13.7 Environmental Quality of Estuaries of the Carolinian Province: 1995

13.7.1 Background/Objectives

A study was conducted to assess the environmental condition of estuaries in the EMAP Carolinian Province (Cape Henry, VA - St. Lucie Inlet, FL; Figure 13-14). The objectives of this study are being addressed using a probability-based sampling design, under which a large regionally extensive population of randomly selected sites is sampled from year to year, following earlier EMAP-E designs (Strobel et al. 1994, Summers et al. 1993). This design makes it possible to produce unbiased estimates of the percent area of degraded vs. undegraded estuaries, based on a series of indicators of environmental quality. Overall, the objectives of the program are to:

- Assess the condition of estuarine resources of the Carolinian Province based on a variety of synoptically measured indicators of environmental quality;
- Establish a baseline for evaluating how the condition of these resources are changing with time;
- Develop and validate improved methods for use in future coastal monitoring and assessment efforts.

A total of 87 randomly located stations were sampled from July 5 - September 14, 1995 in accordance with the probabilistic sampling design. Wherever possible, synoptic measures were made of: 1) general physical habitat condition, 2) pollution exposure, 3) biotic conditions, and 4) aesthetic quality. Percentages of degraded vs. undegraded estuarine area were compared to results of a related EMAP survey conducted in 1994 in this same region as part of a multi-year monitoring effort.

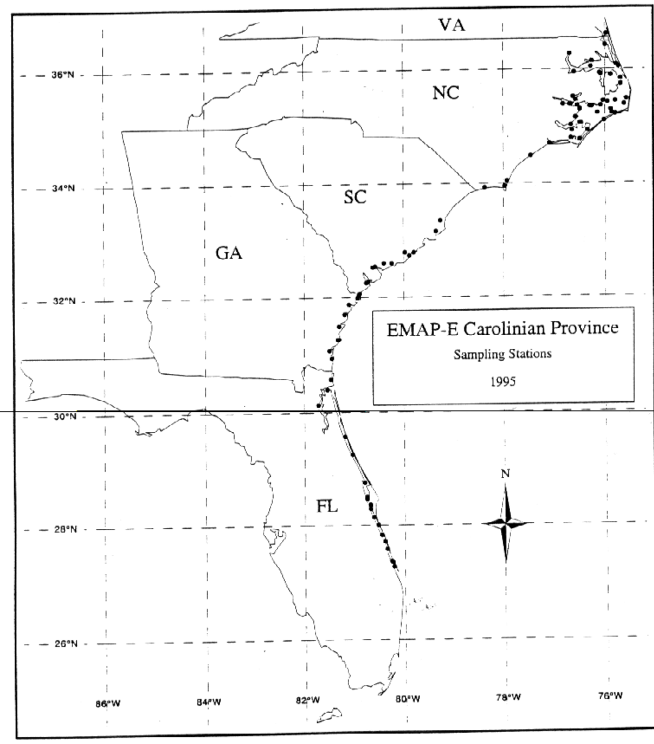
13.7.2 Methods

An overall goal of EMAP is to make statistically unbiased estimates of ecological condition with known confidence. To approach this goal, a probabilistic sampling framework was established among the overall population of estuaries comprising the Carolinian Province. Under this design, each sampling point is a statistically valid probability-based sample. Thus, percentages of estuarine area with values of selected indicators above or below suggested environmental guidelines can be estimated based on the conditions observed at individual sampling points. Statistical confidence intervals around these estimates also can be calculated. Moreover, these estimates can be combined with those for other regions that were sampled in a consistent manner to yield national estimates of estuarine condition. This section describes in brief how stations were selected using the probabilistic design (see also Rathbun 1994). Supplemental sites, selected non-randomly in clean areas and in suspected polluted areas, were included in the survey and are discussed below.

Sampling sites in 1995 consisted of 87 base stations and 21 supplemental stations. Base stations were randomly selected sites that made up the probability-based monitoring design. Four replicate bottom grabs were collected from each station with a 0.04-m^2 young grab sampler. Data collected

Figure 13-14

1995 Carolinian Province sampling stations.



from these sites were used to produce unbiased estimates of estuarine condition throughout the province based on the various synoptically measured indicators of environmental quality. The province-wide distribution of base sites is shown in Figure 13-14. Supplemental stations were selected non-randomly in areas for which there was some prior knowledge of the ambient environmental conditions. These sites, which represented both pristine areas and places with histories of anthropogenic disturbance, were used to test the discriminatory power of various ecological indicators included in the program. Data from supplemental sites were not included in the probabilistic spatial estimates.

