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# The use of biological criteria as a tool for water resource management

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## Abstract

The status of biological criteria in state and federal water quality programs suggest that the majority of North American resource types have at least a single multimetric index developed. Large rivers, wetlands, and lakes are in the process of being studied and reference conditions are being developed but have primarily been developed for the Midwest and Northeastern United States. Biological criteria can include a variety of biological indicators ranging from multimetric indices, univariate indices, standard zoological and botanical indicators, and predictive models. The use of biological models to predict local conditions can result in a variety of spatial scales that biological criteria can address. Biological criteria will be applied as a measure of water resource condition, as biological restoration goals, for enforcement and compliance, for establishing baseline for Natural Resource Damage Assessments (NRDA), for formulating predictive models, and by the Environmental Protection Agency (EPA) for meeting the Government Performance and Results Act Goal 2b. Published by Elsevier Science Ltd.

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## 1. Introduction

The Government Performance and Results Act (GPRA) for the United States Environmental Protection Agency (EPA) Goal 2b is to “conserve and enhance the ecological health of the nation’s (state, interstate, and tribal) waters and aquatic ecosystems (rivers and streams, lakes, wetlands, estuaries, coastal areas, oceans, and groundwater) so that 75% of waters will support healthy aquatic communities by 2005”. The Environmental Protection Agency (EPA) has recommended the use of biological criteria as a mechanism for meeting the requirements of Section 316(a) of the Clean Water Act. Biological criteria would be used to eliminate responsibilities for industries generating thermal discharges that would not be limiting aquatic life within the vicinity of their outfalls.

Biological criteria are ecological benchmarks based on a variety of biological integrity response measures sensitive to human induced modifications (Davis and Simon, 1995; Simon, 1999). Karr and Dudley (1985) described biological integrity as “the capability of supporting and maintaining a balanced, integrated, adaptive community of organisms having a species composition, diversity, and functional organization comparable to that of natural habitats of the region”. Biological criteria are “narrative and numerical expressions that describes the reference [least-impacted] biological integrity of aquatic communities inhabiting waters of a given designated aquatic life use” (US Environmental Protection Agency, 1990). Biological criteria include a variety of indices that have been used to describe the variability and condition of the biological community. Since biological criteria include narrative and numerical expressions, in the broadest sense biological criteria can be based upon a variety of indices including diversity indices (Washington, 1984), univariate indices (e.g., Hilsenhoff biotic index

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(Hilsenhoff, 1982), floristic quality index (Swink and Wilhelm, 1994), index of well-being (Gammon, 1976), and numerous fisheries population and stock assessment indices (Nielsen and Johnson, 1983)), and multi-metric indices of biological integrity and sustainability (e.g. Karr, 1981; Karr et al., 1986; DeShon, 1995; Stewart et al., 1999).

Regional reference conditions are benchmarks that reflect the optimal conditions of the resource type under study (Hughes, 1995) and are formulated on a regional basis to reflect inherent natural variability within similar zoogeographic and geologic areas. Reference conditions for fish assemblages have been developed for a number of water resource types and have been reviewed in Miller et al. (1988), Simon and Lyons (1995), and Hughes and Oberdorf (1999). Macroinvertebrate assemblage multimetric indices have been reviewed by Barbour et al. (1995) and DeShon (1995). Rosen (1995) and Stewart et al. (1999) discussed the use of primary producers as indicators of biological integrity. Stewart et al. (1999) have outlined the framework for development of aquatic macrophyte assemblage indices of biotic integrity. Numerous other indices have recently been developed for fish communities for a variety of water resource types and areas of North America (Simon, 1999).

Biological criteria have numerous applications for state and federal resource agencies. The majority of state water resource agencies collect biological data for completion of their biennial assessment of water quality conditions for Congress otherwise known as the 305(b) report, which describes progress towards meeting the state aquatic life designated uses, an integral part of water quality standards (Southerland and Stribling, 1995). State water quality standards are legal mandates for protecting designated uses within individual watersheds or stream reaches. In addition, many states are developing biological criteria for regulatory purposes to evaluate specific point and non-point sources and will be used to designate water segments for protection and restoration purposes to assist in the formation, and tracking progress, of site-specific goals.

