AED Peer Review '07

Benthic Indices: Developing, Evaluating, and Using Measures of Benthic Condition for Northeast Coastal Waters (ECO MYP)

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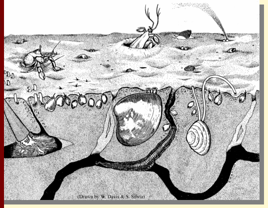
ncy Problem

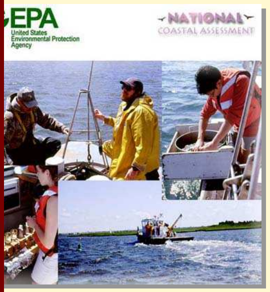
on 305(b) of the Clean Water Act directs States to assess the l quality of their waters, determine whether that quality is ing over time, identify problem areas and management s necessary to resolve those problems, and evaluate the iveness of programs. These activities require reliable tools nitor aquatic resources. EPA promotes use of biocriteria, s benthic indices, by monitoring programs. Our research is cing benthic indices that can be used by the Office of , EPA Regions, and states to characterize and assess the ion of benthic communities in coastal waters of the east.



arch Goals

l investigations have shown a good relationship between etric benthic indices and the quality of the estuarine environment (*e.g.*, Weisberg *et al.* 1997; Paul *et al.* 2001; *et al.* 2002). These indices are often used by monitoring ns to measure the spatial extent of any problems, locate n areas for further study, assess the effectiveness of al programs, and determine whether conditions are ing or deteriorating.

ing a history of benthic index development (beginning e first index for the Virginian Biogeographic Province in Paul *et al.* 2001), we have developed and are refining a index for the Acadian Biogeographic Province (Gulf ne) as part of the National Coastal Assessment (Hale and , in press). Also, we have evaluated two indices from ork/New Jersey Harbor. Currently we are involved in field nat will lead to an index for New Jersey offshore waters. mary goal is to develop and evaluate benthic indices to be Clean Water Act reporting.



Acadian Province Benthic Index

Methods/Approaches

The data set included 248 stations from the nearshore Gulf of Maine (**Fig. 1**) sampled for physical, chemical, and biological variables by the National Coastal Assessment in 2000–2003. We used logistic regression with 49 candidate measures of benthic species diversity, pollution sensitivity-tolerance, and community composition to discriminate sites with high and low benthic environmental quality (BEQ). BEQ was based on the concentrations of metal and organic contaminants in the sediments, total organic carbon, sediment toxicity, and dissolved oxygen level of the bottom water. We developed several candidate benthic indices and tested them with independent data from Massachusetts Bay and Casco Bay to help select and validate the best index.

Results

An analysis of similarity test showed that the community composition of low BEQ stations was significantly different ($p < 0.001$) from high BEQ stations (**Table 1**). Ten of the 49 benthic metrics showed a strong ability to discriminate stations (**Table 2**). A model using the Shannon-Wiener diversity measure, Rosenberg's species pollution tolerance measure (Rosenberg *et al.* 2004), and the percent capitellid polychaetes (or percent *Capitella* spp.) strongly discriminated stations, with an area under the Receiver Operating Characteristic (ROC) curve of 0.82 and a classification accuracy of 80% (**Fig. 2**). With an independent data set from Massachusetts Bay, this index correctly classified 23 out of 28 low BEQs and 18 out of 21 high BEQs, for an accuracy of 84% (**Table 3**). We used signal detection theory (ROC curves and positive-negative predictive value curves) to evaluate the index and to predict how well an index developed for one geographic area might work in another area with a different prevalence of the degraded condition. These techniques can also guide decisions by environmental managers about choosing thresholds and weighing costs and benefits of particular actions.

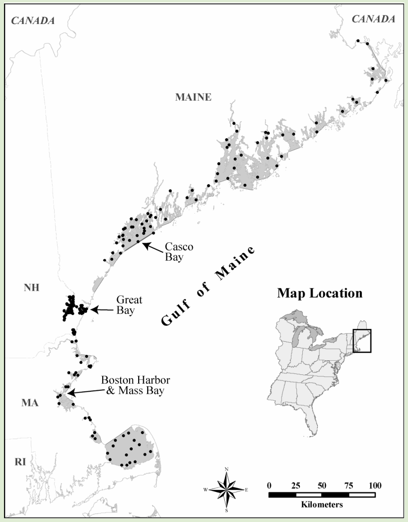


Fig. 1. Station locations in the Gulf of Maine (n = 182).

Table 1. Dominant benthic species at high (n = 81) and low (n = 37) Benthic Environmental Quality (BEQ) stations.