As in other EMAP-E provinces (Strobel et al. 1994, Summers et al. 1993), the sampling design for the base sites in the Carolinian Province was stratified based mainly on the physical dimensions of an estuary. Table 13-15 breaks down the estuarine resources of the Carolinian Province by their size designation. Stratification of the overall sampling area into classes of estuaries with similar attributes was necessary in order to minimize within-class sampling variability. Also, it was not feasible to sample all of the different types of estuaries that exist within a broad geographic region at the same spatial scale. Stratification by physical dimensions of an estuary was adopted because: 1) such attributes usually show minimal change over extended periods; 2) alternative classification variables such as salinity, sediment type, depth, and extent of pollutant loadings would result in the definition of classes for which areal extents could vary widely from year to year; 3) data for physically based classes can be aggregated into geographic units that are meaningful

Table 13-15. Estuarine resources of the Carolinian Province.

	Province	Large Estuaries	Small Estuaries	Large Tidal Rivers
All Years				
Number of Estuaries	200	3	194	3
Area Represented (km^2)	11,622.1	5,581.1	4,907	1,134
In 1995				
Number of Stations	88	16	55[a]	17[b]
Area Represented (km^2)	6,991.8	4,480.0	1,377.8	1,134

[a]Station count includes 6 replicate stations
[b]Station count includes 3 replicate stations

from a regulatory or general-interest perspective; and 4) estuarine boundaries can be delineated more readily and accurately from maps or charts of the physical dimensions of coastal areas than from maps of sediment or water-column characteristics.

Selection of base-site sampling approaches varied on the physical characteristics of the particular estuary being sampled. Base sites in all estuaries were selected using an approach similar to the one used in the EMAP Louisianian Province (Summers et al. 1993). In large estuaries, sites were selected using a sampling grid approach. A triangular lattice was placed initially over the study region and the resulting grid shifted randomly. In large tidal rivers, base sites were selected randomly, using a "spine and rib" approach. Finally, base sites in small estuaries were selected using a random list-frame approach, also similar to the approach used in the EMAP Louisianian Province (Summers et al. 1993). Table 13-16 lists the core environmental indicators sampled at the various sites.

A standard series of environmental parameters was measured at each of the base stations to provide a consistent set of synoptic data for making province-wide estimates of estuarine condition. These "core" environmental indicators included measures of general habitat conditions, pollutant exposure, biotic integrity, and aesthetic quality (Table 13-16). Habitat indicators describe the physical and chemical conditions of sample sites, and provide basic information about the overall environmental setting. Exposure indicators provide measures of the types and amounts of pollutants, or other adverse conditions, that could be harmful to resident biota or human health. Biotic condition indicators provide measures of the status of biological resources in response to the surrounding environmental conditions. Aesthetic indicators provide additional measures of environmental quality from a human perceptual perspective. There is a fair amount of overlap among these various indicator categories. For example, some aesthetic indicators (presence of oil sheens, noxious sediment odors, and highly turbid waters) could also reflect adverse exposure conditions. Another example is dissolved oxygen (DO), listed as an exposure indicator because of the

Table 13-16. Core environmental indicators for the Carolinian Province.

Habitat Indicators
Water depth
Water temperature
Salinity
Density stratification of water column
Dissolved oxygen concentrations
pH
Percent silt-clay content of sediments
Percent TOC in sediments
Sediment acid-volatile sulfides (Yr. 2 only*)
Exposure Indicators
Low dissolved oxygen conditions
Sediment contaminants
Contaminants in fishes and invertebrates (Yr. 2 only)
Sediment toxicity
Biotic Condition Indicators
Infaunal species composition
Infaunal species richness and diversity
Infaunal abundance
Benthic Infaunal Index
Demersal species composition (invertebrates and fish)
Demersal species richness and diversity
Demersal species abundance
Demersal species lengths
External pathological abnormalities in demersal biota
Aesthetic Indicators
Water clarity
Anthropogenic debris (sea surface and in trawls)
Noxious sediment odors (sulfides, petroleum)
Oil sheens (sea surface and bottom sediments)

*Results not shown in this report

potential adverse biological effects of low oxygen concentrations, but which also is clearly a measure of general habitat conditions. These various core environmental parameters included ones used in other EMAP-E provinces (Strobel et al. 1994, Summers et al. 1993) to support regional comparisons and to provide a means for producing combined nationwide estimates of estuarine condition.