The purpose of this paper is to present information that describes the optimal assessment goals that should be developed for biological criteria and describe specific uses of biological criteria for regulatory and assessment purposes.

## 2. Biological reference conditions

Several approaches to establishing the standard for regional benchmark have evolved including reference site measurements, reference condition development, and formulation of predictive models. Hughes et al. (1986) originally used a reference site approach to

develop benchmarks for Ohio. This approach was based on sampling the 'best available' remaining sites typical of the ecoregions under consideration. Reference conditions are based on a cumulative data set approach that does not assume to know where the best sites are, rather the approach evaluates 'least-disturbed' and 'impaired' sites to assess an ecological dose-response curve (Simon, 1999). Predictive models use numerous data layers to evaluate local conditions and the biological community that should occur under the expected thermal, hydrologic, and geologic regimes. These predicted communities are then compared to observed communities at the site and changes in biological assemblages are then considered a residual or deviation from the control (Seelbach et al., 1997).

## 3. Methods development and approaches

Standard collection methods and operating procedures are key to the success of biological studies (Nielsen and Johnson, 1983). The first step in the development of biological criteria is the development of standard collection methodologies, which often requires numerous studies designed to answer resource-specific questions. Preliminary multimetric index development for large and Great rivers are based on efforts on the White (Simon, 1992), Wabash (Simon and Stahl, 1998), and Ohio Rivers (Simon and Emery, 1995). The ground-breaking efforts of Gammon (1976) and Gammon et al. (1981) provided much of the impetus for the development of biological sampling methods. The procedure for the development of biological criteria is based on the Ohio EPA model (Fig. 1). This model includes data collection via sampling, development of metrics for the resource under consideration, calibration and validation of metrics and index, ecoregional classification, and allowances for additional testing using an independent data set when possible.

When using calibrated multimetric indices to determine the condition of biological resources, it is necessary to use the standard operating procedures used to develop the criteria. The development of standard operating procedures are necessary considerations when utilizing multimetric indices. Numerous investigators have indicated that IBIs were not sensitive and could not provide a sharp enough discrimination of different ecological condition. However, after further consideration it is apparent that the investigators did not use the same methods, were outside the index period, or used criteria from areas outside the intended use. It would be inappropriate to use one data set to calculate IBI scores from two different multimetric indices when different collection methods are used to

calibrate these indices. The Wabash River and North Carolina have been used as examples to suggest that significantly different expectations are calibrated for these systems. However, collection approaches and the procedure developed for the Wabash are very different. Gammon has indicated repeatedly that small short-lived species are not targeted using their procedure. The Wabash method developed by Gammon is more appropriately considered a fisheries sustainability assessment or management index than an index of biological integrity while Simon and Stahl (1998) developed their approach consistent with the intentions of Karr (1981).

3.1. Procedures for developing multimetric indices or selecting appropriate metrics

Ohio EPA (1989) and Yoder and Rankin (1995) have described the development, testing, and validation phases used in biological criteria formation. The general procedure includes testing original metrics, development of new metrics, incorporating revealed trends, validation of revised metrics, and iterative monitoring of reference sites to recalibrate the IBI during a 10-year cycle (Fig. 1). Studies that develop a regionally calibrated multimetric index generally begin with the application of the original IBI (Karr, 1981, Karr et al.,