High BEQ

Scientific name	Total Abundance
Ampharete arctica	3863
Tubificidae	2672
Prionospio steenstrupi	2659
Nucula proxima	2648
Polygordius spp.	2390
Streblospio benedicti	2211
Ampelisca	1489
Aricidea catherinae	1438
Pygospio elegans	1382
Tharyx acutus	1307
Gemma gemma	1044
Exogone hebes	1027
Prionospio spp.	960
Mediomastus californiensis	956
Polydora cornuta	893
Nephtys incisa	840
Ninoe nigripes	777
Cirratulidae	692
Nucula tenuis	660
Exogone verugera	639

Low BEQ

Scientific name	Total Abundance
Tubificidae	4903
Polygordius spp.	2568
Mytilus edulis	2353
Streblospio benedicti	1518
Exogone hebes	1112
Monocorophium tuberculatum	1057
Parapionosyllis longicirrata	792
Mya arenaria	605
Heteromastus filiformis	567
Polydora cornuta	554
Tharyx acutus	506
Nucula proxima	482
Marenzellaria viridis	450
Prionospio steenstrupi	438
Spionidae	381
Cyathura polita	378
Nereis diversicolor	373
Nephtys incisa	339
Prionospio spp.	330
Capitella capitata	265

Table 2. Means of benthic metrics used in logistic regressions at high and low BEQ stations (n=118) and significance of difference.

Benthic metric	Mean low BEQ	Mean high BEQ	p
Shannon-Wiener H'	0.71	0.94	0.0001
Gleason's D	2.91	5.05	0.0001
PctDom3	80.0	64.4	0.0001
ES(50)	8.12	12.78	0.0001
$Mn\_ES(50)_{.05}$	6.28	7.58	0.0001
First term of Rosenberg BQI	5.11	6.32	0.002
Taxonomic diversity Δ	50.86	55.50	0.09
Pct Capitellidae	11.2	4.2	0.03
Pct *Capitella*	3.29	0.5	0.0001
Pct Tellinidae	0.4	1.2	0.08

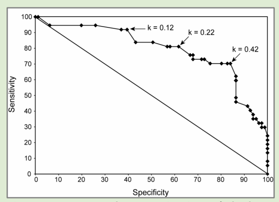


Fig. 2. Receiver operating characteristic (ROC) curve for benthic index ($APBI_1$). k = different values of the cutpoint for building a rule for an indicator.

Table 3. Validation from an independent dataset (Massachusetts Water Resources Authority dataset in Massachusetts Bay). Two-way contingency table showing number of stations expected by the benthic index calculation versus observed number of stations as given Benthic Environmental Quality (BEQ) calculation.

		Benthic Index		
		Low	High	Total
BEQ	Low	23	5	28
	High	3	18	21
	Total	26	23	49

Evaluating Benthic Indices

Methods/Approach

EPA Region 2 developed an Index of Biotic Integrity (IBI) for NY/NJ Harbor as part of a Regional EMAP (REMAP) project (Weisberg *et al.*, 1998, Adams *et al.*, 2003). We are comparing results using those with results from using the Virginian Province benthic index (EMAP BI; Paul *et al.*, 2001). The indices were developed differently: the EMAP BI derived by discriminant analysis for the Virginian Province, and the IBI comprised of five equally weighted metrics developed specifically for the NY Harbor region. Initially, we evaluated the index values site-by-site to determine where they agreed and disagreed in their assessment, and related those to measures of community structure, environmental stress (dissolved oxygen, salinity, and sediment composition), sediment toxicity, and sediment contamination (metals, PAHs, and pesticides). In the next phase, we are making comparisons to highlight the strengths of each index by utilizing radar plots, conditional probabilities, and receiver operating characteristic (ROC) curves.

Key Components Of The Indices

The **EMAP Benthic Index**, developed for the eastern U.S. coast from Cape Cod to the mouth of Chesapeake Bay, incorporated 3 metrics:
- a benthic diversity measure (Gleason's D normalized for salinity),
- expected number of tubificids (normalized for salinity), and
- abundance of spionid polychaetes

The **Benthic Index of Biotic Integrity** incorporated 5 metrics, each graded as a 1, 3, or 5 based on the value of the metric & habitat (grain size & salinity) attributes, averaged for each station.
- number of species
- abundance (#/m^2)
- biomass
- abundance of pollution-indicative taxa
- abundance of pollution-sensitive taxa

Results

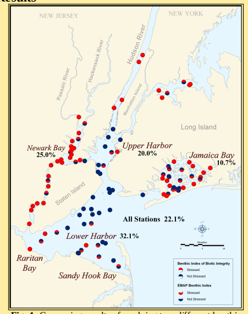


Fig. 1. Comparing results of applying two different benthic indices to the New York / New Jersey Harbor area

- When examining the results from applying two benthic indices, we noticed that there was agreement at most sites.
- However, there was not agreement at all sites (**Fig. 1**).
- The EMAP BI identifies less area impacted than the IBI in four out of five areas (**Fig. 2**).
- These differences complicate interpretation.
- The next step in comparing them is to analyze why we we see different results.

