United States Environmental Protection Agency
Office of Water
Washington, DC 20460
EPA 822-R-02-014
March 2002

Methods for evaluating wetland condition

#1 Introduction to Wetland Biological Assessment

United States Environmental Protection Agency
Office of Water
Washington, DC 20460
EPA 822-R-02-014
March 2002

METHODS FOR EVALUATING WETLAND CONDITION

#1 Introduction to Wetland Biological Assessment

Principal Contributor

Maine Department of Environmental Protection
Thomas J. Danielson

Prepared jointly by:

The U.S. Environmental Protection Agency
Health and Ecological Criteria Division (Office of Science and Technology)

and

Wetlands Division (Office of Wetlands, Oceans, and Watersheds)

Notice

The material in this document has been subjected to U.S. Environmental Protection Agency (EPA) technical review and has been approved for publication as an EPA document. The information contained herein is offered to the reader as a review of the "state of the science" concerning wetland bioassessment and nutrient enrichment and is not intended to be prescriptive guidance or firm advice. Mention of trade names, products or services does not convey, and should not be interpreted as conveying official EPA approval, endorsement, or recommendation.

Appropriate Citation

U.S. EPA. 2002. *Methods for Evaluating Wetland Condition: Introduction to Wetland Biological Assessment.* Office of Water, U.S. Environmental Protection Agency, Washington, DC. EPA-822-R-02-014.

Acknowledgments

EPA acknowledges the contributions of the following people in the writing of this module: Candy Bartoldus (Environmental Concern, Inc.), Robert Brooks (Penn State University), Thomas J. Danielson (Maine Department of Environmental Protection), Jeanne Difranco (Maine Department of Environmental Protection), Mark Gernes (Minnesota Pollution Control Agency), Judy Helgen (Minnesota Pollution Control Agency), James Karr (University of Washington), Ken Kettenring (New Hampshire Department of Environmental Services), Richard Lillie (Wisconsin Department of Natural Resources), and Billy Teels (Natural Resources Conservation Service, Wetland Science Institute).

This entire document can be downloaded from the following U.S. EPA websites:

http://www.epa.gov/ost/standards

http://www.epa.gov/owow/wetlands/bawwg

Contents

List of Tables

List of Figures

Foreword

In 1999, the U.S. Environmental Protection Agency (EPA) began work on this series of reports entitled *Methods for Evaluating Wetland Condition*. The purpose of these reports is to help States and Tribes develop methods to evaluate (1) the overall ecological condition of wetlands using biological assessments and (2) nutrient enrichment of wetlands, which is one of the primary stressors damaging wetlands in many parts of the country. This information is intended to serve as a starting point for States and Tribes to eventually establish biological and nutrient water quality criteria specifically refined for wetland waterbodies.

This purpose was to be accomplished by providing a series of "state of the science" modules concerning wetland bioassessment as well as the nutrient enrichment of wetlands. The individual module format was used instead of one large publication to facilitate the addition of other reports as wetland science progresses and wetlands are further incorporated into water quality programs. Also, this modular approach allows EPA to revise reports without having to reprint them all. A list of the inaugural set of 20 modules can be found at the end of this section.

This series of reports is the product of a collaborative effort between EPA's Health and Ecological Criteria Division of the Office of Science and Technology (OST) and the Wetlands Division of the Office of Wetlands, Oceans and Watersheds (OWOW). The reports were initiated with the support and oversight of Thomas J. Danielson (OWOW), Amanda K. Parker and Susan K. Jackson (OST), and seen to completion by Douglas G. Hoskins (OWOW) and Ifeyinwa F. Davis (OST). EPA relied heavily on the input, recommendations, and energy of three panels of experts, which unfortunately have too many members to list individually:

- Biological Assessment of Wetlands Workgroup
- New England Biological Assessment of Wetlands Workgroup
- Wetlands Nutrient Criteria Workgroup

More information about biological and nutrient criteria is available at the following EPA website:

http://www.epa.gov/ost/standards

More information about wetland biological assessments is available at the following EPA website:

http://www.epa.gov/owow/wetlands/bawwg

List of "Methods for Evaluating Wetland Condition" Modules

Summary

Biological assessments (bioassessments) evaluate the health of a waterbody by directly measuring the condition of one or more of its taxonomic assemblages (e.g., macroinvertebrates, plants) and supporting chemical and physical attributes. A major premise of bioassessments is that the community of plants and animals will reflect the underlying health of the waterbody in which they live. When a waterbody is damaged by human activities, biological attributes such as taxonomic richness, community structure, trophic structure, and health of individual organisms will change. For example, in disturbed systems the number of intolerant taxa typically decreases and the proportion of tolerant individuals typically increases. The biological community will reflect the cumulative effect of multiple stressors, whether they be chemical (e.g., toxic chemical), physical (e.g., sedimentation), or biological (e.g., non-native species).

In recent years, a growing number of State and Federal organizations have started to develop bioassessment methods and Indexes of Biological Integrity (IBI) for wetlands. An IBI is an index that integrates several biological metrics to indicate a site's condition. A common approach among these organizations is to first sample attributes of a taxonomic assemblage in wetlands ranging from good condition to poor condition. The data are reviewed to identify metrics, which are attributes of the assemblage that show a predictable and empirical response to increasing human disturbance. After the metrics are tested and validated, they are combined into an IBI, which provides a summary score that is easily communicated to managers and the public.

Once wetland bioassessment methods are developed, wetland managers can use them for a variety of applications. Wetland managers can use bioassessments to evaluate the performance of wetland restoration activities or best management practices, such as buffer strips, in restoring and protecting wetland health. Wetland managers can also use bioassessments to more effectively target resources for restoring, protecting, and acquiring wetlands. Many States are developing bioassessments to better incorporate wetlands into water quality programs. Bioassessments can help States refine their water quality standards to reflect typical conditions found in wetlands. Using bioassessment information, States can refine the components of water quality standards by designating ecologically based beneficial uses of wetlands and adopting numeric and narrative biological criteria (biocriteria). After improving water quality standards, States can use bioassessments to determine if wetlands are meeting the identified beneficial uses, track wetland quality, and incorporate wetlands into Clean Water Act Section 305(b) water quality reports. Rigorous standards will also help States improve water quality certification decisions for activities that require Federal permits, such as dredge-and-fill permits. Under Section 401 of the Clean Water Act, States can certify, grant, or deny State permits if a proposed activity will harm the chemical, physical, or biological integrity of a wetland as defined in their water quality standards.

Purpose

This module provides an overview of wetland bioassessments and refers the reader to other modules for details on particular topics.

Introduction

Wetlands are important components of watersheds and provide many valuable functions to the environment and to society (Richardson 1994, NRC 1995, Mitsch and Gosselink 2000). Wetland ecosystem functions include the transfer and storage of water, biochemical transformation and storage, the production of living plants and animals, the decomposition of organic materials, and the communities and habitats for living creatures (Richardson 1994). Based on these and other ecological functions, wetlands provide "values" to humans and naturally functioning ecosystems. Important values include, but are not limited to, flood control, filtering and cleansing water, erosion control, food production (shrimp, ducks, fish, etc.), timber production, recreation (boating, fishing, bird watching, etc.), winter deer yards, and habitat for plants and animals, including many rare or endangered species (Box 1).

Wetlands have not always been appreciated for their many benefits. Historically, wetlands were perceived as potentially valuable agricultural land, impediments to development and progress, and harbors of vermin and disease (Fischer 1989, NRC 1995, Dahl and Alford 1996, Mitsch and Gosselink 2000). Prior to the mid-1970s, drainage and destruction of wetlands were accepted practices and even encouraged by public policies, such as the Federal Swamp Land Act of 1850, which deeded extensive wetland acreage from the Federal Government to the States for conversion to agriculture (NRC 1995, Mitsch and Gosselink 2000). Some people today still hold many of these beliefs. These public perceptions of wetlands shaped wetland policy and management during much of the past century. Consequently, wetland policy and management have taken a very different path compared to the policy and management of streams, rivers, and lakes. These other aquatic systems have also been damaged by human activities, but they have not been subject to the same intense onslaught of development and agricultural pressures as wetlands. As a result, whereas most Federal and State policies since the establishment of the Clean Water Act have focused on maintaining and restoring streams, rivers, and lakes, most wetland policies have been focused on preventing wetlands from being converted to uplands.

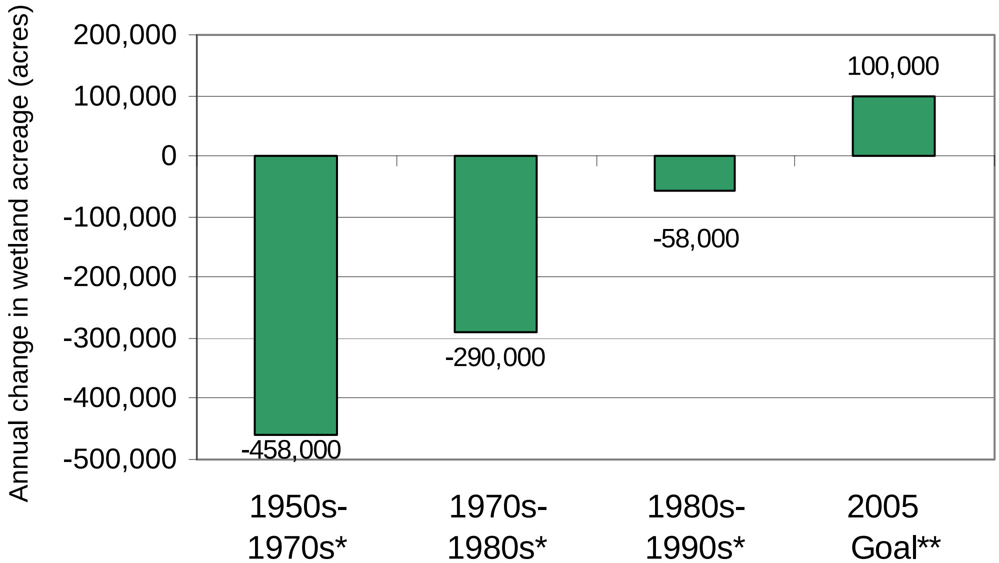
During the 1970s and 1980s, Federal and State agencies did not focus many resources on wetland quality. They were attempting to slow the rate of wetland loss and increase the rate of wetland restoration through various regulatory and voluntary programs. Today, wetlands are still being converted to uplands, but the national rate of wetland loss has decreased over time (Figure 1).

Even though estimates of wetland acreage are not exact, they can show general trends. According to the U.S. Fish and Wildlife Service, more than half of the original wetlands in the continental United States have been lost. (Wilen and Frayer 1990). An estimated 105.5 million acres of wetlands remained in the conterminous United States in 1997 (Dahl 2000). Between 1986 and 1997, the net loss of wetlands was 644,000 acres. The loss rate during this period was 58,500 acres/year, which represents an 80% reduction in the average rate of annual loss compared with the period between the mid-1970s and mid-1980s. Various factors have contributed to the decline in the loss rate, including implementation and enforcement of wetland protection measures, strengthened Federal and State wetland regulatory programs, and elimination of some incentives for wetland drainage. Public education and outreach about the value and function of wetlands, private land initiatives, coastal monitoring and protection programs, and wetland restoration and creation actions have also helped reduce overall wetland losses.

As the Nation draws closer to achieving a "no net loss" in wetland acreage, it is becoming increasingly apparent that more attention and resources must be devoted to addressing the quality of wetlands. The main goal of the Clean Water Act is to "maintain and restore the chemical, physical, and biological integrity of the Nation's waters," including wetlands. However, we know very little about the quality of our Nation's wetlands and whether or not we are

Box 1: Examples of Wetland Values

- 80% of America's breeding bird population and more than 50% of protected migratory bird species rely on wetlands (Wharton et al. 1982).
- More than 95% of commercially harvested fish and shellfish in the United States are directly or indirectly dependent on wetlands (Feierabend and Zelazny 1987).
- Most of the United States' frogs, toads, and many salamanders require wetlands during their life cycle for reproduction or survival.
- A mosaic of small wetlands is important for maintaining local populations of turtles, small birds, and small mammals (Gibbs 1993).
- Although wetlands account for only 3.5% of the United States' land area, about 50% of federally listed endangered animals depend on wetlands for survival (Mitsch and Gosselink 2000).
- Wetlands help prevent flood damage by storing storm runoff and slowly releasing water to streams and groundwater, thereby decreasing the severity of peak floods (Thibodeau and Ostro 1981).
- Removal of floodplain forested wetlands and confinement by levees has reduced the floodwater storage capacity of the Mississippi River by 80% (Gosselink et al. 1981). The severity of the 1993 Great Midwest Flood, which caused $20 billion of property damage, was partially increased by the historical loss of wetlands in the Missouri and upper Mississippi river basins (NOAA 1994, Tiner 1998).
- Wetlands help maintain the quality of streams and rivers by preventing erosion, filtering runoff, reducing peak floods, maintaining base flows, and providing food for stream animals. Streams with drainage areas that contain higher percentages of naturally vegetated land, particularly wetlands, tend to have healthier fish communities, as shown by biological assessments (Roth et al. 1996, Wang et al. 1997).
- Wetlands enhance water quality in streams and watersheds by trapping sediment and by accumulating and transforming a variety of nutrients and other chemical substances (Jones 1976, Mitsch et al. 1979, Lowrance et al. 1984, Whigham et al. 1988, Kuenzler 1989, Faulkner and Richardson 1989, Johnston 1991).



