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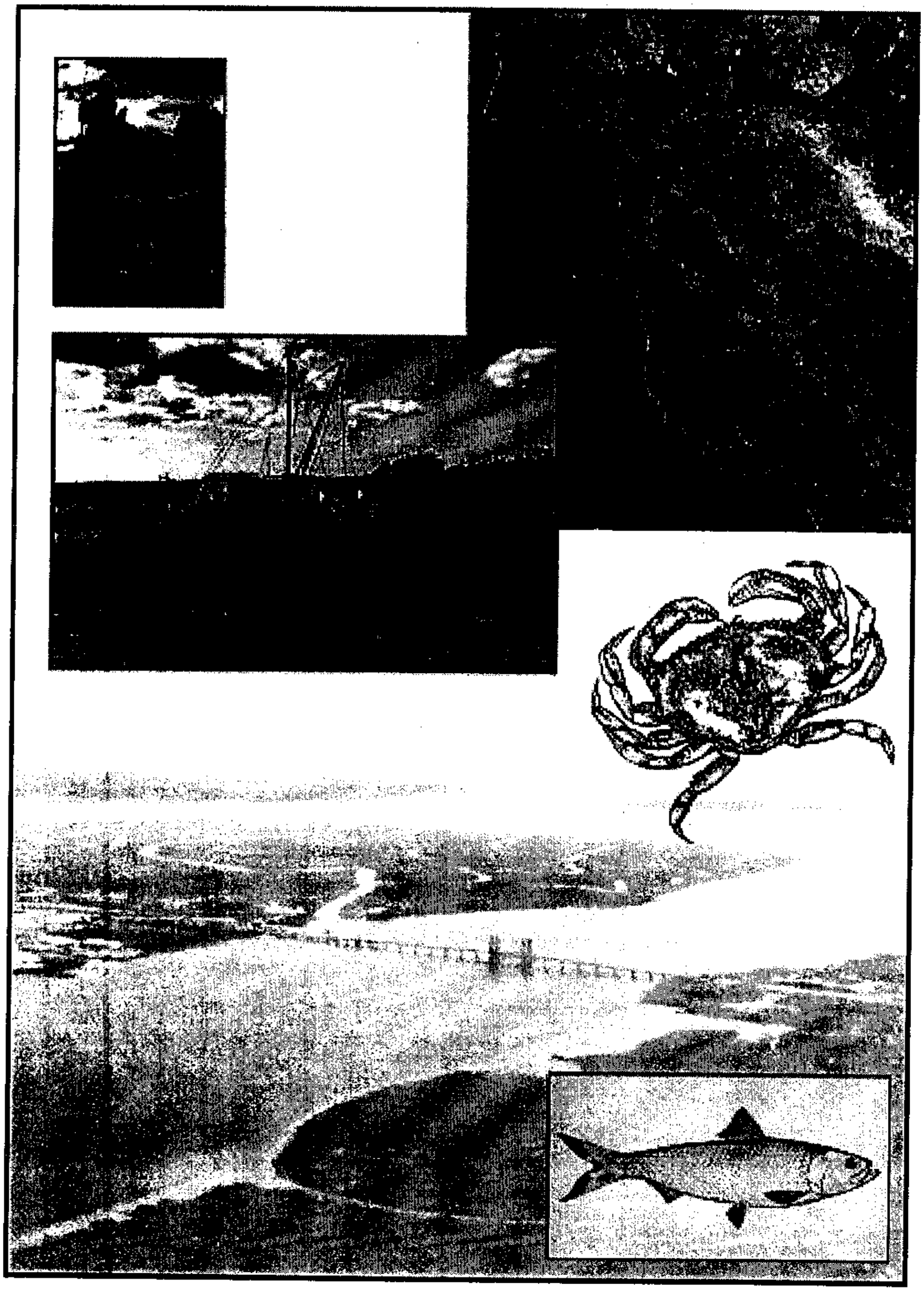
Estuarine and Coastal Marine Waters: Bioassessment and Biocriteria Technical Guidance



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Estuarine and Coastal Marine Waters: Bioassessment and Biocriteria Technical Guidance

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This document is dedicated to the memory of Dr. Douglas Farrell of the Florida Department of Environmental Protection and Dr. Donald Lear, U.S. Environmental Protection Agency (retired). It is fitting that this effort to which they volunteered so much of their invaluable experience and expertise be so dedicated. The benthic community index which Doug developed is also cited here as the "Farrell Index" in further recognition of his unselfish contribution to the protection and management of our coastal resources. Much of the methodology described in the coastal survey portion of this guide was developed from Don Lear's pioneering efforts.

