower Pamunkey and then showed a general increase from the Upper York River to Mobjack Bay. Only the Upper Pamunkey River and Mobjack Bay had a three-year mean B-IBI values at or above the restoration goal (Figure 8). No assessment of the Upper Mattaponi River (segment MPNTF) can be made because no samples were collected in this segment during the last three years.

3. Rappahannock River

In the Rappahannock River, the percentage of area failing the restoration goal was relative stable from 1996 through 1999 ranging from 48% to 60%. The percentage of area failing the restoration goal peaked at 72% in 2000, decreased to 36% in 2001 and has increased steadily during the last two years to 52% in 2003 (Figure 5). The percentage of samples failing the restoration goal due to insufficient abundance and/or biomass was at or above 50% during all years except 1998 and 1999 when this percentage fell to 31% and 35%, respectively. The number of samples failing the restoration goal due to excessive abundance and/or biomass ranged from 33% in 1996 to 0% in 2002 and showed a general decline from the start of monitoring to the present (Figure 6C).

Three-year mean B-IBI values in the Rapphannock River ranged from a maximum of 3.2 in the Upper Rappahannock River (segment RPPTF) and declined moving downstream to a minimum of 2.5 at in the Corrotoman River (segment CRRMH) (Figure 9). Both the Upper and Middle Rappahannock River (segments RPPTF and RPPOH) were at or above the benthic restoration goal.

4. Virginia Mainstem

For the period 1996 through 2002 the percentage of area failing the restoration goal in the Virginia Mainstem was less than or equal to 40% and reached as low as 20% in 1999. In 2003, however, the percentage of area failing the goal reached a maximum for the eight year period of 48% (Figure 5). The percentage of samples failing the restoration goal due to insufficient abundance and/or biomass increased from 44% in 1996 to 80% in 1997 and remained at levels at or above 55%, thereafter. The percentage of samples failing the restoration goal due to excessive abundance and/or biomass were at or below 10%, except for 2000 and 2003, when this percentage reached 25%.

Three-year mean B-IBI values in the Virginia Mainstem ranged from a minimum of 2.7 at CB5MH to a maximum of 3.4 in segment CB6PH and were above the restoration goals in all Virginia Mainstem segments except CB5MH. Although samples were collected in some segments by the Maryland LTB Program only data collected as part of Virginia monitoring program were used to calculate the three-year means presented in this report.

IV. Discussion

In 2003, the total percentage area of bottom failing the Chesapeake Bay Benthic Restoration Goals was 59% for the entire Chesapeake Bay watershed, 52% for Virginia tidal waters, and 65% for Maryland tidal waters. Estimates of benthic community degradation for the Chesapeake Bay and the Virginia tidal waters in 2003 were generally poorer than those reported for 2002 (Llansó et al. 2003). Increases in the percentage of area failing the restoration goal between 2002 and 2003 were observed in all of the Virginia strata although for most, the increase observed was within the increase in was within the margin of error of the estimate.

Spatial patterns in three-year mean B-IBI values appear to reflect status of water quality conditions in most strata in Virginia's tidal waters. Status of nitrogen and phosphorus in the middle and lower segments of the James River (segments JMSOH, JMSMH, and JMSPH) were poorer than in upstream segments and three-year mean B-IBI values in these segments were below the benthic restoration goal. In contrast, status of nutrients in the Upper James (JMSTF) and Chickahominy River (CHKOH) was good or fair. Three-year mean B-IBI values in these segments was above the restoration goal. Status of all nutrient and many non-nutrient parameters was poor in all segments of the Elizabeth River and three-year mean values for the B-IBI were below the restoration goal in all segments. The spatial pattern observed in benthic community conditions in the James River coupled with: (1) the known lack of widespread hypoxia; (2) the relatively high percentages of samples failing due to excessive abundance and biomass and; (3) previously described sediment contamination problems in the Elizabeth River; suggests that the predominant mechanisms resulting in degradation of benthos in this tributary are eutrophication due to anthroprogenic point source nutrients and sediment contamination.

In the York River, status of water quality was good for most parameters in the upper segments of both the Pamunkey and Mattaponi rivers (segments PMKTF and MPNTF) and in Mobjack Bay where the three-year mean B-IBI values either met or were higher than the restoration goal. Water quality status in the remaining segments of the York River was generally poor to fair and three-year means in all of these segments failed to meet the restoration goals. In the York River, restoration goal failure was due in nearly equal parts to insufficient and excessive abundance and/or biomass. The York River does not normally experience large scale hypoxic except for intermittent events that are tied with spring-neap tidal cycles in the lower York River (Haas 1977). Insufficient abundance and/or biomass at many sites may be related to physical disturbance due strong sediment erosion and deposition events caused by tidal exchange and river flow that are know to occur in this tributary (Schaffner et al. 2001). Sites with excessive abundance and/or biomass were probably the result of eutrophication.

Status of water quality conditions within the Rappahannock River was fair or good for most segment/parameter combinations and the predominant problem in this tributary appears to be poor water clarity associated due to high concentrations of total suspended solids and/or chlorophyll *a* localized in the upper and middle segments of the river (segments RPPTF and RPPOH). Three-year mean B-IBI values in the Lower Rappahannock (segment RPPMH) were below the restoration goal probably because many of the samples were collected in and around the deep trench in the lower portion of this segment where a high frequency of low dissolved oxygen events occur due to summer pycnoclines. Restoration Goal failure due to insufficient abundance and/or biomass was more common within the Rappahannock River during the last three years than in other tributaries supporting the idea that low dissolved oxygen events in are the cause of degraded benthic community conditions in the Lower Rappahannock.

