AQUATIC BIOMONITORING SESSION
LECTURE OUTLINE

Presented by:

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I. Definition of Aquatic Biomonitoring

Aquatic biomonitoring techniques include a broad range of methods which use living organisms as indicators of effluent quality, in stream water quality, and/or ecosystem health.

II. Definition of Aquatic Bioassessment

Aquatic bioassessments, as defined in EPA's Rapid Bioassessment Protocols, utilize field studies to assess the degree of water quality or habitat impairment by characterizing instream biological condition.

III. Focus of Today's Lecture

The lecture will concentrate on bioassessment and contaminants studies methodologies, the ecological response of biota <u>in the field</u>.

IV. History of Aquatic Biomonitoring and Bioassessment

During the last 25 years, field surveys of various types have come in and out of vogue on a cyclical basis:

Pre-1962

Emphasis on general field studies to show response of fish and invertebrates to sewage, industrial, and power plant discharges.

During 1962

Silent Spring was published and public and official awareness and concern about pesticides and various other toxic chemicals increased.

Prior to 1970

Studies were done mostly by government and academic groups. Various kinds of field surveys were being done and indicator organisms as well as early aquatic bioassay tasks began getting more attention.

During 1972.

The Clean Water Act changed much of the emphasis towards technology-based improvements (Best Practical and Best Available Control Technologies) of effluents and away from stream-based measurement of biological response. Another factor shifting emphasis away from stream surveys was that they had gotten complicated and expensive. The 1973 EPA methods manual for field surveys required up to 20 hours per sample to identify all invertebrate species. Note: the newer rapid bioassessment protocols in vogue since the late 80's are designed to correct this problem by being easier, quicker, and less expensive.

Mid-Eighties.

In response to Clean Water Act requirements, EPA and the states began to emphasize effluent bioassays to determine whether or not treated effluents were still toxic to aquatic organisms.

During 1986.

James Karr and coauthors published the Index of Biological Integrity (IBI) summary manual for fish surveys. Federal and state agencies began showing renewed interest in stream-based surveys as another way to check biological response to pollution and other habitat impacts.

1989

EPA published its summary document "Rapid Bioassessment Protocols for Use in Streams and Rivers: Benthic Macroinvertebrates and Fish" (see copy of cover in attached materials). Using the

IBI approach, EPA generated several levels of fish surveys and added invertebrate surveys. Many state regulatory agencies begin developing methods based on this manual. EPA suggested 3 levels of surveys, level 1 (very basic and easy), level 2 (still a lot easier than detailed surveys which had been done in the past), and level 3 (more rigorous when additional detail is needed).

During 1990

Many states and individual workers modified the protocols to meet specific needs. For example, the City of Fort Worth developed simple (Level 1) survey methods for inspectors monitoring storm drains and small creeks. The author developed the first rapid bioassessment methods for wetlands, using plants, invertebrates, and birds. EPA published guidance document entitled: EPA Biological Criteria, National Program Guidance for Surface Waters, EPA-440/5-90-004, 57 pp. [1](see attached materials).

1991/1992

In response to EPA's requirement for narrative biocriteria in the next round of updates of water quality standards and numerical criteria within 6 years, many States have either adopted rapid bioassessment/IBI protocols or are currently developing them. Many of these states are also defining reference streams in various ecosystems for comparison to impacted sites.

Narrative biocriteria verbally summarize characteristics of attainable biological integrity (examples: "Aquatic life shall be as naturally occurs" (Maine) or "Fish communities are characterized by...(List of population characteristics and names of species expected in the ecoregion in streams of that type, Arkansas).

Numeric criteria specify an IBI value to be attained after calibration within the geographical area. For example, for Ohio exceptional warm water habitats, biocriteria are set as the 75th percentile of all biological index scores recorded at established reference sites within the ecoregion.

