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Assessing functions of wetlands and the need for reference

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Abstract

Rapid assessment of ecosystem condition plays a useful role in impact evaluation, restoration, and other types of natural resource decision making. The hydrogeomorphic approach, summarized in this paper, is one of several examples developed for wetlands. It differs from earlier approaches by classifying by functional type, employing functions as the metric for evaluating ecological condition, and using a reference system to array sites along a gradient from relatively unaltered to highly impacted. This paper focuses on the need for a reference system to stabilize the rapid assessment approach for repeatable results and practical use. A reference system, developed prior to applying the rapid protocol for routine use, is comprised of structural data (variables) from reference sites, relevant information from the wetland literature, and logic that emerges from ecosystem principles. Most protocols, once established, require less than half a day of field work on a site to complete. We address the problem of using natural or relatively unaltered conditions as an endpoint in landscapes that are highly altered, such as those of Western Europe.

Key words: hydrogeomorphic classification / reference wetlands / ecosystem condition / functional assessment / rapid assessment

Valutazione delle funzioni delle zone umide e relativi sistemi di riferimento

L'analisi speditiva delle condizioni dell'ecosistema è uno strumento utile per la valutazione di impatto e del ripristino ambientale e per altri tipi di decisioni relative alla salvaguardia delle risorse naturali. L'approccio idrogeomorfologico, presentato in questo lavoro, ne è un esempio sviluppato per le zone umide. In pratica, esso differisce dalle metodologie precedenti in quanto utilizza una classificazione per tipologie funzionali, adotta funzioni come metrica per la valutazione delle condizioni ecologiche ed impiega un sistema di riferimento per ordinare i siti in un intervallo di condizioni che variano da relativamente naturali a fortemente alterate. Il presente lavoro ha come obiettivo l'individuazione e la definizione di un sistema di riferimento per rendere operativa, affidabile e ripetibile la valutazione speditiva. Il sistema di riferimento, sviluppato prima dell'utilizzo di routine del protocollo speditivo, consiste di dati (variabili) relativi ai siti di riferimento, informazioni rilevanti tratte dalla bibliografia sulle zone umide e modelli concettuali derivati dall'ecologia. La maggior parte dei protocolli, una volta validati, richiede meno di mezza giornata di lavoro sul campo per completare la valutazione di ciascun sito. Infine viene analizzato il problema di reperire condizioni naturali o relativamente poco alterate in un paesaggio che è fortemente alterato come quello dell'Europa occidentale.

Parole chiave: classificazione idrogeomorfologica / zone umide di riferimento / condizioni dell'ecosistema / valutazione funzionale / valutazione speditiva

VALUES AND FUNCTIONS OF WETLANDS

Perceptions of the value of wetlands have changed significantly in recent years. For many centuries wetlands were seen as breeding grounds for diseases, such as malaria, and wastelands whose primary value was through their reclamation. Venice and much of the agricultural lands of the Po River delta are the result of reclamation programs centuries ago (Stevenson *et al.*, 1999). Within the twentieth century, reclamation programs have continued, including floodplains of the lower Rhine River in Germany and the Netherlands (Brinson and Verhoeven, 1999) and the northern prairie wetlands of the USA (Galatowitsch and van der Valk, 1994). However, in the last forty years many governments and organizations have begun to appreciate the wide variety of goods and services provided by wetlands (Lugo and Brinson, 1979) as well as ecosystem services provided by other ecosystem types (Millennium Ecosystem Assessment, 2005). These goods and services include the provision of food, timber, and recreation; protection from flooding; and removal of pollutants (NRC, 1995). Recognition of these has changed the way that humans assign value to these ecosystems (Maltby, 1986). And as value has been recognized, management of wetlands has changed from strict reclamation to conservation, restoration, and even creation.

The goods and services provided by wetlands are a consequence of their ecosystem functioning (Brinson and Rheinhardt, 1996). Wetlands are commonly located between terrestrial and aquatic ecosystems and have a strong dependence on the availability of water to maintain their existence. The sources of this water have an influence both on the chemical composition of water in the wetland and the periodicity and depth of flooding (Brinson, 1993a). These factors in turn are dependent on the position of the wetland in the landscape. This position, in combination with hydrology, may be used to classify wetlands according to their potential functional characteristics. The taxonomy of wetlands based on this combination is called hydrogeomorphic classification. Wetlands with different hydrogeomorphic settings process the water and its constituents differently. They also may possess different soils and biota that help to determine both the flows of energy and materials within the wetland and imports into and exports out of them. Thus, wetlands with different geomorphic settings may be expected to function differently, and the goods and services provided by them may be expected to differ also (Brinson and Rheinhardt, 1996).