* U.S. Fish and Wildlife Service National Wetland Inventory, 2000
** U.S. EPA goal (U.S. EPA 1998b)

Figure 1: Annual average rate of wetlands loss.

meeting this goal. This limited knowledge is illustrated in the 1998 *National Water Inventory* (U.S. EPA, 1999). The quality of only 4% of the Nation's wetlands was estimated, and only a fraction of these estimates were based on actual monitoring data. State and Federal agencies are receiving increasing pressure to move away from using the number of permits issued or number of wetlands lost as primary data influencing management decisions. Rather, they must develop and use more meaningful measurements to evaluate the quality of the environment and to demonstrate the effectiveness of their programs at improving the environment.

Evaluating Wetland Health

Wetlands and other waterbodies are shaped by the landscape and climate in which they exist (Brinson 1993). Climatic conditions, topography of the landscape, chemical and physical characteristics of underlying geology, and the amount and flow of water within a watershed all contribute to determining what kind of plants and animals survive in a location. The collective interaction of plants and animals with their physical and chemical environment form what we call wetlands and provide many of the functions that are both ecologically and economically important. Many wetlands have been shaped over thousands of years by complex interactions between biological communities and their chemical and physical environment. The very presence of a wetland's natural biological community means that the wetland is resilient to the normal variation in that environment (Karr and Chu 1999).

Certain human activities can alter the interactions between wetland biota and their chemical and physical environment. Figure 2 provides a simplified illustration of the relationship between (a) the health of biological communities of wetlands and (b) human disturbances to wetlands and their watersheds. When human activities within a wetland or its watershed are minimal, the biological communities are resilient and continue to resemble those that were shaped by the interaction of biogeographic and evolutionary processes. At this end of the continuum of biological condition, the community is said to have biological integrity, which is the ability to "support and maintain a balanced adaptive community of organisms having a species composition, diversity, and functional organization comparable to that of natural habitats within a region" (Karr and Dudley 1981). At some threshold (T), which is difficult to measure over short time scales, is the point where degradation of the biological community creates an unhealthy situation because a natural community is no longer sustainable (Karr 2000).

Some human activities are ecologically benign whereas others can alter the environment to the point where there are changes in the biological communities. As the severity, frequency, or duration of the disturbances increase, a wetland may eventually reach a point where many of its plants and animals can no longer survive. When the interaction of wetland plants and animals with their environment is disrupted, many of the functions provided by wetlands will be diminished or lost. At a large scale, the subsequent ecological and economic effects can be dramatic. A wetland's biological community may recover over time and move back up the continuum if the pressures from the environmental disturbances are alleviated. The amount of time required to move back up the continuum will depend on the severity and nature of the disturbance. It may take some wetlands hundreds of years to recover.

The challenge facing wetland biologists is to develop practical ways to measure the biological condition of wetlands in order to make informed resource management decisions aimed at minimizing loss of wetland acreage and function. It is neither scientifically nor economically

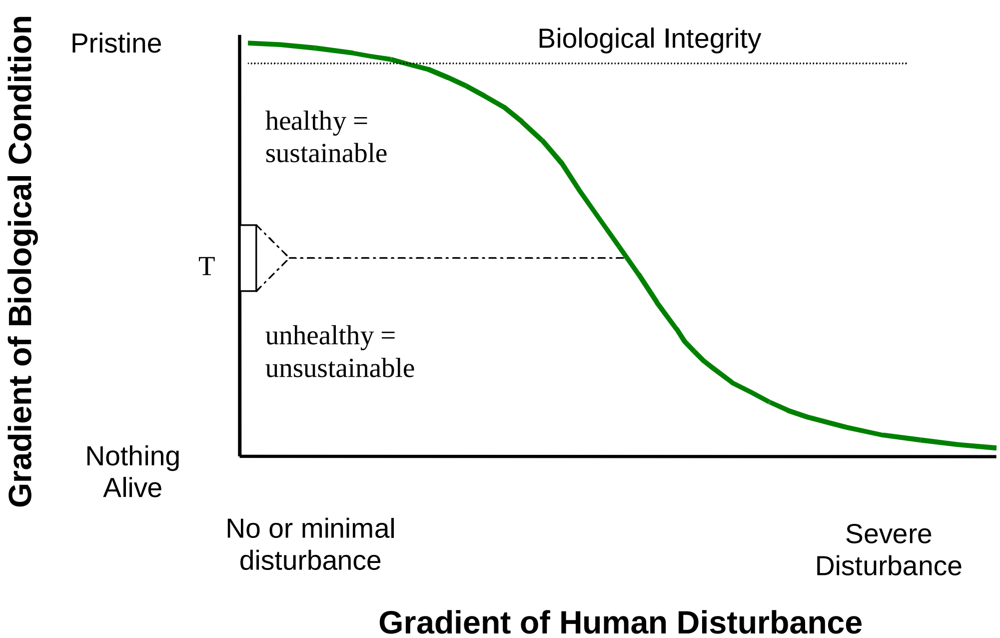


Figure 2: Continuum of human disturbance on biological condition of wetlands (adapted from Karr 2000).

practical to monitor every way that human activities can damage wetlands. For instance, wetlands can be dredged, filled, mowed, logged, plowed, drained, inundated, invaded by non-native or invasive organisms, grazed by livestock, and contaminated by countless kinds of pesticides, herbicides, and other toxic substances. Therefore, wetland biologists must focus on measuring the attributes of wetlands that will reflect biological condition without having to measure each and every disturbance that contributes to that condition.

As mentioned earlier, wetlands are shaped by the interaction of biological communities with their physical and chemical environment. The plants and animals have evolved over time to survive within a given range of environmental conditions. The interaction of wetland organisms with each other and their environment can be altered chemically, physically, or biologically (Figure 3). For example, pesticides and herbicides applied to a golf course can enter and chemically alter a wetland after a rainstorm, resulting in lethal and sublethal affects to aquatic animals. Humans can physically damage wetland biological communities by plowing a wetland or discharging stormwater runoff into wetlands and altering wetland hydrology. Wetland biological communities can be biologically altered by introducing non-native or invasive plants. Wetlands are rarely damaged by a single stressor. Rather, a mixture of chemical, physical, and biological stressors typically impacts them. Measuring all of the stressors that could affect a wetland in a way that is ecologically meaningful is virtually impossible. The only way to evaluate the cumulative effect of all the stressors is to directly measure the condition of the biological community.

The most direct and cost-effective way to evaluate the biological condition of wetlands is to directly measure attributes of the community of plants and animals that form a wetland. With limited financial and staff resources, it is not practical to focus the evaluation of wetland condition on chemical endpoints because there are too many to monitor. Also, the interaction of many chemicals in the environment is poorly understood. Stream bioassessment programs have also found that bioassessments are less expensive than many of the chemical measurements (Yoder and Rankin 1995, Karr and Chu 1999). A focus on physical parameters is impractical because our knowledge of interactions of biological communities and many physical parameters is incomplete. In addition, focusing monitoring efforts on physical parameters would overlook damage caused by chemical and biological stressors.

In addition to reflecting the cumulative effects of multiple stressors, biological communities integrate the effects of stressors over time, including short-term or intermittent stressors. In contrast, it is often difficult to detect changes in chemical and physical stressors over time. The biological effect of many chemicals is often much longer lasting than the pollution event itself. Some chemicals can enter a wetland, damage the biological community, and be biochemically or photochemically altered rather quickly. Even if researchers are attempting to detect a chemical, they may completely miss it unless they are sampling at the right time. The high costs associated with processing water and sediment chemistry samples make it far too expensive to sample with enough frequency to detect many chemicals. Physical alterations can also pose problems with respect to the ability to detect changes in biological condition over time. Some physical alterations to wetlands can change the structure and composition of biological communities for years after the ability to observe the physical alteration has been lost. For example, more than 50 years after some farmed wetlands in Montana were removed from pro-

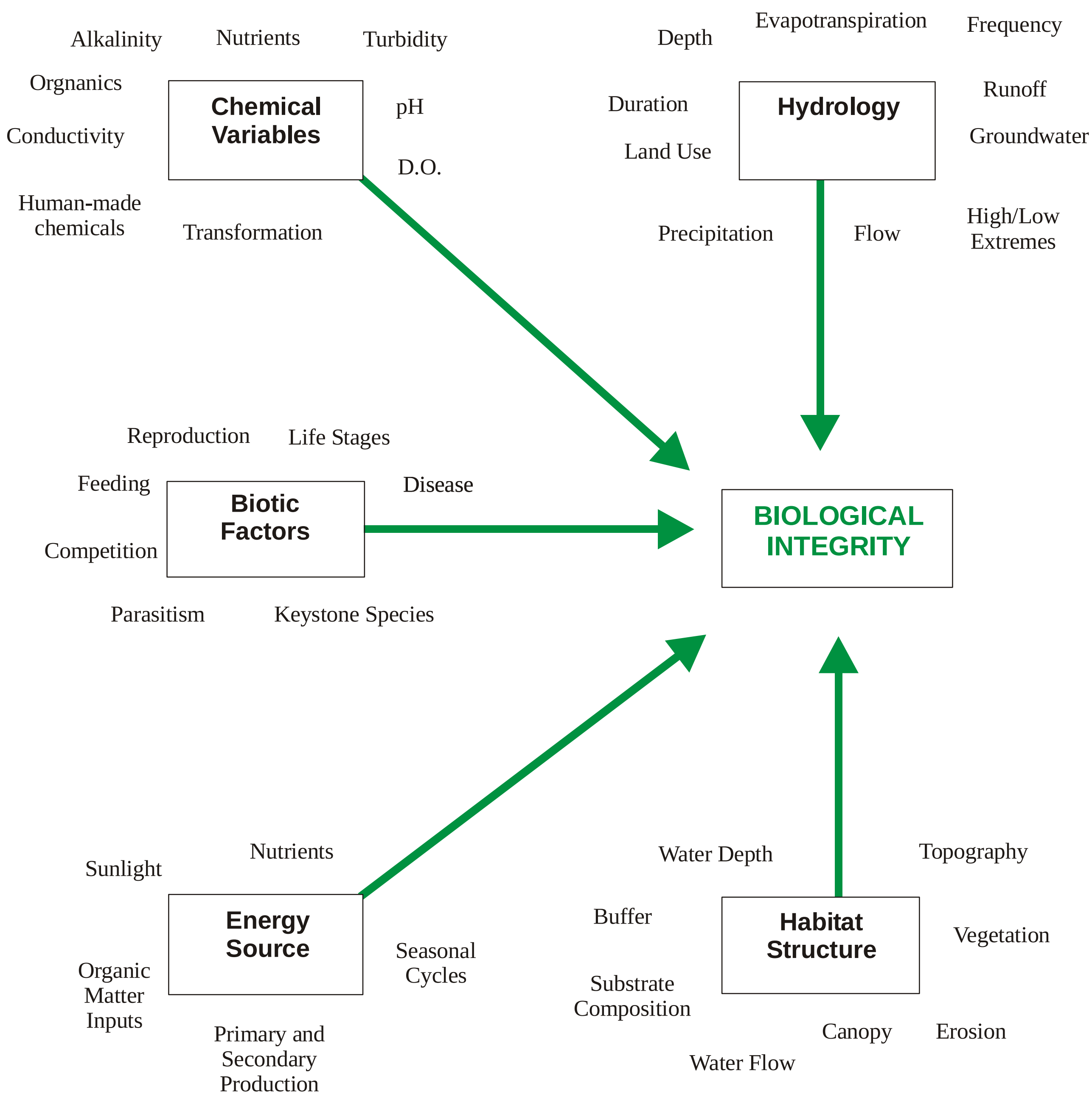


Figure 3: Ecosystem influences on biological integrity (adapted from Karr et al. 1986, Yoder 1995).

duction, their biological communities are still recovering and are noticeably different from minimally disturbed wetlands (Randy Apfelbeck, MT DEQ, pers. comm.).

