



Measuring the attainment of biological integrity in the USA: a critical element of ecological integrity

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Abstract

The concept of ecological integrity has become a worldwide phenomenon and is firmly entrenched into the regulatory structure of environmental law in the United States of America (USA). The attainment of ecological integrity requires the attainment of its three elements: physical, chemical, and biological integrity. In the USA, measures of chemical integrity were implemented first into monitoring programs and were effective in reducing pollutant loadings to the nation's surface waters. Because biological communities integrate the effects of different stressors such as reduced oxygen, excess nutrients, toxic chemicals, increased temperature, excessive sediment loading, and habitat degradation, the advent of bioassessment in regulatory programs has provided a more comprehensive and effective monitoring and assessment strategy. Measures of biological integrity clearly have become a priority in the USA. The development of biological criteria (biocriteria) within regulatory programs to serve as thresholds by which to judge the attainment of designated aquatic life conditions of surface waters is a major focus of states and Indian tribes within the USA. The derivation of reference conditions for the nation's surface waters (i.e., streams, rivers, lakes, wetlands, estuaries, and marine waters) across different physiographic regions is a critical element in the design of biocriteria and is currently a primary initiative in the USA. Nearly all state water resource agencies have developed bioassessment approaches for streams; 1600 to 75 000 km of streams require assessment in each state. Bioassessment development for other water body types is not as advanced to date. The US Environmental Protection Agency (USEPA) has produced technical guidance for developing effective bioassessment programs; they include crucial elements such as defining objectives, classifying water bodies according to expected biological attributes, deriving the reference condition of the site classes, developing standardized protocols for sampling and data analysis, and implementing a quality assurance plan. Approaches to bioassessment in the USA follow a basic design of incorporating various attributes of the elements and processes of the aquatic community, which is either an aggregation into a multimetric index or a series of multivariate analyses using the attributes as input variables. The Clean Water Act of 1972 and its subsequent amendments mandate maintaining, restoring, and protecting the ecological integrity of surface waters. Through use of robust bioassessments and other measures of ecological integrity, the USA has developed a strategic plan to establish priorities to meet this goal.

Introduction

The concept of ecological integrity is firmly entrenched in the regulatory structure of water law in the USA. The Clean Water Act (CWA) of 1972 identified as the fundamental, long-term goal of environ-

mental protection for aquatic resources, the restoration and maintenance of ecological integrity, which is expressed in the law as physical, chemical, and biological integrity (Figure 1). The legislative record clearly documents the intent of the framers of the 1972 Act as well as the tensions between the ability to achieve

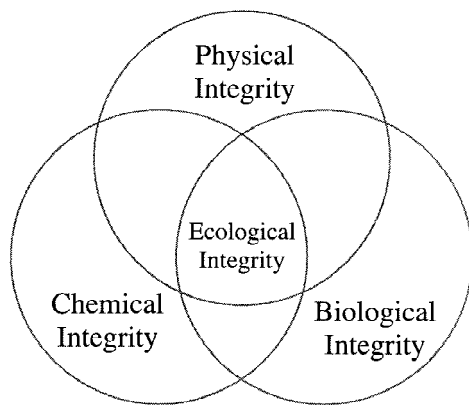


Figure 1. Ecological integrity and its three elements - physical, chemical, and biological integrity.

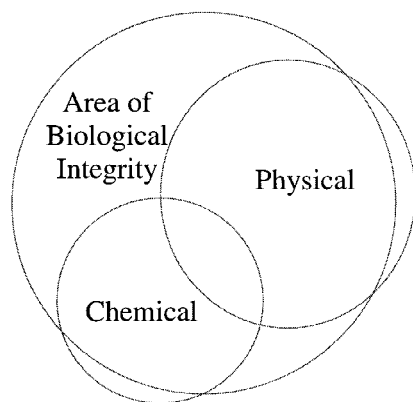


Figure 2. Alternative (dynamic) model of biological integrity (patterned after Yoder, 1995).

this visionary goal and the feasibility of implementation (USGPO, 1972a, b). This dichotomy has been at the heart of continuing debate and discourse as the USA has sought to implement the CWA (Jorling, 1977; Mackenthun, 1977). Karr (1991) argued that the model for ecological integrity (Figure 1) set forth by the USEPA was inadequate and not representative of the variable interaction of the three key components. Yoder (1995) proposed an alternative model (Figure 2) which shows that the overlapping influence of the three major components is both disproportionate and dynamic. The concept of biological integrity is all encompassing and, in essence, is the underpinnings of ecological integrity. This view is consistent with that of many European countries, e.g. Austria (Moog & Chovanec, 2000).