The hydrogeomorphic classification (HGM) approach was developed in the United States for purposes of wetland restoration and management efforts (Smith *et al.*, 1995; Brinson 2009). Parallel efforts are taking place in the European Community (Maltby *et al.*, 1994; Maltby, 1998; Maltby *et al.*, 2009). The approach in the USA has promulgated the use of reference wetlands to determine the condition of these ecosystems. The relatively natural, unaltered or minimally altered condition becomes the benchmark representing reference standards. Wetlands of the same hydrogeomorphic class are compared with the assumption that relatively unaltered wetlands are functioning at appropriate levels for their class and that they are self-sustaining. A wetland under consideration for regulatory action can thereby be evaluated relative to how closely it comes to this condition. The U.S. Army Corps of Engineers has primary responsibility to administer the approach, and has compiled literature on the topic (http://el.erdc.usace.army.mil/wetlands/wlpubs.html).

In this paper we present a summary of the HGM approach used to assess ecosystem function of wetlands. We, also, attempt to place our experiences with reference wetlands into the circumstances of wetland management, as we perceive them, in Italy and other western European countries.

THE HYDROGEOMORPHIC APPROACH: A REFERENCE-BASED ASSESSMENT

There is a need to measure wetland functions to determine whether wetland regulations and enforcement are effective in reducing, increasing, or not changing the overall wetland performance and condition. Activities requiring regulatory intervention may include filling, draining, removing woody vegetation, and altering the flow of water. Functional assessment of wetlands is used to measure the level of wetland performance of hydrological, chemical, and habitat properties and processes. Functional assessment assists in determining whether the activities are likely to lead to a decrease in condition, and by inference, to a departure in functional performance. Rather than assign a single number or metric to represent a wetland's condition, individual functions are used as the currency to estimate those conditions. For example, if a wetland has the capacity to store surface water (as most do), then partially filling the wetland with dredge spoil will reduce that function by some measurable amount.

Functional assessment can be carried out using intensive sampling and sophisticated methods. Such efforts seldom can be justified for routine evaluations, however, where rapid assessments are more practical. Rapid assessment of a wetland's function can be done in a matter of hours using semi-quantitative tools. By using unaltered wetlands as the basis of comparison, assessments rely less on exact measures than they do comparisons with reference wetlands (Brinson and Rheinhardt, 1996). This improves the repeatability of a procedure because everyone uses the same standard of comparison (Whigham *et al.*, 1999). It reduces the amount of time for conducting assessments because relative rather than absolute measures can be used.

Draining, filling, removal of vegetation, and similar activities alter wetland functions. To determine the effects of such activities, measurements are taken before the alteration and estimated from the assumed effects that the project will have. The difference between the two levels of performance, both normalized to unaltered reference conditions, constitutes the loss, as estimated by changes in functioning. Alternatively, if a degraded wetland is to be restored, functional assessment involves comparison of the initially degraded conditions with those anticipated from restoration. The monitoring of a restored site can be followed over time to determine progress toward improved conditions.

Functional assessment methods have been used for over three decades to estimate the capacity of a wetland to perform a particular group of functions (LARSON and MAZZARESE, 1994). However, the hydrogeomorphic (HGM) approach described here differs from foregoing methods in three ways: classification, articulation of functions, and use of reference wetlands as a basis for gauging relative levels of functioning (SMITH *et al.*, 1995).

Classification and articulation of functions

Classification criteria are based on the position of the wetland in the landscape (geomorphic setting), dominant sources of water, and the flow and fluctuation of the water once in the wetland. The principles of this classification are described in BRINSON (1993b), and the classes have been since modified into five hydrogeomorphic groups with two that have major subdivisions: riverine; depressional; slope; flats (including mineral soil flats and organic soil flats); and fringe (including estuarine fringe and lacustrine fringe). They are characterized as follows:

1) Riverine wetlands are linear features in a valley that normally contain a river bed and bank.
2) Depressional wetlands occupy locally low sites. The water sources may vary, but normally these wetlands have fairly small drainage basins. Depressions with outlets will have them at elevations that allow water to be stored in the wetland. Depressional wetlands tend to be numerous in recently glaciated landscapes.
3) Slope wetlands normally occur on gentle gradients where groundwater is a dominant water source. This class is common along the toe slopes of floodplains and at the headwaters of streams where groundwater from upland water tables originates.
4) Flats are broad areas that have seasonally high water tables. They are wetlands because of poor drainage. Precipitation is the primary water source.
    a. Mineral soil flats - Pine savannas or flatwoods of the southeastern USA are examples. Many areas have been drained and converted to agriculture or silviculture.
    b. Flats with organic matter accumulation are peatlands or have soils with a histic epipedon. As such, peat accumulation creates “biogenic” landscapes that may hide the original topographic relief of the land. These areas, if they did not have accumulations of peat, would be considered depressional if they were quite small, or mineral soil flats if very large.
5) Fringe wetlands border large bodies of water and are subdivided on the basis of the water body type.
    a. Tidal fringe - Fringe wetlands occur at the margins of marine and estuarine coasts, and thus have a virtually unlimited source of water. Tidal fringe wetlands (salt marshes and mangroves) typically receive twice daily flooding, at least at the lower elevations of the wetland.
    b. Lacustrine fringe - Seiches are normally the source of water level fluctuation in lacustrine fringe. Examples are unimpounded lakeside marshes of the Laurentian Great Lakes between the USA and Canada.

