Tampa Bay Estuary Program
Technical Publication # 01-06

Development of a Benthic Index to Establish Sediment Quality Targets for the Tampa Bay Estuary

FINAL REPORT

August 2005

Technical Report

Development of a Benthic Index to Establish Sediment Quality Targets for the Tampa Bay Estuary

August 22, 2005

Prepared for:
Tampa Bay Estuary Program
100 8th Ave S.E.
MS I-1/NEP
St. Petersburg, Florida 33701

Prepared by:
Janicki Environmental, Inc.
1155 Eden Isle Dr. N.E.
St. Petersburg, Florida 33704

ACKNOWLEDGEMENTS

This document benefited greatly from multiple meetings held by the Sediment Quality Advisory Committee (SQAG's) and especially from comments and reviews provided by Holly Greening of the Tampa Bay Estuary Program (TBEP). The following staff at Janicki Environmental, Inc. contributed to this document: David Wade, Kate Malloy, Anthony Janicki, Ravic Nijbroek, and Steve Grabe.

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EXECUTIVE SUMMARY

We present a single Tampa Bay Benthic Index (TBBI) that was developed specifically for Tampa Bay. The benthic index was developed in a three step process. First, a regression model was developed to correct for salinity effects among candidate metrics which were identified as being correlated with salinity. Second, stepwise discriminant analysis was applied to the comprehensive list of potential benthic metrics, including salinity corrected metrics. Results from the stepwise procedure identified the set of metrics that best discriminated between “healthy” and “degraded” sediment conditions, as defined by sediment contaminant effect levels and dissolved oxygen (number of species, proportion of total abundance represented by spionid polychaetes, proportion of total abundance represented by capitellidae). Finally, discriminant analysis was applied to the three variables identified in the previous step, to determine the linear combination for the index. After development of the index, it was applied to a preliminary validation data set, consisting of what were considered known degraded sites.

1.0 Introduction

Biological indices are often developed for the purpose of synthesizing large amounts of information into a redily usable and applicable form. These indices are designed to make environmental assessments or characterizations based on a condensed amount of information that has been identified as the most indicative of the condition being assessed (i.e., the best predictor or discriminator of healthy or degraded environmental conditions) (Gerritsen 1995, Smith et al. 2001, VanDolah et al. 1999). Index development relies on the use of potential biological indicators, and over time efforts have shifted from single indicator species to the development of multi-metric indices (Washington 1984).

Numerous versions of multi-metric indices have been developed and modified, first for freshwater (Chessman 1995, Clements et al. 1992, Karr 1981; Kerans and Karr 1994) and subsequently for estuarine systems (Engle et al. 1994; Engle and Summers 1999; Llanso et al. 2002a; Llanso et al, 2002b; McRae et al. 1998; Weisberg et al. 1997). A general approach for developing an estuarine benthic index was initially presented by Weisberg (1992). Various modifications and new indices have since been developed and presented for the southeastern and eastern United States (Engle et al. 1994; Engle and Summers 1999; Llanso et al. 2002a; Llanso et al. 2002b; McRae et al. 1998). In general, these indices favor the ability to monitor and assess estuarine condition over a broad geographic scale and have used a geographically wide range of data to develop and calibrate the models. It has been suggested that sites initially identified as degraded by such an index, would require further investigation at the local level to determine the exact cause and extent of degradation and appropriate management actions (Christman and Dauer 2003, Engle and Summers 1998).

Establishing sediment quality targets for Tampa Bay is one of the major actions currently being undertaken by the TBEP. The comprehensive plan calls for bay-wide benthic monitoring, to supplement the overall monitoring strategy employed for assessing the status and trends of environmental conditions exhibited throughout the bay (TBEP 1996). Recommendations from a workshop held by the TBEP Science Advisory Group (SAG) on the development of a Toxics Action Plan for Tampa Bay, concluded that the benthic community should be the primary measurement tool for establishing and monitoring sediment quality targets. To assess sediment condition in Tampa Bay, the Probable Effects Levels (PEL) established by Long et al.(1994) are used, in combination with dissolved oxygen, to assign the known condition (“healthy” or “degraded”) of a sediment sample. A PEL exceedance for a particular contaminant means that the contaminant is present at a level above which biological effects are likely.

The objective of this technical document is to present the methodology used in the development of the Tampa Bay Benthic Index (TBBI). In general, the TBBI would successfully identify degraded sediments based on the current benthic community structure, and serve as a tool for establishing and monitoring sediment quality targets. Degraded sites are the target, as these are the areas where remediation or other management efforts would be focused.

2.0 Index Development

Index development followed the methodology developed by Engle and Summers (1999), and was developed with the assistance of the TBEP Sediment Quality Advisory Group.

2.1 Data

Available data was provided by the Tampa Bay Benthic Monitoring Program for 1993 to 2000. This program began collecting annual benthic data in 1993 and data collection remains ongoing. Data collection methods followed the probability-based sampling design and field methods established by the U.S. Environmental Protection Agencies (EPA) Environmental Monitoring and Assessment Program (EMAP) for Near-Coastal Waters. The regional design specified by EMAP was tailored to the Tampa Bay Estuary by establishing stratified random sampling. Tampa Bay was divided into seven bay segments as follows: Old Tampa Bay (OTB), Hillsborough Bay (HB), Middle Tampa Bay (MTB), Lower Tampa Bay (LTB), Terra Ceia Bay (TCB), Boca Ciega Bay (BCB) and the Manatee River (MR) (Figure1). Hexagonal grids were randomly placed over the entire estuary and sampling stations were randomly selected from within each bay segment.