Several US federal agencies have different responsibilities associated with the mandates of the CWA. However, it is the US Environmental Protection Agency (USEPA) that, under the Act, is the primary arbiter of whether ecological integrity is being protected or restored in the nation's surface waters. The states and Indian tribes play an equally strong role to the USEPA through the implementation of their water quality standards, which are laws or regulations that the states and Indian tribes adopt to enhance and maintain water quality and to protect public health. These standards provide the foundation for accomplishing the goals and objectives of the CWA.

Although the broad goal of ecological integrity was set forth in federal law in 1972, implementation focused over the next two decades on engineering solutions to controlling toxic and municipal discharges (Adler, 1995). During the 1960s, public support called for more far-reaching, enforceable environmental legislation and regulation because of increasingly visible environmental catastrophes, e.g., widespread fish kills and occurrence of tumors and deformities, obnoxious odors and appearance of waters contaminated by raw sewage, and the loss of charismatic wildlife (such as birds) due to toxics and pesticides in streams and rivers. Chemical pollution, both organic and inorganic, was recognized as a major cause of impaired surface waters. The mobilization of public concern about the environment, culminating in the first Earth Day in 1970, directly led to the passage of the CWA. It was not surprising therefore that initial efforts to implement the CWA of 1972 focused on controlling industrial and municipal discharges into streams, rivers, and coastal waters.

Therefore, measures of chemical integrity were implemented first into monitoring programs. Measures of physical and biological integrity were slow to develop because of the perception that they yielded ambiguous results, were costly, and would add little to the existing monitoring techniques for direct measures of chemical pollution. Additionally, biological information was thought to be too variable in quality to be tolerated within the legalistic framework of public law (Courtemanch et al., 1989). Essentially, water pollution was regarded as an engineering problem that could be managed through engineered solutions to alter the water chemistry. Certain assumptions were made about what chemical criteria were appropriate to protect the aquatic ecosystem. They were based on response by representative test species that loosely acted as surrogates to resident aquatic biota (Cairns, 1980).

Chemical criteria, however, were effective in reducing pollutant loadings to the nation's surface waters. As a consequence, the concept of ecological integrity was narrowly interpreted to mean chemically clean water.

By the 1980s, engineering solutions had provided substantial progress in pollution abatement from point source discharges. However, the gains made in reducing the often catastrophic levels of chemical pollution in waters revealed more subtle and diffuse threats to the ecological integrity of aquatic resources, such as loss of habitat, reproductive defects from bioaccumulative chemicals, diversion of surface and ground waters, nutrient enrichment from stormwater runoff in both urban and agricultural environments, and colonization by nonindigenous species. Water resources, particularly their biological components, continued to be degraded at alarming rates (Karr, 1993). Water resource agencies began to shift their regulatory emphasis toward more complex problems, especially nonpoint sources (NPS). One of the main difficulties facing NPS pollution management over the years has been the lack of techniques to monitor and assess impacts (McCarron & Frydenborg, 1997). Traditional methods (i.e. water quality sampling of storm events) have remained largely inadequate due to the transient and unpredictable nature of NPS pollution (Barbour et al., 1996b). The need to accurately measure and diagnose the cumulative impacts of multiple stressors, not just individual pollutants, became a priority in water resource management.

Through trial and error, the USEPA began to move towards a more integrated, comprehensive approach to water resource protection with development of methods for measuring synergistic interactions of toxic chemicals, assessing biological and habitat indicators of ecosystem condition, and estimating ecological risk. In addition to strengthening the Agency's program to control toxic pollution, amendments to the Clean Water Act in 1977 and 1987 provided impetus for this shift by establishing geographically integrated programs, such as the Great Lakes Research, Chesapeake Bay, and National Estuary Programs, with an increasing emphasis on addressing nonpoint source pollution.

Direct measures and evaluation of the condition of the living system, or biota, are necessary to accurately assess the condition of the aquatic resource (Karr & Chu, 1999), particularly when impacted from multiple stressors. Biological communities integrate the effects of different stressors that water resource agencies are struggling to address, such as reduced oxygen, excess

nutrients, toxic chemicals, increased temperature, excessive sediment loading and habitat degradation. This integration occurs through time, a dimension difficult to measure with chemical information. Thus, measures of biological condition provide a critically needed tool for water resource agencies to detect and evaluate the aggregate impact of the stressors.

