An Introduction to Wetland Bioassessment and Management

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The ability of humans to manage the natural world depends on the wise application of ecological information. Individuals, populations, and communities are influenced by many interacting factors: physical and biological, genetic and environmental, strong and weak, positive and negative, direct and indirect, local and distant, current and historical. Because of the immense complexity of nature, we have a limited understanding of nature from autecological to ecosystem perspectives. However, potential threats to environmental health and integrity require efforts to find immediate solutions. The major themes of this book (wetland bioassessment and management) are particularly timely because of recent emphasis on the fact that wetlands are unique aquatic habitats ecologically separate from rivers, streams, and deep lakes (e.g., Batzer et al. 1999) that provide valuable goods and services for society (e.g., water purification, groundwater recharge, timber, fur, food).

WHAT IS A WETLAND?

Defining what constitutes a wetland is a complicated question because there are many different types of wetlands with different physical, chemical, and biological characteristics (marshes, bogs, swamps, beaver ponds, rock pools, pitcher plants, etc.). This variety makes it difficult to provide a definition that includes all wetlands while excluding other aquatic ecosystems. The U.S. Fish and Wildlife Service (Cowardin et al. 1979) offered the most widely accepted definition. They indicate that wetlands must have both of the following related characteristics: (1) saturated sediments or soils covered by shallow water for at least part of the growing season, and (2) hydrophytes as the dominant plant, at least periodically. Soils saturated by water eventually become anaerobic (low oxygen) or even anoxic (no oxygen), causing the accumulation of toxic compounds (e.g., methane, sulfur dioxide, some fatty acids)
produced by bacterial respiration when oxygen is limiting. Emergent hydrophytes can “pump” oxygen from photosynthetic structures (leaves and stems) to the roots. This oxygen can detoxify noxious compounds, allowing hydrophytes to grow in conditions lethal to other plants. Therefore, plants adapted to anaerobiosis are an important component in defining wetlands (e.g., Tiner 1989, 1991).

Because the study of wetlands is a relatively new endeavor, there has been a recent profusion of terminology, which can often result in considerable confusion. For example, the original definition of wetlands by the U.S. Fish and Wildlife Service emphasized their shallow, often temporary nature and did not include lotic ecosystems (Shaw and Fredine 1956). However, when their objectives were to locate and enumerate “all continental aquatic environments” of the United States, including streams and rivers, the U.S. Fish and Wildlife Service (Cowardin et al. 1979) later decided to reclassify running-water environments as riverine wetlands. Since then, other wetland definitions have also included running waters (e.g., Adamus 1983). Most recently, the U.S. Fish and Wildlife Service defined a riverine wetland as any wetland or deepwater habitat contained within a stream channel (Armantrout 1998). With the exception of beaver dams, water flowing through stream channels has always been a primary characteristic of lotic ecosystems. Expanding the term wetlands to include all aquatic environments of the continental United States (Cowardin et al. 1979), and reclassifying streams and rivers as riverine wetlands not only confuses the distinction between different ecosystems, but fails to recognize the unique properties of wetlands as distinct aquatic environments. Lotic ecosystems are not wetlands. In most cases, stream and river channels are a useful means of separating lotic ecosystems from wetlands associated with running waters. Riverine wetlands are shallow, low-flow habitats adjacent to stream channels (floodplains) or located in river valleys (oxbows).