Status of water quality conditions within the Virginia Mainstem was good or fair for most segment/parameter combinations and the three-year mean values for all segments in the Virginia Mainstem except CB5MH were at or above the restoration goal. Most samples failing the restoration goal had insufficient abundance and/or biomass suggestion that the predominant problem within the Virginia Mainstem is the occurrence of hypoxia.

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Glossary of selected terms

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

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

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

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

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

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

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

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

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

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

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

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

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

Table 1. Allocation of probability-based baywide samples. Virginia strata were sampled by the Virginia Chesapeake Bay benthic monitoring program commencing in 1996.

State	Stratum	Area			Number of Samples
		km^2	State %	Bay %	
Maryland	Mainstem	3,228	51.7	27.8	25
	Eastern Tributaries	534	8.6	4.6	25
	Western Tributaries	292	4.7	2.5	25
	Upper Bay	785	12.6	6.8	25
	Patuxent River	128	2.0	1.1	25
	Potomac River	1,276	20.4	11.0	25
	TOTAL	6,244		53.8	150
Virginia	Mainstem	4,120	76.8	35.5	25
	Rappahannock River	372	6.9	3.2	25
	York River	187	3.5	1.6	25
	James River	684	12.8	5.9	25
	TOTAL	5,363		46.2	100

Table 2. Percentages of sites failing the restoration goals (B-IBI<3) classified as severely degraded, degraded and marginal with percentages failing due to insufficient or excessive abundance and/or biomass for the period 1996 through 2003. Benthic community condition was classified into four levels based on the B-IBI. Values less than 2 were classified as severely degraded; values form 2.0 to 2.6 were classified as degraded; values greater than 2.6 but less than 3.0 were classified as marginal; and values of 3.0 or more were classified as meeting the goal. For insufficient or excessive abundance and/or biomass the percent of the stratum in either category is shown in parentheses.

	Percentage of Samples Failing Classified As			Percentage of Samples Failing With	
Region	Severely Degraded	Degraded	Marginal	Insufficient Abundance and/or Biomass	Excessive Abundance and/or Biomass
James River	36.1	48.5	15.5	36.5 (21.7)	30.8 (18.3)
York River	44.6	38.0	17.4	41.1 (29.1)	28.2 (20.0)
Rappahannock River	49.5	40.4	10.1	61.4 (40.0)	30.0 (12.0)
Virginia Mainstem	28.6	31.4	40.0	65.3 (28.0)	9.3 (4.0)
Potomac River	68.2	25.0	6.8	78.4 (57.7)	14.2 (8.6)
Patuxent River	55.0	31.2	13.8	78.0 (40.0)	11.9 (7.4)
Maryland Western Tributaries	59.8	28.6	11.6	67.0 (40.6)	19.6 (9.1)
Maryland Eastern Tributaries	27.9	52.3	19.8	45.3 (20.0)	30.2 (12.6)
Maryland Mid Bay Mainstem	68.4	17.6	14.0	72.4 (42.3)	14.7 (9.7)
Maryland Upper Mainstem	50.0	40.3	9.7	54.2 (17.7)	27.8 (10.3)