During the 1980s and 1990s, federal and state resource management agencies benefitted from the development of integrative biological approaches with considerable potential to recognize and reverse the declining trends in aquatic resources (Davis & Simon, 1995). Biological monitoring programs were evolving and being expanded in regulatory agencies. This more ecologically realistic approach to water resource management has resulted in a renewed interest in assessment of the condition of aquatic resources and implementation of different monitoring tools, with a major shift in philosophy toward ambient monitoring of biological integrity to protect water resources (Karr, 1991; USEPA, 1988). Biological integrity has become an increasingly important focus within the USEPA for assessing the condition of the nation's surface waters and documenting the success of water resource restoration and protection (Jackson & Davis, 1994; USEPA, 1990). The assessment of the biological community using measures of species richness and composition, relative abundances of species or groups of species, and functional relationships among resident organisms (Karr, 1993) has become the standard in the USA for measuring progress towards achieving the CWA's goal of biological integrity.

Establishing biological criteria for judging attainment of biological integrity

To better protect aquatic ecological integrity, the long-range goal of the USEPA for water quality standards programs in all states and tribes over the next two decades is to:

“...fully integrate biocriteria, nutrient criteria and microbial pathogen control with improved chemical-specific criteria, whole effluent toxicity methods and possible sedimentation, flow and wildlife criteria, into criteria and standards programs to better support watershed management for the protection of human health and the maintenance and improvement of the chemical, physical and biological integrity of the Nation's waters” (USEPA, 1998a).

The USEPA has developed a Water Quality Criteria and Standards Plan (currently an interim final document) that presents a 'vision' and strategy to better protect human health and enhance and maintain the quality of the nation's waterbodies. This interim final plan will guide USEPA and the states and tribes in their development and implementation of criteria and standards over the next decade and sets the goal that biological criteria and assessment methods are to be implemented. The interim final plan identifies the target date of 2005 for achieving this goal.

It is national policy that states and tribes designate aquatic life uses (i.e., environmental goals) for their waters that appropriately address biological integrity and adopt biological criteria necessary to protect those uses. To protect aquatic life, the biological component will dominate the other components because it is the product of the integrated interaction of the chemical and physical components (Yoder, 1995). Designated uses to support aquatic life can cover a broad range, or continuum, of biological conditions, with some waters being closer to an ideal of biological integrity than others. The attainable levels of biological integrity for any water is a state and/or tribal determination involving public participation.

Biocriteria are narrative descriptions or numerical values adopted into state or tribal water quality standards that can be used to factually and quantitatively describe a desired condition for the aquatic life in waters with a designated aquatic life use (USEPA, 1998a). The purpose of biocriteria is to establish enforceable standards based on biological characteristics related to biological integrity that can be used to direct water quality management. Biocriteria are developed by biologists and other natural resource scientists using accepted scientific principles to characterize the regional reference conditions for the different water bodies found within a state or tribal nation.

Defining the reference condition is a critical element in designing biocriteria. It expresses the objective and is the basis of all comparison and ultimately the basis on which attainment of goals is determined. Biocriteria determine the allowable range of condition for the aquatic community with respect to the reference condition. Ideally, reference conditions should represent pristine conditions. Because absolutely pristine sites do not exist (even the most remote lakes and streams are subject to atmospheric deposition), reference conditions typically describe the characteristics of waterbody segments that are minimally impacted by human activities. Acceptable reference

conditions will differ among geographic regions because soil conditions, stream morphology, vegetation, and dominant land use differ. In heavily agricultural, industrial-commercial, or urbanized areas, reference conditions will need to be established based on historical records, simulation models, and expert judgement. Because of the extensive footprint of anthropogenic influence on the landscape, a common definition and nationally consistent approach has been elusive in the USA. However, the ideal reference condition must represent aspects of naturalness such as an aquatic ecosystem that is balanced, adaptive, and reflects natural evolutionary processes. Characteristics of such systems are those that support and maintain a community of organisms having a composition, diversity, and functional organization comparable to that of the natural habitat of a region (i.e., *regional reference conditions*).