As with lotic ecosystems, deep lake basins are also functionally different from shallow wetlands. For example, temperature stratification with increasing water depth and the formation of zones (epilimnion, metalimnion, hypolimnion) with different physical-chemical properties is a common characteristic of lakes in the temperate zone (Wetzel 1983). Temperature stratification in wetlands would be only a temporary phenomenon. As with streams, wetlands associated with lakes are often located along the margin and are seasonally inundated and continuous with the deeper basins of lakes (e.g., Gathman et al. 1999). The boundary separating stream channels or lake basins from associated shallow wetland habitats will fluctuate through time and is often a subjective decision. For bioassessment objectives, the delineation of wetlands is less relevant than classifying the different types in a given area. Delineation provides a systematic procedure for determining wetland boundaries so that different investigators can approximate the same boundaries for similar types of wetlands. Of course, no boundaries actually exist. Wetlands (like other ecosystems) are continuous with other aquatic and terrestrial environments, but for legal purposes, the process has been standardized. Because like all environments, wetlands, are continuous with other ecosystems, some scientists have described them as a transition zone between terrestrial and aquatic environments, suggesting that they are some “halfway
aquatic world” in transition toward the terrestrial environment (e.g., Smith 1980). There is little evidence to support the notion that wetlands are only intermediate stages in some short-lived transition between aquatic and terrestrial environments (hydrarchal succession). Most wetlands are an enduring part of the landscape (see Wissinger 1999).

**How Are Wetlands Unique?**

Wetlands are not unique in the sense that all wetland plants or animals occur only in wetlands and nowhere else. (In this sense, what ecosystems are unique?). However, many taxa are wetland specialists. For example, there are several invertebrates that are never or rarely encountered in other aquatic environments (streams, rivers, deep lakes), such as marsh beetles (Helodidae), minute bog beetles (Sphaeriidae), marsh flies (Sciomyzidae), water measurers (Hydrometridae), fairy shrimp (Anostraca), and tadpole shrimp (Notostraca) (Wissinger 1999). An unusual set of physical and chemical conditions, in addition to saturated soils and hydrophytes, also makes them a unique environment.

Most wetlands are typically low-flow, standing-water habitats that are poorly mixed. That is, flowing/turbulent water is necessary to mix and distribute chemicals and gases throughout the water column. A reduction or absence of flow in many wetlands results in steep chemical gradients (e.g., oxygen, temperature, pH, nutrients) that can fluctuate orders of magnitude over very short distances and on a 24-hour time scale (e.g., Rader and Richardson 1992). Although some wetlands are regularly mixed (e.g., prairie potholes) because they are poorly protected from the wind (e.g., Lovvorn et al. 1999), most wetland organisms are, none the less, adapted to wide chemical fluctuations over short spatial and temporal scales (Williams 1987).

Shallow water depth is also a distinguishing characteristic of wetlands that makes them prone to water-level fluctuations and periodic drying (e.g., Kusler et al. 1994). Many scientists accept the idea that wetlands are less than 2 to 3 m deep at their deepest point when water levels within the basin are at their lowest point (e.g., Mitsch and Gosselink 2000). Two to three meters is usually the maximum depth at which rooted hydrophytes can grow. Therefore, a body of water that is greater than 3 or 4 m deep at its lowest level may be considered a lake, not a wetland, even though the margins may be covered with hydrophytes.

Taken together, anaerobiosis, hydrophytes, water-level fluctuations, and drying can define wetlands. However, the distinction between wetlands and shallow lakes is tenuous. Are the patterns, processes, and functions of lentic systems less than 2 to 3 m deep at their lowest water level (wetlands) different from those of lentic systems 5 to 8 m deep at their lowest level (shallow lakes)? At least with respect to some processes (e.g., phosphorus cycling), wetlands and shallow lakes are similar (Moustafa 2000). Some authors in this book have included shallow lakes and reservoirs (greater than 2 to 3 m deep at their lowest water level) as part of their wetland bioassessment investigations (see Chapters 4 and 7). This should not be confusing as long as investigators describe the different types of water bodies included in their research.
DEFINITIONS

Science is necessarily filled with new terms, as new ideas often demand new terminology. In some cases the definition of old terms can be expanded to include recent concepts. Most biomonitoring and management terminology falls into the latter category. Although Karr and Chu (1999) provide an extensive glossary, a few definitions are necessary here to avoid confusion and refresh current understanding.