The contributors to this manual sincerely hope that the good common sense, attention to scientific veracity, and practical application of the information to protect our marine resources - so ably personified by Don and Doug - is adequately reflected in these pages.

Disclaimer

This manual provides technical guidance to States, Indian tribes and other authorized jurisdictions to establish water quality criteria and standards under the Clean Water Act (CWA), to protect aquatic life from the effects of pollution. Under the CWA, States and Indian tribes are to establish water quality criteria to protect designated uses. State and Indian tribal decision makers retain the discretion to adopt approaches on a case-by-case basis that differ from this guidance when appropriate and scientifically defensible. While this manual constitutes USEPA's scientific recommendations regarding biological criteria to help protect resource quality and aquatic life, it does not substitute for the CWA or USEPA's regulations; nor is it a regulation itself. Thus, it cannot impose legally binding requirements on USEPA, States, Indian tribes or the regulated community, and might not apply to a particular situation or circumstance. USEPA may change this guidance in the future.

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Acronym List

APHA	American Public Health Association
AVS	Acid Volatile Sulfides
BMP	Best Management Practices
CCA	Canonical Correspondence Analysis
CDF	Cumulative Distribution Function
CSREES	Cooperative State Research, Education, & Extension Service
CTD	Conductivity - Temperature - Depth Meter
CV	Coefficient of Variation
CWA	Clean Water Act
DFA	Discriminant Function Analysis
DGPS	Differential Global Positioning System
DMRs	Discharge Monitoring Reports
DNR	Department of Natural Resources
DO	Dissolved Oxygen
EMAP	Environmental Monitoring & Assessment Program
EPA	Environmental Protection Agency
ER-L	Effects Range-Low
ER-M	Effects Range-Median
FEI	Farrell Epifaunal Index
FTE	Full Time Equivalent
GIS	Geographic Information System
GPS	Global Positioning System
IBI	Chesapeake Bay Estuarine Index of Biotic Integrity
ITI	Infaunal Trophic Index

MDS	Multidimensional Scaling
NMDS	Non-metric Multidimensional Scaling
NMFS	National Marine Fisheries Service
NOAA	National Oceanic and Atmospheric Administration
NODC	National Oceanographic Data Center
NPDES	National Pollutant Discharge Elimination System
NS&T	National Status & Trends
PAHs	Polyaromatic Hydrocarbons
PCA	Principle Components Analysis
PCBs	Polychlorinated Biphenyls
PCE	Power Cost Efficiency
PCS	Permit Compliance System
POTW	Publically Owned Treatment Works
QA	Quality Assurance
QC	Quality Control
RBP	Rapid Bioassessment Protocol
RPD	Redox Potential Discontinuity
SAV	Submerged Aquatic Vegetation
SEM	Simultaniously Extracted Metals
SOP	Standard Operating Procedure
SPM	Suspended Particulate Matter
SQG	Sediment Quality Guidelines
SQT	Sediment Quality Triad
STORET	STOrage & RETrieval
TDN	Total Dissolved Nitrogen
TDP	Total Dissolved Phosphorus

TMDL	Total Maximum Daily Loads
TOC	Total Organic Carbon
TPC	Total Particulate Carbon
TPN	Total Particulate Nitrogen
TPP	Total Particulate Phosphorus
TSS	Total Suspended Solids
TVS	Total Volatile Sulfides
TWINSPAN	Two-Way INdicator SPecies ANalysis
UPMGA	Unweighted Pair Group Mean Averages
USDA CSREES	United States Department of Agriculture Cooperative State Research Education Extension Service
USGS	United States Geological Survey

Executive Summary

This technical guidance document is based on the concept that bioassessment and biocriteria programs for estuaries and near coastal waters are interrelated and critical components of comprehensive water resource protection and management. Understanding how estuarine ecosystems function and respond to human activity requires a holistic approach to protection and management that integrates biological assessments into the more traditional chemical and physical evaluations. Section 101 of the Clean Water Act requires federal and state agencies to "restore and maintain the chemical, physical, and biological integrity of the nation's waters." Relatively undisturbed aquatic ecosystems have high *biological integrity,* defined as