The definition of reference needs to account for the conditions of large populations of general waterbody types (e.g., lakes, streams, wetlands), and needs to be acceptable and understandable both by persons most concerned with nature for its own sake and those who are concerned only with what it can provide humans (Hughes, 1995). The traditional upstream-downstream analysis has little value in the context of region-wide assessment programs and water quality standards that include biocriteria. Derivation of reference conditions may need to rely on many sources including empirical data from selected 'reference' sites, historical data, paleoecological data, laboratory studies, or quantitative models (Gibson et al., 1996; Hughes, 1995). Best professional judgement plays a vital role in establishing reference conditions. The initiation of any biological assessment program needs to focus on reference conditions applicable to the water quality program.

Elements of a bioassessment program

Any well-designed monitoring and assessment program is inherently anticipatory in that it will provide information for present needs and those not yet determined (Yoder & Rankin, 1995). Thus, implementation of a program must be proactive, because once the opportunity passes, there is no way to generate the needed data and information after the fact (Barbour & Yoder, in press). Measuring several attributes of the biological community ensures that future object-

ives will be addressed. Programs that are adaptable to immediate and future needs are also cost efficient.

The choice of a particular biological assessment design should be based on the monitoring objectives and ultimate decision process (Barbour et al., 1996a). The recent innovative rapid assessment techniques used in the USA (Barbour et al., 1999; Plafkin et al., 1989) offer cost efficiencies while maintaining data integrity, yet are not intended to replace more rigorous approaches. The constraint of resource investment and the requirement for quick 'turnaround' of biological data for decisions will dictate the nature of the study design. Regardless of approach, a certain amount of preparation is required. For instance, specific objectives must be defined, appropriate indicators selected, sites (or streams) classified into homogeneous classes, reference conditions established, protocols standardized and investigators trained, and a quality assurance plan developed. These elements are further explained, as follows:

Study objectives

To assess anthropogenic perturbations, objectives usually relate to determining the biological condition or status, demonstrating improvements following implementation of mitigation measures or restoration practices, or screening for problems or sensitive areas.

Selection of indicators

Environmental indicators must be relevant to the study objectives. Both technical and program considerations are important in identifying indicators. Keddy et al. (1993) provide guidance for selecting appropriate indicators that should be: (1) ecologically meaningful, i.e., closely related to maintenance of essential environmental processes and ecosystem functions (e.g., primary production); (2) macro-scale, i.e., indicate changes in entire communities rather than selected species; (3) general, i.e., can be measured meaningfully on different community types; (4) sensitive, i.e., quickly respond to stresses and perturbations; and (5) simple, i.e., are easy to measure. Four additional considerations, as articulated by McCarron & Frydenborg (1997), are necessary to incorporate bioassessment information in water management programs: (1) cost-effective, i.e., are within the financial and staffing resources of agencies; (2) scientifically and legally defensible, i.e., impairment caused by human activities must be distinguished from the natural variations

in the biological condition; (3) integration into existing programs, i.e., better decision-making is accomplished by incorporating bioassessment information into regulatory and non-regulatory programs; and (4) effectively communicated, i.e., complicated scientific conclusions from monitoring efforts must be easy to understand for non-technical managers and the public; these scientific findings must tell understandable and compelling stories.

Site classification

A classification process, often based on regional attributes, may be useful to provide an ecological basis for identifying homogeneous areas from which reference conditions can be established. For example, the composition of the biota of coastal plain streams would be expected to be different from the streams of the Appalachian mountains. Site classes should not be constrained by political boundaries. Both the use of biological metrics and multivariate analyses of non-metric data have been shown to be effective classification tools.

Reference condition

Reference conditions are a critical element of assessing the quality or health of the aquatic system. The regional-based reference condition can be derived from an aggregate of reference sites or some empirical model of expectations that may include knowledge of historical condition or extrapolated from ecological principles. The establishment of reference condition is based on identification of minimally disturbed sites that represent the best physical, chemical, and biological condition attainable. The use of a regional-based reference is desired over individual site-specific references for broader application in state water resource programs.

Standardized protocols

Standardization of methods is crucial to establishing the reliability of biological data. Lack of standardization was a problem associated with early biological assessment studies, where diverse methods yielded conflicting information. It may be as important to standardize sampling bias as it is to minimize bias where comparison to a reference condition is required. Replication is necessary to establish the precision of the method. Thorough training of investigators enhances the ability to provide a consistent unit of effort,

thus reducing the qualitative nature of the methods. Standardization is paramount when information will be used in later trend analysis.