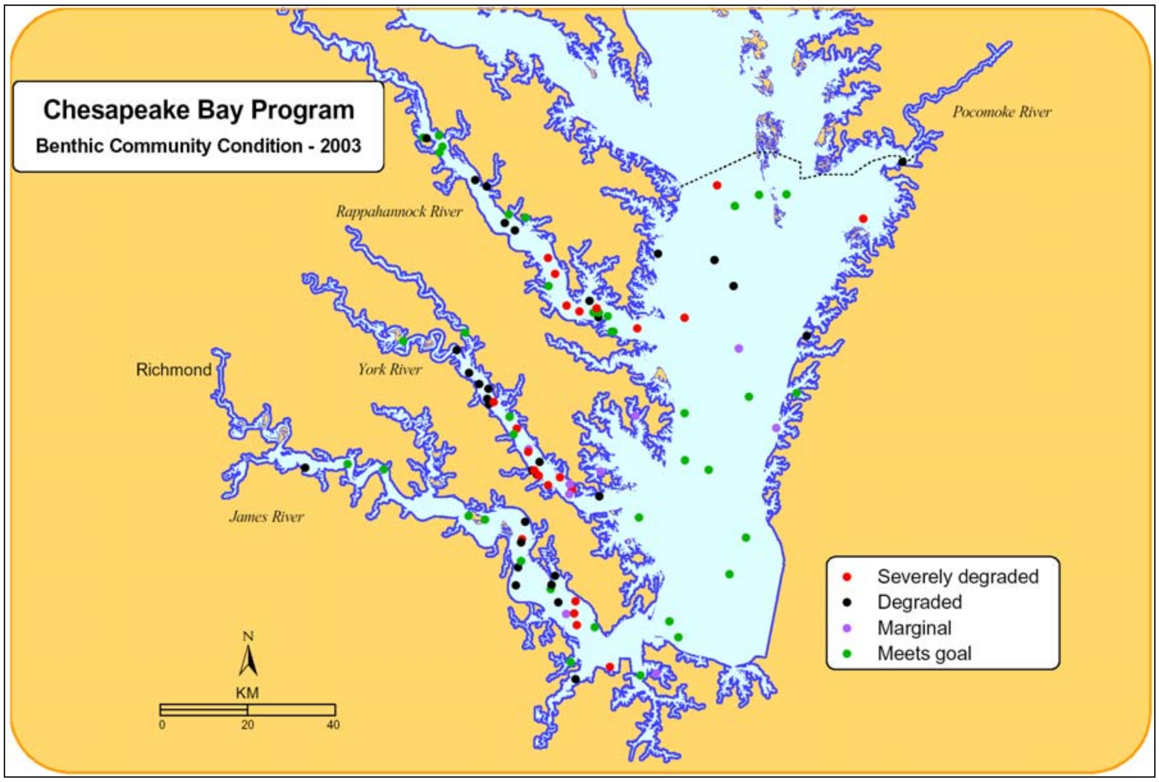

Figure 1. Results of probability based benthic sampling of the Virginia Chesapeake Bay and its tidal tributaries in 2003. Each sample was evaluated in context of the Chesapeake Bay benthic community restoration goals.

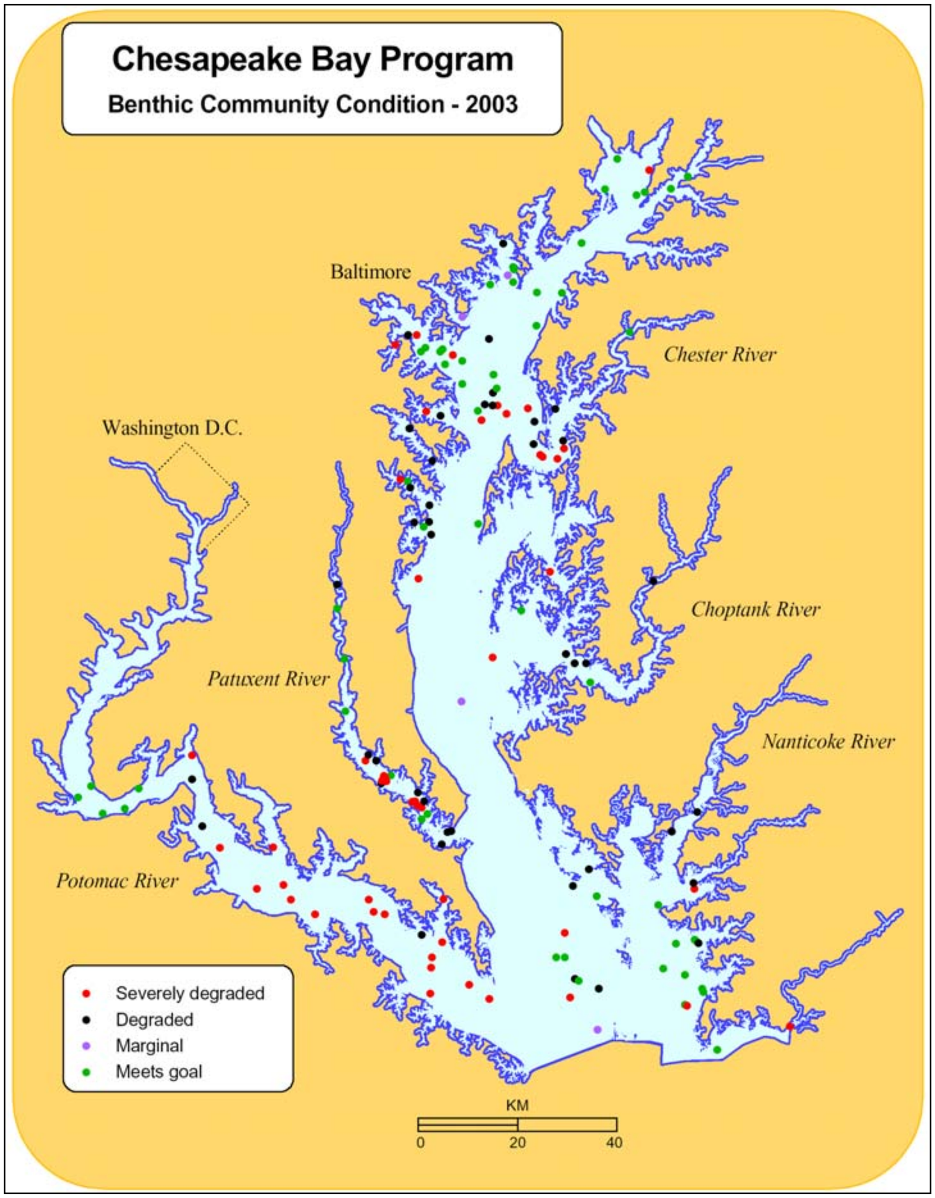

Figure 2. Results of probability based benthic sampling of the Maryland Chesapeake Bay and its tidal tributaries in 2003. Each sample was evaluated in context of the Chesapeake Bay benthic community restoration goals.