In addition to making the standard EMAP-E measurements, an emphasis was placed on developing and validating other complementary methods to aid in evaluating the quality of southeastern estuaries. Such indicators, some still in the development stage, are listed in Table 13-17. They include sediment bioassays with alternative test species, such as the amphipod *Ampelisca verrilli* as an alternative to *A. abdita* in standard 10-day solid-phase toxicity tests; assays with additional sublethal biological endpoints, such as effects on feeding, growth and fertilization success in key estuarine organisms; additional indices of environmental quality for tidal marshes and estuarine fish assemblages; and the incorporation of additional exposure indicators, such as porewater ammonia and hydrogen sulfide concentrations, to help in the

Table 13-17. Exposure indicators under development in the Carolinian Province.

10-day acute-toxicity sediment bioassay with alternative amphipod species, *Ampelisca verrilli*
1-week sublethal bioassay for testing effects of sediment exposure on growth of juvenile clams *Mercenaria mercenaria*
96-hour sublethal bioassay for testing effects of sediment exposure on feeding rates of *Ampelisca verrilli*
1-hour sublethal bioassay using gametes of oysters *Crassostrea virginica* and clams *Mercenaria mercenaria* for testing effects of sediment exposure on fertilization success
Sediment porewater ammonia and hydrogen sulfide concentrations

interpretation of sediment toxicity results.

13.7.3 Benthic Infaunal Index

The modified IBI approach of Weisberg et al. (1997) was used to develop a benthic index for southeastern estuaries. The goal was to develop an index that possessed the following features: (1) suitable for use throughout the region, (2) applicable to a broad range of habitats, (3) easy to understand and interpret, and (4) effective in discriminating between undisturbed and disturbed conditions associated with human influences.

Results of the 1994 survey (Hyland et al. 1996) indicated that several natural abiotic factors (salinity, latitude, silt-clay, and TOC) had strong influences on infaunal variables. In the IBI approach, an attempt is made to account for such variations by defining habitat-specific reference conditions at sites free of anthropogenic stress and then comparing conditions in samples with the expected reference conditions for similar habitat types. The basic steps used to develop the index involved: (1) defining major habitat types based on classification analysis of benthic species composition and evaluation of the physical characteristics of the resulting site groups; (2) selecting a development data set representative of degraded and undegraded sites in each habitat (3) comparing various benthic attributes between reference sites and degraded sites for each of the major habitat types; (4) selecting the benthic attributes that best discriminated between reference and degraded sites for inclusion in the index; (5) establishing scoring criteria (thresholds) for the selected attributes based on the distribution of values at reference sites; (6) constructing a combined index value for any given sample by assigning an individual score for each attribute, based on the scoring criteria, and then averaging the individual scores; and (7) validating the index with an independent data set.

Data from undegraded sites sampled in 1993 and 1994 were first analyzed using classification (cluster) analysis of benthic species composition and evaluation of the physical factors associated with the resulting station clusters to define major habitat types. Several types of cluster analyses were performed. The one that produced the clearest results was a normal (Q-mode) analysis run on log10-transformed data with flexible sorting as the clustering method and Bray-Curtis similarity as a resemblance measure (see Boesch 1977).

Differences in abiotic factors (salinity, latitude, % silt-clay, TOC) among the resulting station clusters were examined by ANOVA and pair-wise multiple comparison tests (Duncan's test and Tukey's HSD) to help delineate the major habitat types. Four site groups resulted: oligohaline-mesohaline stations ($\leq$8%) from all latitudes, polyhaline-euhaline stations (>18%) from northern latitudes (>34.5° N), polyhaline-euhaline stations from middle latitudes (30-34.5° N) and polyhaline-euhaline stations from southern latitudes (<30° N). Seventy-five stations sampled during the 1994 survey were selected for the development data set. These stations provided data from both degraded and undegraded sites in each of the four habitats. Classification of stations into degraded and undegraded categories was based on the combination of chemical and toxicological criteria, mainly DO, and toxicity of sediment bioassays. Marginal sites (minor evidence of stress with toxicity in only one assay and no accompanying adverse contaminant or DO conditions) were not included in the development data set.