> *the condition of an aquatic community inhabiting unimpaired waterbodies of a specified habitat as measured by an evaluation of multiple attributes of the aquatic biota. Three critical components of biological integrity are that the biota is (1) the product of the evolutionary process for that locality, or site, (2) inclusive of a broad range of biological and ecological characteristics such as taxonomic richness and composition, and trophic structure, and (3) is found in the study biogeographic region* (USEPA 1996a)[1]

In water resource monitoring and protection, biological criteria are an important addition to the traditional physical and chemical criteria used by EPA. The relative biological integrity, or quality, of the resource can be assessed by comparing the health and diversity of its biological communities to the health and diversity of biological communities in waters with the same physical characteristics but which are relatively unimpacted by human development . There are basically four elements that comprise biocriteria:

1. Reference waters (relatively undisturbed areas that can be compared to study areas) serve as "benchmarks" of water resource quality decision making.
2. The historical record of the biological quality, diversity and productivity.
3. Model projection of the historical and reference condition data (if necessary).
4. The objective assessment of this information by a regional panel of specialists such as state,

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[1] *Biological criteria: Technical guidance for streams and small rivers.* EPA 822-B-96-001. U.S. Environmental Protection Agency, Office of Water, Washington, DC.

academic, and federal estuarine ecologists, chemists, fisheries biologists, oceanographers, and resource managers.

The summation of these four factors is the biological criterion for a given estuary or class of coastal water in a geographic region. Examples of the parameters included in a biocriterion are community measures or indexes drawn from dynamic assessments of resident fish, benthic invertebrate, macrophyte, and planktonic assemblages making up the biological community.

Many natural resource agencies throughout the United States have begun the process of developing and implementing bioassessments and criteria programs primarily for rivers and streams. This document is part of the effort to advance the use of these strategies with regard to estuaries and near coastal waters, thereby fostering the development of credible and practical bioassessment programs. This document is intended to provide managers and field biologists with functional methods and approaches for bioassessment and biocriteria development.

In developing biological information, it is imperative that the physical and chemical habitat be carefully measured and documented. Information such as salinity, depth, sediment grain size, and water quality (including pH, temperature, DO, nutrients, and toxicants) is essential to proper classification of the waters for comparison and to the potential subsequent investigation of possible causes of degradation so that responsible management can be initiated.

This guidance provides detailed descriptions of the appropriate habitat measurements to make the subsequent physical classification to be achieved. The document then describes four levels of investigative intensity or sampling tiers. These tiers are suggested as one possible approach to organizing the data gathering efforts and investigation needed to be able to establish biocriteria in a scientifically defensible manner. Other approaches using variations of these tiers may be appropriate depending on program objectives.

- Tier 0 is a preliminary review of existing literature and data available for the estuary or coastal water of concern. It provides candidate reference sites for the development of a reference condition;

- Tier I is a one-time site visit with preliminary data gathering to refine the information in Tier 0 and establish candidate biocriteria;

- Tier II repeats and builds on measurements initiated in Tier I and establishes the reference condition data which is combined with the historical record, possible models or other extrapolations, and a consensus of regional expert opinion to establish and employ the biocriteria for management decision making;

- Tier III is the diagnostic investigation requiring the most sampling events and most extensive parameters to help establish management efforts for those waters which do not meet the biocriteria.

Biocriteria development is **not** a *one size fits all* proposition. Biocriteria can be developed on biogeographical province basis or on a smaller local basis to account for the geographic, climatologic, and biologic variation in the country. Reference conditions and biocriteria must be specific to each part of the country in order to be responsive and useful for decision making. It is important to remember that such circumstances vary and that this document cannot address every situation or experience. It is oriented toward practical decision making rather than research. Its primary audience is intended to be state and tribal resource managers. It is also intended to provide managers and biologists with functional methods and approaches to facilitate the implementation of viable bioassessment and biocriteria programs that meet their individual needs and resources.

Biocriteria can be used to help support and protect designated uses of water resources; expand and improve water quality standards; detect problems other water quality measurements may miss or underestimate; help water resource managers set priorities for management planning and, assess the relative success or failure of management projects.

Biocriteria do not supersede or replace physical or chemical criteria for water resource decision making and management. In fact biocriteria augment these established measures so USEPA and the States and Tribes are better informed about the quality of our nations extensive and coastal water resources. The bioassessment/ biocriteria process is a particularly cost effective screening tool to evaluate over all water quality and determine water resource status and trends. The following table shows the progression of the biocriteria process.

Sequential progression of the biocriteria process. Adapted from Paulsen et al. 1991.