The names given to the wetland classes include information about their position within the landscape. The relationships with water are either explicit or inferred and depend on both the water source and hydrodynamics. For simplicity, three water sources are recognized as: (1) precipitation, (2) groundwater discharge (inflow to wetland), and (3) overland and overbank flows. Most wetlands receive two or all three of these sources. The term hydrodynamics refers to the motion of water and the capacity for it to do work (i.e., transport sediments, flush hypersaline waters from sediments, transport nutrients to root surfaces, disperse seeds). Three qualitative categories of hydrodynamics have been identified: (1) bidirectional, lateral surface or near-surface flows due to tides or seiches; (2) unidirectional flows that range from strong channel-contained currents to sluggish overland flow across a floodplain; and (3) vertical fluctuations of the water table that result from evapotranspiration and subsequent replacement by precipitation or ground water discharge into the wetland.

The purpose of the classification is to reduce the amount of natural variation that has to be dealt with in an assessment. The aim is to partition most of this natural variation within relatively homogeneous groups of wetlands. In so doing, functional assessment can be more sensitive to the effects of impacts on functions rather than the extent to which functions may vary among wetland classes. Regional subclasses are recognized as specific examples of the more generic classes just described. For example, regionally important depressional wetlands in the USA include prairie potholes in North and South Dakota to the north, cypress domes in Florida to the south, and vernal pools of southern California to the west.

The second component of the HGM approach is to describe functions that wetlands perform. It has long been recognized that some wetland classes perform certain functions better than others, not because they are impacted in some way, but because they are inherently different. For example, bottomland hardwood forests of the southeastern USA support breeding habitat of neotropical migrants more than rain-fed peat bogs in northern Europe. These two extremes are so radically different that to compare them would severely tax the effectiveness of any wetland assessment method. To avoid this problem, functions are described differently for the seven classes of wetlands mentioned above. Even if the functions should overlap significantly, which they often do, they are likely to be performed at different levels or intensities and in different ways. Therefore, assessment methods among classes differ in the way they detect functional performance. Examples of ecosystem functions of wetland classes are given in Table 1 for riverine wetlands, mineral soil flats, and depressional wetlands. These functions were identified by working groups within the United States responsible for developing guidebooks on regionally important subclasses. Functions fall into four general categories: hydrology, biogeochemistry, plant community maintenance, and faunal support. The lists are not exhaustive, however, but rather are meant to capture some of the characteristic features that distinguish one wetland subclass from another. While it is clear that some functions are found across all three classes (e.g., some aspect of elemental cycling), others, such as energy dissipation, may be associated with specific classes such as the riverine class. At this point in the regulatory schemes of the USA, there has not been any attempt to standardize the number or kinds of functions among different wetland classes.

Central role of reference

The third component of the HGM approach is to establish standards of comparison based on wetland sites that are unaltered or have been minimally altered. Rather than establishing standards on the basis of which level of functioning would result in, say, removing the largest amount of nutrients, standards are determined by field measurements on wetlands that are self-sustaining and representative of the appropriate levels of overall performance for the subclass. This component requires that reference wetlands be established for various wetland classes. Just as soil series are characterized from representative profiles and herbarium specimens represent taxonomic standards for plant species, standards derived from regional subclasses of reference wetland sites in a physiographic province are used to determine reference standards.

The need for reference wetlands is based on the fact that not all wetlands are alike, and that resource management can benefit from recognizing their variety in the development of policy, standards, and guidelines that are directed toward managing them. This is in contrast to a 'top-down' approach that seeks to develop broad definitions and policies to encompass the wide variation in wetland types. Many of the uncertainties that arise from applying a general

Tab. I. Ecosystem functions of riverine (Ainslie *et al.*, 1999), mineral soil flats (Rheinhardt *et al.*, 2002), and depressions (Gilbert *et al.*, 2006).

