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# Linking Ecosystem Processes to Sustainable Wetland Management

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*The sustainability of ecosystems has become an explicitly stated goal of many natural resource agencies. Examples of sustainable ecosystem management, however, are uncommon because management goals often focus on specific deliverables rather than the processes that sustain ecosystems.*

As a result of concern over problems associated with the future of managed wetlands in North America, nearly two dozen wetland scientists and managers met in February 2006 at Bosque del Apache National Wildlife Refuge in New Mexico and discussed a sustainable approach to wetland management. This approach links science with management by focusing on underlying wetland processes. From that meeting, several papers were developed and published in *Wetlands* to address these concerns (Euliss et al. 2008, Smith et al. 2008, Wilcox 2008). This article summarizes our first paper, Euliss et al. (2008). A future *National Wetlands Newsletter* article will summarize Smith et al. (2008).

Realization of the role that complex interactions play in maintaining ecosystems, coupled with increasing demands of humans for ecosystem services, has prompted much interest in ecosystem management. Not surprisingly, sustainability of ecosystems has become an explicitly stated goal of many natural resource agencies and, in some cases, has been legislatively mandated to ensure provision of resources for future generations. However, examples of sustainable ecosystem management are uncommon because management goals often focus on specific deliverables rather than processes that sustain ecosystems. This article has three sections: (1) perspectives in which we provide a bit of history; (2) ecological consequences of a static view; and (3) suggestions to aid wetland managers link management goals with critical ecosystem processes responsible for provision of wetland services.

**Perspective**

Over the last 60 years, habitat loss and declines in wildlife populations provided much of the impetus for intensive wetland management and protection. Much attention was frequently focused on outcomes for wetland birds and their habitats. The National Wildlife Refuge system was formed in 1942, and almost all initial refuge acquisitions were wetland systems. Many were purchased

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with migratory bird stamp funds generated from hunters. Management actions were numerous and diverse, including such activities as impounding perennial and intermittent streams to expand wetland area, maintaining static water levels in otherwise seasonally inundated wetlands, creating islands in natural wetlands for protection of breeding waterfowl from predators, using non-traditional water sources where water is scarce (e.g., agricultural return flows, groundwater), and manipulating native and non-native plant communities to favor game species. However, habitat dynamics or critical ecosystem processes responsible for creating and maintaining habitats received little consideration. Importantly, the surrounding landscape or watershed was often ignored as an influential factor on wetland processes needed to maintain wildlife populations.

As the human population increased over the past century, the demand for resources provided by ecosystems increased over five-fold. As a result, entire landscapes have been modified for human use, and what remains is highly altered. Modern land-use changes have left us with altered ecosystem processes, and we are beginning to document the consequences of biological thresholds being reached. For example, more than 90% of U.S. streams, groundwater, stream and estuarine sediments, and freshwater fish have at least one contaminant at detectable levels. The primary sources of contaminants are excess sediments, nutrients, and toxicants, indicating that land use that alters fundamental ecological processes (e.g., hydrodynamics, erosion, nutrient cycling, and eutrophication) is a leading contributor to degradation. Thus, land-use factors including sedimentation of natural and managed wetlands, altered surface and subsurface hydrology, and excessive accumulations of dissolved constituents (e.g., salts, heavy metals, agrichemicals) in aquatic habitats now commonly confound efforts to manage habitats for conservation.

**A new perspective is needed to achieve long-term sustainability of critical habitats within the constraints of altered landscapes.**

Although interest in protecting wetlands in the United States began with concern over migratory birds, that interest has broadened to include a suite of ecosystem services that wetlands provide. A growing awareness of wetland services, such as water quality improvement, water storage and detention, and a broader view of biodiversity by society led to the 1972 Federal Water Pollution Control Act and amendments to Section 404 of the Federal Water Pollution Control Act (the Clean Water Act) in 1977. We are only beginning to document the full suite of services that natural wetlands provide to society, and future research will likely identify additional important societal benefits derived from wetlands (NRCS 2008, NRC 1995 and 2002). Interest in wetlands from the perspective of basic human services (e.g., water quality improvement) is not exclusive of traditional wildlife management goals. Indeed, managing for the full suite of wetland services requires that wetlands go through wet/dry cycles characteristic of a specific geomorphic setting. Wildlife populations naturally fluctuate through these cycles. Hence, an understanding of how a specific site formed geologically and hydrologically and of how physical and chemical processes function there naturally is critical for effective management of all services, including wildlife.

A new perspective is needed, not to return wetlands to pre-settlement conditions (an unrealistic outcome given requirements to support human populations and previous non-reversible changes), but to achieve long-term sustainability of critical habitats within the constraints of altered landscapes by restoring or simulating natural ecosystem processes. Consideration of all wetland services will present new opportunities and challenges for traditional wetland/wildlife management strategies. New wetland projects will require the application of knowledge of the many scientific disciplines that contribute to the understanding of ecosystem processes on wetland structure and function. Hence, strategies need to be developed that identify the optimal performance of a suite of ecological services provided by wetlands to ensure sustained function over the longest possible period of time.

