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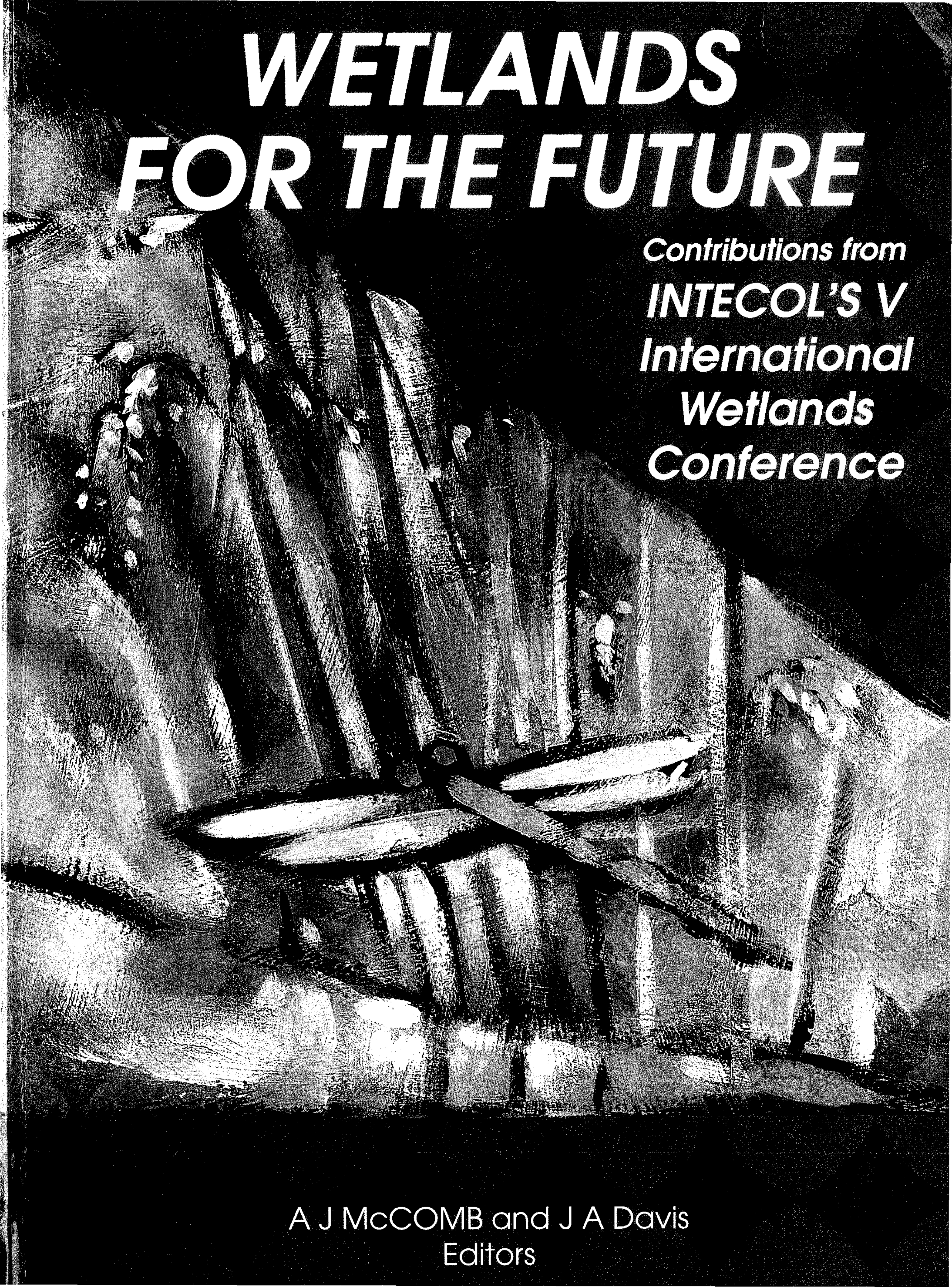

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Progress in development of the hydrogeomorphic approach for assessing the functioning of wetlands