**Ecosystem management** is “driven by explicit goals, executed by policies, protocols, and practices, and made adaptable by monitoring and research based on our best understanding of the ecological interactions and processes necessary to sustain ecosystem composition, structure, and function” (Christensen et al. 1996). In short, we should manage to provide future generations with the opportunities and resources that we enjoy today; we should manage to ensure ecosystem sustainability. **Bioassessment** is the practice of using organisms to detect environmental health and integrity (Rosenberg and Resh 1993). **Health and integrity** refer to the proper functioning of ecosystems (e.g., Karr 1991). Although the term **function** is one of the most frequently used and confusing terms in ecology, in bioassessment it has two separate meanings: functions performed for society and ecosystem functions. Society functions include **goods** that have monetary value in the marketplace (food, medicine, construction materials, recreation) and **services** that are valuable but are rarely bought or sold (groundwater recharge, flood control, toxicant storage, nutrient removal, fish and wildlife habitat, soil maintenance, pest control). When many authors speak of “wetland functions” they are referring to services provided by wetlands to society, not ecosystem functions (e.g., Brinson 1993). **Ecosystem functions** refer to the processes that occur in all ecosystems (decomposition, community respiration, production, element cycling). Ecosystem goods and services depend on the proper functioning of these natural processes. Our ability to determine “proper” functioning of a wetland is based on comparing minimally impacted **reference sites** to **test sites** that are potentially impaired by human intervention. However, our ability to measure ecosystem functions is often limited and almost always costly. Also, Howarth (1991) suggested that the biological component of ecosystems should be more responsive to environmental stress than functional attributes.

RATIONALE FOR BIOASSESSMENT

Ecosystem health and integrity depend on the interaction between living organisms and ecosystem functions (Schulze and Mooney 1994). Ecosystem functions (e.g. decomposition and element cycling) depend on the biota (e.g., bacteria, fungi, and invertebrates) and the biota (e.g., algae and macrophytes) depend on ecosystem functions (decomposition and element cycling). Although it is not always clear how many species can be lost before ecosystem functions begin to fail (e.g., Ehrlich and Walker 1998), it is clear that at some point, the number of species present have an important impact on maintaining ecosystem functions (e.g., Covich et al. 1999).
role of biomonitoring in ecosystem management is to provide assessment prior to the initiation of new management practices, to determine the impact of established practices, or to track the impact of pollutants and other types of human intervention.

Alternative practices for determining ecosystem health (e.g., chemical sampling) may provide valuable information but are not adequate without associated biological data (Hart 1994), especially in wetlands. As mentioned, water chemistry in wetlands (oxygen, pH, nutrients) is extremely variable over small spatial and temporal scales. Numerous samples at appropriate microspatial scales, using 24-hour profiles, on at least a seasonal basis are necessary just to approximate chemical patterns (Rader and Richardson 1992). If we rely on chemical sampling to determine wetland degradation, we would have to separate chemical trends caused by human intervention from a natural signal that shows vast spatial and temporal fluctuation. Wetland organisms, however, provide a temporally integrated assessment of environmental conditions that more precisely represents ecosystem function and significant environmental change (Hart 1994).

**WHICH ORGANISMS ARE THE BEST INDICATORS OF DEGRADATION?**

All organisms or groups of organisms (e.g., algae versus invertebrates) do not respond the same to environmental stress. Depending on various disturbance characteristics (intensity, frequency, etc.), each group may respond at different rates and provide different information. For example, if the objectives are to detect potential environmental change attributed to increases in phosphorus or nitrogen, microbes or plants may best signal early changes and potential degradation (see Chapters 6 and 12). Changes in the abundance of small, rapidly reproducing species with wide dispersal capabilities are among the earliest responses to stress (Schindler 1988). Longer-lived organisms that are slower to recover (macrophytes, some invertebrates, and many fish) may indicate the impact of pulsed stressors that occur only periodically. However, if the objectives are to determine the impact of an exotic invasion, interacting species (prey and competitors) will be the best indicators. Clearly, it will be necessary to examine several groups in order to indicate overall environmental health and integrity given the potential for multiple, difficult to measure, non-point-source pollutants (see Chapters 7, 8, and 11).