Forty different infaunal attributes were tested with the 1994 development data set to determine those that best discriminated between undegraded and degraded sites within each habitat. This initial list of attributes included various measures of diversity, abundance, dominance, and presence of indicator species (e.g., pollution-sensitive vs. pollution-tolerant species, surface vs. subsurface feeders). A subset of six candidate metrics was identified for possible inclusion in the index. Key criteria considered in the selection were whether differences were in the right direction and statistically significant (based on results of Student t-tests, Mann-Whitney *U*-tests, and Komogorov-Smirnov two-sample tests; at $\alpha = 0.1$). These six metrics were: mean number of taxa, mean abundance (all taxa), mean H′ diversity, 100 - % abundance of the two most numerically dominant species, and two different measures of % abundance of pollution-sensitive taxa.

Scoring criteria for each of these metrics were developed based on the distribution of values at undegraded sites: score of 1, if value of metric for sample being evaluated was in the lower 10th percentile of corresponding reference-site values; score of 3, if value of metric for sample was in the lower 10th-50th percentile of reference-site values; or score of 5, if value of metric for sample was in the upper 50th percentile of reference-site values. Scoring criteria were determined separately for each metric and habitat type. A combined index value was then computed for a sample by assigning a score for each component metric (based on the individual scoring criteria for the corresponding habitat type) and then averaging the individual scores. A combined score < 3 suggested the presence of a degraded benthic assemblage (some apparent level of stress to very unhealthy) given that its condition, based on the averaged metrics, deviated from conditions typical of the "best" (upper 50th percentile) reference sites.

Forty different combinations of the six candidate benthic metrics were further evaluated to determine which represented the best combined index. The metric combination that produced the highest percentage of correct classifications; i.e., agreement with predictions of sediment bioeffects based on the chemistry and toxicity data, was then selected to represent the final index. The resulting final index was the average score of four metrics: (1) mean abundance, (2) mean number of taxa, (3) 100 - % abundance of the top two numerical dominants, and (4) % abundance of pollution-sensitive taxa (i.e., percent of total faunal abundance represented by Ampeliscidae + Haustoriidae + Hesionidae + Tellinidae + Lucinidae + Cirratulidae + *Cyathura polita* + *C. burbanki*. The final combined index correctly classified 93% of the stations province-wide in the development data set and 75% of the stations in the independent validation data set.

13.7.4 Results

The multimetric index of biotic integrity index — consisting of measures of abundance, number of species, dominance, and relative abundance of pollution-sensitive taxa — produced a high percentage of correct station classifications; i.e., agreement with predictions of sediment bioeffects based on chemistry and toxicity data, in comparison to other metric combinations that were tested. The index correctly classified stations province-wide 93% of the time in the 1994 development data set and 75% of the time in the independent 1993/1995 validation data set.

Figure 13-15 illustrates that stations with index values below 3 (suggestive of some apparent stress to highly degraded conditions) usually coincided with sites considered to be degraded based on a combination of chemistry and toxicity data, and that stations with scores of 3 or higher usually coincided with undegraded sites. Agreement is the highest at the two ends of the scale. Thus, the evaluation of sediment quality based on the benthic index appears to agree reasonably well with predictions of sediment bioeffects based on the combined exposure data. Additional comparisons revealed that the benthic index detected a higher percentage of samples where bioeffects were expected (based on sediment quality guideline exceedances) than did any of the four individual sediment bioassays (Fig. 13-16a) or individual infaunal attributes (Fig. 13-16b). Benthic index values for base stations sampled in 1995 covered the full scale from 1 to 5. Values < 1.5 (clearest evidence of a degraded benthos) occurred at 14 of the 86 base sites, which represented 21% of the province area (Fig.13-17). Transitional values of 2 to 2.5 (suggestive of some possible stress) occurred at an additional 14 sites, representing another 15% of the province. Values ≥ 3 (suggestive of an undegraded benthos) occurred at the remaining 58 base sites, representing 64% of the area of the province.