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Abstract

The hydrogeomorphic (HGM) approach to assessing the functioning of wetlands has been undergoing development for the past 6 years. We describe progress that has been made since presenting the approach at the last INTECOL conference in 1992. The approach is characterized by three interrelated components: classification, articulation of functions, and the use of reference wetland ecosystems. Classification is used to partition natural variability in wetlands so that the assessment can be built around a smaller subset of wetlands that share common structure and functioning. In so doing, classification improves the capacity to separate sources of natural variation from those due to disturbance by human activities. Articulation of functions includes identifying subsets of wetland processes that either are commonly recognized ecosystem functions or functions specific to particular wetland classes. Logic models are developed to depict recognized functions. The models use ecosystem processes and structural components as variables which serve as surrogates for more detailed measurements of structure and function. Reference wetland systems include the knowledge base for a class as well as sites that encompass the range of variability exhibited by the class including undisturbed and altered sites. Reference wetlands provide a scale for indexing the variables and their associated functions to the least altered wetlands of a particular class. These least altered sites allow the identification of reference standards for the variables and represent characteristic levels of functioning on a sustainable basis. The altered wetlands contribute information useful toward the scaling of variables and functions between characteristic levels of functioning and those at lower levels due to alterations. Considerable iteration is necessary among the three components (i.e., classification, articulation of functions, and the use of reference systems) in developing an assessment method for a particular regional group of wetlands. Once the method is developed, however, the assessment process is rapid and repeatable.

Introduction

The hydrogeomorphic (HGM) approach for assessing the functioning of wetland ecosystems was introduced at the IV INTECOL wetland conference (Brinson *et al.*, 1994). At that time we were in the conceptual stages of its development and the procedure had not been applied in the field. For example, a critical aspect of the procedure, that of using reference wetlands as a basis of comparison, had not been tested. Other facets of the assessment approach have been made more specific. Here we report progress that has been made in the past 4 years. This is ongoing effort that is being conducted in parallel with functional assessment development by the European Union (Maltby *et al.*, 1994).

The HGM approach was initiated as part of a national effort in the USA to enhance the stewardship, management, and regulation of impacts to wetland resources (Smith *et al.*, 1995). The approach, as it is currently developed, is designed to assess the impacts of proposed projects on wetland functions as part of the public interest review process required by the US Federal Clean Water Act, Section 404 (33 USC 1344). At this time, the use of the HGM approach is not specifically required as part of the impact assessment, minimization, or mitigation phases of the Section 404 process.

The Brinson *et al.* (1994) paper (hereafter called the 1994 paper) presented the HGM approach as 5 distinct steps. While the present logic has not changed and is consistent with the steps as originally proposed, application of the HGM approach has allowed us to be much more specific as to the development of useful definitions, and the use of models relating physical and biological structures of ecosystems to their functioning. Rather than repeating the 5 steps, we have organized this paper around the three fundamental properties of the HGM approach: classification, articulation of functions, and the use of reference wetland ecosystems.

Classification

The primary objective of the HGM approach is to determine how anthropogenic disturbance, a project potentially regulated under Section 404, for example, affects the ability of a wetland to perform specific functions. A significant challenge in making this determination is that wetland ecosystems exhibit a wide range of natural variability with respect to which functions they perform, and the magnitude to which they perform the functions (Brinson 1993a; Brinson 1993b). The objective of the HGM classification is to identify a subset of wetlands that function similarly and exhibit a relatively narrow range of variability. To this end, the HGM approach recognizes seven classes: riverine, depressional, slope, lacustrine fringe, estuarine fringe, mineral soil flats, and organic soil flats (Table 1). Each of the classes is associated with a specific geomorphic setting, dominant water source, and dominant hydrodynamics as well as representing a commonly recognized wetland type based on vegetation and soils (Table 1).

Even with seven hydrogeomorphic classes, it is not uncommon for wetland ecosystems within a region to still exhibit a relatively wide range of functional variability. For example, floodplains of first and fifth order streams within a geographic region would both fall within the same generic class—riverine. For the purposes of functional assessment, however, the two floodplains may be so vastly different in soils, vegetation, and hydroperiod that it becomes impractical to assess the two with the same set of standards. Thus, in order to further reduce the range of variability and increase the ability to detect changes resulting from disturbance or alteration, it may be necessary to distinguish regional subclasses for a hydrogeomorphic class. In addition, some wetlands occur as mosaics that contain several subclasses that function differently from one another, yet they are interconnected functionally. Prior to conducting an assessment, these subclasses must be partitioned so the appropriate functional assessment method is applied.