Annually, during a late summer index period (September 1 to October 31), a maximum of 150 benthic samples were collected bay-wide. An index period was chosen to eliminate seasonality as an additional confounding factor in interpreting index scores. Late summer was chosen as the index period because it is a time of degraded local environmental conditions for benthos, due to increases in temperature and decreases in dissolved oxygen concentrations (Summers et al. 1991, Coastal Environmental, Inc. 1996). During locally degraded conditions, benthic macrofauna are highly responsive to stress in their environment and differences between healthy and degraded sediments are more evident (Alden 1997; Engle et al. 1994; Llanso et al. 2002; Weisberg et al.1997).

Benthic sediment samples for biological and contaminant analysis were obtained with a stainless steel Young-modified Van Veen grab sampler ($0.04m^2$)(Grabe et al. 2002). A 0.5 mm sieve was used to sort biological samples. For our analysis, macrofauna was defined as those organisms retained in a 0.5 mm sieve. Water quality measurements were obtained from a Hydrolab Surveyor II or similar unit. Additional field and laboratory procedures followed the protocols outlined in Courtney et al (1993; 1995).

Index development began with a calibration data set (Grabe 2002) and a comprehensive list of candidate biological metrics following Engle and Summers (1999), which were considered to have a potential association with either healthy or degraded benthic sediments (Table 1). Biological variables were transformed and standardized prior to use in the analysis. Transformations of the form ln(abundance + 1) were applied to all abundance data, and arcsine transformations were applied to all proportional measures.

Table 1. Candidate benthic metrics considered for inclusion in the Tampa Bay Benthic Index.

Diveristy and Species Richness Metrics
- Number of species
- Shannon-Wiener Diversity Index

Abundance and Taxonomic Composition Metrics
- Total benthic abundance
- Polychaete abundance
- Proportion of benthic abundance as polychaetes
- Capitellid polychaete abundance
- Proportion of total benthic abundance as capitellid polychaetes
- Spionid polychate abundance
- Proportion of total benthic abundance as spionid polychaetes
- Tubficid abundance
- Proportion of total benthic abundance as tubificids
- Amphipod abundance
- Proportion of total benthic abundance as amphipods
- Isopod Abundance
- Proportion of total benthic abundance as isopods
- Bivalve abundance
- Proportion of total benthic abundance as bivalves
- Cumacean abundance
- Proportion of total benthic abundance as cumaceans
- Dipteran abundance
- Proportion of total abundance as dipterans
- Gastropod abundance
- Proportion of total benthic abundance as gastropods
- Insect abundance
- Proportion of total benthic abundance as insects

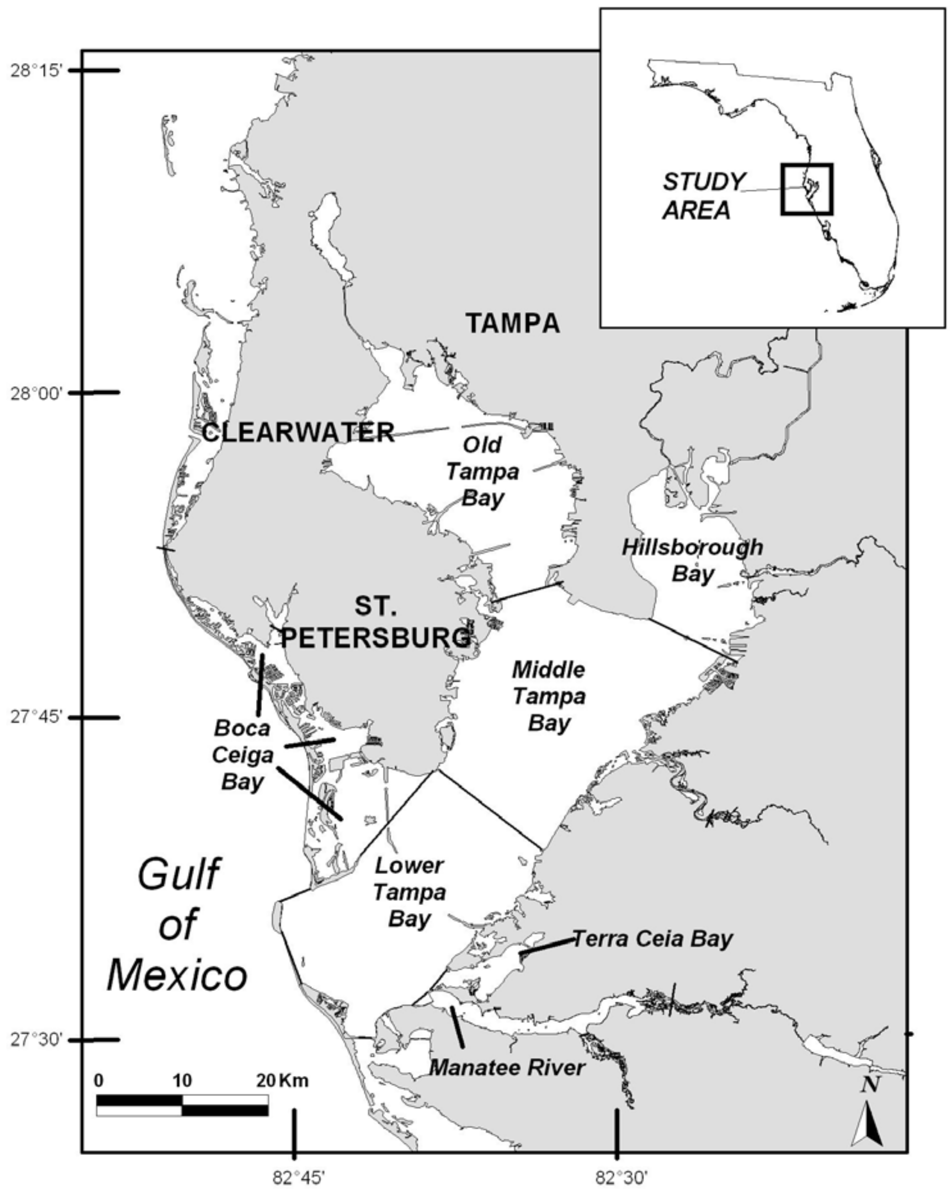

Figure 1. Location of Tampa Bay Estuary Program bay segments, showing major tributaries and cities within the watershed.