Step 1	**Preliminary Classification to Determine Reference Conditions and Regional Ecological Expectations** • Resource classification • Determination of best representative sites (reference sites representative of class categories)
Step 2	**Survey of Reference Sites and Selected Impaired Sites** • Collection of data on biota and physical habitat • Compilation of raw data (taxonomic lists, abundance levels, and other direct measures and observations)
Step 3	**Final Classification** • Test preliminary classification • Revise if necessary
Step 4	**Metric Evaluation and Index Development** • Data analysis (data summaries) • *Testing and validation of* metrics by resource class • Evaluation of metrics for effectiveness in detecting impairment • Selection of biological endpoints • Aggregation of metrics into index. • Test the index for validity on another data set.
Step 5	**Biocriteria Development** • Adjustment by physical and chemical covariates • Adjustment by designated aquatic life use
Step 6	**Implementation of Monitoring and Assessment Program** • Determination of temporal variability of reference sites • *Identification of problems*
Step 7	**Protective or Remedial Management Action** • Initiate programs to preserve exceptional waters • Implement management practices to restore the biota of degraded waters and to identify and address the causes of this degradation
Step 8	**Continual Monitoring and Periodic Review of References and Criteria** • Biological surveys continue to assess efficiency of management efforts • Evaluate potential changes in reference condition and adjust biocriteria as management is accomplished

Chapter 2

Biological Survey

2.1 Indicators of Biological Integrity

A key concept underlying the approach to biological surveys presented in this document is that of biological integrity. Biological integrity, discussed in greater detail in Section 1.7, may be operationally defined as

> "...the condition of the aquatic community inhabiting unimpaired waterbodies of a specified habitat as measured by community structure and function (USEPA 1990)."

Biological integrity is an ideal condition; estuarine and coastal marine communities can approach a condition of biological integrity when they are minimally impaired by human activities. In order to determine the degree to which these communities approach biological integrity, it is necessary to measure attributes (or indicators) of community structure and function and to be able to distinguish between natural variations and anthropogenic impacts.

Various techniques can be used at any level to document the effects of anthropogenic perturbations on biological communities. Discussion of these techniques falls into three general areas, the first two of which are measurement processes and the third is a data processing technique. They are:

- Measures of community condition and change;
- The presence or absence of indicator taxa;
- The use of indexes to compile and evaluate large amounts of biological data for evaluation.

The suitability of many of the approaches in each of these categories has long been the subject of debate among biologists and natural resource managers. The following discussion examines both the utility and uncertainty surrounding these community assessment tools.

2.2 Primary Measures of Community Condition and Change

Whenever possible, the investigator should try to examine two or more assemblages because different organism groups react differently to perturbation. The more diverse the measures used, the more robust the investigative technique is and the more confidence the manager can place in the results. However, this idea must be reconciled with the limitations of the costs of multiple and diverse surveys and the relative availability of reliable scientific methods to measure some assemblages. The prevalent approaches today are measures of benthic macroinvertebrate infauna, fish, and aquatic vegetation.

2.2.1 Benthic Macroinvertebrates

The benthic infauna have long been used for water quality assessments because of their tendency to be more sedentary and thus more reliable site indicators over time compared to fish and plankton. Consequently, a larger body of data has been accumulated for this assemblage. Examination of benthic community structure and function is a valuable tool for evaluating the condition of benthic habitats, for monitoring rates of recovery after environmental perturbations and potentially to provide an early warning of developing impacts to the system. Bilyard (1987) and USEPA (1991) cite the following specific advantages of monitoring benthic infauna to determine overall aquatic community health:

- Benthic infauna are typically sedentary and therefore are most likely to respond to local environmental impacts, thus narrowing the list of possible causes of impairment;
- Benthic infauna are sensitive to disturbances of habitat such that the communities respond fairly quickly with changes in species composition and abundance;
- Benthic infauna are important components of the food chain and often act to transport not only nutrients, but also toxicants, to the rest of the system;
- Monitoring benthic infauna provides an *in situ* measure of relative biotic integrity and habitat quality;
- Of the biota typically measured, this assemblage has the strongest supporting database. Thus, it has extensive historical and geographic application.