State progress includes the following:

Four states, Arkansas, North Carolina, Maine and Ohio, are leading the way by currently using biological criteria to define aquatic life use classifications and enforce water quality standards. IBI formulations and scoring criteria have been finalized for 5 states. Eight other states are calibrating IBI scoring criteria, and even more are using biocriteria. Delaware, New Jersey, Virginia, and Maryland are jointly developing biocriteria for coastal regions for invertebrates. Ohio and Arkansas have developed comprehensive ecoregion classifications to complement their protocols and standards. Texas is developing protocols for both fish and invertebrates. Florida has specific biocriteria, based on invertebrate diversity, in state water quality standards. Nebraska is developing protocols for several different ecoregions based on fish and invertebrates. Most states are getting started on programs either for invertebrates or fish.

June, 1993, update on development of rapid bioassessment protocols by states (Mike Barbour, Tetra Tech, personal communication):

The 1989 EPA Rapid Bioassessment Protocols document was an initial attempt to incorporate to time savings, cost effectiveness into biological collecting methods and to encourage the use of biological criteria into state water quality regulatory systems. Nine states have biomonitoring protocols which are not especially closely related to EPA Rapid Bioassessment Protocols. About half the states have protocols based reasonable closely to EPA Rapid Bioassessment Protocols one way or the other. Benthic invertebrates are collected by most states, with the only exceptions being the states not developing biological monitoring protocols for use in the measurement of attainment of biological criteria (in 1993, this group included CA, NV, SD, GA, and VA). About half the States are also using fish. Most states are doing field processing of fish samples, using large samples. Subsampling is incorporated as a basic element in most protocols. Subsampling for macros is used to cut down on processing times. Interstate cooperative efforts are becoming popular. Over half the states are using ecoregions and reference sites.

Alaska Contact: Jeff Hock, ADEQ, Juneau, works on Rapid Bioassessment Protocol Development for State of Alaska (907) 790-2169

Note: As of the fall of 1993, Alaska was under-manned and behind in this process.

V. Recommendations for Park Service Specialists

1. The author recommends aquatic bioassessments based on EPA's protocols be developed and included in biomonitoring programs wherever they are deemed suitable by Park Service Specialists, especially when it is appropriate to:

   a) Obtain a better understanding of the natural variability of aquatic fish and invertebrates which currently exist in Park wetlands, creeks, rivers, and other aquatic habitats. Doing simple studies more often may tell you more about the variability in the system than doing more rigorous studies less often. Becoming familiar with the invertebrates and small fish in Park waters might also help the park naturalist program. The public is becoming more knowledgeable on aquatic issues and will be asking more questions as time goes along. Rapid bioassessments are oriented towards naturalist issues and would provide information helpful to Park Service Staff in developing interpretive programs (new campfire slide shows, etc.).

   b) Have a baseline for future comparisons to document changes resulting from future impacts (oil spills, etc.). Having pre-impact bioassessment data helps you document impact for Natural Resource Damage Assessments required by the Department of Interior. Having bioassessment data from relatively pristine National Park Service lands would also help state agencies looking for data from relatively clean sites to compare with data from impacted sites.

   c) Develop national or regional databases to monitor long term trends.

2. Since many states have started developing rapid bioassessment protocols, it will often be appropriate to use the ones they have already developed. States such as Arkansas, Maine, and Ohio would probably be glad to assist the Park Service in getting started in these efforts. For those states which do not have protocols developed, the 1988 EPA guidance manual [2] can be used as a guide to develop appropriate protocols.

Note: recent data [3] for benthic invertebrates indicates two metrics recommended in the 1988 document should not be used: 1) scrapers/filterers, and 2) EPT/Chironomid abundances. Among the benthic invertebrate metrics are still recommended [3]:

Structure Metrics:

1. **Taxa richness**
2. **EPT taxa index**
3. **Pinkham-Pearson Index**
4. **Quantitative Similarity Index for Taxa**

Community Balance Metrics:

5. Hilsenhoff Biotic Index
6. % Dominant Taxa
7. Dominants-in-common for five most abundant taxa
8. Hydropsychidae/Trichoptera

Functional Feeding Group Metrics:

9. Abundance of scrapers/(scrapers + filterers)
10. Abundance of shredders/total
11. Quantitative Similarity Index for Functional Feeding Groups.