By estuarine class, the estimated percentage of area with degraded benthic assemblages was the highest for large tidal rivers and the lowest for large estuaries (Fig. 13-18). By subregion, this percentage was the highest in Florida estuaries and the lowest in South Carolina/Georgia estuaries.

Extracted or summarized from the EMAP Carolinian Province Report, Annual Statistical Summary for the 1995 EMAP - Estuaries Demonstration Project in the Carolinian Province (Hyland et al. 1998).

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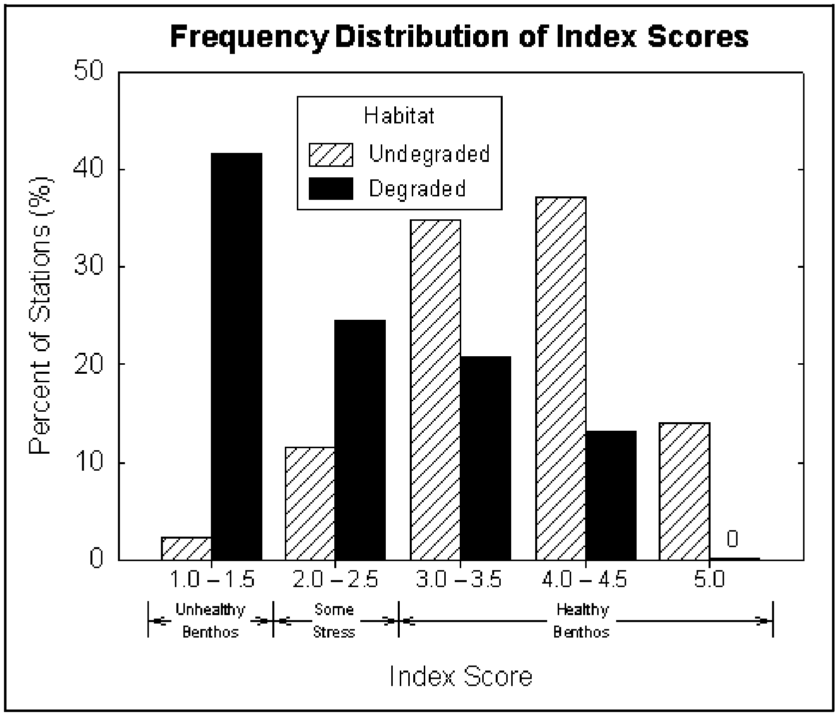
Figure 13-15

Frequency distribution of index scores for undegraded vs. degraded stations in 1993/1995 “development” data set.