2.2 Development of Operational Definitions

The next step was to select sediment contaminant measures that were relatable to the benthic community. A variety of scalars have been used to define sediment contaminant levels that result in measurable biological responses in the benthic community. These scalars include "Effects Range Median" and "Effects Range Low", known as ERMs and ERLs (Long et al. 1995); "Probable Effects Level" and "Threshold Effects Level", known as PELs and TELs (MacDonald Environmental Services Ltd. 1994); and a ratio combination of these measures, known as PEL quotients. We have chosen to apply the PEL-TEL approach, as it was developed specifically for Florida estuarine sediments (MacDonald Environmental Services Ltd. 1994). The Threshold Effects Level for a given contaminant is the level below which adverse biological effects are not likely. The Probable Effects Level is the level above which adverse biological effects are likely.

To establish a provisional gradient of benthic condition, an operational *condition* variable was created and applied to the data to identify observations that represented healthy and degraded sediment quality. The *condition* variable was used to establish two groups that were separated along an axis of sediment degradation. The *condition* variable was based on operational definitions of "healthy" and "degraded" sites, which were defined by the TBEP Sediment Quality Action Group from known sediment contamination levels and bottom water dissolved oxygen. Healthy benthic sediments were defined as having mid-day bottom dissolved oxygen levels > 4.5 mg/L *and* no TEL or PEL exceedances. Degraded conditions were defined as either having mid-day bottom dissolved oxygen levels < 2.5 mg/L *or* having 1 or more PEL exceedance. To qualify for inclusion in the "healthy" class, samples were required to have dissolved oxygen, metals, and 19 of 22 possible organic compounds reported. To qualify for inclusion in the "degraded" class, samples were not required to be complete with respect to the number of contaminants reported (i.e., occurrence of any reported PEL exceedances was considered sufficient).

Of the 578 sample sites considered for this analysis, operational healthy conditions in the calibration dataset were defined for 302 sites (52 %). Degraded conditions were defined for 73 sites (13 %). Sites preliminarily classified as healthy and degraded were located across the range of salinity conditions (Figure 2). Sites preliminarily classified as degraded were located across the range of percent silt-clay conditions, but sites preliminarily classified as healthy were located primarily in sandy sediments (Figure 2).