Class	Subclass	*Function category*	Function
Riverine	*Low gradient riverine*	*Hydrologic*	Temporarily store surface water Maintain characteristic subsurface hydrology
		Biogeochemical	Cycle nutrients Remove and sequester elements and compounds Retain particles Export organic carbon
		Plant Community	Maintain characteristic plant community
		Animal Habitat	Provide habitat for wildlife
Mineral Flats	*Wet pine savanna*	*Hydrologic*	Maintain characteristic water level regime
		Biogeochemical	Maintain characteristic biogeochemical processes
		Plant Community	Maintain characteristic plant community
		Habitat/food web	Maintain characteristic animal community
Depression	*Temporary and seasonal northern prairie*	*Hydrologic*	Storing water Recharging groundwater
		Biogeochemical	Retaining particulates Removing, converting, and sequestering dissolved substances
		Biotic and Habitat	Plant community resilience and carbon cycling Providing faunal habitat

definition to a local wetland condition can be attributed to climatic and physiographic variation. In contrast, a bottom-up approach consistent with reference wetlands is based on identifying relatively unaltered conditions within a relatively homogeneous group of wetlands.

One of the misconceptions of many ecologists is that standards are to be fixed, invariant numerics. Such an approach is inappropriate for ecosystems that have broad natural variation. One of the challenges is to describe appropriately the natural variation, not to ignore it or define it too narrowly. Examples illustrate this point. Most wetlands undergo patterns of variation at different time and space scales. Prairie pothole depressions undergo multi-year drought cycles and wet pine savannas of the southeastern USA undergo multi-year fire cycles, overlaying seasonal changes (KANTRUD *et al.*, 1989; VAN DER VALK, 1981; CHRISTENSEN, 1981, 1993). Sites within riverine wetlands undergo spatial changes in vegetation and elevation when cutbanks are eroded, point bars are formed, and debris dams create new flow paths (BRINSON and VERHOEVEN, 1999). Such spatial and temporal variability, however, can be subsumed as a property of the wetland class. Thus, cyclic succession at a site is part of a reference condition, whether it involves a few years or hundreds of years. For example, fire frequencies of 3-5 years in wet pine flats are necessary for the maintenance of the characteristic forb community as a highly species-rich assemblage (WALKER and PEET, 1983). At the other extreme, post-fire succession of boreal wetlands to black spruce in regions of discontinuous permafrost may require a century or more (VAN CLEVE *et al.*, 1991). As such, reference sites monitored over long periods provide the basis for documenting such temporal changes. Reference standards (defined below) should be developed for each significant source of variation.

Terminology of reference

The term reference in the context of functional assessment is used as a basis for comparing two or more wetlands of the same subclass. Reference is useful because (1) everyone uses the same standard of comparison, (2) the comparisons are among real ecosystems, and (3) relative rather than absolute measures allow better resolution, efficiency in time, and consistency in measurements. Terminology used for reference follows (SMITH *et al.*, 1995):

Reference domain - All wetlands within a defined geographic region that belong to a single hydrogeomorphic subclass.

Reference wetlands - Wetland sites within the reference domain that encompass the known variation of the subclass. They are used to establish the ranges of functions.

Reference standard sites - Sites within a reference wetland data set from which reference standards are developed. They are judged to be functioning at the appropriate, sustainable level for the subclass and are assigned an index of 1.0 (the highest possible) for all functions. These sites are considered to be minimally or least altered.

Reference standards - Conditions exhibited by a group of reference wetlands that correspond to the appropriate level of functioning for the subclass.

Site potential - The level of functioning possible given local constraints of disturbance history, land use, or other factors. Site potential may be equal to or less than levels of functioning established by reference standards.

Project target - The level of functioning identified for a restoration or creation project. Conditions specified for the functioning are used to judge whether a project reaches the target and is developing toward the site potential.

Project standards – Performance criteria and/or specifications used to guide the restoration toward the project target. Project standards should specify reasonable contingency measures if the project target is not being achieved.

These categories were developed, in part, to provide clarification within the regulatory framework for protection and restoration that exists in the USA. For example, project target requires that estimates be made on the condition of a wetland within a specified period of time after restoration. For the restoration of forested wetlands, a relatively mature wetland may require 50 years to develop and another 100 years to reach old growth status. There are few institutions capable of dealing with such time frames, so hydrologic regime, seedling establishment, sapling growth, soil organic matter development and other indicators of progress should be set as targets.