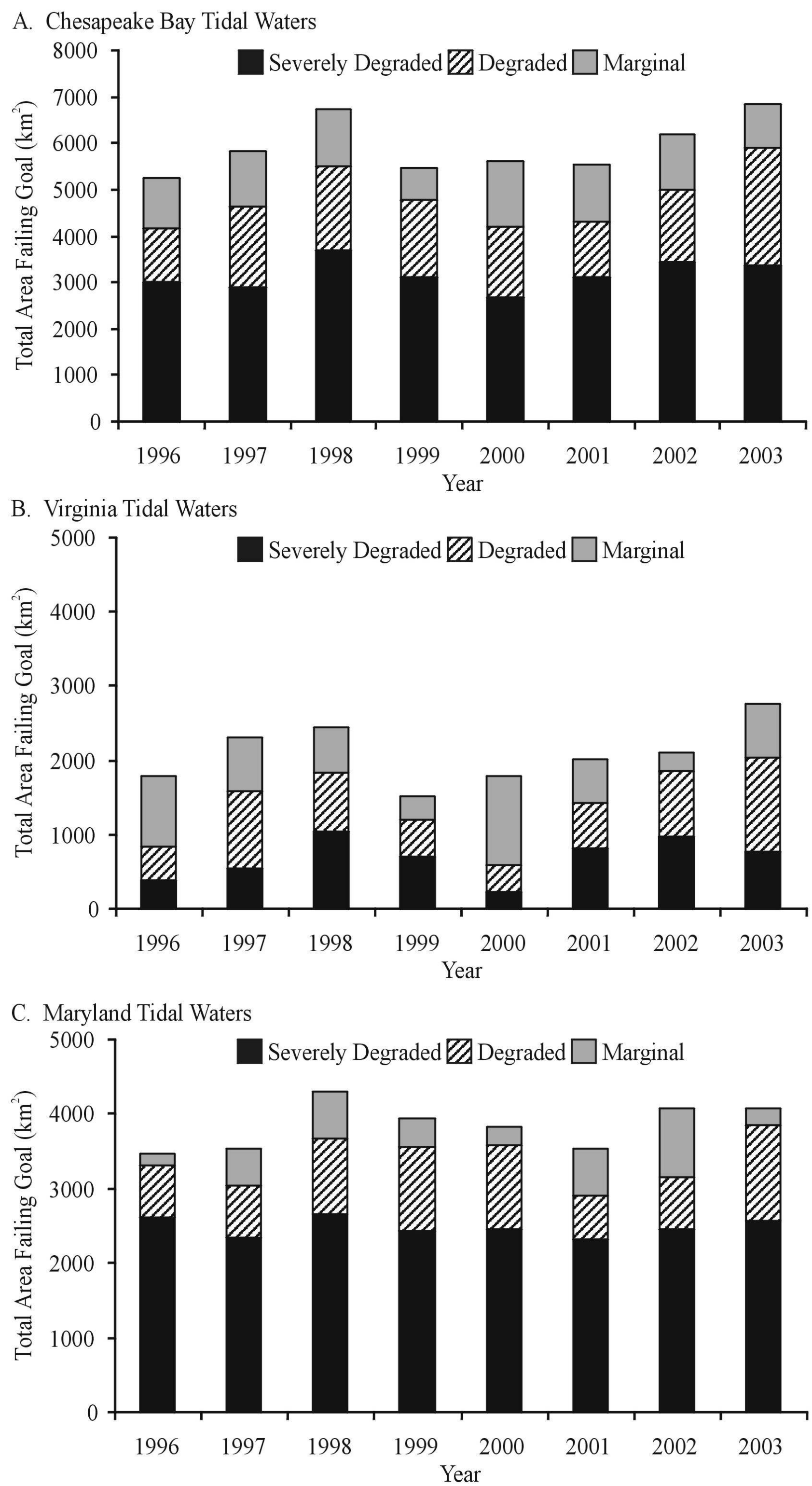

Figure 3. Change in the total area failing the Benthic Restoration Goals from 1996 through 2003 for the: A. Chesapeake Bay Tidal Waters, B. Virginia Tidal Waters, and C. Maryland Tidal Waters.