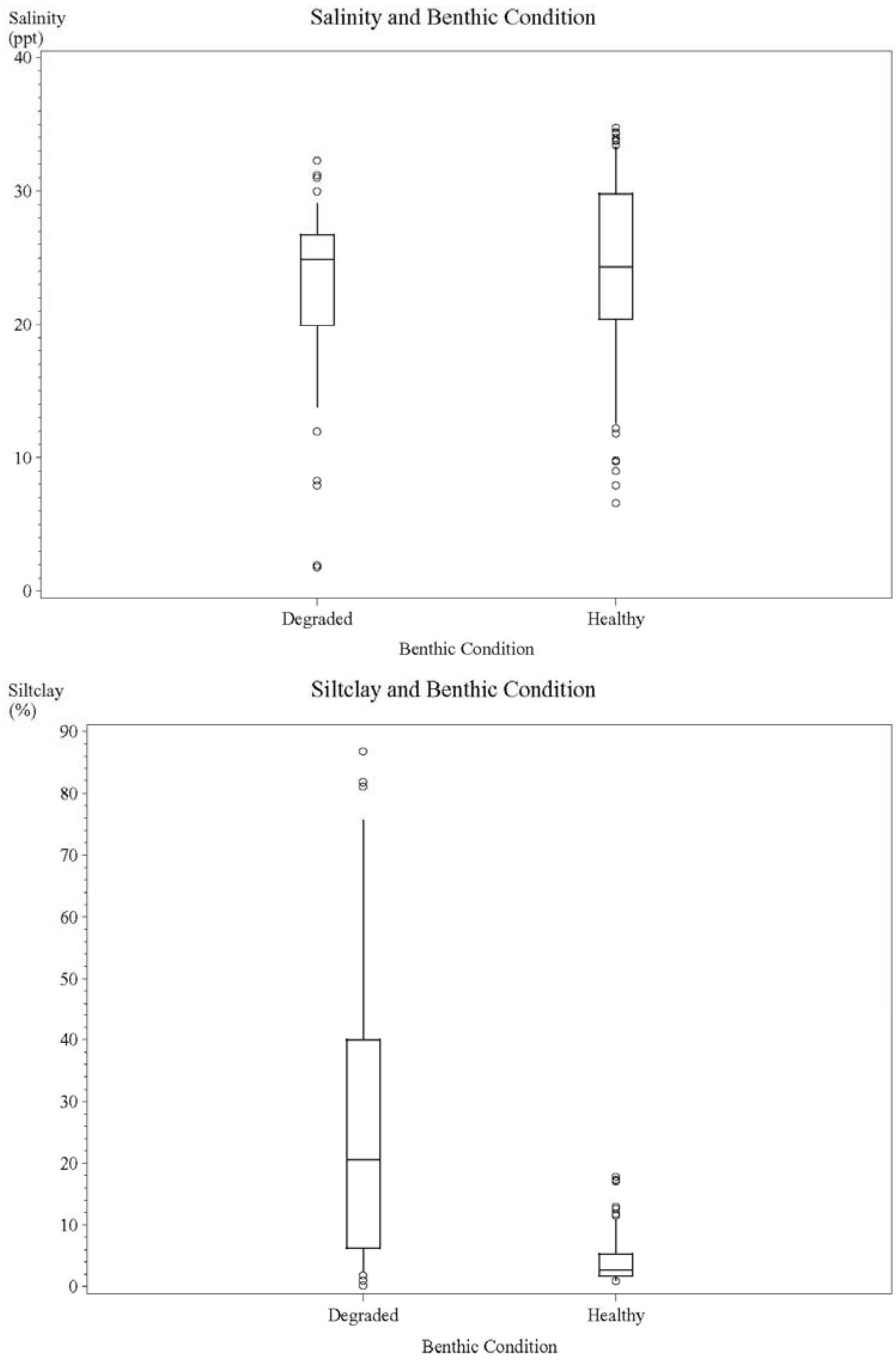

Figure 2. Distribution of salinity and sediment type (percent silt-clay) as they occur across healthy and degraded sites in Tampa Bay, as defined by our condition variable.

2.3 Salinity Correction Using Regression

Salinity can confound the interpretation of the relative effects of sediment contaminants on benthic community structure. Confounding influences of salinity were removed from the candidate benthic variables prior to analyzing the relationships of contaminants and benthic community structure, following Engle and Summers (1999). Initial correlation analysis showed that several of the candidate benthic community metrics were correlated with salinity or silt-clay percentage, and required adjustment for the effects of salinity as specified by Weisberg (1992) and Engles et al. (1994). Benthic metrics were adjusted if the Pearson correlation coefficient was statistically significant at an alpha level of 0.05 and had an r value >0.25.

Regression models were developed to predict expected values of the correlated benthic metrics using observations from benthic samples that were designated as healthy. This was done by first calculating the 90th percentile of the candidate benthic metric for overlapping salinity intervals of 5 ppt. Polynomial curves were then fit through the 90th percentile of the benthic metric and the midpoints of the salinity intervals.

The polynomial function developed for the relationship between the 90th percentile of the number of species and salinity is shown in Figure 3. The model (Figure 3) was a saturated model used to describe a reference point for the greatest number of species expected for salinity over a model domain of 15 ppt to 35 ppt. The explained variation (R^2) for the above relationships ranged between 0.80 and 0.95 ($p<0.0001$) for all metrics except for the expected abundance of cumacean species, and expected abundance of isopoda species, which were 0.57 and 0.61 ($p<0.0001$) respectively.

Finally, the benthic metrics were corrected for salinity effects by expressing the values as the proportion of the expected benthic metric value measured at the time the sample was collected.

Expected Shannon-Weiner Diversity Index =
10.54385 - (0.82678 x salinity) + (0.03497 x salinity^2) – (0.00045992 x salinity^3)
Expected number of benthic species =
3.29830 - (0.23576 x salinity) + (0.01081 x salinity^2) – (0.00015327 x salinity^3)
Expected abundance of cumacean species=
-9.66892 + (1.47054 x salinity) – (0.05796 x salinity^2) + (0.00072610 x salinity^3)
Expected abundance of isopoda species=
-0.31943 + (0.04647 x salinity) – (0.00194 x salinity^2) + (0.00002602 x salinity^3)

The proportion of total benthic abundance as polychaetes and the proportion of total benthic abundance as gastropods were correlated with silt-clay percentage and had r values of 0.28 and 0.25, respectively ($p<0.0016$). The adjustment procedure used to correct for salinity could not be replicated for silt-clay due to the absence of healthy sediments in samples with high silt-clay percentages (Figure 2).

All of the salinity-corrected and uncorrected candidate benthic metrics were standardized to a common scale using the mean and standard deviation for each variable from the 1993-2000 data (Table 2).

Table 2. Constants obtained from calibration data set, 1993-2000, representing the mean and standard deviation to be applied to data set prior to index application.

Variable	Mean	Standard Deviation
Number of Species	0.84227	0.18952
Proportion of Total Abundance as Spionid Polychaete	0.11646	0.18554
Proportion of Total Abundance as Capitellidae 0.041249	0.080250	