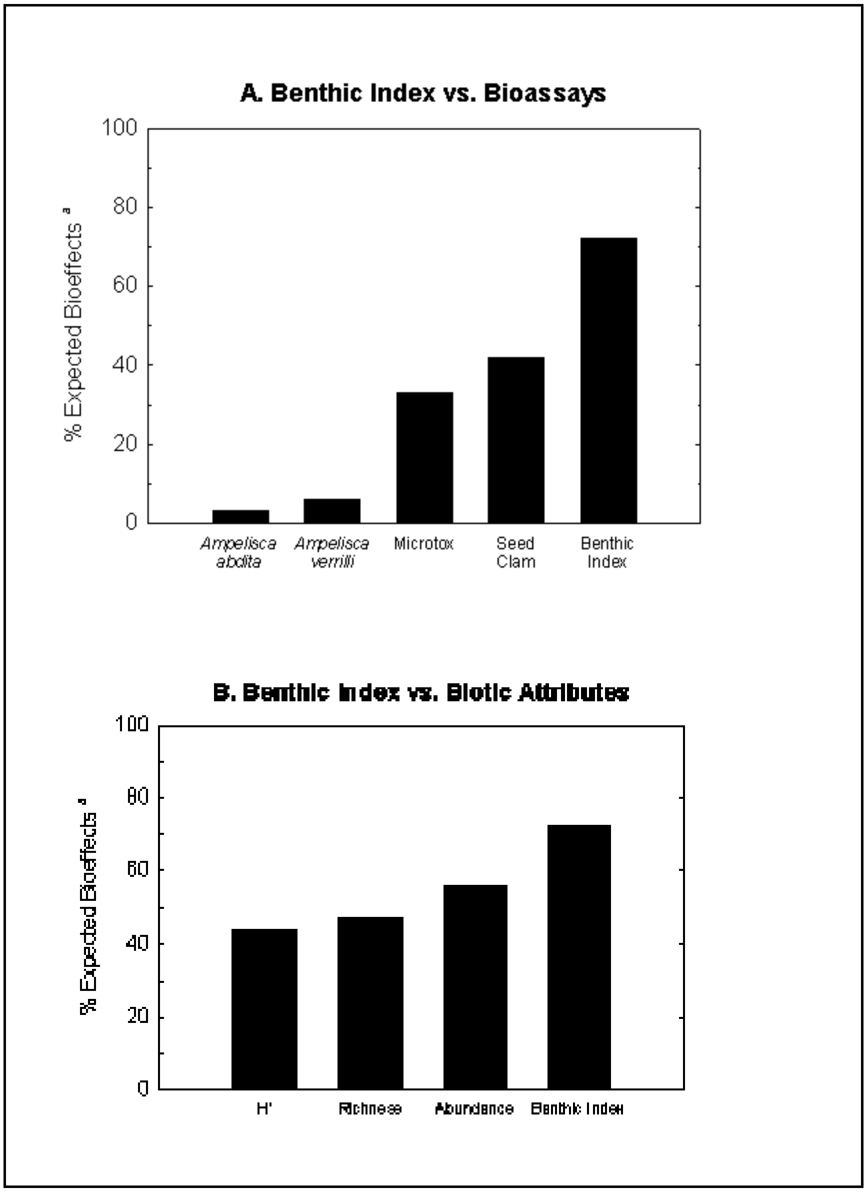


Figure 13-16

Comparison of the percent of expected bioeffects detected with the benthic index vs. (A) four sediment bioassays and (B) three individual infaunal attributes. [a]Percent expected bioeffects - # stations (1995 core & supplemental) where an effect was detected / # stations with ≥ 1 ER-M/PEL or ≥ 3 ER-L/TEL exceedance.

Figure 13-17

Percent area (and 95% C.I.) of CP estuaries with high (≥ 3), intermediate (> 1.5 to < 3), and low (≤ 1.5) benthic index values.

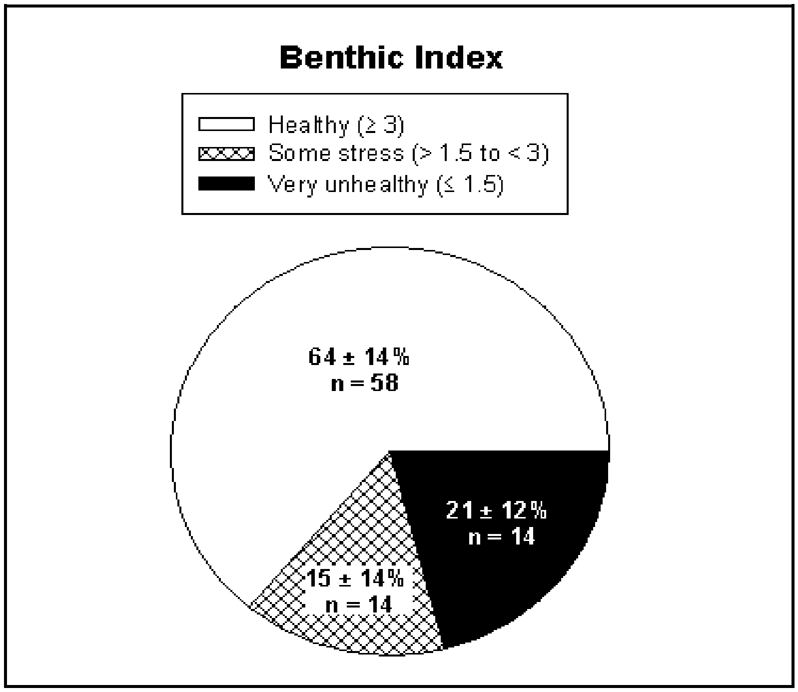


Figure 13-18

Comparison of benthic index values by estuarine class and subregion.