The efficient use of the HGM approach is possible because it is supported by a robust and well developed reference system. The *reference system* includes, but is not limited to, the following: (1) a synthesis of the relevant research and literature of the subclass and related subclasses, (2) professional judgment by regional experts on the range of natural variation and the characteristic functions of subclass, (3) reference sites in the landscape that are representative of both the natural variation and typical sites degraded by common impacts, (4) data sets and their synthesis that document the reference sites and determine standards for the range of natural variation, and (5) documentation of use of the procedure based on field testing by practicing professionals in the region. To capture the variation of a subclass, a large number of sites may have to be evaluated. For example, RHEINHARDT and colleagues (1999) assessed the wetlands of 25 headwater streams in the coastal plain of North Carolina, including 16 unaltered ones, to develop a reference domain. In the development of a reference set for wet pine flats, RHEINHARDT *et al*. (2002) included 71 reference sites of which 40 were in reference standard condition. Consequently, rapid assessment is not inexpensive to develop. However, savings are experienced during its routine use in which reliable impact assessments can be conducted rapidly upon a foundation of the best science available. The investment in the reference system provides the credibility of the tool and of assessments as long as they are properly executed.

Functions as a way to express wetland condition

A series of indicators and variables are brought together to estimate functioning through rapid assessment. These are derived from measurements made during the study of reference wetland sites. These measurements are chosen for two basic reasons: (1) they are features that relate to one or more of the functions identified and (2) they are useful in distinguishing between properties of reference standard wetlands and wetlands that have been altered.

Using the function of "Detain Floodwater," the use of indicators and variables can be illustrated for selected wetland subclasses in the Lower Mississippi Alluvial Valley (SMITH and KLIMAS, 2002). The function reflects the capacity of wetlands to store, convey, and reduce the velocity of floodwater as it moves through a wetland. An estimate of the function is derived from multiplying the frequency of flooding (V_{FREQ}) by the mean of various hydraulic roughness variables to characterize the function: log density (V_{LOG}), ground vegetation cover (V_{GVC}), shrub-sapling density (V_{SSD}), and tree density (V_{TDEN}), and is expressed as follows

$$\text{Detain Floodwater} = V_{FREQ} \text{ x } (V_{LOG} + V_{GVC} + V_{SSD} + V_{TDEN})/4$$

The equation is kept simple and parsimonious. The variables are all derived from measurements, visual indicators, and other sources that allow the variable to be scaled between zero and 1.0. By definition, the 1.0 score is equivalent to reference standards. This equation is structured so a value of zero results if flooding does not occur. If there were research to reveal that one of the other variables was more influential than others, or that there was a dependence of one variable upon another, adjustments could be made to the equation to reflect the more detailed information.

An example of a biodiversity-related property is the function, "Maintain Characteristic Plant Community." For Bunchgrass/Pine Savanna wetlands of southern Atlantic and Gulf of Mexico coastal plains of the USA, fire frequency and seasonal soil saturation are critical components of maintaining exceptionally high species diversity on a small scale (WALKER and PEET, 1983). Either of two components, native bunchgrass cover (V_{NBG}) or herbaceous species diversity (V_{HERB}), whichever is higher, is used to score this function as follows

$$\text{Characteristic Plant Community} = \text{MAX}\ (V_{NBG}, V_{HERB})$$

Fire frequency, on the order of every 2-5 years, is necessary to maintain the high species diversity in this wetland type. Without frequent fire, encroachment by shrubs shades and out-competes the bunchgrasses and native herbs. A principal application of the HGM approach is the evaluation of impacts of highway projects and other types of development. As such, assessments must be conducted within a short timeframe to satisfy regulatory requirements, usually within a few months of permit application. If the assessment is conducted soon after a fire, V_{HERB} is temporarily missing, but native bunchgrass cover, V_{NBG}, persists as an observable variable, and would allow the assessment to be conducted regardless of how recently the area burned. This illustrates the need for flexibility in the choice of variables and their application within a regulatory program.

Interpretations of assessments and the need for policy

The United States has a policy of "no net loss" of wetlands (THE CONSERVATION FOUNDATION, 1988). This means that any impacts to wetlands are to be compensated, typically by restoring a degraded wetland to one in better condition. However, the measure of loss is not simply area. Rather total functional loss is the metric. This may be accomplished as follows. Each of the functional changes can be scaled up to indicate functional change times area, which allows the function index to be expressed as Functional Capacity Units (FCU) (SMITH *et al.*, 1995). For example, if the hydrology of a forested wetland if the lower Mississippi alluvial valley were altered by changing the flooding frequency variable from 1.0 to 0.3, but no other alterations were imposed, the Detain Floodwater function would be lowered as follows

$$\text{Detain Floodwater Function} = 0.3 \text{ x } (1.0 + 1.0 + 1.0 + 1.0)/4 = 0.3$$

and the loss would be 1.0 - 0.3 = 0.7 from its original reference standard condition. Using the FCU (function x area) approach, and assuming a wetland of 2.0 ha in size, the loss of FCUs would be estimated at 1.4 (2 ha x 0.7).