Having different protocols and biocriteria for different states and different ecoregions might seem to pose a standardization/field validation problem, however:

a) **It is unavoidable, since different ecoregions and habitat types (wetlands versus rivers, versus lakes, etc.) will always require different rapid bioassessment methods, different scoring schemes, and different biocriteria.**

b) **As long as the field methods and biocriteria are developed according to EPA's general guidance [1,2] or (better yet) specific protocols developed by an individual state to measure compliance with biological criteria, the data obtained can be at least roughly compared. This is because results and biocriteria comparisons are computed in terms of departures from the ideal of "what should be there" if the site were not impacted (100% scores are from the "relatively undisturbed" reference sites).**

If you later determine you need more detailed information, the rapid bioassessment data will useful in selecting sites for more rigorous and more quantitative biomonitoring [4], analyses utilizing more complex community structure indices [5], or toxicity testing (for sites where bioassessment data suggests a toxicity factor may be preventing a normal biological community from being established or maintained).

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2. **Plafkin, J.L., M.T. Barbour, K.D. Porter, S.K. Gross** and **R.M. Hughes**. 1989. Rapid bioassessment protocols for use in streams and rivers - macroinvertebrates and fish. EPA, Washington, D. C., EPA/444/4-89-001, available through EPA Office of Water (WH-553).

3. **Barbour, M.T, J.L. Plafkin, B.P. Bradley, C.G. Graves,** and **R.W. Wisseman**. 1992. Evaluation of EPA's Rapid Bioassessment Benthic Metrics: Metric Redundancy and Variability Among Reference Stream Sites. Environmental Toxicology and Chemistry **11**:437-449.

4. **Klem, D.J., P.A. Lewis, F. Fulk, and J.M. Lazorchak** 1990. Macroinvertebrate field and laboratory methods for evaluating the biological integrity of surface waters. EPA Environmental Monitoring Systems Laboratory - Cincinnati, EPA/600/4-90/030. 256 pp.

5. **Boyle, T.P, G.M. Smillie, J.C. Anderson,** and **D.R.Beeson**. 1990. A sensitivity analysis of nine diversity and seven similarity indices. Research Journal Water Pollution Control Federation **62**(6):649-762.

Biological Criteria:
Summary Items from the following reference:

U.S. Environmental Protection Agency. 1990. EPA Biological Criteria, National Program Guidance for Surface Waters, EPA-440/5-90-004, 57 pp.. (Distributed by the U.S. Environmental Protection Agency, Office of Water, Regulations and Standards (WH-585), 401 M. Streets S.W., Washington, D.C. 20460).

An **AQUATIC COMMUNITY** is an association of interacting populations of aquatic organisms in a given waterbody or habitat.

A **BIOLOGICAL ASSESSMENT** is an evaluation of the biological condition of a waterbody using biological surveys and other direct measurements of resident biota in surface waters.

BIOLOGICAL CRITERIA, or biocriteria, are numerical values or narrative expressions that describe the reference biological integrity of aquatic communities inhabiting waters of a given designated aquatic life use.

BIOLOGICAL INTEGRITY is functionally defined as the condition of the aquatic community inhabiting unimpaired waterbodies of a specified habitat as measured by community structure and function.

BIOLOGICAL MONITORING is the use of a biological entity as a detector and its response as a measure to determine environmental conditions. Toxicity tests and biological surveys are common biomonitoring methods.

A **BIOLOGICAL SURVEY,** or biosurvey, consists of collecting, processing and analyzing representative portions of a resident aquatic community to determine the community structure and function.

A **COMMUNITY COMPONENT** is any portion of a biological community. The community component may pertain to the taxomonic group (fish, invertebrates, algae), the taxonomic category (phylum, order, family, genus, species), the feeding strategy (herbivore, omnivore, carnivore) or organizational level (individual, population, community association) of a biological entity within the aquatic community.