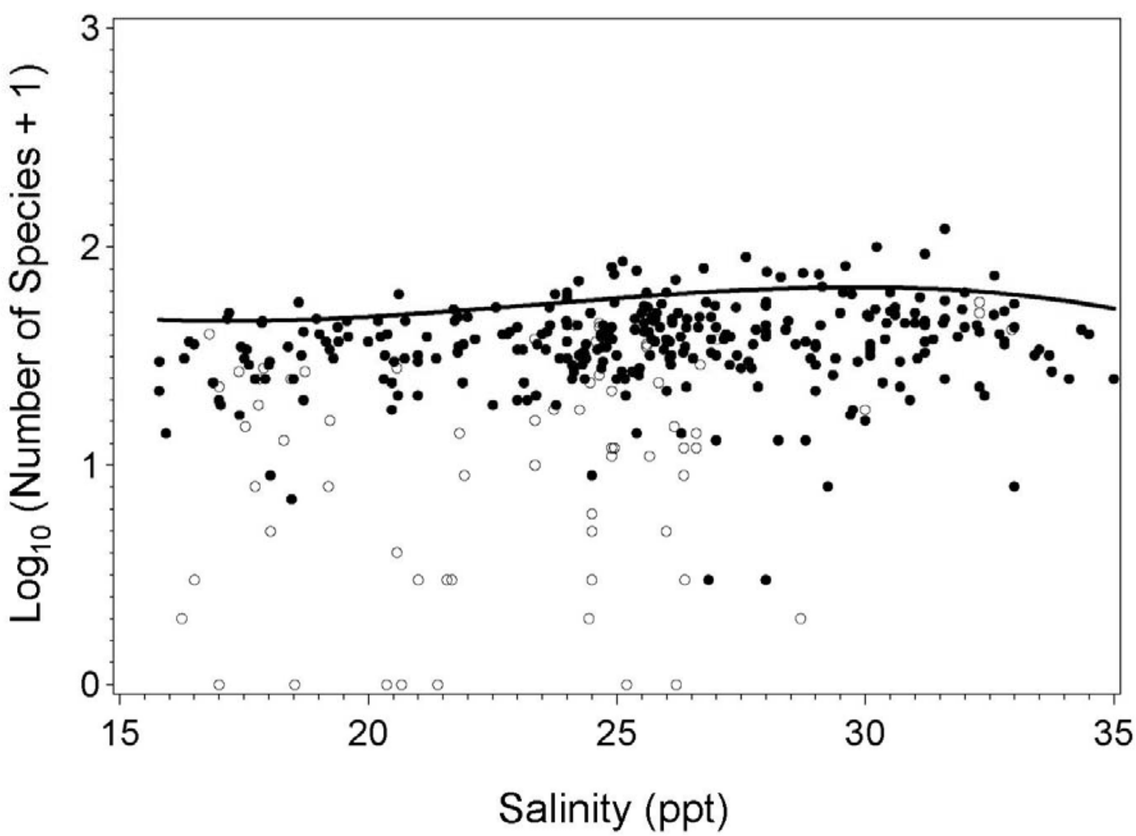

Figure 3. Relationship between the 90th percentile of the number of species and salinity, as represented by a polynomial regression. Solid circles are Healthy sites, the open circles are Degraded sites, the line represents a fitted model of the 90th percentile of the log number of species as a function of bottom salinity at capture.

2.4 Stepwise Discriminant Analysis

Stepwise discriminant analysis was performed to identify the benthic metrics from the candidate list that best discriminated between sediments classified as “healthy” or “degraded” based on known sediment quality conditions (SAS Institute, 2001). A set of three benthic metrics from the input list of candidate metrics were identified by the stepwise discriminant analysis as explaining a statistically significant portion of the variation between benthos in healthy and degraded sediment conditions (Table 3).

Table 3. Results of the stepwise discriminant analysis, showing the candidate metrics that were selected as the best discriminators between healthy and degraded sediment conditions, as selected for use in the TBBI. Metrics corrected for the effects of salinity prior to use in analysis are annotated with the symbol *.

Candidate Metrics	Partial R^2	F	Pr>F	Average Squared Canonical Correlation
Number of Species*	0.33	182.85	<.0001	0.33
Proportion of Total Abundance as Spionid Polychaetes	0.12	50.17	<.0001	0.41
Proportion of Total Abundance as Capitellidae	0.05	21.33	<.0001	0.44

2.5 Linear Discriminant Analysis

A linear discriminant function was applied to the variables selected by the stepwise procedure, to obtain the discriminant scores (coefficients for each of the variables) that comprise the TBBI (SAS Institute, 2001). The index was defined as:

TBBI = - 0.11407
+ 0.32583 x proportion of expected number of species
- 0.15020 x proportion of total abundance as spionid polychaetes
- 0.60943 x proportion of total abundance as capitellidae

2.6 Normalizing Index Scores

The final step was to apply the index to the data and normalize the final index scores from 0 to 100. The formula for normalizing the index score based on Engles et al. (1999) was applied, as follows:

Normalized TBBI Score= ((Raw TBBI score - (M))/ R) x 100

where M= the minimum TBBI score
R= the range of TBBI scores

2.7 Placing Values on Index Scores

In order to give the resultant index scores "value", which will be used in the future to assess the sediment quality of the site, it was necessary to select cut-off or break points to define index scores that represent "healthy" and "degraded" conditions. Based on a review of the cumulative distribution frequency of index scores (Figure 4) by the Sediment Quality Advisory Group, and a consideration of goals of the TBEP, index scores >= than 87 are defined as "healthy" and scores < than 73 are defined as "degraded". Intermediate sites consist of index scores ranging from 73-86. These cut points were applied to the calibration data set for initial model verification. These cut points were largely based on the goal of maximizing the ability of the index to accurately identify truly degraded sites, and limiting the rate of false positives and false negatives to 10% (Figure 4). False positives occur when the index incorrectly identifies a site as degraded; false negatives occur when the index fails to identify a site that is degraded.