Some limitations of benthic infauna sampling include:

- Relatively few state and federal programs have the necessary in-house taxonomic expertise to support extensive monitoring activities;
- Current methods can distinguish severely impaired sites from those that are minimally impaired. However, it can be difficult to discriminate between slightly or moderately impaired areas, particularly in estuaries (due to their natural spatial and temporal variability);
- The condition of benthic habitats can vary over relatively small scales. Therefore, if too few samples are collected from a specified area, the ambient heterogeneity to be expected may be missed, potentially leading to incorrect conclusions regarding the biological and water quality conditions in the area;
- The cost and effort to sort, count, and identify benthic invertebrate samples can be significant, requiring tradeoffs between expenses and the desired level of confidence in decisions based upon the collected data.

2.2.2 Fish

Fish are an important component of estuarine and marine communities because of their economic, recreational, aesthetic and ecological roles. The abundance and health of the fish community is also the primary indicator used by the public to discern the health of a water body. Fish are good indicators of ecological health because:

- They are relatively sensitive to most habitat disturbances;
- Being mobile, sensitive fish species may avoid stressful environments, leading to measurable population patterns reflecting that stress;

- Fish are important in the linkage between benthic and pelagic food webs;

- They are long-lived and are therefore good indicators of long-term effects;

- They may exhibit physiological, morphological, or behavioral responses to stresses;

- Fish may exhibit obvious external anatomical pathology due to chemical pollutants;

- Fish databases originally compiled to support state and federal fisheries management programs may be available. These databases may require integration with other data (e.g., water quality) to be useful for bioassessment and biocriteria purposes.

The limitations on the use of fish in community bioassessments include:

- Fish represent a relatively high trophic level, and lower level organisms may provide an earlier indication of water quality problems;

- Some fish are resident species with relatively limited lifetime spatial ranges. Others have relatively large ranges, making it difficult to isolate probable causes of degradation that could occur anywhere within their range. Thus, the spatial scale of sampling is an issue and because of seasonal, open water migrations, temporal adjustments may also be necessary;

- Mobile organisms such as fish may avoid stressful environments, reducing their exposure to toxic or other harmful conditions;

- Fish surveys may be biased because of recreational and commercial fishing pressures on the same or related fish assemblages;

- Some fish are very habitat selective and their habitats may not be easily sampled (e.g., reef- or marsh-dwelling species);

- Since they are mobile, spatial variability is very high, requiring a large sampling effort to adequately characterize the fish assemblage.

2.2.3 Aquatic Macrophytes

Aquatic macrophytes in estuarine and coastal marine waters may include vascular plants (e.g., seagrasses) and algae (e.g., sessile and drift). Vascular aquatic macrophytes are a vital resource because of their value as extensive primary producers in estuaries. They are a food source for waterfowl, a habitat and nursery area for commercially and recreationally important fish species, a protection against shoreline erosion, and a buffering mechanism for excessive nutrient loadings. The primary productivity that has been observed for submerged aquatic vegetation (SAV) communities in estuaries is among the highest for any aquatic system (USEPA 1992). Excessive nutrient loadings lead to prolific phytoplankton and epiphytic macroalgal growth on seagrass which out-compete the seagrass through shading, as evidenced by the 1970s and 1980s decline of eelgrass in the Chesapeake Bay along with the current decline in Waquoit Bay. Because of the combined high productivity and habitat function of this plant community, any or all of the other estuarine or coastal marine biota can be affected by the presence or absence of macrophytes.

Some of the advantages of using aquatic macrophytes in biological surveys are:

- Vascular plants are a sessile community. There is essentially no mobility to rooted vascular or holdfast-established algal plant communities, so expansion or contraction of seagrass beds can be readily measured as an environmental indicator;
- Measurement of macrophyte community extent and relative density can be fairly easily accomplished by remote means, such as aerial photography, if the water is clear or shallow;
- Sampling frequency is reduced because of the relatively low community turnover compared to other biota such as benthic invertebrates or fish;
- Taxonomic identification in a given area is generally consistent and straight-forward.

Some of the disadvantages of macrophyte surveys are:

- Relatively slow response by the plant community to perturbation makes this a delayed indicator of water quality impacts. This could be critical if prompt management responses are needed;
- Successional blooms of some macrophytes means seasonal cycles need to be identified and accommodated by the survey schedule to avoid misinterpretation of data and false assumptions of water quality impacts;
- Changes in abundance and extent of submerged macrophytes are not necessarily related to changes in water quality;
- Aquatic macrophytes do not stand alone as an indicator of ecosystem condition; additional parameters (e.g., water column nutrient concentrations, light penetration) are required to interpret macrophyte data.

