How Nature Builds Wetlands

Wetland restoration teams and wetland managers are continually called upon to identify sustainable interventions and follow-up management actions for use in degraded wetlands. To provide assistance, researchers have studied pieces of the puzzle but often from a narrow perspective tied to their mission, personal expertise and interest, the immediate need, or funding opportunities. The natural evolution of science into narrow specialties over time has constrained our ability to view wetlands as integrated systems where complex interactions among the living and non-living components create often-unique ecosystems.

When natural processes initially created wetlands, climate interacted with the morphologic and geologic features unique to specific sites and created unique abiotic conditions. The abiotic conditions, in turn, defined the composition of the initial biotic community and directed changes over time due to successional processes and alteration of abiotic characteristics. The intimate relations between wetland and upland processes complicated the issue, especially with regard to functions tied to surface- and ground-water hydrology. Consequently, wetlands are among the most complex ecosystems on earth, where achieving sustainable success in restoration and management requires a systems approach to understand how, and especially why, a given wetland functions as it does. Only then can we assess how human activities have altered those functions and how a restoration strategy might be developed to reestablish functions that have been degraded.

The hydrogeomorphic (HGM) approach has been used to assess wetland functions, but the drivers that support those functions must be understood also, thus allowing interventions at specific geographic locations to be designed to avoid a constant battle with nature. Such information is generally lacking for individual wetland sites and would require considerable time and money to acquire, likely leaving few funds for actual restoration or management activities. A national program that lays the foundation for understanding how unique wetlands function at specific geographic locations (how they were built by nature) would improve our understanding of the underlying drivers of wetland functions. Below, I outline some steps that such a program might embrace and suggest that this approach is needed as a foundation for future wetland restoration programs.

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1. Increase scientific understanding of the linkages of wetland development, structure, temporal and spatial dynamics, and functions within and between wetlands and the surrounding landscapes. The question I often ask is, "Why this wetland type here?" Wetland ecosystems function at multiple spatial and temporal scales and cannot be divorced from their surrounding watersheds, landscapes, and developmental history. Although wetland functions have been assessed by the HGM approach in some areas, wetland origins are poorly understood for the variety of wetland types in most regions. Understanding the drivers behind natural wetland functions requires knowledge of landscape setting, underlying geology, resultant hydrology, ensuing biological development, and the time scale of wetland development.

The abundance of geographical information now available on the web could lay the foundation for landscape assessment, likely in a geographic information system (GIS) environment. General geological information may also be available, but few managers and wetland scientists have the ability to interpret the data or the capability to acquire additional detailed data, which may be necessary for determining the role of groundwater in wetland hydrology. Thus, the key to understanding how wetlands are built may be to bring more hydrogeologists into the game. "Ecohydrology" is a growing field, but greater emphasis should be placed on the geology that shapes the hydrology that makes the wetland wet.

Wetland managers and restoration practitioners often have the backgrounds in plant and/or wildlife biology that are necessary to work with the extant wetland flora and fauna at a project site. However, they likely do not have knowledge of how or when many of those organisms arrived at the site. Paleoecology, especially the use of macrofossils deposited locally, should then be a component of understanding how a wetland is built, provided that sites have suitable preservation. Paleoecology can provide both the sequence and timing of wetland development needed to know how a wetland functions.

A mechanistic understanding of the fundamental patterns, processes, and controlling factors in different types of wetland ecosystems is necessary to develop commonalities for extrapolating information to multiple sites within a geographic area. Reconstruction of the developmental processes of wetlands in representative, long-term reference systems would allow us to acquire the necessary comprehensive data and to develop a deeper understanding of wetlands within a hierarchy of spatial and temporal scales. Within a landscape context, information on underlying geology, hydrology, and the succession and variation of communities and pro-

cesses over geological and historical time would provide managers with guidelines for decisionmaking across differing scales, as appropriate by site and by management issue. With such a perspective, adaptive resource management could be tested in appropriate temporal and spatial frames; reference ecosystems under rehabilitation or management could be compared to unmanaged analogues. This approach is also applicable in site-specific studies driven by immediate management concerns, and the outcomes of those studies can add to the database developed at reference sites. Carrying this process one step further, models of wetland ecosystems could be developed that demonstrate natural processes and functions and provide managers with knowledge of the resources they manage.

2. Increase scientific understanding of how interactions between physical and biological processes affect wetland ecosystems. If we understand the physical development of wetland ecosystems, the next logical step is to characterize chemical and physical properties as they change across the continuum from upland to aquatic environments. How do landscape setting, geology, and hydrology affect distribution of biological components? What stressors and stressor feedbacks occur among biological, chemical, and physical properties? With such information in hand, the next task would be to develop spatial models of wetland ecosystems that incorporate landscape heterogeneity, fragmentation, connectivity, and barriers to biological movement between, within, and among components.

3. Increase scientific understanding of effects of anthropogenic disturbance on wetland ecosystems. Once we have a better understanding of natural processes affecting wetlands, we can address the effects on wetland habitats from human stressors, such as climate change, disruption of upland-to-aquatic linkages, shoreline modification, altered sediment supply and transport, altered hydrology, land-use change, development on uplands, chemical and microbiological alterations, invasive species and introduction of nonnative organisms, and disruption of fire regimes. This requires evaluation of the temporal implications of disturbance regimes, including length of disturbance events, frequency of recurrence, severity, and long-term effects. Methods can then be developed to quantify the effects of disturbance, including interaction of multiple threats, and develop predictive tools and indicators for evaluating disturbance effects. Again, going one step further, mechanistic models could be developed for wetland processes and disturbance effects that enable managers to understand the implications of disturbance regimes to habitats, biota, and critical processes that extend beyond the wetland.

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4. Increase scientific understanding of restoration, mitigation, and management methodologies for conservation of wetland ecosystems. Focusing on restoration and management, the information gained from efforts described above could help determine the realistic possibilities for reversing physical and biological changes or restoring degraded ecosystems, thus allowing sound goals for restoration to be set. New and improved methods could be developed for restoring, rehabilitating, managing, and protecting wetland ecosystems and their component flora and fauna that incorporate an ecosystem approach and establish or retain connectivity across the landscape. Knowledge of how a wetland is built could assist in envisioning realistic trajectories. Models could be developed for predicting success of projects, including indicators and performance criteria that quantify ecological responses. Working in partnership with managers, the success of on-land applications of management practices could be assessed, including development of monitoring programs tailored to allow adaptive management that retains successes achieved.

5. Increase scientific understanding of the potential future of wetland ecosystems. Taking a long-term perspective, the probable evolution of the landscape, wetland processes, and wetland ecosystems in the absence of human disturbance could be assessed to understand how the natural system might have behaved if not disturbed. Landscape and successional trajectories and models could then be developed that predict and project how the altered wetlands will behave in the future.

It is difficult to repair or maintain anything mechanical without knowing the parts, how they function, how they break, how they can be fixed, and how they fit back together. Automobile repair and maintenance should not be a guessing game and neither should wetland restoration and management. Unfortunately, wetlands do not come with repair manuals prepared by the manufacturer. If wetland restoration and management are to be sustainable, we need to know how specific wetland types are built so that we know how the pieces function, how they break and can be repaired, and how the repaired pieces might be put back together to work properly for a long time, as wetlands do not come with warranties, either. This essay is written as a plea to those who develop and promote wetland restoration programs to recognize that sustainable restorations must rely on having the necessary knowledge of how a wetland functions. A national program that is geared toward understanding how wetlands are built by nature would be a wise investment that could help ensure the success of future restorations and subsequent management efforts. ■

-Douglas A. Wilcox