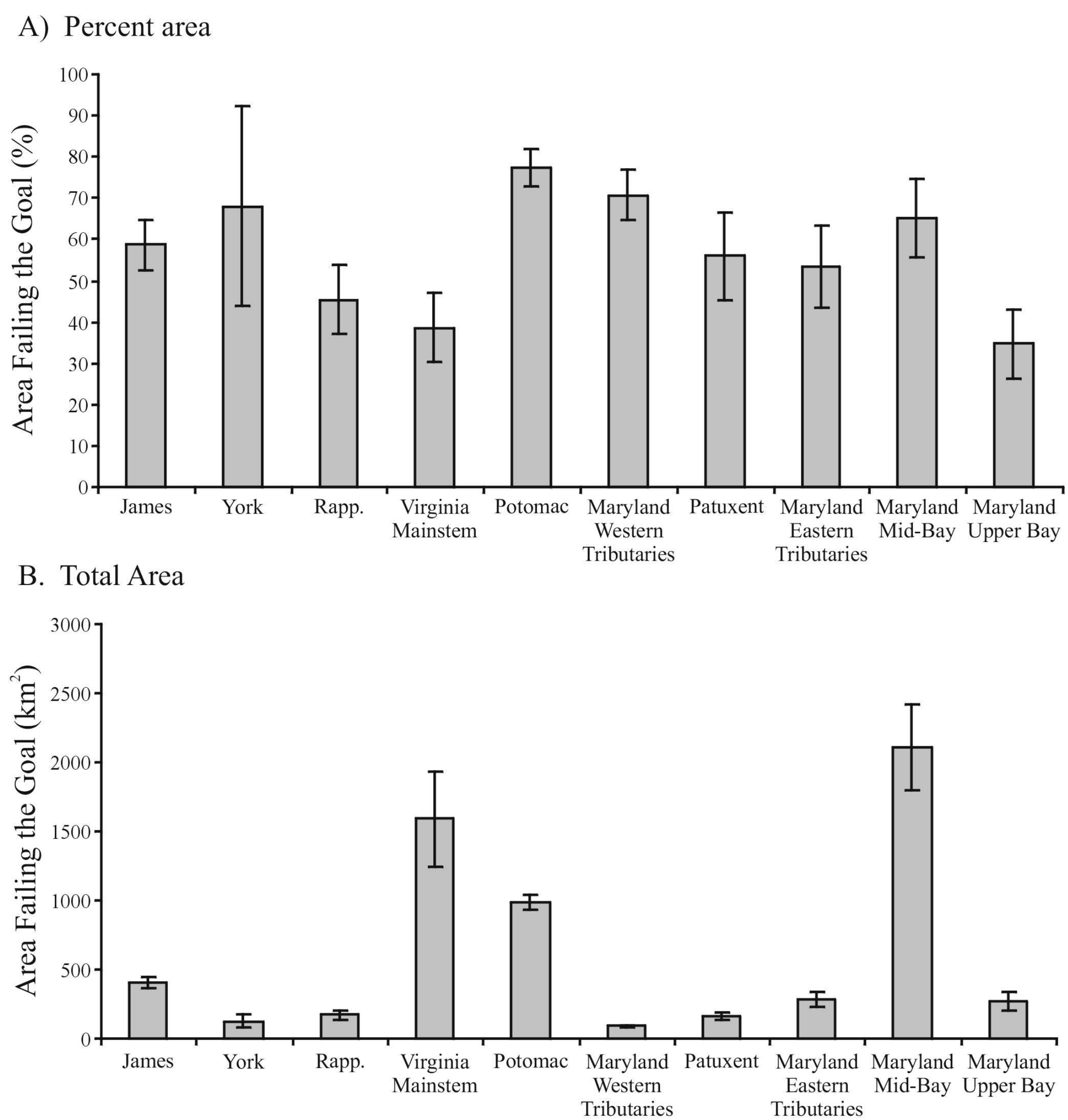

Figure 4. Differences in A. Percent Area and B. Total Area failing the Benthic Restoration Goal between sampling strata within Chesapeake Bay. Values presented are three year means ± one standard error for the period of 2001 through 2003.