Table 1. Hydrogeomorphic classes of wetlands showing associated dominant water source, hydrodynamics, and examples of subclasses (Brinson *et al.*, 1995).

Hydrogeomorphic class	Dominant water source	Dominant hydrodynamics	Examples of subclasses	
			Eastern USA	Western USA & Alaska
Riverine	Overbank flow from channel	Unidirectional and horizontal	Bottomland hardwood forests	Riparian forested wetlands
Depressional	Return flow from groundwater and interflow	Vertical	Prairie pothole marshes	California vernal pools
Slope	Return flow from groundwater	Unidirectional, horizontal	Fens	Avalanche chutes
Estuarine fringe	Overbank flow from estuary	Bidirectional, horizontal	Chesapeake Bay marshes	San Francisco Bay marshes
Lacustrine fringe	Overbank flow from lake	Bidirectional, horizontal	Great Lakes marshes	Flathead Lake
Mineral soil flats	Precipitation	Vertical	Wet pine savannas	Large playas
Organic soil flats	Precipitation	Vertical	Peat bogs; portions of Everglades	Peat bogs

To illustrate these concepts, we present two examples of classifications that have been performed regionally: riverine wetlands in the Piedmont of the Carolinas and Georgia and black spruce wetlands of interior Alaska. This is done to show that the generic classification scheme is mainly a guide for illustrating differences in functioning among geomorphic settings, water sources, and hydrodynamics, and that it is a misconception to expect that (1) all locally identified wetlands fit neatly into one of the seven generic classes, or (2) further subdivisions into regionally specific classes are unwarranted. We use the black spruce wetlands of interior Alaska (Post, 1996) to illustrate the first point of how a rigid adherence to the generic classes may not be practical nor desirable.

Much of the wetland landscape of interior Alaska consists of repeating patterns of organic soil flats with depressions embedded in them. The region is underlain by discontinuous permafrost and is subjected to infrequent fires that burn the insulating organic layer, thereby creating depressions and initiating succession of vegetation and thawing of permafrost. The wetland mosaic could be broken into distinct subclasses based on successional stages of vegetation and the degree of wetness. However, the considerable research on black spruce wetlands recently synthesized (Post, 1996) did not provide sufficient documentation to separate depressional and flat classes based on how they function.

From a practical standpoint of a functional assessment program, classification into small landscape units did not seem warranted. The natural variation due to differences in vegetation and wetness were instead handled within the functional models rather than by classification. This is a common practical matter that must balance the taxonomy of classification with the knowledge available on ecosystem functioning. If sufficient information is available on wetland functioning, then further separation into subclasses may be warranted. One of the guiding principles for classification is avoid more separation than is warranted by the information or the practicality of its application.

In contrast to the black spruce example, riverine wetlands of the Piedmont region of the Carolinas and Georgia illustrate the need to generate subclasses beyond the riverine class described in Table 1. These wetlands are in a state of transition due to changes in land use during the past 200 years. For example, the floodplains of some of these rivers continue to receive overbank flow as a dominant source of water, while others have undergone channel widening and deepening so that the floodplains now receive water mainly from lateral sources (i.e., groundwater discharge and overland flow from adjacent uplands) (Burke and Nutter, 1995). In addition, other floodplains now have raised water tables that are elevated and stabilized by beaver dams due a resurgence of beaver populations in the geographic region in the past two decades. The changes have fundamentally altered how the wetlands in the Piedmont function and require that several regional subclasses be distinguished based on functional differences. The three subclasses are (1) overbank source dominated, in which channels are not yet deeply incised, thus allowing inundation of the floodplain approximately annually, (2) riparian source dominated, in which channel incision has increased channel conveyance so floodplains receive most of their water from groundwater discharge and overland flow from adjacent uplands, and (3) beaver dam dominated, in which water level fluctuations are stabilized, velocities are reduced, and water is deeper than in areas without beaver dams (Brinson *et al.*, 1996).

Articulation of Functions

Wetland functions are defined as the normal or characteristic activities that take place in wetland ecosystem, or simply the things that wetlands do (Smith *et al.*, 1995). Functions, a subset of ecosystem attributes and processes, have been widely used historically for the assessment of wetlands (Adamus, 1983; Adamus *et al.*, 1987;

Larson and Mazzarese, 1994). Examples of functions include maintenance of primary productivity, cycling of elements, maintenance of site water balance, and maintenance of vertebrate populations.