1986). It is while testing the original metrics, after recalibration using the watershed or regional application of data, that problems with the original IBI for that area become apparent. The original IBI included metrics in several categories including species richness and composition, pollution tolerance and sensitivity, trophic guilds, reproductive guilds, relative abundance, and fish health and condition. Species displacement (i.e., percentage of headwater species or percentage of pioneer species) (Simon, 1991) and obligate habitat specialists are also substituted (Simon and Emery, 1995). Karr (1981) has indicated that substitution of metrics is possible as long as the original intent of the metric is considered. For example, if the metric is a habitat specialist metric the replacement should be consistent with habitat. Fausch et al. (1984) suggested that the percentage of green sunfish metric can be replaced with a more holistic metric that encompasses all tolerant species. This metric is one of the most frequently replaced since green sunfish are not ubiquitous in all watersheds or sizes within watersheds. Another metric that is often replaced includes the percentage of hybrids. Several studies have seen hybrids in reference condition watersheds and cannot be sure whether these are a result of environmental degradation or simply biological variability. Many versions of the IBI have instead substituted a reproductive guild metric such as

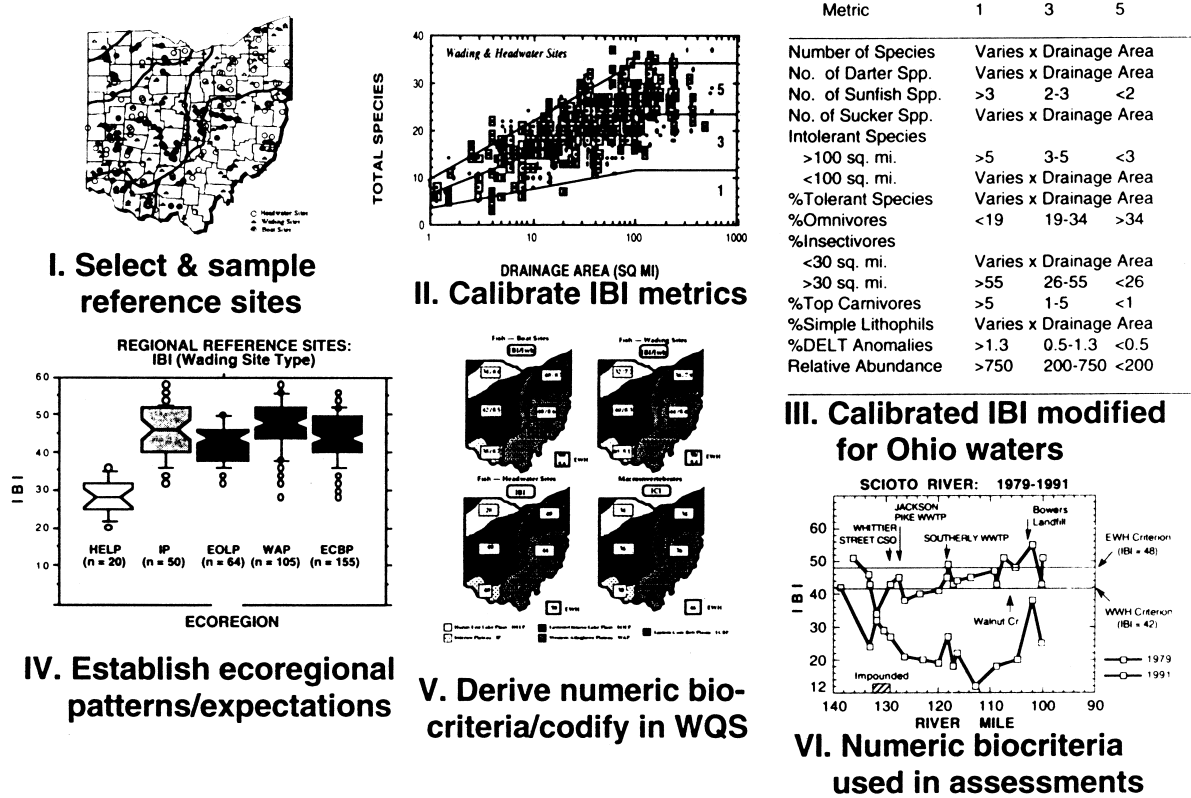


Fig. 1. Ohio EPA model illustrating key steps in the derivation and use of biological criteria for the IBI (Yoder and Rankin, 1995).

the percentage of simple lithophilous spawners. These species will reflect a change in siltation and other factors that were cited by Karr as the reason to use the percentage of hybrids metric. These substituted metrics are usually the result of brainstorming by numerous professional biologists with significant experience with the ecoregion, watershed, or regional framework being evaluated. For example, during the development of the biological criteria for the ecoregions of Indiana we evaluated 56 alternative metrics (Simon, 1991; Simon and Emery, 1995; Simon and Stahl, 1998).