Beyond traditional management goals, in today's environment, many wetlands are impacted by activities resulting from physical, off-site activities and societal decisions that have either constrained the ability to implement many commonly used strategies or modified responses of habitats to them. Clearly, the wetland conservation perspective needs to be modified and refined as needed to "fit" better within the context of ecosystem processes and social and political realities.

To place the functioning of wetlands into an effective framework for management in today's highly modified landscape, we suggest that geomorphology be the initial focus because it constrains the expression of hydrology and the full suite of abiotic features for unique ecosystems across all temporal scales. Such a perspective will make it easier to understand how specific ecosystem processes are affected and how they relate to conservation outcomes. We do not suggest that wetland scientists and managers have not applied the process we are advocating. Our motivation is simply to see this viewpoint more broadly and immediately applied

**Implications of Static Conditions**

Most managed wetlands are manipulated to maintain a static temporal relationship between wildlife productivity and specific habitat conditions. Yet, the ecosystem processes that sustainably yield specific habitat conditions and wildlife productivity have an important temporal component. Furthermore, management has mostly been directed toward wetlands and wetland conservation lands as isolated habitats rather than as nested within larger, and often highly modified, landscapes. There must be an ecological fit between management prescriptions and the position of wetlands in space and time in order to achieve sustainability. Whether or not a particular management prescription can be applied successfully at a specific site depends significantly on the spatial and temporal context in which it was developed. For example, in the Prairie Pothole Region of North America, science-based information for a specific wetland type cannot necessarily be applied to management of a different wetland type. Likewise, information derived during a dry phase cannot be applied to the same wetland type during a wet period.

Alteration of natural hydrologic cycles by traditional management approaches can have cascading negative effects on ecosystem processes. In most inland-managed wetlands, water-control structures were designed to hold water at specific elevations higher and with less fluctuation in water depth than the historical norm. This stable and extended hydroperiod can suppress the hydrologic regime necessary for processes inherent to the geomorphic setting in favor of relatively homogenous, impoundment-like biogeochemical cycling of a modified wetland type. The effects on hydrologic heterogeneity are enormous. The more sustained (temporal) and broader (spatial) inundation can suppress the expression of patchy moisture conditions (e.g., groundwater discharge and recharge features) and their temporal fluctuations. For example, local groundwater discharge zones may be reversed by the backpressure of the higher water level, while former groundwater recharge zones become fed by upland runoff as well as direct precipitation. Hence, biotic associations and trophic patterns across subtle and gross subsurface and surface moisture gradients within the wetland may diminish or disappear.

Further, as in any lake or impoundment, the process of holding water behind the control structure changes the entire ecology of the wetlands and may force the system toward eutrophy. Due to the larger storage volume and longer hydraulic residence time, capture and retention of sediments and nutrients from highly altered landscapes, both between and during flood pulses, is more efficient. Because wetland biota have access to a larger pool of available nutrients, biomass may proliferate toward a maximum density and shift toward more eutrophic communities. The consequent accumulation of organic detritus can be excessive, particularly where the influx of phosphorus and other agrichemical nutrients further exacerbates or accelerates eutrophication. The rapid buildup of organic matter (in some cases 1-2 meters) on top of sediments already blocking seed and invertebrate egg banks further compromises reestablishment of original wetland communities.

The flushing of mineralized nutrients from impounded wetlands after sustained dry periods can keep eutrophication in check by exporting nutrients to downstream ecosystems. However, sustained dry periods tend to become less frequent and reliable in impounded wetlands because control structures are not typically designed to simulate the dry marsh phase, and the excessive accumulations of detritus and root mats are difficult to dewater. The wetter moisture regime generally favors anoxia and consequently inhibits the release of nutrients that otherwise could contribute to pulses in primary production by slowing their mineralization in relation to aerobic processes. Further, the flood peaks necessary to scour sediment and transport mineralized nutrient from the wetland are increasingly damped by impoundment, and accumulations of dense organic matter constrain direct contact between flowing waters and buried sediment.

Water-control structures may also profoundly affect the salinity and toxic chemical (natural and anthropogenic) burden in wetlands due to increased hydroperiods that favor evapotranspirative losses from the wetland and promote the evapoconcentration of solutes. The effects on the nature and health of biotic communities are likely to be most pronounced in drier or more arid regions where, due to a moisture deficit, salts or toxic substances (e.g., selenium) have the potential to accumulate at excessive levels harmful to biota.

Thus, many problems that exist in managed wetlands result when alteration of natural hydrologic cycles subsequently alters ecosystem processes, setting up a poor ecological fit. Traditional management goals often strive to provide the same conditions from year-to-year without providing the temporal variability needed to sustain ecosystem processes. This may lead to decreasing productivity for target fish and wildlife because natural wetland hydrology has been stabilized. Wetlands are "productive" because they dry out periodically, and wildlife populations, therefore, naturally fluctuate with hydrologic cycles in wetlands. Management for natural dynamic hydrologic processes is the key to maximizing diverse wetland services over long periods of time and avoiding costly remedial actions that may be required to return wetlands to a productive state.