REGIONS OF ECOLOGICAL SIMILARITY describe a relatively homogeneous area defined by similarity of climate, landform, soil, potential natural vegetation, hydrology, or other ecologically relevant variable. Regions of ecological similarity help define the potential for designated use classifications of specific waterbodies.

DESIGNATED USES are those uses specified in water quality standards for each waterbody or segment whether or not they are being attained.

An **IMPACT** is a change in the chemical, physical or biological quality or condition of a waterbody caused by external sources.

An **IMPAIRMENT** is a detrimental effect on the biological integrity of a waterbody caused by an impact that prevents attainment of the designated use.

A **POPULATION** is an aggregate of interbreeding individuals of a biological species within a specified location.

A **WATER QUALITY ASSESSMENT** is an evaluation of the condition of a waterbody using biological surveys, chemical-specific analyses of pollutants in waterbodies, and toxicity tests.

An **ECOLOGICAL ASSESSMENT** is an evaluation of the condition of a waterbody using water quality and physical habitat assessment methods.

In accordance with priorities established in the *FY 1991 Agency Operating Guidance,* States are to adopt narrative biological criteria into State water quality standards during the FY 1991-1993 triennium. To support this priority, EPA is developing a *Policy on the Use of Biological Assessments and Criteria in the Water Quality Program* and is providing this program guidance document on biological criteria.

Narrative biological criteria are definable statements of condition or attainable goals for a given use designation. They establish a positive statement about aquatic community characteristics expected to occur within a waterbody (e.g., "Aquatic life shall be as it naturally occurs" or "A natural variety of aquatic life shall be present and all functional groups well represented"). These criteria can be developed using existing information. Numeric criteria describe the expected attainable community attributes and establish values based on measures such as species richness, presence or absence of indicator taxa, and distribution of classes of organisms. To implement narrative criteria and develop numeric criteria, biota in reference waters must be carefully assessed. These are used as the reference values to determine if, and to what extent, an impacted surface waterbody is impaired.

To apply biological criteria in a water quality standards program, standardized sampling methods and statistical protocols must be used. These procedures must be sensitive enough to identify significant differences between established criteria and tested communities. There are three possible outcomes from hypothesis testing using these analyses: (1) the use is impaired, (2) the biological criteria are met, or (3) the outcome is indeterminate. If the use is impaired, efforts to diagnose the cause(s) will help determine appropriate action. If the use is not impaired, no action is required based on these analyses. The outcome will be indeterminate if the study design or evaluation was incomplete. In this case, States would need to re-evaluate their protocols.

There is considerable State interest in integrating biological assessments and criteria in water quality management programs. A minimum of 20 States now use some form of standardized biological assessments to determine the status of biota in State waters. Of these, 15 States are developing biological assessments for future criteria development. Five States use biological criteria to define aquatic life use classifications and to enforce water quality standards. Several States have established narrative biological criteria in their standards. One State has instituted numeric biological criteria.

The principal objectives of the Clean Water Act are "to restore and maintain the chemical, physical and biological integrity of the Nation's waters" (Section 101).

Narrative criteria can take more specific forms than illustrated in the Maine example. Narrative criteria may include specific classes and species of organisms that will occur in waters for a given designated use. To develop these narratives, field evaluations of reference conditions are necessary to identify biological community attributes that differ significantly between designated uses. For example in the Arkansas use class _Typical Gulf Coastal Ecoregion_ (i.e., South Central Plains) the narrative criterion reads:

> *Streams supporting diverse communities of indigenous or adapted species of fish and other forms of aquatic life. Fish communities are characterized by a limited proportion of sensitive species; sunfishes are distinctly dominant, followed by darters and minnows. The community may be generally characterized by the following fishes: Key Species-Redfin shiner, Spotted sucker, Yellow bullhead, Flier, Slough darter, Grass pickerel,, Indicator Species-Pirate perch, Warmouth, Spotted sunfish, Dusky darter, Creek chubsucker, Banded pygmy sunfish (Arkansas DPCE 1988).*

In Connecticut, current designated uses are supported by narratives in the standard. For example, under Surface Water Classifications, Inland Surface Waters Class AA, the Designated Use is: "Existing or proposed drinking water supply; fish and wildlife habitat; recreational use; agricultural, industrial supply, and other purposes (recreation uses may be restricted)."