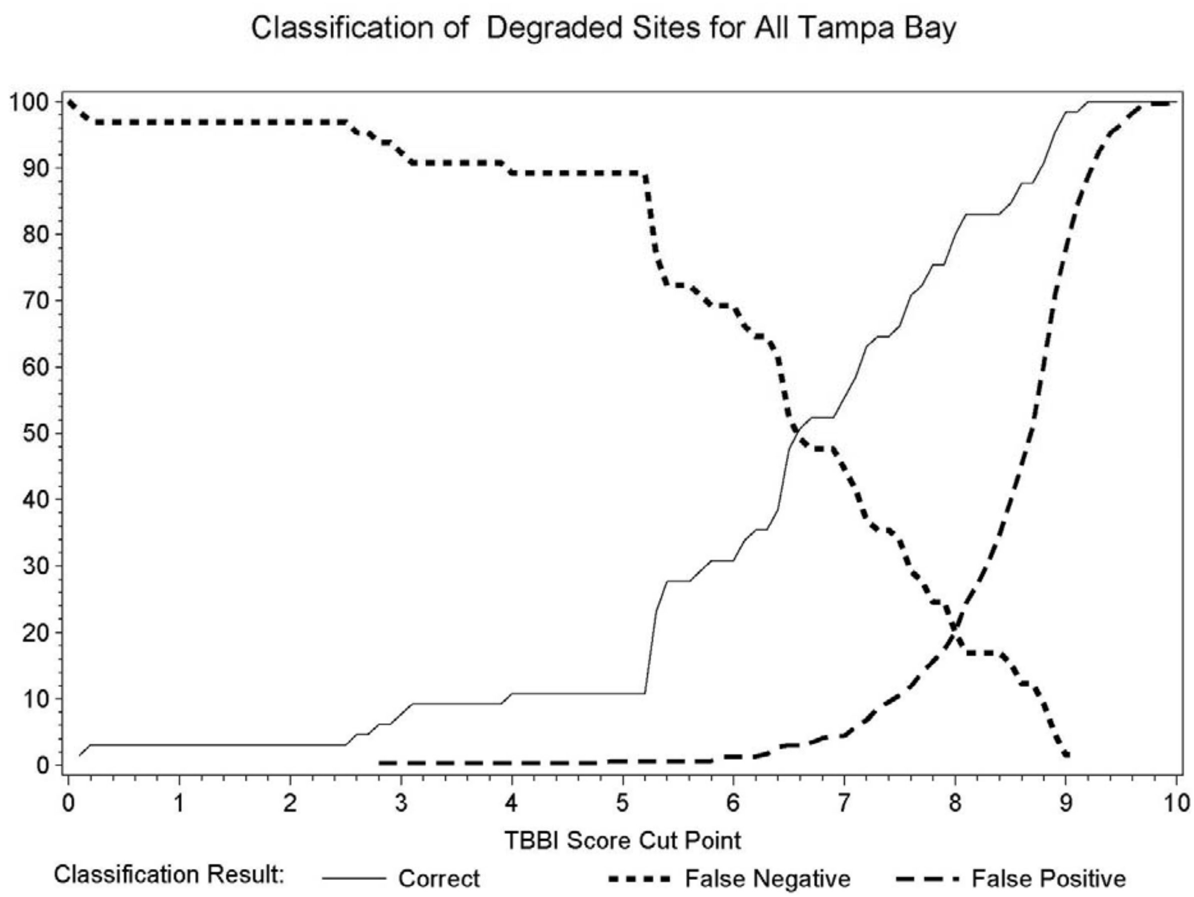

Figure 4. Cumulative distribution frequency plot showing the relationship between percentage of sites identified correctly as degraded, false negatives and false positives, and the relationship between the TBBI score.

3.0 Validation Using Independent Benthic Samples

The resultant TBBI was then applied to an independent dataset for validation. These indepdent data were data collected in habitats expected to be degraded.

3.1 Validation Data

The validation dataset consisted of data collected as part of a directed study in 2002 (Special Studies data). The 2002 special benthic study targeted areas previously identified as degraded by sediment contamination (Long et al. 1994). Only samples collected within the 15 ppt to 35 ppt salinity model domain for the TBBI were evaluated.

Data were evaluated from this special study if sufficient data (i.e., biological data, DO data, metals data, and 19 of 22 possible organic compounds). Data were also evaluated for samples which were known to be DO degraded even if insufficient contaminant data were reported. The validation dataset consisted of 36 samples, collected throughout Bayboro Harbor (4), Bay Side Bridge (3) and Ybor Channel (29).

3.2 Validation Results

TBBI scores were calculated for each benthic sample from the validation dataset following the methods previously described. Fixed values for use in the standardization of index metrics were derived from the calibration data set (Table 2). Fixed values for use in final normalization of index scores were also derived from the calibration data set. Table 4 presents the TBBI score for each of the validation samples and the observed values of parameters important to TBBI score calculation.

In Bayboro Harbor, each of the four benthic samples was correctly identified by the index as degraded (Table 4). These samples were collected in late August of 2002, were found to be defaunated, and were found to be relatively highly contaminated. Each of these four samples had sufficient metals and organics data reported to qualify for evaluation. The Bayboro Harbor samples were reported to have TEL exceedances on the majority of contaminants tested, and multiple PEL exceedances in three of the four samples. The PEL exceedances included organic compounds, pesticides, copper, zinc, lead, and cadmium.

In the Bayside Bridge region of Old Tampa Bay, all three samples evaluated were classified as degraded based on low DO values at the time of sampling (Table 4). These samples were collected in mid August of 2002. Based on TBBI scores only, one of the sites was classified as degraded, two as intermediate. In general, these sites were observed to have a relatively large number of benthic species for the low DO conditions that were reported.

In the Ybor Channel region, all 29 samples evaluated from August to September of 2002 were identified as degraded due to low DO values (Table 4). Many of these sites were also identified as being degraded due to PEL exceedances. A group of 15 out of 31 samples were correctly identified as degraded based on a TBBI score of less than 73 (Table 4). This group of samples with a TBBI score of less than 73 were found to have frequent PEL and TEL exceedances for multiple contaminants and few species. A second group of 14 samples were classified as intermediate based on low TBBI scores that ranged from 76 to 85. This second group had almost no PEL exceedances, fewer TEL exceedances than the first group, and higher numbers of species than the first group.

Table 4. Summary table of validation data set, showing parameters important to index score calculation.