Data analysis

For the bioassessment approach adopted by most state water resource agencies, metrics chosen for relevancy and sensitivity are calibrated for the site class and reference condition. This requires regional validation efforts. In aggregated indices, values of different scales are transformed to score categories; this is done from calibrated thresholds based on a selected percentile of the site class. Information from the individual metrics, as well as an aggregated index, allows judgement of the biological status of the assemblage.

Quality assurance (QA) plan

The development of an effective QA plan is paramount to the success of the program. It should assign responsibility, define personnel qualifications, establish protocols, define preventive and corrective action, provide information tracking, and ensure that study objectives are met. Quality assurance plans are especially important to regulate the performance and maintain data integrity.

Overview of state bioassessment programs in the USA

Much has been accomplished since the start of the biological assessment and criteria program in the USA in 1988. However, further progress is necessary to realize the full potential of bioassessments and biocriteria for managing water quality and protecting aquatic life.

The water resource programs in the USA have multiple objectives related to the sections of the Clean Water Act (Figure 3). The numerous programs of water resource agencies are best served by indicators that can be used for these multiple purposes. The ability to sustain a balanced biological community is one of the best indicators of the potential ecological integrity of a water resource (Karr, 1993). Bioassessment initially serves state and tribal monitoring needs through three primary functions or uses: (1) screening or initial assessment of conditions; (2) characterization of impairment and diagnosis; and (3) trend monitoring to evaluate improvements or further degradation (Barbour & Yoder, in press). Beyond monitoring and assessment functions, biological information can fill

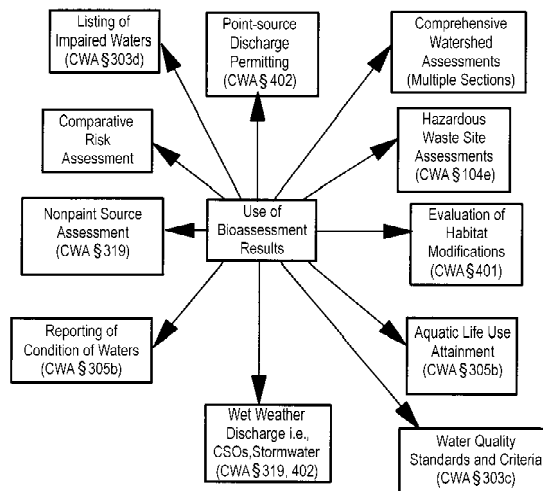


Figure 3. Applications of bioassessment data to water resource management programs in the USA (taken from Barbour & Yoder, in press).

an important gap in overall water resource management by indicating ecological condition (Courtemanch et al., 1989; Yoder, 1995). This critical transformation of utility for management occurs when states codify, into regulations, their expectations for acceptable biological conditions in a technically explicit way. These aquatic life expectations are referred to as biological criteria, and when codified in state law they are referred to as designated aquatic life uses. Biological assessment provides crucial water quality planning information for managing more complex water quality problems by providing a measure of aggregate impact (Courtemanch et al., 1989). This is valuable for state and tribal pollution control programs seeking to prioritize water quality problems, set restoration goals and new performance standards, and document results. Ohio and Maine, for example, have codified aquatic life uses in water quality standards. Here, such standards serve an 'action-forcing' function allowing water resource management decisions to be influenced by the extent to which actual ecological condition (as measured by the fish or benthic macroinvertebrate community) approaches aquatic life expectations.

The water resource agencies in the 50 states of the USA are in various stages of development and implementation of bioassessment. This is illustrated in maps updated by a report by the USEPA (Davis et al., 1996). With the publication of the USEPA Rapid Bioassessment Protocols (Plafkin et al., 1989) and the Program Guidance for Biocriteria (USEPA, 1990), the

use of bioassessment by state water resource agencies in streams and wadeable rivers has advanced well beyond the other waterbody types (i.e., non-wadeable rivers, lakes and reservoirs, estuaries and coastal marine waters, and wetlands). Each state has from 1600 to 75 000 km of streams (exceptions are 423 km in Hawaii and 584 000 km in Alaska), whose ecosystem health needs to be assessed (Davis et al., 1996). Assessing the condition of so many stream kilometers is daunting and will require many years and substantial technical resources. Biological assessment approaches have therefore been designed to allow multiple-site investigations within a field season, be cost-effective, and yet be scientifically robust to judge biological condition (Barbour, 1997). All but three states (94%) have either developed, or are in the process of developing, bioassessment approaches for streams (Figure 4a). These three states, namely Nevada, South Dakota, and Utah, all have less than 20% of their stream kilometers characterized as perennial (Davis et al., 1996). Bioassessment approaches are lacking for intermittent streams, which are abundant in these typically arid states. State water resource agencies that have pioneered the development of bioassessment approaches in the USA include Ohio EPA (1987), Maine Department of Environmental (Courtemanch et al., 1989), and North Carolina Department of Environmental Management (Lenat, 1988). Common elements of these programs are the identification of reference conditions and the use of a suite of biological metrics to assess ecosystem health.