**LEGAL MANDATE**

The tradition of land management began with the Organic Act of 1897. Since that time, several laws and statutes form the legislative mandate for current land management in the United States:

- *Organic Act of 1897*: specified the purposes (e.g., timber harvest and water supply) for which forest reserves could be established and managed
Multiple-Use Yield Act of 1960: directed that the national forests be managed for multiple uses, including recreation, wildlife, and fish while providing a sustained yield of products and services (e.g., timber and water)

Clean Water Amendments Act of 1972: established a policy to restore and maintain the chemical, physical, and biological integrity of the nation’s waters

Endangered Species Act of 1973: set the policy for conserving species and habitat of fish, wildlife, and plants that are in danger of or threatened by extinction

The Forest and Rangelands Renewable Resources Planning Act of 1974: required a national assessment every 10 years to identify acceptable, deteriorating, or seriously impaired natural resources

This legislation shows a trend of increasing awareness of the relationship between healthy natural ecosystems and their ability to provide goods and services for humans. The most important legislation for wetlands are Sections 404 and 104 (b)(3) of the Clean Water Act (1972 and 1974). Section 404 regulates the dredging and filling of “waters of the United States”. Also, Section 104 of the Clean Water Act specifies that water quality standards need to be developed to protect the beneficial uses of lakes, rivers, and streams. Wetlands are also included. Furthermore, many threatened and endangered mammals, birds, reptiles, and fish depend on wetlands for all or part of their life cycle (Niering 1988). Protecting and maintaining wetlands is an important part of maintaining overall ecosystem integrity (e.g., forest health) and achieving legally mandated management objectives.

BOOK ORGANIZATION AND OBJECTIVES

This book is separated into two sections: bioassessment and wetland management. The bioassessment section begins with Chapter 2, in which general principles and guidelines for establishing a biomonitoring program are described. This chapter is also designed to place the subsequent chapters on bioassessment into a larger context, pointing the reader to specific topics in each chapter. In general, the next three chapters cover statistical issues related to sampling numerous sites across the landscape (Chapter 3), the application of multivariate procedures (Chapter 4), and invertebrate functional groups (Chapter 5) to wetland bioassessment. Chapters 6 to 8 are case studies detailing the results of wetland bioassessment using various organismal groups in three different regions of the United States. One of the intriguing themes connecting these three case studies is how they integrate the two primary approaches to bioassessment, multimetric indices and multivariate statistics. In Chapters 9 to 11 the relationship between bioassessment and wetland restoration is discussed, beginning in Chapter 9 with a detailed explanation of how to restore wetland plant communities. In the remaining four chapters in Part 1 the authors describe how to use and sample bacteria (Chapter 12), algae (Chapter 13), macrophytes (Chapter 14), and invertebrates (Chapter 15) in wetland bioassessment.
When people hear the words, *wetland management* they often think of manipulating wetlands to maintain or maximize waterfowl production. Although waterfowl are certainly an important component of wetlands, other management topics are of equal importance. Numerous publications emphasize waterfowl management, including recent reviews by Baldassarre and Bolen (1994) and Weller (1999). Similarly, amphibians in wetland environments have been reviewed (Olson et al. 1997). Therefore, we have chosen to concentrate our efforts on other important but less known topics. Chapters 16 to 18 provide an extensive summary and review of how to manage fish (Chapter 16), waterbirds (Chapter 17), and mosquitoes (Chapter 18), in wetlands. Chapter 19 includes the first review of the effects of timber harvest on wetland ecosystems, with information on how to assess and manage wetlands to avoid the adverse impact of cutting practices. Finally, a comprehensive discussion of the impacts of an exotic invader, the macrophyte purple loosestrife, is given in Chapter 20. These chapters summarize information previously neglected in wetland management.

More and more, resource managers must attempt to strike a balance between resource exploitation to meet immediate human needs and resource protection to meet future human needs. Science has the responsibility of providing information to assist in finding this important balance.

**REFERENCES**