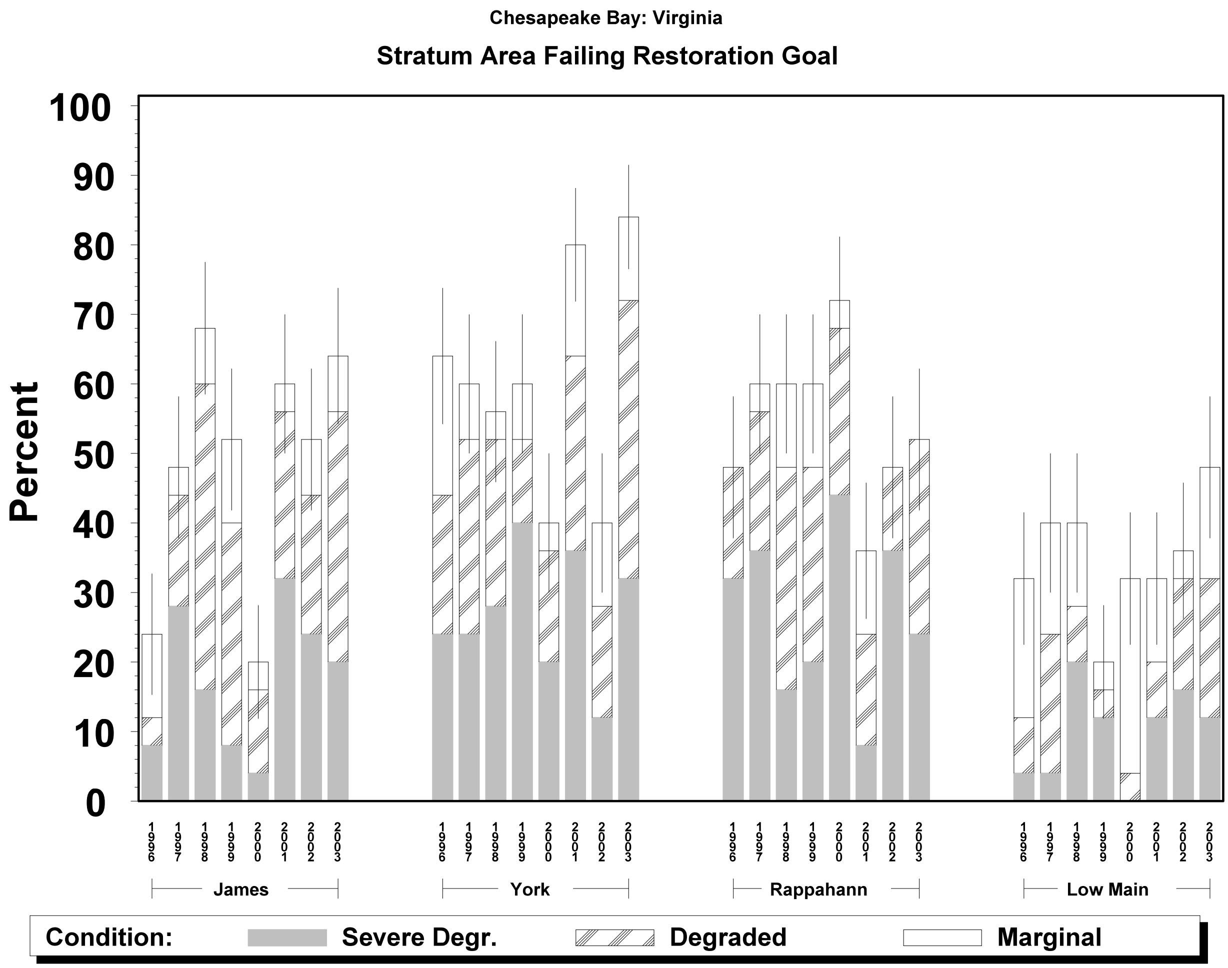

Figure 5. Proportion of the Virginia sampling strata failing the Chesapeake Bay benthic community restoration goals, 1996 to 2003. The error bars indicate ± 1 standard error.

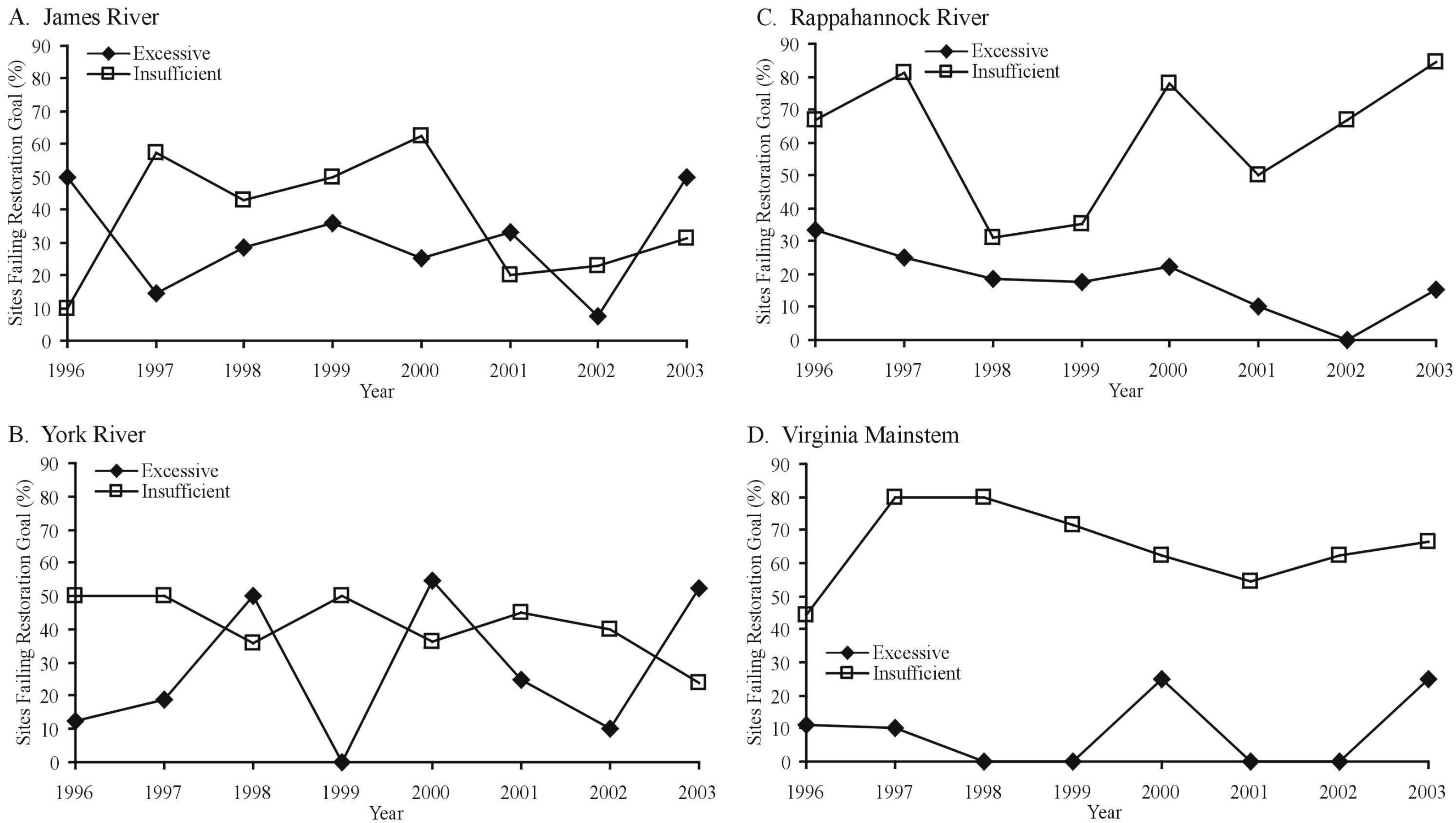

Figure 6. Change in percentages of sites failing the restoration goals due to insufficient and excessive abundance in the A. James River, B. York River, C. Rappahannock River, and D. Virginia Mainstem for the period of 1996 through 2003.