Bioassessment in most states is an effective tool to identify impairment from multiple sources of perturbation (i.e., chemical discharges and runoff, invasive land use to alter watershed characteristics and stream morphology, and air-borne deposition). However, the use of bioassessments for regulatory programs can apply to several mandates of the CWA (see Barbour & Yoder, in press, for a more detailed description of these applications). The primary application of bioassessment in state agencies is to evaluate the condition of the surface waters with respect to their designated aquatic life use. Approximately 60–70% of the states use bioassessment for this purpose (Figure 4b). They must report the condition of their surface waters to the US Congress under section 305b of the CWA.

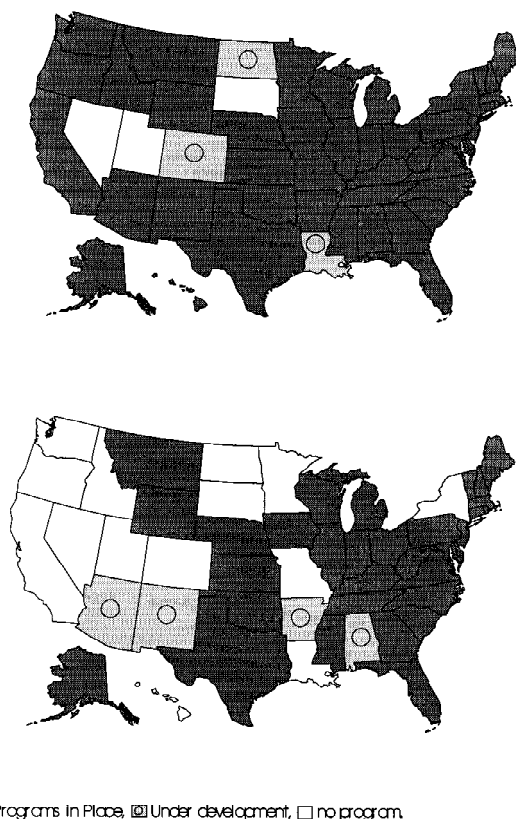


Figure 4. Map of the US illustrating use of stream bioassessment in state water resource programs. (a). Bioassessments used in water resource management (screening); (b). Bioassessments used to interpret aquatic life use attainment (reporting).

Selected bioassessment programs in the USA

Biological assessment programs have evolved to measure a range of attributes that represent various components of biological integrity. Biological integrity means more than achieving a high level of species diversity (Angermeier, 1997; Angermeier & Karr, 1994; Barbour & Yoder, in press). The bioassessment approach that relies on metrics derived from biological information is the technique most frequently used by the state water resource agencies. It provides a means of compiling and comparing ecological information relating to important elements and processes of naturally functioning aquatic communities and our current knowledge about those relationships (Barbour & Yoder, in press). The actual application of biological metrics in an assessment differs from state to state.

The most typical application of metrics is exemplified by Ohio, where the metrics are aggregated into

Table 1. Maine's water quality classification system for rivers, streams, and lakes, and associated biological standards (taken from Courtemanch, 1995)

Class	Management perspective	Biological standard
AA	High-quality water for recreation and ecological interests. No discharges or impoundments permitted	Habitat natural and free flowing. Aquatic life as naturally occurs
A	High-quality water with limited human interference. Discharges restricted to noncontact process water or highly treated wastewater equal to or better than the receiving water. Impoundments allowed	Habitat natural. Aquatic life as naturally occurs
B	Good-quality water. Discharge of well-treated effluent with ample dilution permitted	Habitat unimpaired. Ambient water quality sufficient to support life stages of all indigenous aquatic species. Only nondetrimental changes in community composition allowed
C	Lowest water quality. Maintains the interim goals of the Federal Water Quality Act (fishable/swimmable)	Ambient water quality sufficient to support life stages of all indigenous fish species. Change in community composition may occur but structure and function of the community must be maintained
GPA (lakes)	Protection of present high quality for recreation and ecological interests. No discharges allowed. Change of land use may not cause trophic state increase	Habitat natural. Aquatic life as naturally occurs. Maintain stable or decreasing trophic state