Selection of Functions

Prior to selecting functions for a particular wetland subclass, the relevant research literature should be analyzed to establish how the wetland subclass works. Community profiles published by the US Fish and Wildlife Service are good examples of literature syntheses for broad categories of wetlands (Golet *et al.*, 1993, Odum *et al.*, 1984; Wharton *et al.*, 1982). Unfortunately, there is seldom an extensive research base on particular regional subclasses. For this reason, professionals who are familiar with the scientific literature or who have conducted research on similar wetlands need to determine which functions will be attributed to a particular regional subclass. Local experts familiar with the subclasses should also be consulted. If funds are available for actually characterizing several functions on broad geographic scales, then functions can be articulated with much more specificity. For example, the function 'removal of nutrients' by riverine wetlands might be replaced by 'removal of nitrogen' if research results reveal this to be a common and important process. A field research based approach is being taken in Europe through a study supported by the European Union that examines these more specific functions (Maltby, Hogan, and McInnes, 1996).

The choice of functions should be relatively broad and relevant to the purpose of the assessment. A function like the cycling of elements is broad because it applies to all ecosystems. It is also relevant because it contributes to the maintenance of water quality, a condition that is consistent with a national mandate (e.g., the Federal Water Pollution Control Act in the USA, 'to maintain and restore the chemical, physical, and biological integrity of the nation's waters.').

Other functions may be fundamental but not perceived as relevant. For example, the function of sequestering atmospheric carbon dioxide in peat swamps and other wetlands with organic rich soils has global implications (Armentano and Menges, 1986). However, the influence of any one wetland on atmospheric carbon dioxide would be minuscule and, as such, the function may be relevant only at landscape scales. Currently, the section 404 program in the USA does not explicitly address landscape-scale functioning, although approaches have been published for doing so (Gosselink *et al.*, 1990; Leibowitz *et al.*, 1992).

It may be useful to incorporate functions that are specific to particular wetland subclasses, but not necessarily common or relevant to all of those in one of the seven classes. For example, headwater riverine floodplains in coastal plain regions of the mid and south Atlantic coastal plain remove nitrogen and phosphorus generated by land use activities, such as farming and urbanization (Whigham, Chitterling, and Palmer, 1988). In such cases, nutrient removal rather than elemental cycling may be a function of greater practical and wetland-specific importance.

Regardless of the functions chosen, all available information should be brought to bear in developing models that express the function. For wetland subclasses lacking research, reliance on general information and the judgement by experts must be utilized. In such cases, models of functions represent hypotheses with no explicit testing. This does not lessen the need, however, to make management decisions on wetland resources. Thus, the HGM approach is not a substitute for professional judgement, but rather a framework in which judgement can be documented and applied consistently.

Measurement and incorporation of variables into models

Once functions are identified, the variables that contribute to a function must be determined. Variables are attributes of a wetland that can be measured directly or indirectly. They become components of logic models or equations that depict a function, as described below. Continuing with the example of 'cycling of elements', variables that contribute to the function include biomass components that accumulate elements through growth and recycle elements through decomposition. Variables that are proportional to the actual components of living and dead biomass (e.g., basal area of forests, percent cover of herbs, volume of coarse woody debris, etc.) can be used as surrogates to rapidly assess for biomass components.

In order to scale a particular variable to a high or low level of functioning, the range over which the variable fluctuates must be established. Reference wetlands, described in the next section, are sampled to determine characteristics of variables at various levels of function. A major assumption in the HGM approach is that unaltered wetlands (i.e., undisturbed by human activity) have characteristic levels of functioning. Variables are assigned a score of 1.0 when they correspond to the characteristic level of functioning of the subclass (Smith *et al.*, 1995). At the other end of the scale is the absence of any variables. For these a score of 0.0 is assigned to the variables. Between the 0.0 and 1.0 scores is a range of variable expression that represents a scale of the variable. Functions may be represented by a single or a group of variables.