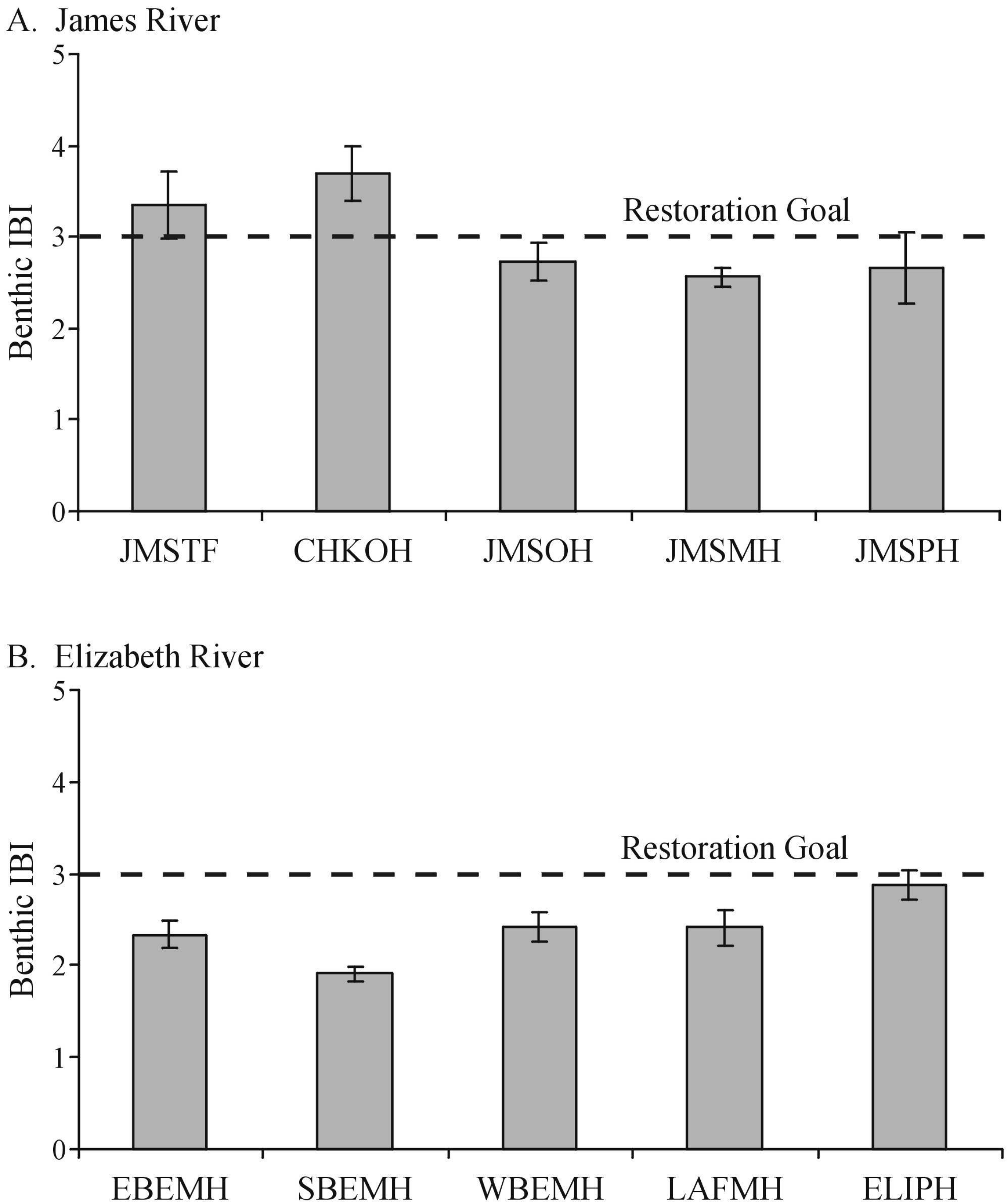

Figure 7. Three-year mean B-IBI values ± one standard error for CBP segments in the A. James River and B. Elizabeth River for the period of 2001 through 2003.

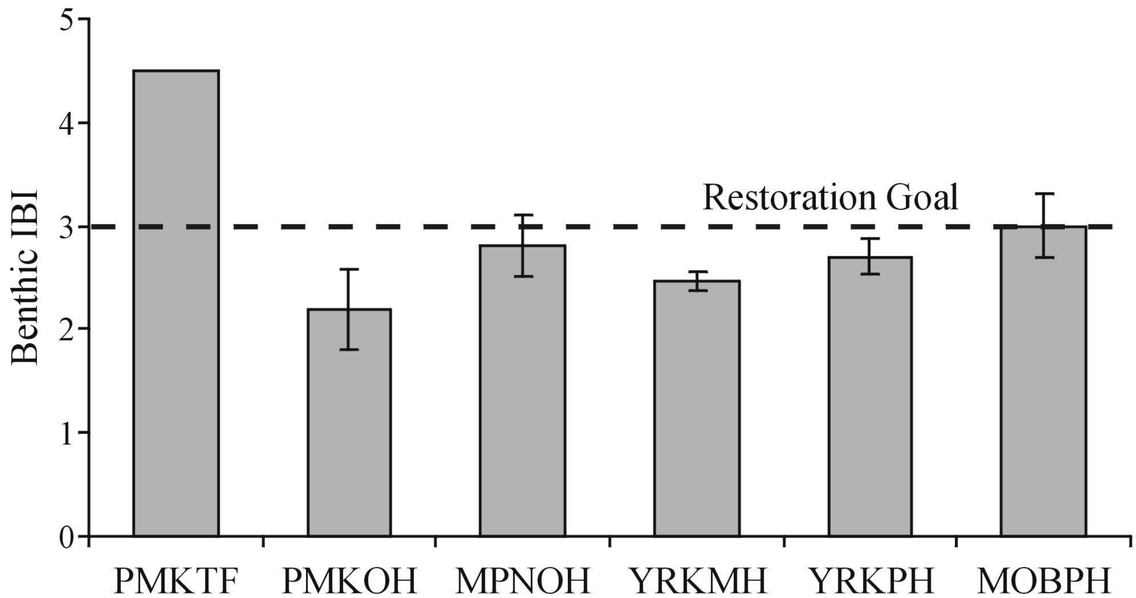

Figure 8. Three-year mean B-IBI values ± one standard error for CBP segments in the York River for the period of 2001 through 2003.