In summary, the most direct and effective way of evaluating the biological condition of wetlands is to directly monitor the biological component of wetlands through the use of bioassessments and to support that information with chemical and physical data. Relying on surrogate measurements (e.g., water chemistry) or using monitoring tools designed for other purposes (e.g., rapid functional assessments) may provide incomplete and misleading results. Bioassessments can help prioritize where to follow up with additional monitoring, help diagnose the causes of degradation, and provide data to make informed management decisions about protecting and restoring wetlands.

Bioassessment Methods

During the past decade, wetland biologists began to develop bioassessment methods to evaluate the condition of wetlands and determine whether these wetlands are maintaining biological integrity. Bioassessment methods focus on measuring attributes of a wetland's biological community that are reliable indicators of wetland condition. Many bioassessment projects also include measures of physical and chemical attributes that are used to help diagnose potential sources of degradation.

Bioassessments are based on the premise that the community of plants and animals living in a wetland will reflect the health of a wetland. When a wetland is damaged, the diversity of animals and plants often decreases and the composition of species changes. Typically, the proportion of organisms that are intolerant to human disturbances will decrease while the proportion of individuals or species that are more tolerant to the disturbance will increase. In comparison to a minimally disturbed site, a plowed wetland located in a cornfield may have fewer plant and animal species. It also may be dominated by organisms that can tolerate poor environmental conditions. After examining an assemblage of plants or animals in wetlands ranging from high quality to poor quality, scientists can use this known range to estimate the relative health of other wetlands.

Wetland biologists are fortunate to have several decades of knowledge and experience related to evaluating the biological condition of streams and rivers to help guide them. Although wetlands and their biological communities are different from streams and rivers, many of the approaches and experiences from stream bioassessments can be applied to any biological system. In fact, bioassessment methods developed for streams and rivers have been adapted to wetlands, lakes, estuaries, and terrestrial systems (U.S. EPA 1998a, 2000a, Karr and Chu 1999, Rader et al. 2001).

The U.S. Environmental Protection Agency (EPA) formed the Biological Assessment of Wetlands Workgroup (BAWWG, pronounced "bog") in 1997 to help State agencies develop and apply wetland bioassessments (Box 2). Many BAWWG members are conducting pilot projects, which are described in Wetland Bioassessment Case Studies (U.S. EPA, in prep.). BAWWG has produced a series of reports to help other State, Federal, and Tribal agencies develop and implement bioassessment methods for wetlands (Table 1). The remainder of this report will introduce the development and application of wetland bioassessments, provide recommendations from BAWWG, and refer to the other reports in the series for more detailed information.

Wetland bioassessments involve the following six general stages of development:

- Selecting one or more biological assemblages to monitor
- Classifying wetlands
- Selecting wetlands across a gradient of human disturbance

Box 2: The Biological Assessment of Wetlands Workgroup (BAWWG)

The Biological Assessment of Wetlands Workgroup (BAWWG, pronounced "bog") was formed in 1997 to help advance the science and application of wetland bioassessments. Many people have participated in BAWWG meetings over the years, but the following list of people includes the core BAWWG members who have dedicated a considerable amount of time to advancing the goals of the workgroup. The New England Biological Assessment of Wetlands Workgroup (NEBAWWG) was formed in 1998 and its members have also helped advance wetland bioassessments.

Paul Adamus, Oregon State University
Bill Ainslee, U.S. EPA, Region 4
Randy Apfelbeck, Montana Department of Environmental Quality
Rob Brooks, Penn State Cooperative Wetlands Center
Mark Brown, University of Florida, Center for Wetlands
Tom Danielson, Maine Department of Environmental Protection
Jeanne DiFranco, Maine Department of Environmental Protection
Naomi Detenbeck, U.S. EPA, Ecology Division
Mike Ell, North Dakota Department of Health
Sue Elston, U.S. EPA, Region 5
Chris Faulkner, U.S. EPA, Office of Wetlands, Oceans, and Watersheds
Russ Frydenborg, Florida Department of Environmental Protection
Mark Gernes, Minnesota Pollution Control Agency
Mike Gray, Ohio Environmental Protection Agency
Judy Helgen, Minnesota Pollution Control Agency
Denice Heller Wardrop, Penn State Cooperative Wetlands Center
Doug Hoskins, Connecticut Department of Environmental Protection
Susan Jackson, U.S. EPA, Office of Science and Technology
James Karr, University of Washington
Ryan King, Duke University Wetlands Center
Don Kirby, North Dakota State University
Peter Lowe, USGS Biological Resources Division
John Mack, Ohio Environmental Protection Agency
Ellen McCarron, Florida Department of Environmental Protection
Mick Micacchion, Ohio Environmental Protection Agency
Steve Pugh, U.S. Army Corps of Engineers, Baltimore District
Klaus Richter, King County Department of Natural Resources, Washington
Matt Schweisberg, U.S. EPA, Region 1
Don Sparling, USGS Biological Resources Division
Art Spingarn, U.S. EPA Region 3
Jan Stevenson, Michigan State University
Linda Storm, U.S. EPA, Region 10
Rich Sumner, U.S. EPA, Environmental Research Laboratory
Billy Teels, NRCS Wetlands Science Institute
Doreen Vetter, U.S. EPA, Office of Wetlands, Oceans, and Watersheds

Table 1: Reports Related to Wetland Bioassessments in the Monitoring Wetland Condition Series

Title	Description
Wetlands Classification	Introduces several wetland classification systems and describes how they can be used in wetland monitoring programs.
Study Design for Wetlands Monitoring	Introduces different study designs available for monitoring wetlands.
Developing Metrics and Indexes of Biological Integrity	Introduces the process of testing metrics and creating an Index of Biological Integrity (IBI)
Using Algae to Assess Environmental Conditions in Wetlands	Introduces field sampling and analytical methods available for using algae in wetland bioassessments.
Using Amphibians in Bioassessments of Wetlands	Introduces field sampling and analytical methods available for using amphibians in wetland bioassessments.
Biological Assessment Methods for Birds	Introduces field sampling and analytical methods available for using birds in wetland bioassessments.
Developing an Invertebrate Index of Biological Integrity for Wetlands	Introduces field sampling and analytical methods available for using macroinvertebrates in wetland bioassessments.
Using Vegetation to Assess Environmental Conditions in Wetlands	Introduces field sampling and analytical methods available for using plants in wetland bioassessments.
Volunteers and Wetland Biomonitoring	Describes use of volunteers in wetland bioassessment projects.
Wetland Bioassessment Case Studies	Provides case studies of current wetland bioassessment projects across the country.

- Sampling chemical and physical characteristics of wetlands
- Analyzing data
- Reporting results

Choosing Assemblages

As discussed in Wetland Bioassessment Case Studies (U.S. EPA, in prep.), BAWWG members have used a variety of biological assemblages in wetland bioassessments, including algae, amphibians, birds, fish, macroinvertebrates, and vascular plants. Each assemblage has its own strengths and limitations for developing wetland bioassessment methods. Convenience, money, and time are often key factors in selecting a biological assemblage (Karr and Chu 1999). The selected assemblage must be cost-effective to sample and identify. However, a number of other factors affect an assemblage's practical usefulness and ability to reflect real changes in wetland condition (Table 2). Plants and macroinvertebrates are the most commonly used assemblages in wetland bioassessments. Vegetation is a convenient assemblage because it occurs in most wetland types and there are well-established sampling protocols; however, identifying metrics can be challenging (U.S. EPA 2002a). Macroinvertebrates have been widely used in stream bioassessments and show a lot of promise for wetlands, but current sampling methods focus on wetlands with standing water (U.S. EPA 2002b). Algae have been used to a

Table 2: Strengths and Limitations of Assemblages for Use in Wetland Bioassessments

Attribute of Assemblage	Algae	Amph	Birds	Fish	Invert	Plants
An IBI has been developed in one or more States	2	3	2	2	1	1
Prior research in wetland bioassessments	2	3	2	2	1	1
Present and able to be sampled in multiple wetland types	1	2	1	3[a]	1	1
Social recognition of importance	3	1	1	1	3	2
Difficulty of sampling protocols (time, effort, etc.)	1[b]	3[c]	3[c]	2	2	2
Ease of identification (number of species, relative skill required to identify to genus or species)	3	1[d]	2[e]	2	3[f]	2
Laboratory analysis (time, cost)	2[g]	2	1	1	3[h]	1
Taxonomic richness (effects ability to identify metrics)	1	3[i]	2	3[i]	1	1
Relative knowledge of taxa life history requirements, tolerances, habits	1	2	1	1	2	3
Short time lag of response to stressor	1	2	3	2	1	3
Integrate effects over time	2	1	1	1	1	1
Integrate effects over broad landscape	3	1	1	2	2	2
Reflection of individual wetland condition	1	2	3	2	1	2[j]
Reflection of connectivity to other wetlands and natural habitats	3	1	2	2	1	3
Sensitivity to nutrient enrichment	1	3	3	2	1	1
Sensitivity to metals and contaminants	3[k]	2	2	2	1[l]	2[l]
Sensitivity to herbicides	1	2	3	3	2	1
Sensitivity to pesticides	3	2	2	2	1	3
Sensitivity to hydroperiod alteration	2	1	3	3	2	1
Sensitivity to habitat alteration of individual wetland	3	2	2	2	2	1
Ability to discern individual health (malformations, deformities, lesions) from exposure to wetland conditions	3	1	2[m]	2[m]	1	2
Ability to diagnose potential stressor	1	3	3	3	2	2

Numerical Scores: 1 = best, 2 = intermediate, 3 = worst.

a Fish are restricted to small number of wetland types.
b Sampling methods are easy, but may require multiple site visits.
c Analysis will likely require multiple site visits during season.
d Adults are easy to identify, but some larvae are difficult to identify and may require rearing for positive identification.
e Many amateurs are sufficiently trained to identify birds.
f Identification of diatoms is aided by pictorial keys, but relatively few people are trained.
g Wisconsin DNR is attempting to develop family-level assessment methods instead of identifying macroinvertebrates to genus and species.
h Dip net and especially stovepipe samples can involve a lot of time-consuming picking; however, Minnesota PCA uses method to reduce time. Activity traps generally require less picking because they do not pick up as much detritus.
i Amphibians and fish may have insufficient taxonomic diversity to be effectively used in bioassessment in some wetland types or parts of the country.
j Historical land use practices and immediate landscape have significant influence on community.
k Algae are sensitive to copper sulfate.
l Many of these chemicals have very high affinities to charged particles and end up in higher concentration in the sediments than in the water column. Minnesota PCA has found strong responses in the plant community to sediment concentrations of Cu, Zn, Cd, and other metals.
m Deformities, lesions, etc. have been found in the field, but typically appear only in highly contaminated situations.

limited degree but offer an inexpensive and effective alternative for some wetland types (U.S. EPA 2002c). Amphibians offer many advantages but have insufficient taxonomic diversity in some regions for traditional bioassessment methods (U.S. EPA 2002d). The mobility of birds makes them well suited for landscape-level assessments (U.S. EPA 2002e). Fish have many advantages that have been demonstrated in other waterbodies, but the fish assemblage is limited to a few wetland types, such as emergent wetlands on the fringes of lakes and estuaries. In summary, different assemblages have different advantages depending on the purpose of the project, region of the country, and wetland types being evaluated. BAWWG members recommend sampling two or more assemblages because it provides more confidence in management decisions and substantially improves the ability to diagnose the causes of degradation.

Classifying Wetlands

The goal of bioassessments is to evaluate the condition of wetlands as compared to reference conditions and determine if wetlands are being damaged by human activities. An obvious challenge facing wetland scientists is to distinguish changes in biological communities caused by human disturbances from natural variations. This challenge is complicated by the natural variation found among the variety of U.S. wetland types (Cowardin et al. 1979, Mitsch and Gosselink 2000, Brinson 1993). One way to simplify the evaluation is to classify the wetlands and only compare wetlands with others within the same class. BAWWG members have found that some type of classification method is necessary when developing bioassessment methods for wetlands (U.S. EPA 2002f).