This estimated change in condition could be used in one of several ways. One would be to determine if the change in condition is acceptable based on existing policies and regulations for hydrologic change in a region (assuming that such policies and regulations exist). Another would be to evaluate the magnitude of the proposed hydrologic change relative to other alternatives (e.g., greater or lesser magnitudes of hydrologic change). A third use would be to estimate the nature and amount of compensation necessary to offset the degradation caused by the alteration. For example, an existing altered wetland nearby that is already degraded due to flooding reduction could be restored to make up for the lost functions (FCUs). This could be accomplished by partially restoring a degraded wetland forest by increasing the FCUs of the wetland by 1.4. For the purpose of demonstration, assume that the variable V_{FREQ} is 0.6 for a partially leveed or dyked forested wetland. By increasing the flooding frequency to a 0.8 level, and assuming no other changes, it is estimated that the function would increase by 0.2. If this hydrologic restoration were applied to 7 hectares of the degraded wetland forest, the gain in FCUs would be 1.4 (0.2 x 7 ha). This gain would fully compensate for the functional loss from the original impact to 2 ha.

In this example, the variable (V_{FREQ}) that resulted in losses of the detain floodwater function was the same one being restored. It would be unlikely to find degraded floodplain forests, available for compensatory mitigation, to have an exact match to losses suffered in a project (only hydrology in this case). A more likely scenario would be that losses of more than one function occurs in an original project (e.g., biogeochemical and habitat, Table 1), and that the wetlands available for restoration are more generally degraded than the simple example of only hydrology given for illustration. The length of time for a function to be restored can also be taken into consideration.

The HGM approach makes no judgments as to whether a wetland alteration should be recommended or not. There is no determination of economic or social consequences of a project. An assessment brings together information on hydrological, biogeochemical, and habitat condition, and evaluates what the expected consequences would be. Restoration projects would be evaluated in the same way, except the expectation would be an increase in functioning rather than a decrease. The rate at which this occurs may be determined from previous restoration projects within the subclass or from successional studies of the subclass. Decisions as to the importance of restoring one or all functions are beyond the bounds of the science of the approach. This is where policies should be invoked so that decision makers can address societal values.

Calculation of metrics for functional assessment can easily and quickly be taken beyond the logic of a rapid assessment procedure. It is difficult to imagine a project in the real world that would lose one function in the impacted wetland by a given amount and provide compensation in the restoration wetland by exactly the same amount and for the same function. Consequently, there is a need for policy to provide guidance. Without such guidance, one can imagine high quality wetlands being lost, only to be compensated with partially restored degraded wetlands. By the same token, the output from a functional assessment could suggest that degraded urban wetlands should be eliminated because FCU losses would be low relative to many rural wetlands of the same subclass. This and other scenarios clearly indicate the need for a policy framework so the final outcome does not result in the "tyranny of small decisions" (ODUM, 1982). More recent guidance by the Corps of Engineers and Environmental Protection Agency acknowledges the need to approach restoration in a more holistic fashion (http://www.epa.gov/owow/wetlands/pdf/wetlands_mitigation_final_rule_4_10_08.pdf).

Lastly, we give another note of caution concerning rapid assessment, as described here. Results should not be used for all environmental issues related to wetlands. As examples, rapid functional assessment will not provide the appropriate information on the effects of a project on release of mercury from sediments, the potential nutrient loading downstream to an aquatic ecosystem, a change in plant species composition from hydrological changes, or the effect on an endangered species. Rather, specific studies of those issues using appropriate methodologies should be used.

ASSUMPTIONS AND POTENTIAL PROBLEMS WITH REFERENCE

By using a relatively unaltered or "natural" condition as the basis for assessment and restoration, several problems with reference have arisen. In the following sections we first provide the rationale for using relatively unaltered, self-sustaining conditions as the benchmark for programs in the USA. We then point out some of the problems and shortcomings, realizing that socioeconomic forces may override policies that begin with "natural" as a basic management philosophy. Finally, we discuss partial solutions to these problems in the context of much of Europe that lacks reference standard conditions for most wetland subclasses.