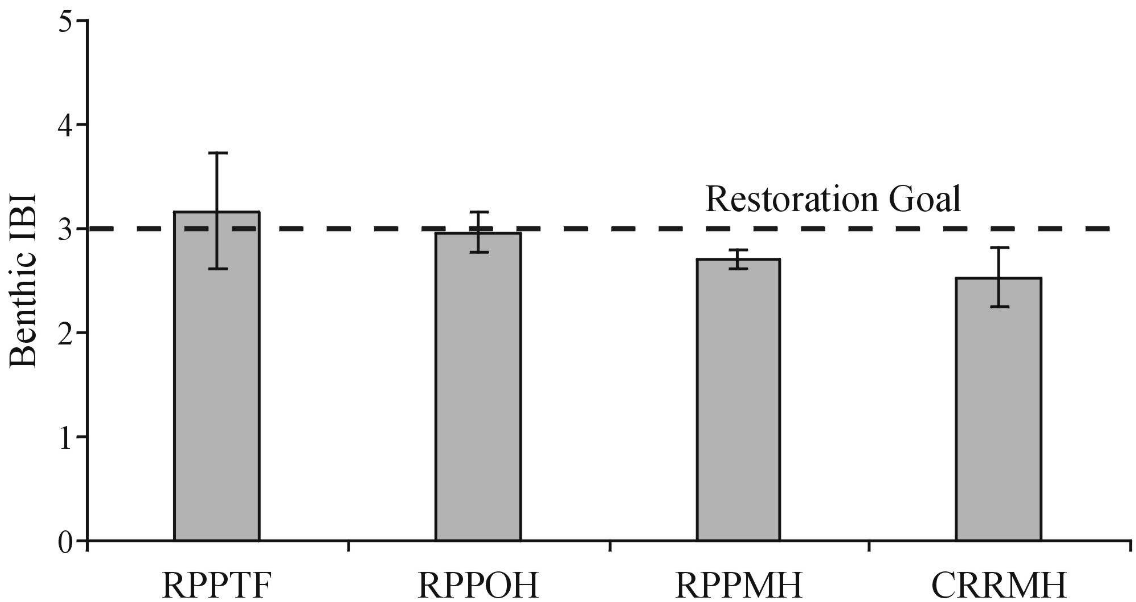

Figure 9. Three-year mean B-IBI values ± one standard error for CBP segments in the Rappahannock River for the period of 2001 through 2003.

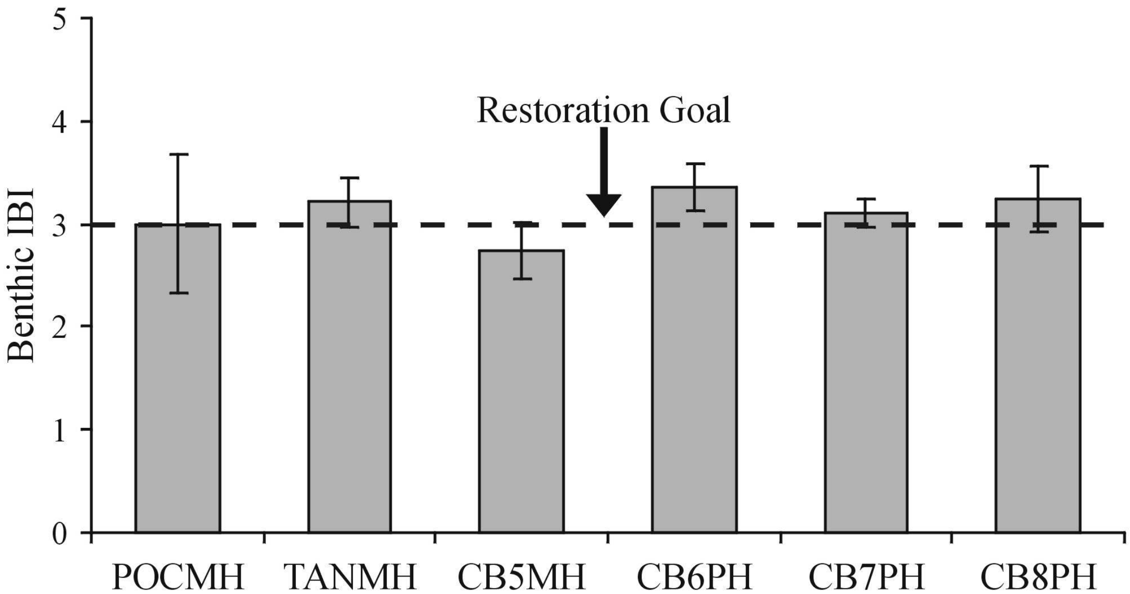

Figure 10. Three-year mean B-IBI values ± one standard error for CBP segments in the Virginia Mainstem for the period of 2001 through 2003.