Several important criteria for selecting replacement metrics should be discussed. First, an a priori hypothesis of the expectation for the reference condition should be suggested before the data is graphically expressed. Understanding the direction that disturbance should drive the community is an important consideration in the development process. For example Mundahl and Simon (1999) described the expected pattern of metrics used in their biological integrity index for coldwater streams in the Midwestern United States. The further testing of revealed trends becomes apparent as the developed multimetric index is applied. Simon and Rothrock (2000a) found that several of the metrics used to develop a plant IBI for southern Lake Michigan did not perform as originally designed and required further modification. The application of a fish IBI for the Central Corn Belt Plain ecoregion into the Grand Calumet River found that the presence of high minnow diversity was not necessarily a reflection of high biological integrity (Simon et al., 2000b). The presence of numerous exotic minnow species (i.e., carp *Cyprinus carpio*, goldfish *Carassius auratus*, and rudd *Scardinius erythrothalmus*) was causing the ecoregion expectation to get close to the highest levels of biological integrity that were observed from native minnow species. The original intentions of the metrics were not being met and thus Simon et al. (2000b) suggested that further scoring modifications were necessary. The State of Ohio has recommended that biological data collection must be an iterative process since it is necessary to recalibrate the reference condition after implementation of management plans and goals has had a chance to change stream designated uses.

## 4. Results and discussion

### 4.1. Uses of biological criteria

Biological criteria have been developed for six primary uses including, (1) measurement of water resource condition, (2) establishing restoration goals and targets, (3) enforcement and compliance monitoring, (4) establishing baseline for Natural Resource Damage Assessment (NRDA), (5) establishing predic-

tive models, and (6) measuring progress towards broad resource goals such as GPRA and total maximum daily loads (TMDL).

### 4.2. Measure of water resource condition

Southerland and Stribling (1995) and Davis et al. (1996) reviewed the status of biological criteria within States' programs in the US. Many of the programs that have developed numerical expectations for specific indicators have done so to assess the quality of biological communities under the requirements of 305(b) of the Clean Water Act. Midwestern states such as Ohio, Indiana, Illinois, Wisconsin, and Minnesota have established indicator specific expectations for preparing 303(d) lists, for 316(a) and (b) monitoring, and 305(b) assessment. Biological criteria becomes a primary step in determining whether a waterbody is meeting designated uses or whether additional monitoring is necessary. Probabilistic sampling have been used to describe the quality of entire watersheds to provide a more statistically confident measure of water resource quality (Larsen, 1995).

### 4.3. Biological restoration goals

Simon and Stewart (1999) used biological criteria estimates from the Central Corn Belt Plain to evaluate the Indiana Dunes National Lakeshore's protection of native fish assemblages. They found that public lands were less protective of native species than private lands. Additional efforts in Fish Creek, Indiana, and Leading Creek, Ohio, used biological targets to enable the restoration of fish, mussel, invertebrate, and amphibian assemblages after environmental impacts caused from diesel oil and acid mine leachate spills, respectively (EPA court settled consent decrees, unpublished). The advantage of using biological criteria for restoration goals is that for systems where limited information is available the waterbody can be modeled after similar waterbodies in the same ecoregion. For streams with some historical information, additional indicators can be developed for indicator specific key species, IBI, ICI, and modified index of well-being goals.