TBBI Score	Segment	Known Condition	DO (mg/L)	TEL Exc	PEL Exc	Metals Reported	Organics Reported	# Species	Proportion of Expected Species	Spionid	Capitellid
5.27939	BH	Degraded	1.745	21	3	7	20	0	-4.4441	-0.5276	-0.5140
5.27939	BH	Degraded	2.1	22	11	7	19	0	-4.4441	-0.5276	-0.5140
5.27939	YBC	Degraded	1.13	16	1	0	20	0	-4.4441	-0.5276	-0.5140
5.27939	YBC	Degraded	1.115	15	0	0	19	0	-4.4441	-0.5276	-0.5140
5.27939	YBC	Degraded	0.685	0	0	0	19	0	-4.4441	-0.5276	-0.5140
5.27939	YBC	Degraded	1.31	0	0	*	*	0	-4.4441	-0.5276	-0.5140
5.27939	YBC	Degraded	1.02	18	5	0	19	0	-4.4441	-0.5276	-0.5140
5.27939	YBC	Degraded	1.175	24	7	7	20	0	-4.4441	-0.5276	-0.5140
5.27939	BH	Unknown	4.05	20	0	7	20	0	-4.4441	-0.5276	-0.5140
5.31619	BH	Degraded	1.695	24	16	7	19	0	-4.4441	-0.6277	-0.5140
5.98278	YBC	Degraded	0.3	0	0	0	19	1	-3.5627	-0.5277	-0.5140
5.98546	YBC	Degraded	1.57	19	4	0	20	1	-3.5594	-0.5277	-0.5140
5.99380	YBC	Degraded	0.235	14	2	0	20	1	-3.5489	-0.5277	-0.5140
6.39728	YBC	Degraded	1.645	17	2	0	20	2	-3.0433	-0.5277	-0.5140
6.47652	YBC	Degraded	1.6	16	0	0	19	4	-2.3926	0.6684	-0.5140
6.5557	BSB	Unknown	5.625	0	0	0	19	42	0.5341	0.2429	1.1026
6.5888	BSB	Unknown	4.465	0	0	0	19	19	-0.5145	0.5443	0.4455
6.8226	YBC	Degraded	1.495	24	5	7	20	6	-1.9589	0.6684	-0.5140
6.8778	YBC	Degraded	1.12	15	1	0	19	5	-2.1618	0.0673	-0.5140
6.9623	BSB	Degraded	2.175	0	0	0	19	25	-0.2011	-0.5007	0.6204
7.1007	YBC	Degraded	1.57	15	3	0	20	5	-2.1618	-0.5277	-0.5140
7.1032	YBC	Degraded	1.615	10	0	0	19	5	-2.1586	-0.5277	-0.5140
7.1178	BSB	Unknown	4.37	0	0	0	19	49	0.7309	2.4042	0.2986
7.4463	BSB	Unknown	4.31	0	0	0	19	14	-0.9066	1.2559	-0.5140
7.5708	YBC	Degraded	0.9	10	1	0	20	10	-1.3443	-0.0321	-0.5140
7.6680	YBC	Degraded	0.975	14	1	0	20	10	-1.3973	-0.4112	-0.5140
7.7072	YBC	Degraded	1.15	0	0	0	19	11	-1.2406	-0.1781	-0.5140
7.7169	YBC	Degraded	1.49	7	0	0	20	10	-1.3897	-0.5277	-0.5140
7.8053	YBC	Degraded	1.435	4	0	7	20	27	-0.1559	0.3758	-0.1363
7.8231	YBC	Degraded	0.985	5	0	7	20	19	-0.5525	-0.3671	-0.17718
7.8541	YBC	Degraded	1.06	0	0	0	19	11	-1.2178	-0.5277	-0.5140
7.9176	YBC	Degraded	1.265	8	0	0	20	20	-0.5296	0.7924	-0.5140
7.9591	YBC	Degraded	2.22	12	0	0	20	20	-0.5296	0.6795	-0.5140
7.9718	YBC	Degraded	1.53	2	0	7	19	14	-1.0025	-0.3810	-0.5140
8.0119	BSB	Degraded	0.965	0	0	*	*	21	-0.4287	0.7551	-0.5140
8.0959	YBC	Degraded	1.765	0	0	0	20	28	-0.0454	-0.2447	-0.1184

TBBI Score	Segment	Known Condition	DO (mg/L)	TEL Exc	PEL Exc	Metals Reported	Organics Reported	# Species	Proportion of Expected Species	Spionid	Capitellid
8.1577	YBC	Degraded	2.27	6	0	0	20	17	-0.7213	-0.2759	-0.5140
8.2185	YBC	Unknown	2.515	0	0	0	19	14	-0.7611	-0.5277	-0.5140
8.2186	YBC	Degraded	0.53	2	0	7	20	30	-0.0250	0.8720	-0.4655
8.2852	BSB	Unknown	4.65	0	0	0	19	19	-0.5308	-0.2093	-0.5140
8.3992	BSB	Unknown	5.39	0	0	0	19	42	0.4717	-0.3630	-0.0165
8.4033	YBC	Unknown	3.24	0	0	0	20	32	0.3242	-0.5219	-0.0590
8.4578	YBC	Degraded	2.495	11	0	7	19	26	-0.2028	-0.3816	-0.4119
8.4777	YBC	Degraded	1.795	1	0	7	19	37	0.3225	0.6457	-0.3975
8.9363	BSB	Unknown	3.83	0	0	0	19	34	0.2319	-0.4973	-0.4716

4.0 References

Alden III, R. W., Ewing, R. M., Helmsetter, M. F., Winfield, J. G., Burdige, D. J., Rule, J. H., Wong, G. T F., Swift, D. J. P., and A. Muller. 1991. Distribution and management implications of contaminants in Elizabeth River sediments. Applied Marine Research Laboratory Report No. 741-I.