The supporting narratives include:

> *Benthic invertebrates which inhabit lotic waters: A wide variety of macroinvertebrate taxas should normally be present and all functional groups should normally be well represented ... Water quality shall be sufficient to sustain a diverse macroinvertebrate community of indigenous species. Taxa within the Orders Plecoptera(stoneflies), Ephemeroptera (mayflies), Coleoptera (beetles), Tricoptera (caddisflies) should be well represented (Connecticut DEP 1987).*

Narrative biological criteria are similar to the traditional narrative "free froms" by providing the legal basis for standards applications. A sixth "free from" could be incorporated into standards to help support narrative biological criteria such as "free from activities that would impair the aquatic community as it naturally occurs." Narrative biological criteria can be used immediately to address obvious existing problems.

Numerical indices that serve as biological criteria should describe expected attainable community attributes for different designated uses. It is important to note that full implementation of narrative criteria will require similar data as that needed for developing numeric criteria. At this time, States may or may not choose to establish numeric criteria but may find it an effective tool for regulatory use.

To derive a numeric criterion, an aquatic community's structure and function is measured at reference sites and set as a reference condition. Examples of relative measures include similarity indices, coefficients of community loss, and comparisons of lists of dominant taxa. Measures of existing community structure such as species richness, presence or absence of indicator taxa, and distribution of trophic feeding groups are useful for establishing the normal range of community components to be expected in unimpaired systems. For example, Ohio uses criteria for the warmwater habitat use class based on multiple measures in different reference sites within the same ecoregion. Criteria are set as the 25th percentile of all biological index scores recorded at established reference sites within the ecoregion. Exceptional warmwater, habitat index criteria are set at the 75th percentile (Ohio EPA 1988a). Applications such as this require an extensive data base and multiple reference sites for each criteria value.

To develop numeric biological criteria, careful assessments of biota in reference sites must be conducted (Hughes et al. 1986). There are numerous ways to assess community structure and function in surface waters. No single index or measure is universally recognized as free from bias. it is important to evaluate the strengths and weaknesses of different assessment approaches. A multimetric approach that incorporates information on species richness, trophic composition, abundance or biomass, and organism condition is recommended. Evaluations that measure multiple components of communities are also recommended because they tend to be more reliable (e.g., measures of fish and macroinvertebrates combined will provide more information than measures of fish communities alone). The weaknesses of one measure or index can often be compensated by combining it with the strengths of other community measurements.

The particular indices used to develop numeric criteria depend on the type of surface waters (streams, rivers, lakes, Great Lakes, estuaries, wetlands, and nearshore marine) to which they must be applied. In general, community-level indices such as the Index of Biotic Integrity developed for midwestern streams (Karr et al. 1986) are more easily interpreted and less variable than fluctuating numbers such as population size. Future EPA technical guidance documents will include evaluations of the effectiveness of different biological survey and assessment approaches for measuring the biological integrity of surface water types and provide guidance on acceptable approaches for biological criteria development.

Arkansas rewrote its aquatic life use classifications for each of the State's ecoregions. This has allowed many cities to design wastewater treatment plants to meet realistic attainable dissolved oxygen conditions as determined by the new criteria.

North Carolina developed biological criteria to assess impairment to aquatic life uses written as narratives in the State water quality standards. Biological data and criteria are used extensively to identify waters of special concern or those with exceptional water quality. In addition to the High Quality Waters (HOW) and Outstanding Resource Waters (ORW) designations, Nutrient Sensitive Waters (NSW) at risk for eutrophication are assessed using biological criteria. Although specific biological measures are not in the regulations, strengthened use of biological monitoring data to assess water quality is being proposed for incorporation in North Carolina's water quality standards.