### 4.4. Enforcement and compliance monitoring

As numerical biological criteria are developed, calibrated, tested, and validated a logical use is to assess permitted dischargers. Biological criteria provide an increased benefit to regulatory agencies in that the biological indicator is a constant monitor of the quality of the effluent. Unlike toxicity testing or chemical sampling, which only reflects a single moment in time based on the collection of a grab sample of water, the

biological organisms that inhabit an area feed, live, and reproduce within the reach under consideration. Long-term impacts are often more dramatic than short-term single excursions from permit compliance. Thus, the regulatory or monitoring agency can determine the magnitude and extent of the impact within a short time period without having to actually witness an impact event. US Environmental Protection Agency, Region 5, Indiana Department of Environmental Management, Illinois EPA, and Ohio EPA have used biological criteria as a standard to establish discharger compliance with their National Pollutant Discharge and Elimination System (NPDES) permit. The advantage of biological criteria is that they give the monitoring agency the opportunity to compare various biological and chemical indicators to pinpoint response signatures for specific categories of impact.

#### 4.5. *Natural resource damage assessment (NRDA)*

The US Fish and Wildlife Service has a legal mandate to establish a baseline for natural resource damage assessment (NRDA) in order to determine the level of change between the impaired areas and a reference condition. In addition, the Service has also used biological criteria as restoration models for improving areas that are impairing natural resources. These damage assessments have been based on a variety of biological indicators including deformities, community and assemblage alterations, and increases in lost natural resources, and aesthetics. The Fox River, Wisconsin, Leading Creek, Ohio, and Grand Calumet River, Indiana, have used biological criteria expectations to establish baseline for biological assemblages. These systems are models for how the Service will use biological community information to restore natural resources to previous designated uses and levels of biological integrity.

#### 4.6. *Predictive models*

The development of predictive models using landscape-scale information and geographic information systems (GIS) are a future use of biological criteria. As more information becomes available from ecoregion level assessments, additional models will be formulated that will allow biologists to evaluate site-specific conditions based on local microhabitat rather than ecoregion level information. For example, the State of Michigan in collaboration with the University of Michigan has developed the Michigan Rivers Inventory (Seelbach et al., 1997). This predictive model is based on surficial geology, groundwater flow and quantity patterns, thermal patterns, and biological community information for the lower peninsula of Michigan. The potential of these predictive models for

monitoring designated uses or determining compliance with NPDES permits can likely be broken down into a simple comparison of predicted vs observed community assemblages and then evaluating differences between these expectations. This residual in biological community expectations can be compared to natural differences due to inherent variation.

#### 4.7. *Measuring progress towards broad resource goals such as GPRA and TMDL*

Measuring progress towards broad resource goals such as GPRA is an important use of biological criteria since it ensures that regulatory agencies are accountable to the people of the United States. State and Federal governmental agencies must ensure that impacts they detect are 'real' impacts before expensive corrective actions are required. Biological criteria is an approach that will ensure that the nation reaches environmental restoration goals and that aquatic life designated uses are restored. Biological criteria will evaluate whether some of the environmental regulatory programs can actually be translated into ambient improvements in the environment through TMDL assessments.

## 5. Conclusions

Biological criteria have been used for a variety of assessment applications including measurement of water resource condition, for establishing restoration goals and targets, for enforcement and compliance monitoring, for establishing baseline for NRDA, for establishing predictive models, and for measuring progress towards broad resource goals such as GPRA. The ability of biological criteria to meet the needs of monitoring agencies is based on the premise that biological indicators are better at assessing aquatic life designated uses than chemical or surrogate indicators. Numerous environmental indicators have shown that biological data is a better predictor of environmental impact than chemical or toxicological data in the absence of any other information.

As biological response signatures are refined and further developed to pinpoint impacts from specific classifications of chemical contaminants, use of biological criteria will be an important tool for resource agencies. Biological criteria will not be able to determine some impacts including PCB or dioxin contamination that would affect fish tissue consumption. In addition, some environmental impacts are similar in how they respond and specific response signatures may not be possible to separate different impact types. Further evaluation of patterns is necessary to discover

subtle aspects that these assemblage indicators may reveal.

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