Consider an easy example of comparing a salt marsh to an oligotrophic bog. Each wetland is shaped by the interaction of plants and animals with a variety of factors, including its landscape position, hydrologic characteristics, water chemistry, underlying geology, and climatic conditions. Each type of wetland consists of plants and animals with adaptations to survive and reproduce in a certain range of environmental conditions. For example, organisms that inhabit salt marshes must have physical, chemical, or behavioral adaptations to withstand variable salinity and alternating wet and dry periods. In contrast, organisms that inhabit oligotrophic bogs must have adaptations to tolerate acidic conditions and obtain and retain scarce nutrients. An organism adapted for life in a bog would not likely survive in a salt marsh, and vice versa. As a result, the biological community of a bog will be much different from the biological community of a salt marsh. No one would disagree that it is inappropriate to directly compare the biological communities of a salt marsh to a bog.

The validity of making other comparisons is often debated. For example, is it appropriate to compare the biological communities of an emergent marsh on the edge of a pond to an emergent marsh on the edge of a slow-moving river? Are the biological communities similar enough to lump into one class or do they need to be split into two classes? There are no easy answers to these questions. They must be answered, however, to ensure scientific validity of the bioassessment results and management decisions. The use of a classification system provides a framework for making these decisions.

For purposes of developing bioassessment methods, the goal is to establish classes of wetlands that have similar biological communities that respond similarly to human disturbances. As discussed in Wetland Classification (U.S. EPA 2002f), a variety of wetland classification systems have already been developed for a variety of purposes. BAWWG members have used many of these classification systems (U.S. EPA

2002f; in prep.) to avoid "comparing apples to oranges" and have come up with the following list of observations and recommendations:

- *Do not reinvent the wheel.* BAWWG members suggest starting with one or more existing methods and, if necessary, modifying the classification to establish classes of biologically similar wetlands. Developing an entirely new system should not be necessary.

- *Classification is often an iterative process.* Researchers often start with one or more systems and then lump or split classes as needed to end up with an appropriate number of groups of biologically distinct wetlands. For example, when the Montana Department of Environmental Quality (MT DEQ) developed its IBI, it used ecoregions as a first tier and then further separated wetlands by landscape position and other characteristics (e.g., acidity and salinity). MT DEQ later determined that it could lump the wetlands of two ecoregions because their macroinvertebrate communities were similar and responded similarly to anthropogenic stressors. While establishing classes, examine other natural factors that may affect wetland communities (e.g., size, successional stage, age of the wetland, salinity) to determine if they should be included in the classification system.

- *Do not become preoccupied with classification.* Even though proper classification is necessary to minimize natural differences among wetlands, the goal of this exercise is not to develop a new classification method. Rather, the goal is to improve the ability of wetland scientists to detect signals from the biology about the condition of wetlands.

- *Classify wetlands to a suitable level.* Ecologists need to develop wetland classes that are broad enough to allow comparisons of several wetlands, yet narrow enough to provide biologically meaningful comparison. All ecologists are faced with a dilemma: the more ecologists learn about natural systems, the more they realize how little they actually know. As a result, it is tempting to delve ever deeper into biology to help identify differences between wetlands and develop more subclasses. However, ecologists are faced with another dilemma: limited financial and staff resources. For each wetland class that is identified, a new set of wetlands must be sampled to calibrate analytical methods. The endpoint therefore represents a balance of (1) a need to have broad inclusive classes that will facilitate the comparisons of many wetland types, (2) a desire to have a narrow classification that includes detailed bioassessment data, and (3) constraints on financial and staff resources. Another limiting factor when classifying wetlands is having enough wetlands of each class to calibrate analytical methods.

- *Recognize that the wetland classification and classes used for one assemblage may not be suitable for another assemblage.* For example, wetland classes developed to obtain biologically similar macroinvertebrate communities may not work when applied to another assemblage, such as plants. Always test existing wetland classes to ensure that they are biologically meaningful in identifying the effects of human disturbances on the selected assemblage(s).

Selecting Wetlands Across a Disturbance Gradient

After classifying wetlands, researchers select sampling sites across a disturbance gradient for each wetland class. These sites are used to document how a biological assemblage responds to increasing levels of anthropogenic stressors (U.S. EPA 2002g). A common way of portraying bioassessment results is to create a graph with a measure of human disturbance along the X-axis and a biological endpoint along the Yaxis (Figure 2). As discussed in Developing Metrics and Indexes of Biological Integrity (U.S. EPA 2002g), no standard method for establishing gradients of human disturbance exists. Some BAWWG members have tried to quantify disturbance by using surrogates such as the percentage of impervious surfaces or agriculture in a watershed. Other projects have used qualitative indices of human disturbance that incorporate a combination of watershed and wetland information. Regardless of the gradient used, it is crucial to select wetlands that range from minimally disturbed reference sites to severely degraded wetlands, with some sites in between. BAWWG members have the following observations and recommendations about gradients of human disturbance:

- *Do not become preoccupied with disturbance gradient.* It is impossible to develop a disturbance gradient that incorporates every way that humans can damage wetlands. The disturbance gradient should provide a gross estimate that can be used in the site selection process and the calibration of metrics. The biological information will ultimately be much more reliable and trustworthy in evaluating wetland condition than the disturbance gradient (Karr and Chu 1999).

- *Define and describe the expected disturbance gradient before sampling sites.* If the disturbance gradient is established after the sites are sampled, then there is the risk of sampling too few wetlands at either end of the gradient.

- *Use targeted sampling while developing bioassessment methods.* As discussed in Study Design for Monitoring Wetlands (U.S. EPA 2002h), statistical sampling designs provide many advantages when attempting to estimate the percentage of waterbodies that are meeting their designated uses. However, BAWWG members have found that the targeted selection of sampling sites is preferable when developing bioassessment methods. It is important to get sufficient numbers of minimally disturbed sites and severely degraded sites to (1) document the condition of a biological assemblage at the two extremes and (2) calibrate analytical methods. Statistical sampling methods often fail to select enough wetlands at either end of the disturbance gradient.

Selecting Sampling Methods

Sampling methods used in a wetland bioassessment project will depend on the taxonomic assemblage and wetland class being sampled. Specific sampling methods for each assemblage, except fish, are described in the reports listed in Table 3. Regardless of the assemblage selected, BAWWG members have the following observations and recommendations:

- *Use standardized sampling methods.* It is very important to standardize sampling methods and establish quality assurance protocols to ensure the comparability of data. In addition, equal sample effort must be given to each wetland. EPA recommends developing Quality Assurance Project Plans (QAPP) to help maintain consistency at every stage of sampling from collection to transportation of samples and laboratory procedures (U.S. EPA 1995b).

- *Ensure that sampling methods are repeatable.* BAWWG members recommend testing all sampling methods to make sure that they provide repeatable and consistent results in different wetlands and with different field technicians.

- *Standardize the sampling period.* The composition and abundance of taxa in a biological assemblage will change during the course of a year. Individual taxa within a biological assemblage breed at different times of the year, mature at different rates, and have a variety of behavioral and physical adaptations for life in wetlands. Depending on the assemblage, sampling the same wetland at different times of the year can yield strikingly different communities. It is necessary to establish a standard period of time within the year to collect samples that (1) minimizes variation caused by natural, seasonal changes in community composition; (2) provides sufficient differentiation of communities across a disturbance gradient; and (3) is logistically practical.

- *Retain some flexibility in sampling period.* Although it is important to maintain a standard sampling period, it helps to retain some flexibility in scheduling sampling. Annual climatic variations can delay or accelerate biological processes. For example, a particularly warm winter can cause adult amphibians to breed much earlier than they normally would. It is important to pay attention to these variations and adjust the sampling scheme accordingly to secure samples that are not biased toward certain taxa and do not misrepresent relative abundance.

- *Consider time and resource constraints.* Biologists are often tempted to create elaborate sampling designs using several methods to ensure that all species are captured and represented in a sample. However, the complexity of sampling methods must be balanced with the time and resources available. Remember that the goal of the assessments is to evaluate the condition of a wetland relative to a known range of condition from wetlands across a disturbance gradient. It is not necessary to monitor everything within a wetland to detect differences in biological communities across this gradient. Rather, the sampling effort should be focused on identifying characteristics of biological communities that show measurable and consistent relationships. For example, the Maine Department of Environmental Protection is focusing macroinvertebrate monitoring in emergent wetlands at the transition zone between open water and emergent vegetation rather than attempting to sample every microhabitat within a wetland (Jeanne Difranco, Maine DEP, pers. comm.). Recognizing that wetlands are often mosaics of different vegetative communities and microhabitats, the Minnesota Pollution Control Agency targets an area of the wetland that is representative of the wetland as a whole and uses a releve sampling method to evaluate the plant assemblage (U.S. EPA 2002a).

Collecting Chemical and Physical Data

Used independently, measurements of a wetland's physical characteristics or chemicals in a wetland's water or sediment are not appropriate for estimating wetland health because they do not adequately reflect the condition of biological communities. The ability to infer biological condition from physical and chemical data is often limited to severely altered or polluted conditions. Water chemistry, in particular, is very expensive to analyze, can vary widely over time, and can be difficult to interpret. Methods that focus primarily on a wetland's physical structure, such as functional assessment methods, fail to detect damage from subtle stressors such as the effects of pesticides. Physical and chemical information can be very useful while classifying wetlands, interpreting biological data, and identifying potential stressors. BAWWG members use a variety of physical and chemical data in their projects, including:

- Water chemistry (e.g., nutrients, pH, DO, conductivity, dissolved metals, turbidity)

- Substrate (e.g., type of soil, sediment chemistry)
- Wetland topography and water depth (e.g., functional assessment data)
- Characteristic vegetative structure
- Characteristics of immediate surrounding land use
- Watershed characteristics (e.g., land use, percent natural vegetation, nearest wetland)

These chemical/physical data provide valuable information for interpreting biological data, verifying wetland class, and diagnosing potential stressors. However, these data should not be used alone to infer biological condition. Several States have found that using chemical data to infer the biological condition of streams is dangerously misleading. States that have invested in strong stream bioassessment capabilities have discovered that chemical assessments vastly overestimated the quality of their streams. Using the traditional chemical assessments, Ohio EPA estimated that approximately 30% of streams were not meeting the minimum standards for maintaining chemical, physical, and biological integrity. Using their bioassessment methods, Ohio EPA now estimates that about 70% of the same streams are not meeting their designated uses (Chris Yoder, Ohio EPA, pers. comm.). Other States, such as Delaware, have come to a similar conclusion (John Maxted, Delaware Department of Natural Resources and Environmental Control, pers. comm.). Using chemistry data or physical data to infer biological condition of wetlands would likely produce similar misleading and inaccurate results. Experiences like these show that one of the most meaningful ways to evaluate the health of streams, and arguably any habitat, is to directly evaluate the plant and animal communities that live in them.

Analyzing Data

After biologists sample and identify the taxa in an assemblage, they can prepare a list of taxa names and the abundance or percent cover for each. The challenge facing the biologists is to identify ways to analyze these data to provide meaningful measures of biological condition. Remember that the goal is to evaluate the data and determine to what degree the wetlands are being damaged by human activities. Both multimetric indexes, such as Indexes of Biological Integrity (IBI), and statistical approaches have been used in stream, lake, and estuary bioassessments (Davis and Simon 1995, Barbour et al. 1999, U.S. EPA 1996a,b, 1998a, 2000a). The virtues of the two analytical methods have been debated in the scientific literature (Norris and Georges 1993, Suter 1993, Gerritsen 1995, Norris 1995, Wright 1995, Diamond et al. 1996, Fore et al. 1996, Reynoldson et al. 1997, Karr and Chu 1999).

As described in Wetland Bioassessment Case Studies (U.S. EPA, in prep.), most wetland bioassessment projects use IBIs to analyze data. Some States are exploring the use of advanced statistics to analyze data. Maine Department of Environmental Protection is exploring the use of a combination of metrics and statistics to evaluate macroinvertebrate data. Montana Department of Environmental Quality uses canonical correspondence analysis and TWINSPAN to evaluate wetland algal data. Magee and others used canonical correspondence analysis and TWINSPAN to illustrate the extent to which wetlands in urbanizing landscapes are floristically degraded in comparison to relatively undisturbed systems (Magee et al. 1999).

IBIs and related multimetric indexes identify attributes of an assemblage that show empirical and predictable responses to increasing human disturbance (Karr 1981). Each metric is scored individually. These scores are then combined into an overall index. The process of identifying metrics and developing IBIs is discussed in detail in Developing Metrics and Indexes of Biological Integrity (U.S. EPA 2002g). Data from most attributes can be used to generate scatter plots, i.e., plot each measure for an attribute (Y variable) against a measure for human disturbance (X variable). Some attributes (e.g., abundance, density, production) typically form shotgun patterns because they are naturally variable. Figure 4 provides an example of an attribute that shows no dose-response relationship when compared to a disturbance gradient; this attribute would not be used as a metric. Other attributes will show clear dose-response patterns and thus would be considered as potential metrics. Figures 5 and 6 illustrate attributes with dose-response relationships when compared to disturbance gradients; these attributes could be used as metrics.