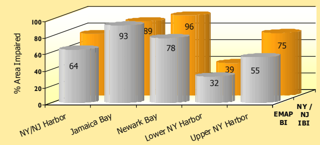
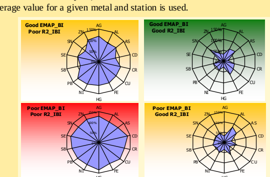


Fig. 2. Comparison of the % area of the benthos impaired in the New York/New Jersey Harbor area using the EMAP BI and NY/NJ IBI

Radar Plots

Radar plots facilitate analysis of more than one analyte at a time. Using metals as an example of a group of parameters to view together, radar plots show a relationship of metals to the condition indicators in four possible scenarios (both indices indicate good, both indicate poor, EMAP BI indicates good but the IBI indicates poor, and the IBI indicates good but EMAP BI indicates poor). With this, we can start to assess index responses. In order to put all the metals on the same scale, a percent of the average value for a given metal and station is used.

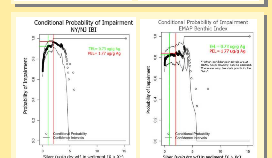
- Metal concentrations are generally lower when both indices indicate good condition (green box)
- Conversely, most metal concentrations are higher where both indices indicate poor condition (red box)
- The two orange boxes highlight disagreement between the indices. In the upper left orange box, metal concentrations are higher than the lower right orange box and the green box. This indicates that the IBI could be reflecting metal contamination more than the EMAP BI.



Conditional Probability Plots

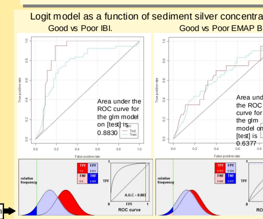
These graphs show the predicted probability of impairment as defined by the IBI or EMAP BI with a given concentration of Ag in the sediment. Threshold Effects Level (TEL) and Probable Effects Level (PEL) from MacDonald *et al.*, 1996.

- Silver shows little relationship to the EMAP BI
- As silver concentrations increase, there is an increasing probability of impairment using the IBI
- As seen in the wide confidence intervals above 5 ug/g dry weight Ag, there are few data points and no confidence in determining the probability of impairment.



Receiver Operator Characteristic (ROC) curves for comparison of diagnostic power

- Area under the curve is greater for the IBI indicating it is more responsive than the EMAP BI to the concentration of Ag
- Area under the curve for EMAP BI indicates almost no relationship to sediment Ag concentrations
- The separation of the True Positives (benthic condition is poor with high concentrations of Ag) and False Negatives (benthic conditions is poor with low concentration of Ag) is better with the IBI



http://www.anaesthetist.com/mnm/stats/roc/Findex.htm

Impact and Outcomes

These indices provide environmental managers a way to assess the condition of coastal benthic communities both spatially and temporally.

- The Acadian Province index has been used in the National Coastal Condition Report III, the National Coastal Assessment Northeast report, and the State of New Hampshire in their 305(b) report.
- It will be used in the next State of Maine 305(b) report and is being evaluated by Massachusetts.
- Use of this index improves the quality of environmental condition assessment and reporting to support Clean Water Act objectives.
- Region 2 successfully convinced the State of New Jersey of the strength of using probability-based monitoring programs based on REMAP results.
- An improvement was detected in the condition of NY/NJ Harbor based on the 1993 and 1998 monitoring data.
- The Atlantic Ecology Division has advised the Long Island Sound Study (Region 2) on development of a benthic index for Long Island Sound; consulted with Region 3 on use of Chesapeake Bay Index of Biotic Integrity in 305(b) reporting; and advised Region 1 on use of the Virginian Province benthic index in the Taunton River, Mass.

Future Directions

- The Acadian Province index will be refined as more datasets become available, particularly to better account for habitat effects.
- Future work must include an inter-calibration exercise between the benthic indices of the Virginian and Acadian (and possibly the Carolinian) Biogeographic Provinces to determine whether the indices differ in sensitivity and scaling.
- We need to do biogeographical studies on benthic communities not stressed by anthropogenic factors. These studies are under way.
- We need to analyze the NCA 2000-2006 data in the Virginian Province index to see if the index based on 1990-1993 data needs to be refined.
- Analysis of trends following 10-year revisit in NY / NJ Harbor
- A new Regional-EMAP project focusing on benthic conditions in the New Jersey offshore region out to three nautical miles is currently in progress to provide a better benthic assessment in an area with discharges from 11 coastal sewage treatment plants in sediments ranging from sand to gravel and hard mud.

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