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### A Suggested Direction Based on Ecosystem Processes

We believe that the solution to provide effective management in today's modified landscape will require a change in the approach by wetland managers, applied scientists, natural resource agency administrators, and educators. However, we believe that the shift will be palatable and easy to implement because it will facilitate recognition and placement of management goals for conservation outcomes into basic wetland cycles. The shift would stimulate a more ecosystem-based perspective that takes into account spatial and temporal processes required for long-term sustainable productivity. A major focus would be on restoring ecosystem processes. Infrastructures (e.g., water-control structures), if needed, would be scheduled to emulate critical processes that maximize the flow of energy between and among the trophic strata within managed wetlands.

With this management approach, the importance of a specific wetland to individual plant and animal communities will vary greatly from year-to-year such that the physical appearance and productivity would change on an inter-annual basis. The expression of temporal intra- and inter-annual variability provides great benefit because optimal conditions would be provided at all times, albeit for different species of plants and animals over time. Restoring processes within a temporal framework removes subjective values given to certain groups of wildlife and affords managers an objective base to develop and justify management actions. Hence, the focus would be on ecosystem function, with the goal of intergenerational sustainability. Managers would, for example, focus on replication of critical ecosystem processes rather than simply setting pool depths based on the requirements of targeted species. Even species that use wetlands only when they contain water (e.g., waterfowl and amphibians) benefit from the dry phase because nutrients are recycled as needed to enhance the food webs when wetlands reflood. Historically, wetland ecosystems fluctuated between wet and dry conditions and the habitat they provided in any given year was good for some species and bad for others. However, the process generally optimized sustainability of the ecosystem and optimized its value to a diverse plant and animal community.

The concept behind our call for this approach is that wetlands occur at positions in the landscape where the underlying geology creates hydrologic conditions suitable for their development. Therefore, geology, landscape setting, hydrology, and developmental processes must be understood before interpretations of natural wetland functions and effects of management actions can be made. Wise management decisions are dependent on a thorough knowledge of how a wetland works. Management actions that defy natural processes will be doomed to an eternal battle with nature and will risk long-term, high maintenance costs or failure.

A step-wise mechanism is needed for using this approach. The landscape setting, underlying geology, resultant hydrology, ensuing biological development, time scale of development, and interactions should first be determined for the wetlands to be managed. Ideally, models of wetland ecosystems that demonstrate natural processes could be developed to provide managers with knowledge of the resources they manage, and reference sites could be established to document unmanaged wetland evolution. Chemical and physical properties of wetlands across the continuum from upland to aquatic environments and their role in determining distribution of biological systems should be characterized. Natural stressors, including stressor feedbacks among biological, chemical, and physical properties, should be identified. Spatial models of wetland ecosystems that incorporate landscape heterogeneity, fragmentation, connectivity, and barriers to biological movement between, within, and among components could be developed.

The temporal implications of disturbance regimes can then be evaluated, including length of disturbance events, frequency of recurrence, severity, and long-term effects. It would then be possible to develop methods to quantify the effects of disturbance, including interaction of multiple threats, and develop predictive tools and indicators for evaluating disturbance effects. Mechanistic models for wetland processes and disturbance effects could be developed that enable managers to understand the implications of disturbance regimes to habitats, biota, and critical processes that extend beyond the wetland being managed.

Intuitively, several steps can be followed to increase scientific understanding of management, restoration, and mitigation methodologies. The realistic possibilities for reversing physical and biological changes or restoring degraded ecosystems first must be evaluated, thus allowing sound goals to be set. New and improved methods might be developed for managing, restoring, rehabilitating, protecting, and creating wetland ecosystems and their component flora and fauna that incorporate an ecosystem approach and establish or retain connectivity across the landscape. Models for predicting success of projects could also be developed, including indicators and performance criteria that quantify ecological responses.

Finally, wetland scientists, working in partnership with managers, need to evaluate the success of applications of management practices to ensure relevance, including development of monitoring programs tailored to allow adaptive management that retains successes achieved. Scientific understanding of the potential future of the managed wetlands might be gained by evaluating the probable long-term evolution of the wetlands in the absence of human disturbance to understand how the natural system might have behaved if not disturbed or managed. Landscape and successional trajectories and models could then be developed that predict and project how the altered, managed wetlands will behave in the future. ■

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*We dedicate this article to Bryant Browne (November 4, 1952—December 6, 2008) whose passion for understanding complex chemical processes in wetlands was an inspiration to all, especially his many colleagues and the numerous students he mentored over the years. Bryant contributed significant new knowledge and greatly improved our understanding of wetland processes. He was truly an outstanding example of what can be achieved when scientists from diverse disciplines and managers work together.*

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