2.2.4 Phytoplankton

Many estuaries and marine waters can be considered "plankton-dominated" systems, which implies that this assemblage should provide valuable information in an assessment of ecosystem condition. Advantages of using plankton include:

- Plankton provide the most notable indication of eutrophication in estuarine environments. Changes in nutrient concentrations can result in long-term changes in estuarine community structure and function and planktonic primary producers are one of the earliest communities to respond;
- Changes in plankton primary production will in turn affect higher trophic levels of macroinvertebrates and fish;
- Many states routinely monitor chlorophyll *a* as part of water quality monitoring due to the ease and relatively low cost of analysis;
- Plankton have generally short life cycles and rapid reproduction rates making them valuable indicators of short-term impact.

As with all other assemblages, there are disadvantages associated with using phytoplankton in a biosurvey:

- The fact that phytoplankton are subject to rapid distribution with the winds, tides, and currents means they may not remain in place long enough to be source identifiers of short-term impacts. This problem is compounded by the ability of some phytoplankton to synthesize atmospheric sources of nitrogen, thus confounding the identification of runoff sources of nutrients in estuaries and the resultant changes in the aquatic biota;

- Taxonomic identification of phytoplankton can be difficult and time-consuming;

- Competition by aquatic macrophytes, higher respiration rates, and increased grazing by zooplankton may counteract increased phytoplankton biomass resulting from nutrient enrichment. These reasons argue for investigating phytoplankton and zooplankton together as biological indicators;

- Phytoplankton can undergo blooms, the causes of which might be indeterminate, at varying frequencies.

2.3 Measures of Community Condition and Change Being Developed

Two assemblages (zooplankton, epibenthos) have considerable potential for expanding the biological information available for biocriteria development and bioassessments. These assemblages, however, are considered "developmental" at this time. As survey methods become more refined and routine, databases for these assemblages will expand and the techniques are expected to become sufficiently robust to be incorporated in biocriteria development and environmental management decision making. Paleoenvironmental reconstruction is an additional technique being developed. This technique allows investigators to infer past conditions from the remains of several groups of organisms found in sediment cores, and to compare those past conditions to current ones.

2.3.1 Zooplankton

Zooplankton consist of two basic categories: holoplankton which spend their entire life cycle as plankton, and meroplankton which are only plankton while in the larval life stage.

Holoplankton are characterized by rapid growth rates, broad physiological tolerance ranges, and behavioral patterns which promote their survival in estuarine and marine waters. The calanoid copepods are the numerically dominant group of the holoplankton, and the genus *Acartia* (*A. tonsa* and *A. clausi*) is the most abundant and widespread in estuaries. *Acartia* is able to withstand fresh to hypersaline waters and temperatures ranging from 0° to 40°C.

The meroplankton are much more diverse than the holoplankton and consist of the larvae of polychaetes, barnacles, mollusks, bryozoans, echinoderms, and tunicates as well as the eggs, larvae, and young of crustaceans and fish.

Zooplankton populations are subject to extensive seasonal fluctuations reflecting hydrologic processes, recruitment, food sources, temperature, and predation. They are of considerable importance as the link between planktonic primary producers and higher carnivores. As such, they are also early indicators of trophic shifts in the aquatic system.

Advantages of zooplankton sampling are similar to phytoplankton:

- The rapid turnover of the community provides a quick response indicator to water quality perturbation;
- Sampling equipment is inexpensive and easily used;
- Compared to phytoplankton, sorting and identification is fairly easy.

Some limitations of using zooplankton in biosurveys are:

- The lack of a substantial data base for most regions;
- The high mobility and turnover rate of zooplankton in the water column. While this permits a quick response by zooplankton to environmental changes on the one hand, it also increases the difficulty of evaluating cause and effect relationships for this assemblage.

2.3.2 Epibenthos

The sampling of those animals living on the sediments or on structures may prove to be the link between relatively low cost but highly variable fish community information, and the more consistent but expensive benthic macroinvertebrate surveys. The process has been tested with considerable success in Washington, North Carolina, and Florida (Chapter 13).

Advantages of using this assemblage are:

- The relatively sedentary life style of some epibenthic fauna can result in an in-place accumulation of indicative pathogens and toxicants in individuals while the community composition reflects the average salinity, temperature and dissolved oxygen of that locale over an extended period of time (Day et al. 1989);
- Ease of data collection by use of small otter trawls or beam trawls;
- Relative ease of identification because taxonomic lists of local crustaceans, mollusks, and echinoderms can be fairly easily compiled;
- Sampling is as inexpensive as fish surveys, and can often be done with the same or similar equipment during the same survey;
- Decapod crustacea are usually very important prey for fish and are important components in benthic food webs. Some (e.g., shrimp and crabs) are harvested for human consumption.