After graphically and statistically analyzing potential metrics, researchers select the best performing metrics to include in an IBI. Ideally, an IBI should consist of approximately 8-12 metrics (Karr and Chu 1999). One way of combining metrics into an IBI is to assign values of 5, 3, or 1 to the measures for each metric, where a 5 corresponds with the least disturbed condition, a 3 corresponds to intermediate disturbance, and a 1 corresponds to the most disturbed condition (U.S. EPA 2002g). For a metric such as the number of intolerant taxa, a wetland with a lot of intolerant taxa may receive a 5 and a wetland with no intolerant taxa may receive a 1. The metric scores associated with a wetland are usually added together to calculate the IBI score. Figure 7 provides an example of IBI scores of individual wetlands plotted across a gradient of human disturbance. The IBI consists of 10 metrics, which were scored using the 5/3/1 system and then added together. Thus the highest possible IBI score in this example is 50 and the lowest possible IBI score is 10. Some States use different scoring values (e.g., 6/4/2/0 or 10/7/3/0) to make the lowest possible IBI score equal 0.

On the basis of their experience, BAWWG members have the following recommendations related to developing metrics and IBIs:

- *Develop a separate IBI for each assemblage.* BAWWG members recommend developing separate IBIs for each assemblage because it makes it easier for other organizations to use or adapt the IBI. Advantages of having two or more IBIs include (1) having additional data that may reinforce the bioassessment findings, and (2) a second IBI may reveal different findings because some assemblages may respond more to certain stressors.

- *Never use an attribute as a metric without testing it first.* BAWWG members recommend that all sampling and analytical methods, including metrics, should be tested, verified, and calibrated to regional conditions before they are used in a new area of the country (U.S. EPA 2002g).

- *Investigate outliers.* Scatterplots of the metric or IBI values of individual wetlands plotted against a disturbance gradient often have outliers, or values that are inconsistent with the majority. BAWWG members have found that outliers are often the result of misclassifying the wetland or damage to the wetland from a stressor that is not accounted for in the human disturbance gradient. Investigation of outliers can identify important stressors and land use characteristics.

- *Avoid directly comparing the IBI scores of wetlands in different classes.* IBI scores should be calibrated for each wetland class as defined by the classification system used. Consider an IBI consisting of 10 metrics,

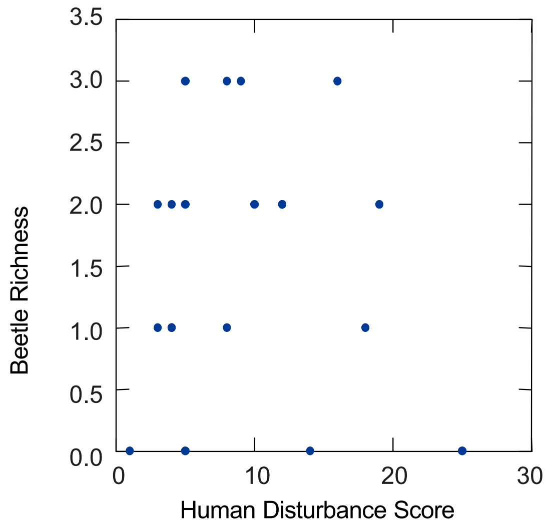


Figure 4: Number of beetle genera plotted against a human disturbance gradient (Source: Maine DEP).

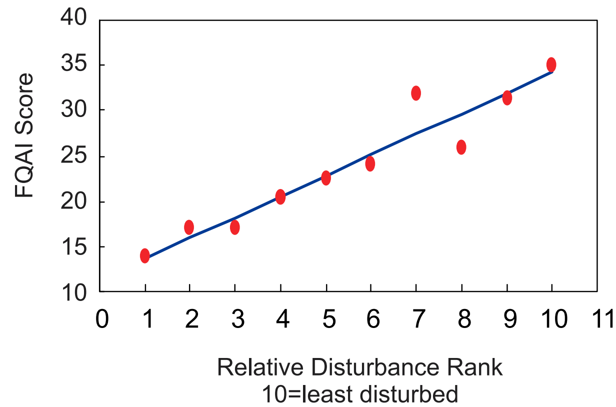


Figure 5: Floristic quality assessment index plotted against a human disturbance gradient (Source: Ohio EPA).

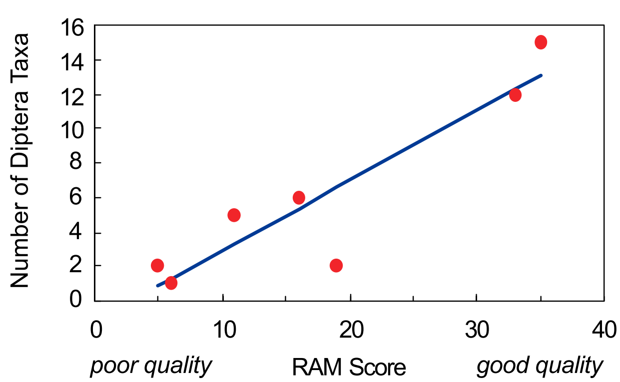


Figure 6: Number of Diptera taxa plotted against Rapid Assessment Method (RAM) scores, a rapid functional assessment (Source: Ohio EPA).

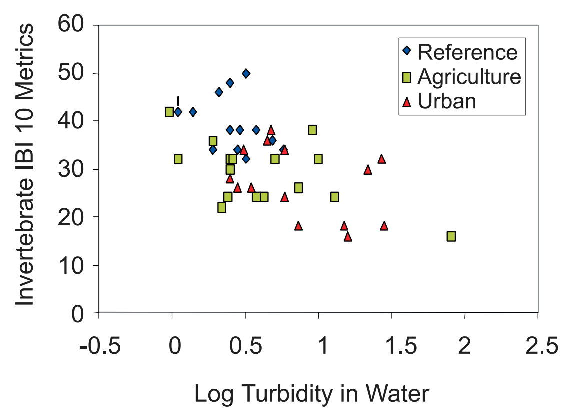


Figure 7: A 10-metric macroinvertebrate IBI plotted against turbidity (Source: Minnesota PCA).

each scored with a 5, 3, or 1 where 5 represents good condition and 1 represents poor condition. The best potential IBI score for a bog, when compared with similar bogs, should be 50 (i.e., 10 metrics × 5 = 50). Similarly, the best potential marsh IBI score should be a 50 when compared with other marshes (i.e., 10 metrics × 5 = 50). When the same metrics are used, avoid establishing a scoring system where a minimally disturbed bog would receive a significantly lower score (IBI = 25) than a minimally disturbed marsh (IBI = 50).

Reporting Results

Perhaps the greatest benefit of an IBI is that it summarizes and presents complex biological information in a format that is easily communicated to managers and the public. Most people can more easily understand plant and animal IBIs than complex statistical calculations or abstract chemical and physical data. Although an IBI score is helpful for quickly communicating the overall condition of a wetland, most of the valuable information lies in the individual metrics. When reporting bioassessment results, the IBI score should be accompanied by the following information:

- Narrative description of overall biotic condition in comparison to reference wetlands of the same region and wetland type
- Number values (e.g., number of taxa) and scores (e.g., 5, 3, or 1) for each metric
- Narrative descriptions of each metric in comparison to reference conditions of the same region and wetland type

Using Biological Information To Improve Management Decisions

Biological monitoring provides a framework for improving wetland management, protection, and restoration. Bioassessments provide information about a wetland's present biological condition compared to expected reference conditions. By studying biology, wetland scientists can better understand how a wetland's biological community is influenced by the wetland's present geophysical condition and human activities within a watershed (Figure 8). Managers, policymakers, and society at large can use this information to decide if measured changes in biological condition are acceptable and set policies accordingly (Courtemanch et al. 1989, Courtemanch 1995, Yoder 1995, Karr and Chu 1999). As shown by many of the projects in Wetland Bioassessment Case Studies (U.S. EPA, in prep.), States can use information from wetland bioassessments to improve many management decisions, including:

- Strengthening water quality standards
- Strengthening State wetland regulatory programs
- Improving wetland tracking
- Improving water quality decisions
- Improving plans to monitor, protect, and restore biological condition
- Evaluating the performance of regulatory, protection, and restoration activities
- Incorporating wetlands into watershed management
- Improving risk-based management decisions

Physical, chemical, evolutionary, and biogeographic processes interact to produce

Physical and Geographic Context
Landscape position
Geological substrate
Climate, elevation
Wetland type

Biological Integrity
Taxa richness
Species composition
Tolerance/intolerance
Adaptive strategies (ecology, behavior, morphology)

The baseline without human disturbance is influenced by

Human Activities
Land use (building, farming, logging, grazing, etc.)
Changes in hydrology
Introduction of pesticides, herbicides, and other chemicals
Introduction of non-native plants and animals

which alter the biogeochemical processes to influence one or more of

Six Factors
Wetland hydrology
Physical habitat structure
Water quality
Energy source
Biological interactions
Connectivity to other natural systems

thereby altering

Geophysical Condition
Storage and flow of water
Biogeochemical processes
Groundwater interaction
Accumulation of sediment and organic matter

Biological Condition
Taxa richness
Taxonomic composition
Individual health
Ecological processes
Evolutionary processes

Unacceptable divergence of

Biological Condition from Biological Integrity

stimulates

Environmental Policies
Regulations, incentives
Management, conservation, restoration

to protect

Wetland Biological Communities and the Functions That They Provide

Figure 8: Framework for improving wetland management (adapted from Karr and Chu 1999).

Strengthening Water Quality Standards

The most common application of wetland bioassessments is to improve the way wetlands are incorporated into State water quality standards. States can use the information from bioassessments to develop ecologically based designated uses and biocriteria to determine if those uses are being met. Under CWA Section 303, States and eligible Tribes develop water quality standards to ensure that their waters support beneficial uses such as aquatic life support, drinking water supply, fish consumption, swimming, and boating. As envisioned by Section 303(c) of the Clean Water Act, developing water quality standards is a joint effort between States and the EPA. The States have primary responsibility for setting, reviewing, revising, and enforcing water quality standards.

EPA develops regulations, policies, and guidance to help States implement the program and oversees States' activities to ensure that their adopted standards are consistent with the requirements of the CWA and relevant water quality standards guidelines (40 CFR Part 131). EPA has authority to review and approve or disapprove State standards and, where necessary, to promulgate Federal water quality standards. A water quality standard defines the environmental goal for a waterbody, or a portion thereof, by designating the use or uses to be made of the water, setting criteria necessary to protect those uses, and preventing degradation of water quality through antidegradation provisions (U.S. EPA 1991) (Appendix). Criteria are the narrative or numeric descriptions of the chemical, physical, or biological conditions found in minimally impacted reference areas (Table 3). By comparing the condition of a wetland to appropriate criteria, States can determine if the wetland is supporting its designated uses. For examples of how States have incorporated wetlands into water quality standard programs, please refer to the Wetland Bioassessment Case Studies module (U.S. EPA, in prep.).

Most States do not have wetland-specific designated uses or criteria to adequately protect wetland biological integrity. In their absence, States must rely on designated uses and criteria developed for lakes, streams, or other waterbodies that often have different ecological conditions. In addition, States historically focused on developing chemical and physical criteria based on sampling ambient water column conditions and conducting laboratory toxicity tests. The information on ambient water column conditions and toxicity tests was then used to infer biological condition of aquatic habitats. The development and widespread use of formal biocriteria has lagged behind chemical-specific and toxicity based water quality criteria (U.S. EPA 1996a,b). However, EPA requires that States adopt biocriteria as part of their water quality criteria for wetlands (U.S. EPA 1990).

States can use bioassessment methods to establish standards and criteria that are ecologically appropriate for conditions found in wetlands. Biocriteria for aquatic systems describe (in narrative or numeric criteria) the expected biological condition of a minimally impaired aquatic community (U.S. EPA 1992, 1996a). These criteria can be used to define ecosystem rehabilitation goals and assessment endpoints. Bioassessments are especially useful for assessing damage from hard-to-detect chemical problems and nonchemical stressors. Thus, biocriteria fulfill a function missing from EPA's traditionally chemical-oriented approach to pollution control and abatement (U.S. EPA 1994d).