Maine has enacted a revised Water Quality Classification Law specifically designed to facilitate the use of biological assessments. Each of four water classes contains descriptive aquatic life conditions necessary to attain that class. Based on a statewide database of macroinvertebrate samples collected above and below outfalls, Maine is now developing a set of dichotomous keys that serve as the biological criteria. Maine's program is not expected to have a significant role in permitting, but will be used to assess the degree of protection afforded by effluent limitations.

Ohio has instituted the most extensive use of biological criteria for defining use classifications and assessing water quality. Biological criteria were developed for Ohio rivers and streams using an ecoregional reference site approach. Within each of the State's five ecoregions, criteria for three biological indices (two for fish communities and one for macroinvertebrates) were derived. Ohio successfully uses biological criteria to demonstrate attainment of aquatic life uses and discover previously unknown or unidentified environmental degradation (e.g., twice as many impaired waters were discovered using biological criteria and water chemistry together than were found using chemistry alone). The upgraded use designations based on biological criteria were upheld in Ohio courts and the Ohio EPA successfully proposed their biological criteria for inclusion in the State water quality standards regulations.

Water Quality Standards Handbook (U.S. EPA 1983a), Technical Support Manual. Waterbody Surveys and Assessments for Conducting Use Attainability Analyses (U.S. EPA 1983b); Technical Support Manual., Waterbody Surveys and Assessments for Conducting Use Attainability Analyses, Volume II: Estuarine Systems (U.S. EPA 1984a); and Technical Support Manual. Waterbody Surveys and Assessments for Conducting Use Attainability Analyses, Volume III: Lake Systems (U.S. EPA 1984b). Future technical guidance will build on these documents and provide specific guidance for biological criteria development.

Amphipods, for example, dominate many aquatic communities and are more sensitive than other Invertebrates such as polychaetes and molluscs to a wide variety of pollutants including hydrocarbons and heavy metals (Reich and Hart 1979; J.D. Thomas, pers. comm.).

Biological surveys that use two or three taxonomic groups (e.g., fish, macroinvertebrates, algae) and, where appropriate, include different trophic levels within each group (e.g., primary, secondary, and tertiary consumers) will provide a more realistic evaluation of system biological integrity. This is analogous to using species from two or more taxonomic groups in bioassays. Impairments that are difficult to detect because of the temporal or spatial habits or the pollution tolerances of one group may be revealed through impairments in different species or assemblages (Ohio EPA 1988a).

High variability reduces the power of a statistical test to detect real impairments (Sokal and Rohlf, 1981).

Data collection protocols should incorporate (1) spatial scales (where and how samples are collected) and (2) temporal scales (when data are collected) (Green, 1979).

For example, if fish are sampled only from fast flowing riffles within stream A, but are sampled from slow flowing pools in stream B, the data will not be comparable.

Rapid bioassessment methods can be cost-effective biological assessment approaches when they have been verified with more comprehensive evaluations for the habitats and region where they are to be applied.

For example, assessment methods for algae (e.g. measures of biomass, nuisance bloom frequency, community structure) have been used for lakes.

(e.g., chemical verses biological criteria). No type of criteria can "prove" attainment; each type of criteria can disprove attainment.

In Maine, a more complex problem arose when effluents from a textile plant met chemical-specific and effluent toxicity criteria, yet a biological survey of downstream biota revealed up to 80 percent reduction in invertebrate richness below plant outfalls. Although the source of impairment seemed clear, the cause of impairment was more difficult to determine. By engaging in a diagnostic evaluation, Maine was able to determine that the discharge contained chemicals not regulated under current programs and that part of the toxicity effect was due to the sequential discharge of unique effluents (tested individually these effluents were not toxic; when exposure was in a particular sequence, toxicity occurred). Use of biological criteria resulted in the detection and diagnosis of this toxicity problem, which allowed Maine to develop workable alternative operating procedures for the textile industry to correct the problem (Courtemanch 1989, and pers. comm.).

For example, sedimentation of a stream caused by logging practices is likely to result in a decrease in species that require loose gravel for spawning but increase species naturally adapted to fine sediments.

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