Possible difficulties involve:

- Potential equipment snags and difficulties in macrophyte beds;
- Benthic infauna would likely be included in the trawl sample due to disturbance of surface sediments;
- As when using otter trawls for fish, benthic habitat may be destroyed;
- There is greater potential for avoidance by organisms than when sampling for benthic macroinvertebrates, though not as great as with fish surveys;
- Because of relatively low taxa numbers in some environments, especially coastal marine waters, impact response may not be as sensitive as desired; this could be

addressed by the use of indicator species instead of a multimetric approach;

- Epibenthos are very sensitive to substrate type;
- Relative sensitivity remains to be determined in many areas.

2.3.3 Paleoenvironmental Reconstruction: preserved remains

Several groups of organisms in estuaries leave remains in the bottom sediments. Some of the remains are resistant to decay and become a permanent biological record of the life in that waterbody. Comparisons of present-day biota to that of the past allow past environmental conditions to be inferred. Several groups of organisms have been used for this type of study in estuaries including diatoms, dinoflagellates, and foraminifera (Latimer et al. 1997).

The approach is to elucidate relationships between environmental conditions (for example, temperature, dissolved oxygen, nutrient concentrations) and the relative abundance of target species. These known relationships are then used to infer past conditions from the observed remains in the sediment. Advantages of studying paleoenvironmental systems include:

- diatoms, dinoflagellate cysts, and foraminifera found in sediments integrate conditions over broad spatial scales and over time periods of one year or more, so that short-term variability does not confound assessment;
- there is no need to adhere to an index period for sampling;
- paleoenvironmental reconstruction can provide a site-specific reference by showing conditions in the past.

Disadvantages of studying paleoenvironmental systems include:

- it requires a relatively stable depositional environment; it is not suitable for shallow estuaries subject to frequent resuspension;
- it requires conditions for preservation of target assemblages in the sediment;
- temporal resolution is limited by the rate of accumulation (between 1-10 years); it cannot be used to assess short-term response to stressors or to restoration efforts;
- at the time of this writing, technical expertise for estuarine paleoecology is specialized, with only a small handful of research institutions active in North America.

2.4 The Use of Indexes to Compile And Evaluate Biological Data

It is evident that biological surveys can generate tremendous amounts of raw data. The usual approach to sorting this wealth of observations is to summarize a series of diverse community measurements into one or more dimensionless indexes, much as the cumulative performance of a student's work for a year can be reduced to annual grades.

As with student grades, the use of dimensionless indexes is a well-established and consistent way to evaluate and compare many discrete units as a continuum of performance or condition. Also similar to student grading, detailed insight is lost when the complex interplay of so many discrete variables is reduced to a single score. The reasons for high or low scores are not always evident and the accuracy of the scoring process itself is always subject to debate. Indexing is the only way to rank order information for decision making. However, valuable insight is lost at every level of data reduction. There is no alternative to the process short of relying entirely on the professional judgment and wide variation of skill of individual biologists. The strengths of index development and use are:

- It is a rational, consistent way to reduce large amounts of data to unitless, meaningful interpretations;
- It is a quantitative treatment of the observations which permits statistical assessments;
- Interpretive bias is reduced in the treatment of the data.

Conversely, indexing:

- Removes the decision-making from detailed evaluation of the data and information to just reporting of simplified indexes;
- May be viewed as irrefutable, despite evidence to the contrary;
- May obscure important and confounding interrelationships in the aquatic environment contributing to the index score(s);
- Obscures more information as each level of data reduction is performed leading to an index value, so that some indexes are not sufficiently sensitive to reflect biotic change;
- Provides no indications of causes of the relative condition of the system.

The best way to guard against the problems of indexing, while using it to expedite decision-making, is to always retain the raw data. These files can be used to translate historical data sets into present indexes for temporal continuity, and even more important, they can be evaluated to provide an interpretation and potential diagnosis for management action when a particular site is being evaluated.

Indexes are most often used to measure community composition such as species abundance, diversity, evenness, richness, and dominance or conditions such as incidence of disease, malformation, and distributions of year classes. These can be used to assess the changes in community structure that occur as a result of anthropogenic perturbations (Boyle et al. 1990). Community function can also be described through indexes such as the Infaunal Trophic Index (Word 1978, 1980, USEPA 1987).