Table 3: Types of Water Quality Criteria (adapted from Elder et al. 1999)

	Narrative	Numeric
Chemical	▪ Important backstop to numeric chemical criteria, especially when one considers that there are thousands of chemicals with no established criteria ▪ Often expressed with general Statements, such as "waters shall be free from concentrations of pollutants injurious to aquatic life"	▪ Most of the criteria fall in this category ▪ Usually expressed as a maximum or minimum allowed concentration of a chemical, such as X mg/L of copper
Physical	▪ Important backstop to numeric physical criteria, especially because few physical criteria have been developed	▪ Not as well developed as chemical criteria ▪ Can include criteria for temperature, habitat condition, etc.
Biological	▪ Possibly more important than narrative chemical and physical criteria because it is often difficult to describe conditions of a healthy biological community in numeric terms alone ▪ Very general narrative criteria have been on the books in some States for years ▪ More need to be developed, and many of those already on books need to be made clearer, more specific, and more applicable to wetlands	▪ Describe the condition of biological communities (e.g., macro invertebrates) of healthy waterbodies ▪ Often provide comparisons between actual condition in a waterbody to reference conditions

Strengthening State Wetland Regulatory Programs

Wetland bioassessments can help strengthen State wetland regulatory programs and improve confidence in management decisions. Ohio Environmental Protection Agency's (Ohio EPA) work with an IBI and rapid functional assessment provides a good example. The Ohio Rapid Assessment Method (ORAM) is a rapid functional assessment, which was developed by the State for use in reviewing numerous wetland permit applications. Recognizing that it could not perform bioassessments with all wetland permit applications, Ohio EPA calibrated its detailed bioassessments with ORAM. Ohio EPA now has more confidence in ORAM results when the scores are within given ranges. When ORAM scores are inconclusive, Ohio EPA can justify delaying a decision on the application to perform a detailed bioassessment to provide a more reliable assessment of wetland condition.

Improving Wetland Tracking

Under Section 305(b) of the Clean Water Act (CWA), States submit reports to EPA every 2 years that summarize the quality of their aquatic resources. In the 305(b) reports, States summarize the amount of streams, rivers, lakes, estuaries, and wetlands that are (1) meeting their designated uses, (2) partially supporting their designated uses, and (3) not supporting their designated uses. In the 1998 *National Water Quality Inventory*, a summary of the State 305(b) reports provided by EPA to the U.S. Congress, States determined designated use support for only 4% of the Nation's wetlands. Of the 4% that were included in the report, only a small fraction of the decisions were based on actual monitoring data. Wetland bioassessments provide badly needed information to track wetland condition and determine if wetlands are supporting their designated uses. In addition, a number of Federal funding sources are tied to the information provided in 305(b) reports. By not including wetlands in the report, States are potentially missing out on resources for their programs.

Improving Water Quality Decisions

Water quality standards provide a programmatic foundation for a number of other water quality programs. By using bioassessment data to improve water quality standards, States can also improve these other water quality programs. For example, bioassessments can help assess the impacts from nonpoint-source pollution (CWA Section 319) or from point-source discharges (CWA Section 402). States can use bioassessments to evaluate the effects of stormwater discharges on the biological condition of wetlands. Another potentially powerful tool is the water quality certification process. Under CWA Section 401, States have the authority to grant or deny "certification" of federally permitted or licensed activities that may result in a discharge to wetlands or other waterbodies. The certification decision is based on whether the proposed activity will comply with State water quality standards. Under this process, a State can use information from bioassessments to determine if a proposed activity would degrade water quality of a wetland or other waterbodies in a watershed. If a State grants certification, it is essentially saying that the proposed activity will comply with State water quality standards. Likewise, a State can deny certification if the project would harm the chemical, physical, or biological integrity of a wetland as defined by water quality standards. A State's Section 401 certification process is only as good as its underlying water quality standards. States can use bioassessments to refine narrative and numeric criteria to make them more suitable for conditions found in wetlands and subsequently improve the Section 401 certification process.

Improving Plans To Monitor, Protect, and Restore Biological Condition

Wetlands are often damaged by a complex mix of chemical, physical, and biological stressors. It can be difficult to pinpoint specific stressors using biological information or any single source of information alone. However, properly planned, designed, and implemented bioassessments are not performed in a vacuum (Yoder 1995). Proximity to known sources of pollution, knowledge of the surrounding landscape, and supporting chemical and habitat data are all important sources of information to help identify how and why a wetland is being damaged. Recent advances in stressor identification and evaluation provide a framework for systematically examining all available data, identifying probable stressors, and documenting the decisionmaking process (U.S. EPA 2000b). The

Stressor Identification framework offers three approaches to identify probable causes: (1) eliminate, (2) diagnose, and (3) assess strength of evidence (Figure 9). The strength-of-evidence approach will often be the most helpful approach when the biota exhibits impairment and there is no clear stressor. In some cases, the stressor identification process will indicate that additional monitoring of the biological community is required or will provide a shortened list of potential chemical or habitat stressors to be investigated. Thus, bioassessments and the stressor identification process can help States identify problem areas and then target the use of more expensive chemical and physical measurements on these sites. When the stressor identification process identifies a probable stressor, appropriate actions can be taken to restore wetland condition. Under Section 303(d) of the Clean Water Act, States are required to submit lists to EPA of waterbodies that do not attain their designated uses and criteria, such as biocriteria. Subsequently, States can use bioassessment data and the stressor identification process to apply a variety of management tools (e.g., total maximum daily loads, Section 319 nonpoint source pollution reduction, NRCS wetland conservation programs) to improve wetland condition. Bioassessment data will also be useful for States and municipalities when they target resources to protect or purchase easements on high-quality wetlands.

Evaluating the Performance of Regulatory, Protection, and Restoration Activities

States can evaluate the success of restoration activities and best management practices, such as buffer strips, by requiring followup assessments in management plans. By periodically conducting bioassessments, States can track the condition of wetlands and learn which management activities work best. States can use this information to improve future management plans and save time and money by targeting the most effective restoration projects and best management practices that achieve greater environmental benefits. Wetland biologists can also use bioassessment data to track wetland biota recovery time and to identify which features of wetland restoration projects, such as diverse microtopography, are most important in improving biological condition. The USGS Biological Resources Division, NRCS Wetland Science Institute, and EPA Wetlands Division cooperatively worked on a project to develop bioassessment methods to evaluate the condition of restored wetlands on the Delmarva Peninsula in Maryland.

Incorporating Wetlands into Watershed Management

The watershed management cycle is based on sound monitoring data (U.S. EPA 1995a, 1996c). Collectively, watershed stakeholders employ sound scientific data, tools, and techniques in an iterative decisionmaking process (Figure 10). This process includes:

- *Strategic monitoring.* Target monitoring to inform management decisions
- *Assessment.* Evaluate data to determine condition of waterbodies, identify stressors, or evaluate effectiveness of prior management plans
- *Assigning priorities and targeting resources.* Rank water quality concerns and decide how to allocate resources to address priority concerns
- *Developing management strategies.* Develop clear goals and objectives to address priority concerns, identify a range of management strategies, and evaluate their effectiveness

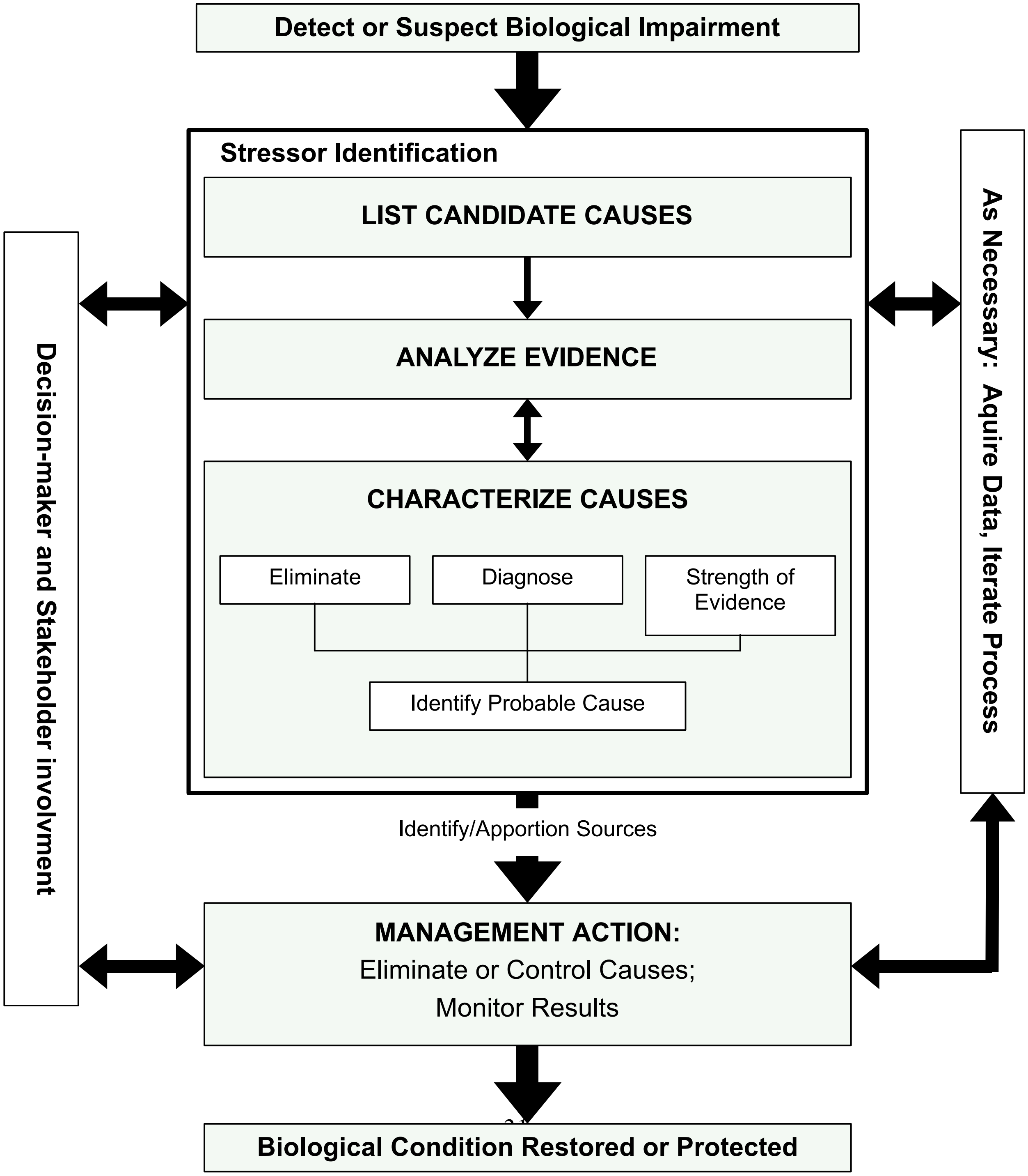


Figure 9: The management context of the Stressor Identification (SI) process
(the SI process is shown in the center box with bold line).

- *Management plans.* Specify how goals will be achieved, who is responsible for implementation, on what schedule, and how the effectiveness of the plan will be assessed
- *Implementation.* Implement activities described in management plans

Information from wetland bioassessments is necessary to evaluate the condition of wetlands, set environmental objectives, and evaluate the success of management actions. Without information from bioassessments, watershed management plans will not adequately address or will completely overlook the biological condition of wetlands. Wetlands will continue to be included in watershed management plans as buffers to maintain streams and lakes, but not as important components of the environment that should be maintained and protected based on their own intrinsic functions and values. Failure to protect wetland condition in watershed plans will likely diminish the health of other aquatic systems in a watershed.

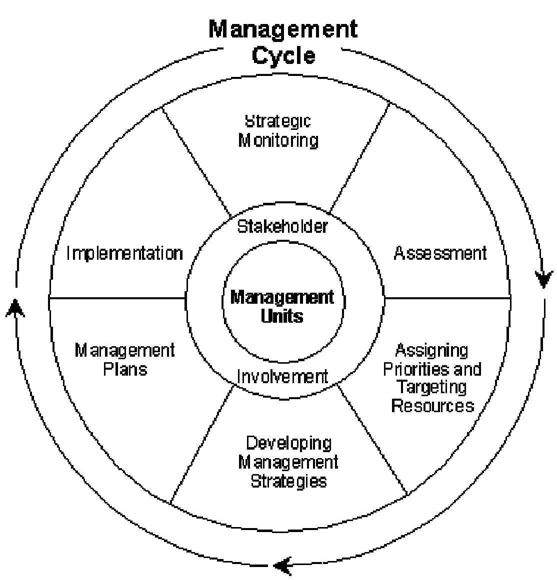


Figure 10: Watershed management cycle.