Rationale for natural conditions

The need for assessment of wetlands is inextricably linked with the protection of these ecosystems and restoration programs that are the basis for goals of no-net-loss. Wetland protection in the USA can be characterized as passive management, or a "hands-off" approach, that is implicit in the permit review process (Smith *et al.*, 1995). Alterations to wetlands are expected to be avoided or minimized. Given this context, expectations are not to maximize individual functions at the expense of others, but rather to protect characteristic conditions and functions that are representative of the type of wetland in question. The end-product of restoration, from this perspective, should not only be self-sustaining, but should transform a greatly altered or degraded wetland site into one that is considered more "natural." Types of degradation can range widely, from invasion of exotics species to changes in hydrology. Implicit in these examples is an effort to find out what went wrong, and to fix it, through restoration. An alternative perspective is active management (or goal oriented management) where wetlands are perceived to be sources of specific functions and values that are maintained, altered, or enhanced through federal, state, and local statutes. For example, the management of bottomland hardwoods as greentree reservoirs by state or federal wildlife agencies is a practice that trades an increase in waterfowl habitat for a loss in sustainability of mixed hardwood forests that typically dominate floodplains with a natural regime of seasonal flooding (King, 1995). Other goals might include maximizing sediment removal through the design of riparian buffer strips for filtering runoff or maximizing timber production by converting mixed species forests with short-rotation silviculture. Such goals would fall into the category of primarily satisfying economic values.

The self-sustaining property of natural or relatively unaltered ecosystems is generally easy to accept from an ecological perspective, given the history of ecology in the USA (Hunter, 1996). For example, the study of ecosystems has placed emphasis on characterizing and understanding processes in relatively unaltered ecosystems (Hagen, 1992). Even with more recent studies of agroecosystems and urban ecosystems (Grimm *et al.*, 2000), we still use ecosystem energy flow, material cycling, and population dynamics of relatively natural systems as a baseline for understanding the consequences of alteration by humans (Vitousek *et al.*, 1997). For wetlands, alterations include changes in hydrologic regime leading to wetter or drier wetland classes, increases in nutrient stocks leading to altered biogeochemistry, changes in cover of vegetation leading to reduced, enhanced, or redistributed primary production, changes in species composition, etc. Even in uplands, gradients of land use from undisturbed to urban lead to functional differences, as exemplified by changes in avian species diversity (Blair, 1996).

Numerous opportunities exist within most parts of the USA for reference sites. Field experiments in ecological studies often manipulate background conditions to gain insight not only into how ecosystems function, but also how they might respond to alteration by humans. Experimental treatments involve manipulations, relative to the "control" plots (i.e., reference standard conditions), of removing or adding species, supplementing nutrients, altering hydrology, changing the level of shading, and simulating disturbances such as wrack deposition in coastal marshes, hurricane blowdown in forests, and soil compaction by machinery. Also, many of the National Science Foundation's Long Term Ecological Research (LTER) sites and a number of privately operated research centers contain permanent plots, equivalent to reference sites, dedicated to monitoring. They not only document and validate models of succession, but also serve to detect aspects of global change (Franklin *et al.*, 1990). Many of the 26 LTER sites, however, are centered on atmospherically-controlled biomes (short-grass prairie, temperate deciduous forest, etc.) rather than wetlands. Nevertheless, many of these sites encompass wetlands that could provide opportunities for long-term monitoring and cross-site comparison of similar wetlands in different climatic regimes; similar approaches have been used to compare upland ecosystems (Kratz *et al.*, 1991).

Problems in applying reference

Reference standard sites of relatively natural or minimally altered wetlands are difficult to find in many regions. For example, urbanized regions may be so severely altered that no natural wetlands are present for comparison because the landscape cannot support them (Ehrenfeld and Schneider, 1993). In such cases, specific socioeconomic goals dominate management decisions. This requires that wetlands be managed actively to maintain the status quo or to enhance specific functions and values as described earlier. The problem is acute in many areas of Europe where both the landscape and wetlands have been extensively altered and have existed in that condition for decades or centuries.

Socioeconomic forces may dictate that *minimally* altered conditions are not necessarily "desirable" endpoints for wetland ecosystems. Within the bounds of maintaining wetlands and aquatic sites, there are common examples that enhance one or several existing functions and values. They include waterfowl impoundments; reservoirs for fisheries, recreation, and water supply; marsh impoundments for mosquito control (an "enhancement" to actually minimize selected habitat conditions); waste treatment marshes; and flats converted to agriculture or short rotation silviculture. In the United States, these enhancements do not necessarily eliminate regulatory "waters of the USA", but they generally change "state" or subclass by altering water sources, hydrodynamics, and plant community type. Such departures from natural conditions normally carry with them maintenance costs and responsibilities that society chooses to support. For example, reservoirs convert riverine wetlands to deepwater aquatic ecosystems, a condition that bears little resemblance to the original wetland. Rather than passively regulating activities in a riverine wetland through avoidance, conversion to reservoir status includes maintenance of a dam and other costs associated with reservoir management. The issue is whether new reference conditions should be established for the enhanced condition or new state, or whether the new conditions should represent altered and degraded examples of the original riverine wetland. Arguments can be made for either approach.