Although indexes have long been used in applied and theoretical ecology, it is recognized that some of them, when applied individually, are insensitive to stress-induced changes in naturally occurring biological communities (Boyle et al. 1990). Because of varying sensitivities of the community indexes, several of them should be used concurrently for evaluating impacts. This approach provides greater certainty of the data interpretation than reliance on any single index. Conversely, while Ludwig and Reynolds (1988) indicate that the most reliable community measures in evenly matched surveys are number of individuals and number of taxa as direct measures; it has been observed in the coastal marine studies associated with this guidance manual that, at least in two mid-Atlantic Bight outfall studies, the diversity index and the richness index both appear to be more responsive than number of individuals or number of taxa to sewage impacts (Gibson, Chapter 13). For a more detailed discussion of the different indexes and their particular applications see Chapter 11 (Index Development) and Chapter 13 (Case Studies).

2.5 Indicator Taxa

Indicator taxa or species are those organisms whose presence (or absence) at a site indicates specific environmental conditions. If an organism known to be intolerant of pollution is found to be abundant at a site, high water quality conditions can be inferred. On the other hand, dominance by pollution tolerant organisms implies a degraded condition. When available, indicator taxa are an important, cost-effective preliminary survey tool for site assessments. However, the investigator should always ascertain that absence of an indicator organism is a fact and not merely a reflection of insufficient sampling.

Swartz et al. (1985, 1986, 1994) have demonstrated the sensitivity of the amphipod *Rhepoxynius abronius* to the complex contaminant mixture that often characterizes coastal marine benthic pollution. Their studies were performed along pollution gradients from the Los Angeles County Sanitation Districts' sewage outfalls to control conditions in Santa Monica Bay. The results showed that there were significant increases in the concentration of most sediment contaminants and significant decreases in benthic taxa richness and abundance at stations where sediment was acutely toxic to *R. abronius* (Swartz et al. 1985). More studies performed by Swartz et al. (1994) at a designated Superfund site in San Francisco Bay also showed that acute sediment toxicity lab tests of *R. abronius* correlated with biologically adverse sediment contamination in the field. Other EMAP studies (Summers et al. 1992) included a 10-day acute test using the tube-dwelling amphipod, *Ampelisca abdita*. The majority of sediments proving significantly toxic to *A. abdita* were found in Louisiana and Alabama estuarine waters.

A well-known indicator for degraded systems is the polychaete *Capitella capitata*. *C. capitata* and its related species are collectively known as the *C. capitata* complex. In general, the presence of this indicator species corresponds to a dominance of deposit feeders that colonize an area as organic pollution increases. Swartz et al. (1985) observed dominance of *Capitella* near sewage outfalls. A recent study in the Mid-Atlantic Bight by the U.S. Army Corps of Engineers (1996) suggests that the polychaete *Amastigos caperatus* may have indicator potential similar to the *Capitella* complex.

A problem with using pollution tolerant indicator organisms is that some of these organisms may be ubiquitous and found in naturally occurring organically enriched habitats as well as in minimally impaired waters. To be useful as an indicator, they must have displaced other, less robust taxa and have achieved numeric dominance. Tolerant and ubiquitous organisms can be found in sediments far away from sources of sewage pollution and long after plumes have dispersed.

The use of the concept of "clean" indicator species is less subject to this form of misinterpretation. These "clean" or highly sensitive organisms are less likely to be found in both polluted and high quality habitats.

The best option may be the paired use of both pollution tolerant *and* intolerant indicator species. If both indicators change concurrently in opposite directions, more confidence can be placed in the interpretation.

As part of the biological survey process, individual indicator species are useful in reducing analytical costs. They are not only a valuable preliminary assessment tool, they are a cost-effective way to define the magnitude, spatial, and temporal extent of an impact (USEPA 1992). Selected indicators should possess the following characteristics (Green 1984):

- Provide sufficiently precise and accurate appraisals of:
    - species of concern
    - magnitude of anthropogenic disturbance;
- Be cost-effective and statistically reliable as an alternative to monitoring all critical community measures;
- Appropriate to the spatial and temporal scale demanded by the study objectives.

When indicator species are employed in tandem for impact investigations, a gradient of species distribution can often be identified. Such a gradient might progress from the most degraded waters, having low diversity communities dominated by pollution tolerant opportunistic species, to unimpaired or minimally impaired waters having diverse communities that are comprised of a wide range of taxa, including pollution sensitive ones and some that are pollution tolerant.