Chessman, B. C. 1995. Rapid assessments of rivers using macroinvertebrates: A procedure based on habitat-specific sampling, family level identification, and a biotic index. Australian Journal of Ecology 20:122-129.

Christman, C. S. and D. M. Dauer. 2003. An approach for identifying the causes of benthic degradation in Chesapeake Bay. Environmental Monitoring and Assessment 81: 187-197.

Clements, W. H., D. S. Cherry and J. H. Van Hassel. 1992. Assessment of the impact of heavy metals on benthic communities in the Clinch River (Virginia): evaluation of an index of sensitivity. Canadian Journal of Fisheries and Aquatic Sciences 49:1686-1694.

Coastal Environmental, Inc. 1996. Statistical Analysis of the Tampa Bay National Estuary Program 1993 Benthic Survey. Prepared by Coastal Environmental, Inc., St. Petersburg, FL.

Courtney, C. M., R. Brown, and D. Heimbuch. 1993. Environmental Monitoring and Assessment Program Estuaries-West Indian Province: Volume 1. Introduction, Methods and Materials, and Quality Assurance Field and Laboratory Operations Manual for a Synoptic Survey of Benthic Macroinvertebrates of the Tampa Bay Estuaries. Environmental Protection Commission of Hillsborough County, Tampa, FL.

Courtney, C. M., S. A. Grabe, D. J. Karlen, R. Brown and D. Heimbuch. 1995. Laboratory Operations Manual for a Synoptic Survey of Benthic Macroinvertebrates of the Tampa Bay Estuaries. Environmental Protection Commission of Hillsborough County, Tampa, FL.

Engle, V. D. and J. K. Summers. 1999. Refinement, validation, and application of a benthic condition index for northern Gulf of Mexico estuaries. Estuaries 22: 624-635.

Engle, V. D., J. K. Summers, and G. R. Gaston. 1994. A benthic index of environmental condition of Gulf of Mexico estuaries. Estuaries 17:372-384.

Gerritsen, J. 1995. Additive biological indices for resource management. Journal of the North American Benthological Society 14: 451-457.

Grabe, S. A. , D. J. Karlen, C. M. Holden, B. Goetting and T. Dix. 2002. Tampa Bay Benthic Monitoring Program: Status of Hillsborough Bay 1993-1998. Environmental Protection Commission of Hillsborough County.

Karr, J. R. 1981. Assessment of biotic integrity using fish communities. Fisheries 6:21-27.

Kerans, B. L. and J. R. Karr. 1994. A benthic index of biotic integrity (B-IBI) for rivers in the Tennessee Valley. Ecological Applications 4:768-785.

Llanso, R. J., L. C. Scott, J. L. Hyland, D. M. Dauer, D. E. Russell and F. W. Kutz. 2002a. An estuarine benthic index of biotic integrity for the mid-atlantic region of the United States. I. Classification of Assemblages and Habitat Definition. Estuaries 25:1219-1230.

Llanso, R. J., L. C. Scott, J. L. Hyland, D. M. Dauer, D. E. Russell and F. W. Kutz. 2002b. An estuarine benthic index of biotic integrity for the mid-atlantic region of the United States. II. Classification of Assemblages and Habitat Definition. Estuaries 25:1231-1242.

Long, E. R., D. A. Wolfe, R. S. Carr, K. J. Scott, G. B. Thursby, H. L. Windom, R. Lee, F. D. Calder, G. M. Sloane, and T. Seal. 1994. Magnitude and Extent of Sediment Toxicity in Tampa Bay, Florida. NOAA Technical Memorandum NOS ORCA 78, Silver Spring, Maryland.

Long, E. R., D. D. MacDonald, S. L. Smith and F. D. Calder. 1995. Incidence of adverse biological effects within ranges of chemical concentrations in marine and estuarine sediments. Environmental Management 19:81-97.

MacDonald Environmental Services, Ltd. 1994. Approach to the Assessment of Sediment Quality in Florida Coastal Waters. Volume 1. Development and Evaluation of Sediment Quality Assessment Guidelines. Prepared for Florida Department of Environmental Protection. MacDonald Environmental Services, Ltd. Ladysmith, B.C. Canada.

McRae, G., D. K. Camp, W. G. Lyons and T. L. Dix. 1998. Relating Benthic Infaunal Community Structure to Environmental Variables in Estuaries Using Nonmetric Multidimensional Scaling and Similarity Analysis. Environmental Monitoring and Assessment 51: 233-246

Smith, R. W. , M. Bergen, S. B. Weiseberg, D. Cadien, A. Dalkey, D. Montagne, J. K. Stull, and R. G. Velarde. 2001. Benthic response index for assessing infaunal communities on the Southern California mainland shelf. Ecological applications 11:1073-1987.

Summers, J. K., J. M. Macauley, and P. T. Heitmuller. 1991. Environmental Monitoring and Assessment Program. Implementation Plan for Monitoring the Estuarine Waters of the Louisianian Province- 1991 Demonstration. EPA/600/5-91/228. United States Environmental Protection Agency, Office of Research and Development, Environmental Research Laboratory, Gulf Breeze, Florida.

Tampa Bay Estuary Program. 1996. Charting the Course: The Comprehensive Conservation and Management Plan for Tampa Bay. Tampa Bay Estuary Program, St. Petersburg, Florida.

VanDolah, R. F., J. L. Hyland, A. F. Holland, J. S. Rosen, T. R. Snoots. 1999. A benthic index of biological integrity for assessing habitat quality in estuaries of the southeastern USA. Marine Environmental Research 48:269-283.

Washington, H. G. 1984. Diversity, biotic and similarity indices: A review with special relevance to aquatic ecosystems, Water Research 18:653-694.

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