From a practical point of view, if an alteration is considered reversible from a technical or socioeconomic perspective, the original unaltered condition could represent the basis of comparison (i.e., the reference standard). For example, many waterfowl impoundments, while they represent significant alterations of hydrology, can be feasibly converted back to their original state from a technical standpoint (although there may be significant resistance from duck hunters). At the other extreme are irreversible alterations such as levees that protect large cities along the Mississippi or Po Rivers. Both technical and socioeconomic hurdles are formidable in these cases, thus supporting the recognition of a new ecosystem state. For example, the new reference condition of reservoir lakes without toxins or eutrophication (the reference standard) would be ranked above those containing evidence of contamination and nutrient enrichment. The reference standard condition of the original riverine wetland would not be the appropriate context if this approach were taken. Such issues cannot be adequately addressed with a rapid assessment method.

The irreversibility issue is particularly apparent in urban locations and in landscapes that have been altered for hundreds or even thousands of years. For example Ehrenfeld (2000) questions the usefulness of using natural wetlands as the basis for comparison and evaluations under these circumstances. Such landscapes have been altered due to changes in hydrology (largely due to increases in impervious surface), soils (through excessive sedimentation), and vegetation (in part due to the previous two, but also exposure to invasive aliens). Restoration projects that ignore such constraints on wetland condition may set unreasonable and unsustainable goals if unaltered conditions are used indiscriminately as reference. Studies are now available that examine both the usefulness and the limitations of the HGM approach (Cole and Brooks, 2000; Ehrenfeld, 2005) and that point to the need for additional data to address specific ecosystem functions (Cole, 2006; Stander and Ehrenfeld, 2009).

A partial solution for reference in Europe

Our experiences have been largely in the United States. The approach we have described is one that has been developed where many of the wetland subclasses can be found in minimally altered states, and reference standard conditions can be established. We recognize that these circumstances may be less evident in Europe where human impacts on the landscape have occurred for a longer time and may be more intense. We therefore present observations in the following section as a prompt for thought and discussion, rather than as an established paradigm.

In an effort to develop a functional assessment method for Europe, Maltby *et al.*, (1994) found it necessary to classify at smaller scales than the geomorphic setting as suggested for the HGM approach. This is partly because most European wetlands have been more highly modified and modified for longer periods of time than those in the USA. As such, a "natural" condition is nearly impossible to define and largely irrelevant in the highly managed landscapes. The unit of assessment is the hydrogeomorphic unit (HMGU), defined as an area of homogeneous geomorphology, hydrology/hydrogeology and, under normal conditions, homogeneous soil (Maltby *et al.*, 1996, Maltby, 1998).

Following the logic of comparing "reference standard" wetlands as a benchmark, the HMGU approach could determine which units are best for improvement in water quality, habitat for desired species, etc. Consistent with the reference approach, however, these sites should be identified in the field, and their capacity to perform various functions should be estimated. Unlike the HGM approach, the HGMU approach may require better documentation on the level at which specific functions are occurring. The assumption of the HGM approach is that natural conditions are acceptable, and that unaltered wetlands function at appropriate levels for the subclass, whatever they may be. In a highly altered landscape where there is no hope for "naturalness," wetlands may be highly integrated into society's history and culture. It then becomes the decision of society, based largely on its values, as to the array of wetland types that would be most appropriate for supporting the desired goods and services.

Altered wetlands are still capable of a number of functions, and some at very high levels. In fact, wetland riparian buffers are commonly established for streams in agricultural landscapes to protect water quality and to improve habitat quality (NRC, 2002). Wetlands for the treatment of wastes have higher levels of nitrogen and phosphorus cycling than most natural wetlands. Each of these wetland types can be designed to optimize or maximize certain functions, within certain constraints. Therefore, it should be possible to develop reference in highly altered landscapes for performing specific functions. It is realized that one of the results of compromising from the 'minimally altered' condition is that they will not be as self-sustaining as their natural counterparts. In many cases, this is not a great deterrent, given some of the positive benefits that naturalized wetlands can provide, sometimes at low cost.

With the HGMU approach to reference, standards are just as critical as they are in the HGM approach. Perhaps greater initial effort must be made to measure levels of function in the HGMU approach, since it can't rely on the assumption that "natural is an appropriate standard." Society must find a balance between using the natural energies of water flow and sunlight and the societal energies of planning and fossil fuel. Finding the appropriate balance is a challenge beyond the determination of wetland functioning. There are numerous wetlands of various types in European landscapes that can serve as grist for a reference HGMU system. The challenge is to construct the classification matrix, make it sufficiently general for broad application, and provide the tools to evaluate the balance between naturalness and design for function. European programs for functional assessment have made great strides in this regard (Maltby *et al.*, 2009), and have now linked HGMU classification with geographic information systems and modeling tools for decision-making in wetland management (Janssen *et al.*, 2005).

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