an index (Yoder & Rankin, 1995), patterned after the Index of Biotic Integrity (Karr, 1981; Karr et al., 1986). Ohio has developed an index for the benthic macroinvertebrate assemblage, the Invertebrate Community Index (ICI) (DeShon, 1995), and two for the fish assemblage, the Index of Biotic Integrity (IBI) and the Modified Index of Well-Being (MIwb) (Ohio EPA, 1987; Yoder & Rankin, 1995). The metrics represent various attributes of the assemblages, are calibrated to regional reference conditions, and transformed to unitless scores for aggregation into an index. Many papers describe the approach to aggregating metrics into an index (see for example, Barbour & Yoder, Barbour et al., 1995, Karr, 1991, 1993; Karr & Chu, 1999; Karr et al., 1986; Yoder & Rankin, 1995; in press). Some states, such as North Carolina, evaluate individual metrics and make decisions relevant to the response of those metrics (Lenat, 1988, 1993; Lenat & Barbour, 1994).

Maine has adopted an alternative approach using a probabilistic model to measure attainment of aquatic life goals. It follows the model developed by Reckhow.

Reckhow (1994) developed a decision framework for complex environmental issues (e.g., development of biocriteria), recommending that management agencies should (1) clearly identify management objectives, (2) identify attributes to measure achievement of the objectives, and (3) identify feasible management options to achieve the objectives. A range of goals were identified for aquatic life condition from 'natural' to a maximum allowable change, described in four different water classes (see Table 1) and incorporated into state law. The law includes definitions of ecological terms that clarify management intent that can be translated into objective, measurable ecological attributes. Numerical biocriteria, using benthic macroinvertebrate assemblage metrics, were developed to quantify attainment of the attributes assigned to each classification. Maine's numeric criteria are based on a probability model for each of the four water quality classes for rivers and streams. A priori assemblage groups were identified by expert biologists' judgement of membership within the water quality classes. The models are linear discriminant functions that collect-

ively use 23 variables, or metrics, relating to richness and abundance attributes of the benthic macroinvertebrate assemblage (Courtemanch, 1995). Constructing linear discriminant models yields advantages: (1) the analysis provides an objective means of identifying the most significant variables contributing to definition of the determined groups; (2) the weight of each variable used in classification is different and is determined by the analysis, contributing interpretive value; and (3) probabilities of fit can be calculated that provide information about the strength of a classification assignment when a new site is evaluated using the models (Courtemanch, 1995). The use of the decision analytic approach to establishing biological criteria offers many advantages to managers. Reckhow (1994) argues that careful decision-making about over-arching objectives for aquatic resources forces managers and scientists to ask key questions about (1) the characteristics of attributes that may be selected to measure achievement of those objectives (e.g., choice of biological metrics and indices), (2) the societal and ecological relevance of the selected measurable attributes, (3) the management options to more closely approach goals, and (4) the most technically appropriate assessment methods to quantify the selected attributes. Maine's use of probabilities offers certain advantages for implementation within the regulatory program for management of water quality. It is possible to use differing probabilities for regulatory and non-regulatory decisions. Assessment, which is used for status reporting, program management, and prioritization, can tolerate the use of weaker probabilities because these activities are administered continuously and interactively. Enforcement, on the other hand, is a discrete function, in which the action should not allow for much indecision in the model. Differing decision probabilities from the model can satisfy these management needs (Courtemanch, 1995). The New Brunswick, Canada Department of the Environment is proposing to adopt Maine's narrative aquatic life standards in their water classification regulation. Because Maine and the Province of New Brunswick share a largely overlapping physiographic region the Province is exploring the feasibility of also adopting Maine's numeric biocriteria model.

Each of the major approaches to implementing of bioassessment information has strengths and weaknesses relative to the four considerations listed by McCarron & Frydenborg (1997). Rigor of the methods varies with each approach and has to be weighed against the nature of information needed by program

managers, the challenges it may evoke scientifically or legally, and the overall cost to the agency. The use of biological metrics is generally regarded as simple and easy to understand; it is a practical and very cost-effective screening tool to integrate water quality information at large numbers of sites. The decision analytic approach, utilizing multivariate techniques, while more complex in design may offer advantages for planning and adaptive management applications.