Improving Risk-Based Management Decisions

By identifying the biological and ecological consequences of human actions, biological monitoring provides an essential foundation for assessing ecological risks (Karr and Chu 1999). To date, most ecological risk assessments focus on using laboratory analysis of chemical endpoints and extrapolate the results to the natural environment because of perceived shortcomings in ecosystem-level risk assessment (Suter et al. 1993). The combined information from bioassessments and stressor identification may fulfill many of the perceived shortcomings of ecosystem-level risk assessments. Through the process of developing wetland bioassessments, wetland biologists identify a biological endpoint (i.e, a biological assemblage), group wetlands into classes that respond similarly to stressors, establish standard sampling methods, determine what time of year to sample, establish known reference conditions, and provide a way to measure divergence from biological integrity. Results from bioassessments are combined with other available data in the stressor identification process to determine the most probable stressor causing damage. The combined information from wetland bioassessments and the stressor identification process provide a foundation for improving whole-ecosystem studies. In many cases, bioassessments may provide more realistic predictions than chemical laboratory tests of the impacts that stressors have on the natural environment (Perry and Troelstrup 1988). These types of analyses also will be useful for projects involving the cleanup of contaminated Superfund and RCRA sites.

References

Barbour MT, Gerritsen J, Snyder BD, Stribling JB. 1999. Rapid Bioassessment Protocols for Use in Wadeable Streams and Rivers: Periphyton, Benthic Macroinvertebrates, and Fish, 2nd ed. Office of Water, U.S. Environmental Protection Agency, Washington, DC. EPA 841-B-99-002.

Brinson MM. 1993. A Hydrogeomorphic Classification for Wetlands. U.S. Army Corps of Engineers, Wetlands Research Program Technical Report WRP-DE-4. Washington, DC.

Courtemanch DL. 1995. Merging the science of biological monitoring with water resource management policy: Criteria development. In: Davis WS, Simon TP, eds. Biological Assessment and Criteria: Tools for Water Resource Planning and Decision Making. Boca Raton, FL: Lewis Publishers, pp. 315-325.

Courtemanch DL, Davies SP, Laverty EB. 1989. Incorporation of biological information in water quality planning. Environ Manage 13(1):35-41.

Cowardin LM, Carter V, Golet FC, LaRoe ET. 1979. Classification of Wetlands and Deepwater Habitats of the United States. U.S. Department of the Interior, Fish and Wildlife Service, FWS/OBS-79/31, Washington, DC.

Dahl TE. 2000. Status and Trends of Wetlands in the Conterminous United States 1986 to 1997. U.S. Department of the Interior, Fish and Wildlife Service, Washington, DC. 82 pp.

Dahl TE, Alford GJ. 1996. History of wetlands in the conterminous United States. In: Fretwell JD, Williams JS, Redman PJ, eds. National Water Summary on Wetland Resources. U.S. Geological Survey, Water-Supply Paper 2425, Washington, DC. pp. 19-26.

Davis WS, Simon TP. 1995. Biological Assessment and Criteria: Tools for Water Resource Planning and Decision Making. Boca Raton, FL: Lewis Publishers.

Diamond JM, Barbour MT, Stribling JB. 1996. Characterizing and comparing bioassessment methods and their results: A perspective. J N Am Benthol Soc 15(4):713-727.

Elder D, Killam G, Koberstein P. 1999. The Clean Water Act: An Owner's Manual. River Network, Portland, OR.

Faulkner SP, Richardson CJ. 1989. Physical and chemical characteristics of freshwater wetland soil. In: Hammer DA, ed. Constructed Wetlands for Wastewater Treatment. Chelsea, MI: Lewis Publishers, pp. 41-72.

Feierabend JS, Zelazny JM. 1987. Status Report on Our Nation's Wetlands. Washington, DC: National Wildlife Federation.

Fischer DH. 1989. Albion's Seed. New York, NY: Oxford University Press.

Fore LS, Karr JR, Wisseman RW. 1996. Assessing invertebrate responses to human activities: evaluating alternative approaches. J N Am Benthol Soc 15(2):212-231.

Gerritsen J. 1995. Additive biological indices for resource management. J N Am Benthol Soc 14(3):451-457.

Gibbs JP. 1993. Importance of small wetlands for the persistence of local populations of wetland-associated animals. Wetlands 13(1):25-31.

Gosselink JG, Conner WH, Day JW Jr, Turner RE. 1981. Classification of wetland resources: land, timber, and ecology. In: Jackson BD, Chambers JL, eds. Timber Harvesting in Wetlands. Baton Rouge, LA: Louisiana State University.

Johnston CA. 1991. Sediment and nutrient retention by freshwater wetlands: Effects of surface water quality. Critical Rev Environ Control 21:491-565.

Jones JR, Borofka BP, Bachmann RW. 1976. Factors affecting nutrient loads in some Iowa streams. Water Res 100:117-122.

Karr JR. 1981. Assessment of biotic integrity using fish communities. Fisheries 6(6):21-27.

Karr JR. 2000. Health, integrity, and biological assessment: The importance of whole things. In: Pimentel D, Westra L, Noss RF, eds. Ecological Integrity: Integrating Environment, Conservation, and Health. Washington, DC: Island Press, pp. 209-226.

Karr JR, Chu EW. 1999. Restoring Life in Running Waters: Better Biological Monitoring. Washington, DC: Island Press.

Karr JR, Dudley DR. 1981. Ecological perspective on water quality goals. Environ Manage 5:55-68.

Karr JR, Fausch KD, Angermeier PL, Yant PR, Schlosser IJ. 1986. Assessment of biological integrity in running waters. A method and its rationale. Illinois Nat Hist Surv Spec Publ 5.

Kuenzler EJ. 1989. Value of forested wetlands as filters of sediments and nutrients. In: Hook, DD, Lea R, eds. Proceedings of the Symposium: Forested Wetlands of the Southern States. USDA Forest Service, Gen Tech Rep SE-50, Southeastern Forest Experiment Station, Asheville, NC. pp. 85-96.

Lowrance RR, Todd RL, Fail J, Hendrickson O, Leonard R, Asmussen LE. 1984. Riparian forests as nutrient filters in agricultural watersheds. BioScience 34:374-377.

Magee TK, Ernst TL, Kentula ME, Dwire KA. 1999. Floristic comparison of freshwater wetlands in an urbanizing environment. Wetlands 19(3):517-534.

Mitsch WJ, Dorge CL, Wiemoff JR. 1979. Ecosystem dynamics and phosphorous budget of an alluvial cypress swamp in southern Illinois. Ecology 60:1116-1124.

Mitsch WJ, Gosselink JG. 2000. Wetlands. New York: Van Nostrand Reinhold.

National Oceanic and Atmospheric Administration. 1994. The Great Flood of 1993. Natural disaster survey report, Washington, DC.

National Research Council (NRC), Committee on Characterization of Wetlands. 1995. Wetlands: Characteristics and Boundaries. Washington, DC: National Academy Press.

Norris RH. 1995. Biological monitoring: The dilemma of data analysis. J N Am Benthol Soc 14:440-450.

Norris RH, Georges A. 1993. Analysis and interpretation of benthic macroinvertebrate surveys. In: Rosenberg DM, Resh VH, eds. Freshwater Biomonitoring and Benthic Macroinvertebrates. New York: Chapman and Hall, pp. 234-285.

Perry JA, Troelstrop NH Jr. 1988. Whole ecosystem manipulation: A productive avenue for test system research? Environ Toxicol Chem 7:941-951.

Reynoldson TB, Norris RH, Resh VH, Day KE, Rosenberg DM. 1997. The reference condition: A comparison of multimetric and multivariate approaches to assess water-quality impairment using benthic macroinvertebrates. J N Am Benthol Soc 16(4):833-852.

Richardson CJ. 1994. Ecological functions and human values in wetlands: A framework for assessing forestry impacts. Wetlands 14:1-9.

Roth NE, Allan JD, Erickson DL. 1996. Landscape influences on stream biotic integrity assessed at multiple scales. Landscape Ecol 11(3):141-156.

Suter GW. 1993. A critique of ecosystem health concepts and indexes. Environ Toxicol Chem 12:1533-1539.

Suter GW II, Barnthouse LW, Bartell SM, Mill T, Mackay D, Peterson S. 1993. Ecological Risk Assessment. Boca Raton, FL: Lewis Publishers.

Thibodeau FR, Ostro BD. 1981. An economic analysis of wetlands protection. J Environ Manage 12:19-30.

Tiner RW. 1998. In Search of Swampland. New Brunswick, NJ: Rutgers University Press.

U.S. Environmental Protection Agency (U.S. EPA). 1990. Water Quality Standards for Wetlands: National Guidance. Office of Water, Washington, DC. EPA 440-S-90-011.

U.S. EPA. 1991. Biological Criteria: State Development and Implementation Efforts. Office of Water, Washington, DC. EPA 440-5-91-003.

U.S. EPA. 1992. Procedures for Initiating Narrative Biological Criteria. Office of Water, Washington, DC. EPA 822-B-92-002.

U.S. EPA. 1995a. Watershed Protection: A Statewide Approach. Office of Water, Washington, DC. EPA 841-R-95-004.

U.S. EPA. 1995b. Generic Quality Assurance Project Plan Guidance for Programs Using Community-Level Biological Assessment in Wadable Streams And Rivers. Office of Water, Washington, DC. EPA 841-B-95-004.

U.S. EPA. 1996a. Biological Criteria: Technical Guidance for Streams and Small Rivers. Office of Water, Washington, DC. EPA 822-B-96-001.

U.S. EPA. 1996b. Summary of State Biological Assessment Programs for Streams and Rivers. Office of Water, Washington, DC. EPA 230-R-96-007.

U.S. EPA. 1996c. Watershed Approach Framework. Office of Water, Washington, DC. EPA840-S-96-001.

U.S. EPA. 1998a. Lake and Reservoir Bioassessment and Biocriteria: Technical Guidance Document. Office of Water, Washington, DC. EPA 841-B-98-007.

U.S. EPA. 1998b. Clean Water Action Plan: Restoring and Protecting America's Waters. Office of Water, Washington, DC. EPA 840-R-98-001.

U.S. EPA. 2000a. Estuarine and Coastal Marine Waters: Bioassessment and Biocriteria Technical Guidance. Office of Water, Washington, DC. EPA 822-B-00-024.

U.S. EPA. 2000b. Stressor Identification Guidance Document. Office of Water, Washington, DC. EPA 822-B-00-025.

U.S. EPA. 2002a. Methods for Evaluating Wetland Condition: Using Vegetation To Assess Environmental Conditions in Wetlands. Office of Water, U.S. Environmental Protection Agency, Washington, DC. EPA-822-R-02-020.

U.S. EPA. 2002b. Methods for Evaluating Wetland Condition: Developing an Invertebrate Index of Biological Integrity for Wetlands. Office of Water, U.S. Environmental Protection Agency, Washington, DC. EPA-822-R-02-019.

U.S. EPA. 2002c. Methods for Evaluating Wetland Condition: Using Algae To Assess Environmental Conditions in Wetlands. Office of Water, U.S. Environmental Protection Agency, Washington, DC. EPA-822-R-02-021.

U.S. EPA. 2002d. Methods for Evaluating Wetland Condition: Using Amphibians in Bioassessments of Wetlands. Office of Water, U.S. Environmental Protection Agency, Washington, DC. EPA-822-R-02-022.

U.S. EPA. 2002e. Methods for Evaluating Wetland Condition: Biological Assessment Methods for Birds. Office of Water, U.S. Environmental Protection Agency, Washington, DC. EPA-822-R-02-023.

U.S. EPA. 2002f. Methods for Evaluating Wetland Condition: Wetlands Classification. Office of Water, U.S. Environmental Protection Agency, Washington, DC. EPA-822-R-02-017.

U.S. EPA. 2002g. Methods for Evaluating Wetland Condition: Developing Metrics and Indexes of Biological Integrity. Office of Water, U.S. Environmental Protection Agency, Washington, DC. EPA-822-R-02-016.

U.S. EPA. 2002h. Methods for Evaluating Wetland Condition: Study Design for Monitoring Wetlands. Office of Water, U.S. Environmental Protection Agency, Washington, DC. EPA-822-R-02-015.

U.S. EPA. In preparation. Methods for Evaluating Wetland Condition: Wetland Bioassessment Case Studies. Office of Water, U.S. Environmental Protection Agency, Washington, DC.

Wang L, Lyons J, Kanehl P, Gatti R. 1997. Influences of watershed land use on habitat quality and biotic integrity in Wisconsin streams. Fisheries 22(6):6-12.

Wharton CH, Kitchens WM, Pendleton EC, Snipe TW. 1982. The Ecology of Bottomland Hardwood Swamps of the Southeast: A Community profile. U.S. Fish and Wildlife Service, Biological Services Program, FWS/OBS-81/37.

Whigham DF, Chitterling C, Palmer B. 1988. Impacts of freshwater wetlands on water quality: A landscape perspective. Environ Manage 12:663-671.

Wilen WO, Frayer WE. 1990. Status and trends of U.S. wetlands and deepwater habitats. Forest Ecol Manage 33/34:181-192.

Wright JF. 1995. Development and use of a system for predicting the macroinvertebrate fauna in flowing waters. Austral J Ecol 20:181-197.

Yoder CO. 1995. Policy issues and management applications of biological criteria. In: Davis WS, Simon TP, eds. Biological Assessment and Criteria: Tools for Water Resource Planning and Decision Making. Boca Raton, FL: CRC Press, pp. 327-343.

Yoder CO, Rankin ET. 1995. Biological criteria program development and implementation in Ohio. In: Davis WS, Simon TP, eds. Biological Assessment and Criteria: Tools for Water Resource Planning and Decision Making. Boca Raton, FL: CRC Press, pp. 109-144.

Glossary

Aquatic life use A type of designated use pertaining to the support and maintenance of healthy biological communities.

Assemblage An association of interacting populations of organisms that belong to the same major taxonomic groups. Examples of assemblages used for bioassessments include: algae, amphibians, birds, fish, amphibians, macroinvertebrates (insects, crayfish, clams, snails, etc.), and vascular plants.

Attribute A measurable component of a biological system. In the context of bioassessments, attributes include the ecological processes or characteristics of an individual or assemblage of species that are expected, but not empirically shown, to respond to a gradient of human disturbance.

Benthos The bottom fauna of waterbodies.

Biological assessment (bioassessment) Using biomonitoring data of samples of living organisms to evaluate the condition or health of a place (e.g., a stream, wetland, or woodlot).

Biological integrity "the ability of an aquatic ecosystem to support and maintain a balanced, adaptive community of organisms having a species composition, diversity, and functional organization comparable to that of natural habitats within a region" (Karr and Dudley 1981).

Biological monitoring Sampling the biota of a place (e.g., a stream, a woodlot, or a wetland).

Biota All the plants and animals inhabiting an area.

Composition (structure) The composition of the taxonomic grouping such as fish, algae, or macroinvertebrates relating primarily to the kinds and number of organisms in the group.

Community All the groups of organisms living together in the same area, usually interacting or depending on each other for existence.

Competition Utilization by different species of limited resources of food or nutrients, refugia, space, ovipositioning sites, or other resources necessary for reproduction, growth, and survival.

Criteria A part of water quality standards. Criteria are the narrative and numeric definitions conditions that must be protected and maintained to support a designated use.

Continuum A gradient of change.

Designated use A part of water quality standards. A designated use is the ecological goal that policymakers set for a waterbody, such as aquatic life use support, fishing, swimming, or drinking water.

Disturbance "Any discrete event in time that disrupts ecosystems, communities, or population structure and changes resources, substrate availability or the physical environment" (Picket and White 1985). Examples of natural disturbances are fire, drought, and floods. Human-caused disturbances are referred to as "human disturbance" and tend to be more persistent over time, e.g., plowing, clearcutting of forests, conducting urban stormwater into wetlands.

Diversity A combination of the number of taxa (see taxa richness) and the relative abundance of those taxa. A variety of diversity indexes have been developed to calculate diversity.

Dominance The relative increase in the abundance of one or more species in relation to the abundance of other species in samples from a habitat.

Ecological risk assessment An evaluation of the potential adverse effects that human activities have on the plants and animals that make up ecosystems.

Ecosystem Any unit that includes all the organisms that function together in a given area interacting with the physical environment so that a flow of energy leads to clearly defined biotic structure and cycling of materials between living and nonliving parts (Odum 1983).

Ecoregion A region defined by similarity of climate, landform, soil, potential natural vegetation, hydrology, and other ecologically relevant variables.

Gradient of human disturbance The relative ranking of sample sites within a regional wetland class based on degrees of human disturbance (e.g., pollution, physical alteration of habitats, etc.)

Habitat The sum of the physical, chemical, and biological environment occupied by individuals of a particular species, population, or community.

Hydrology The science of dealing with the properties, distribution, and circulation of water both on the surface and under the earth.

Impact A change in the chemical, physical (including habitat), or biological quality or condition of a waterbody caused by external forces.

Impairment Adverse changes occurring to an ecosystem or habitat. An impaired wetland has some degree of human disturbance affecting it.

Index of biologic integrity (IBI) An integrative expression of the biological condition that is composed of multiple metrics. Similar to economic indexes used for expressing the condition of the economy.

Intolerant taxa Taxa that tend to decrease in wetlands or other habitats that have higher levels of human disturbances, such as chemical pollution or siltation.

Macroinvertebrates Animals without backbones (insects, crayfish, clams, snails, etc.) that are caught with a 500-800 micron mesh net. Macroinvertebrates do not include zooplankton or ostracods, which are generally smaller than 200 microns in size.

Metric An attribute with empirical change in value along a gradient of human disturbance.

Minimally impaired site Sample sites within a regional wetland class that exhibit the least degree of detrimental effect. Such sites help anchor gradients of human disturbance and are commonly referred to as reference sites.

Most-impaired site Sample sites within a regional wetland class that exhibit the greatest degree of detrimental effect. Such sites help anchor gradients of human disturbance and serve as important references, although they are not typically referred to as reference sites.

Population A set of organisms belonging to the same species and occupying a particular area at the same time.

Reference site (as used with an index of biological integrity) A minimally impaired site that is representative of the expected ecological conditions and integrity of other sites of the same type and region.

Stressor Any physical, chemical, or biological entity that can induce an adverse response.

Taxa A grouping of organisms given a formal taxonomic name such as species, genus, family, etc. The singular form is taxon.

Taxa richness The number of distinct species or taxa that are found in an assemblage, community, or sample.

Tolerance The biological ability of different species or populations to survive successfully within a certain range of environmental conditions.

Trophic Feeding, thus pertaining to energy transfers.

Wetland(s) (1) Those areas that are inundated or saturated by surface or groundwater at a frequency and duration sufficient to support, and that under normal circumstances do support, a prevalence of vegetation typically adapted for life in saturated soil conditions [EPA, 40 C.F.R.§ 230.3 (t) / USACE, 33 C.F.R. § 328.3 (b)]. (2) Wetlands are lands transitional between terrestrial and aquatic systems where the water table is usually at or near the surface or the land is covered by shallow water. For the purposes of this classification, wetlands must have one or more of the following three attributes: (a) at least periodically, the land supports predominantly hydrophytes, (b) the substrate is predominantly undrained hydric soil, and (c) the substrate is nonsoil and is saturated with water or covered by shallow water at some time during the growing season of each year (Cowardin et al. 1979). (3) The term "wetland" except when such term is part of the term "converted wetland," means land that (a) has a predominance of hydric soils, (b) is inundated or saturated by surface or ground water at a frequency and duration sufficient to support a prevalence of hydrophytic vegetation typically adapted for life in saturated soil conditions, and (c) under normal circumstances does support a prevalence of such vegetation. For purposes of this Act and any other Act, this term shall not include lands in Alaska identified as having a high potential for agricultural development which have a predominance of permafrost soils [Food Security Act, 16 U.S.C. 801(a)(16)].

Appendix: Water Quality Standards and Criteria

The main objective of the Clean Water Act (CWA) is to "restore and maintain the chemical, physical, and biological integrity of the Nation's water." To help meet these objectives, States must adopt water quality standards (WQS) for all "waters of the U.S." within their boundaries, including wetlands. Water quality standards, at a minimum, consist of three major components: (1) designated uses, (2) narrative and numeric water quality criteria for supporting each use, and (3) an antidegradation Statement.

Designated Uses

Designated uses establish the environmental goals for water resources. States and Tribes assign designated uses for each waterbody, or segment of a body of water, within their boundaries. Typical uses include public water supply, primary contact recreation (such as swimming), and aquatic life support (including the propagation of fish and wildlife). States and Tribes develop their own classification system and can designate other beneficial uses including fish consumption, shellfish harvesting, agriculture, wildlife habitat, and groundwater recharge.

Since designated uses can vary, States and Tribes may develop unique water quality requirements or criteria for their designated uses. States and Tribes can also designate uses to protect sensitive or valuable aquatic life or habitat, such as wetlands. When designating uses for wetlands, States may establish an entirely different format to reflect the unique functions and values of wetlands. At a minimum, designated uses must be attainable uses that can be achieved using best management practices and other methods to prevent degradation. States and Tribes can also designate uses that have not yet been achieved or attained. Protecting and maintaining such uses may require the imposition of more stringent control programs.

Water Quality Criteria

Federal water quality regulation requires States to adopt criteria sufficient to protect and maintain designated uses. Water quality criteria may include narrative Statements or numeric limits. States and Tribes can establish physical, chemical, and biological water quality criteria. Wetland biological monitoring and assessment programs can help States and Tribes refine their narrative and numeric criteria to better reflect conditions found in wetlands.

Narrative water quality criteria define conditions that must be protected and maintained to support a designated use. States should write narrative criteria to protect designated uses and to support existing uses under State antidegradation policies. For example, a State or Tribe may describe desired conditions in a waterbody as "waters must be free of substances that are toxic to humans, aquatic life, and wildlife." In addition, States and Tribes can write narrative biological criteria to describe the characteristics of the aquatic plants and animals. For example, a State may specify that "ambient water quality shall be sufficient to support life stages of all native aquatic species."

Narrative criteria should be specific enough that States and Tribes can translate them into numeric criteria, permit limits, and other control mechanisms including best management practices. Narrative criteria are particularly important for wetlands, since States and Tribes cannot numerically describe many physical and biological impacts in wetlands by using current assessment methods.

Numeric water quality criteria are specific numeric limits for chemicals, physical parameters, or biological conditions that States and Tribes use to protect and maintain designated uses. Numeric criteria establish minimum and maximum physical, chemical, and biological parameters for each designated use. Physical and chemical numeric criteria can include maximum concentrations of pollutants, acceptable ranges of physical parameters, minimum thresholds of biological condition, and minimum concentrations of desirable parameters, such as dissolved oxygen.

States and Tribes can adopt numeric criteria to protect both human health and aquatic life use support. For example, numeric human health criteria include maximum levels of pollutants in water that are not expected to pose significant risk to human health. The risk to human health is based on the toxicity of and level of exposure to a contaminant. States and Tribes can apply numeric human health criteria (such as for drinking water) to all types of waterbodies, including wetlands.

Numeric chemical or physical criteria for aquatic life, however, depend on the characteristics within a waterbody. Since characteristics of wetlands (such as hydrology, pH, and dissolved oxygen) can be substantially different from other water bodies, States and Tribes may need to develop some physical and chemical criteria specifically for wetlands.

Numeric biological criteria can describe the expected attributes and establish values based on measures of taxa richness, presence or absence of indicator taxa, and distribution of classes of organisms. Many States have developed biological assessment methods for streams, lakes, and rivers, but few States and Tribes have developed methods for wetlands. Several States, including Florida, Maine, Massachusetts, Minnesota, Montana, North Dakota, Ohio, and Vermont are currently developing biological assessment methods for monitoring the “health” of wetland plant and animal communities. Wetland biological assessment methods are essential to establish criteria that accurately reflect conditions found in wetlands.

Antidegradation Policy

All State standards must contain an ***antidegradation policy***, which declares that the existing uses of a waterbody must be maintained and protected. Through an antidegradation policy, States must protect existing uses and prevent waterbodies from deteriorating, even if water quality is better than the minimum level established by the State or tribal water quality standards. States and Tribes can use antidegradation Statements to protect waters from impacts that water quality criteria cannot fully address, such as physical and hydrologic changes.

States and Tribes can protect exceptionally significant waters as outstanding national resource waters (ONRWs). ONRWs can include waters with special environmental, recreational, or ecological attributes, such as some wetlands. No degradation is allowed in waters designated as ONRW. States can designate waters that need special protection as ONRWs regardless of how they ecologically compare to other waters. For example, although the water of a swamp may not support as much aquatic life as a marsh, the swamp is still ecologically important. A State or Tribe could still designate the swamp as an ONRW because of its ecological importance.

Applications of WQS

Water quality standards provide the foundation for a broad range of management activities and can serve as the basis to:

- Assess the impacts of nonpoint source discharges on waterbodies under CWA §319,
- Assess the impacts of point source discharges on waterbodies under CWA §402,
- Determine if federally permitted or licensed activities maintain WQS under CWA §401 water quality certification
- Track and report if waterbodies are supporting their designated uses under CWA §305(b)