Case study of the value of bioassessment

A recent case demonstrates the potential for applying bioassessment information and associated biocriteria. Maine's Presumpscot River exhibits non-attainment of aquatic life standards in several locations from many potential sources of perturbation. In recent years, the USEPA has required that a Total Maximum Daily Load (TMDL) of pollutants be established for impaired river systems, such as the Presumpscot, where existing, required pollution controls are inadequate to attain applicable water quality standards. Recently, the USEPA approved Maine's TMDL assessment for the river. This approval was significant for several reasons. First, numeric biocriteria were used to evaluate the aquatic life standard and to determine that the biological condition was not attained. Second, bioassessment findings were used to identify the specific pollutant stressor. Of particular value, biological information served as the quantitative response variable or modeling endpoint used to develop a new pollutant discharge limit. This was accomplished by using data from other sites in the state where similar stressors were involved and where different levels of aquatic life attainment had been measured. The wastewater discharge license that resulted from this effort requires an initial 30% reduction in the discharge of total suspended solids and biochemical oxygen demand. Provisions are included in the license for phased reductions (up to 61%) if the benthic assemblage does not respond sufficiently to attain aquatic life standards. Maine DEP was able to apply this innovative approach to improving water quality and aquatic life conditions in the Presumpscot River because of the convergence of three factors: (1) the State had a sound legal basis for using biological monitoring findings to force action because clearly defined aquatic life standards exist in Maine's Water Quality Classification law, and scientifically defensible numeric criteria have been established by Maine DEP; (2) data, which

were essential to model the recommended total suspended solids load reductions on the Presumpscot River, had been collected using standardized procedures that were consistent with studies performed in other parts of the State; and (3) teamwork and collaboration between Maine DEP water quality modelers and aquatic biologists resulted in an approach that integrated technical information and expertise from both disciplines; it enabled for Maine DEP to control the input of a stressor for which the State has no water quality standards.

This example demonstrates the use of biological information to directly manage multiple stressors affecting biological integrity in a complex river system. Biological response to these stressors was needed to identify and characterize impairment because performance standards for suspended solids (the primary stressor) did not exist. Interpreting the characteristics of the observed biological response and eliminating other plausible causes of impairment led investigators to focus on suspended solids from a specific industry. Extrapolation of biological assessment data from other similar sites in the State allowed managers to make predictions about allowable pollutant loads that could be incorporated into a new waste discharge permit. In Maine, biological assessment is directing ongoing adaptive management actions in that it serves as the measure of performance for the industry under its new license and as the overall barometer of the success of Maine's management of the resource.

USEPA's long range goal of assessing and restoring the nation's surface waters

A number of key activities are necessary to meet USEPA's long-range goal of assessing and restoring surface waters (USEPA, 1998a). First, USEPA must complete the issuance of a series of biocriteria technical guidance manuals. These manuals provide states and tribes with scientific information and procedures used to conduct bioassessments and develop biocriteria. Bioassessment and biocriteria development manuals have been published for streams and small rivers (Barbour et al., 1999; Gibson et al., 1996; Plafkin et al., 1989) and lakes and reservoirs (USEPA, 1998b). A final draft manual is prepared for estuaries and near-coastal waters, and USEPA plans in the next 5 years to develop manuals for wetlands, large rivers and coral reefs.

Biocriteria are developed by the states and tribes by applying these methods to their respective ecolo-

gical regions. Once the biocriteria technical guidance documents are complete, states and tribes will need additional resources and expertise to derive biocriteria and to incorporate biocriteria into their water quality standards. Policy, program, and legal issues often arise as the scientific and technical capabilities to implement biocriteria are developed. USEPA will assist the efforts of the states and tribes by providing technical assistance through funding, research and development, and policy and program guidance. Six long-term objectives of the USEPA for using bioassessments and biocriteria in the USA include: (1) all states use bioassessments to evaluate the health of aquatic life in all waterbodies; (2) bioassessment data are used to better define aquatic life uses of surface waters; (3) quantifiable biocriteria are in all state/tribal water quality standards to protect aquatic life uses; (4) biocriteria/bioassessments are used in ongoing regulatory programs; (5) biocriteria/ bioassessments are used to assess the effectiveness of water quality management efforts; and (6) bioassessment data and biocriteria are used to better communicate the health of the nation's waters.

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