To illustrate the use of variables and their incorporation into models, we continue with the example on the cycling of elements. Equation 1 shows how various biomass components can be combined into logic equations to depict an Index of Function. Because the HGM approach was designed to generate rapid assessment procedures, most variables (where V_i is the index for a variable) are surrogates of biomass or other structural features of an ecosystem rather than direct measures. For example, basal area (V_{BA}) is used as a surrogate for the aboveground woody biomass component of elemental cycling. While such an approach does not meet the rigorous standards of detailed biogeochemical research, the purpose is to arrive at management decisions in a timely fashion for specific parcels of wetland slated for alteration. The 'data' are not meant to contribute to the research literature on elemental cycling in wetland ecosystems. Regardless, the variables encompass most structural components that can be rapidly and practically measured or assessed.

$$\text{Index of function} = \left(\frac{\dfrac{\left(V_{BA} + V_{SUBC} + \left[\dfrac{V_{HERB} + V_{SDLG}}{2} \right] \right)}{3} + \dfrac{\left(V_{SNAG} + V_{FWD} + V_{LTD} + \left[\dfrac{V_{DECY} + V_{CWD}}{2} \right] \right)}{4}}{2} \right)$$

The variables in this equation and the rationale for their use are briefly explained:

- V_{BA} (basal area) is the total cross-sectional stem area occupied by canopy trees. For elemental cycling it represents elements incorporated into woody biomass of canopy trees which may be immobilized for several decades.
- V_{SUBC} (subcanopy vegetation) is the density of shrubs and understory trees. This component represents elements incorporated into subcanopy stratum; elements may be immobilized for several years or decades.
- V_{HERB} (herbaceous vegetation) is measured as percent cover of annuals, biennials, or perennial herbs that normally immobilize nutrients in aboveground biomass for less than 1 year.
- V_{SDLG} (seedlings) are seedlings of canopy trees which were not included in V_{SUBC}. Seedlings incorporate elements into biomass for varying periods depending on mortality patterns.
- V_{SNAG} (snags) is the basal area of dead canopy trees from which elements will be mineralized through slow decomposition.
- V_{FWD} (fine woody debris) is the percent cover of small branches and twigs on the forest floor which will decompose more rapidly than V_{SNAG}.
- V_{LITR} (leaf litter) is the depth of leaf litter on forest floor and represents the most rapidly decomposing material.
- V_{DECY} (decay classes) is the number of decay classes of coarse woody debris which represents the mixture of decomposition stages.
- V_{CWD} (coarse woody debris) is the volume of large woody material on the forest floor that will decompose over the long term and release elements slowly.

The variables that are measured become shorthand depictions of ecosystem factors that influence a function without measuring the factors directly. In the example, the assumption is made that if live and dead biomass are present, then elements must be cycling (e.g., through uptake in the production of biomass and release from decomposition of detritus). In short, the totality of the living and detrital biomass is assumed to correspond to the stock of elements that are currently participating in elemental cycling through uptake, release, or storage. If any of these variables depart from the levels characteristic of unaltered sites (either more or less), then the index of functioning should fall below the 1.0 level.

The equations used for the logic models contain one or more variables, a format similar to of the Habitat Evaluation Procedure (US Fish and Wildlife Service, 1981).

Variables are often combined into equations to reflect their relative importance to a particular function as perceived by teams of experts. Without actual data on elemental uptake and release, first approximations must be invoked. In the equations presented above, groups of variables are averaged to mathematically reduce their influence on the index of function relative to ones that are not averaged. Several years of research may be necessary to empirically test these relationships. Until such validation is possible, research on functionally related wetlands elsewhere must provide the basis for making judgements on model configuration.

The HGM approach to assessment is designed to measure changes in the performance of a function, as would occur before and after an alteration, relative to the 1.0 level. This is done by scaling levels of functioning through changes in relevant variables, before and after alteration. As an example, V_{BA} of the highest functioning and unaltered sites may average 30 m^2/ha which would be assigned a score for V_{BA} of 1.0. An altered site may have a V_{BA} of 15 m^2/ha, which, as a first approximation, might be indexed at 0.5, or one-half of unaltered level. Indexing is repeated for each variable prior to substitution in the equations that are used to scale functions. The equations are configured mathematically to yield an index of function of 1.0 for the unaltered sites. The current proposed convention (Brinson *et al.*, 1995) uses discrete categories for variables with the simplest being 1.0, 0.5, and 0.0. More categories (e.g., 1.00, 0.75, 0.50, 0.25, 0.10, 0.00) can be employed as more ecological data become available to relate the structural variables measured to ecological functions. An example that employs intervals is shown for stem density in Table 2.

In summary, the articulation of functions includes a number of activities: (1) synthesizing available information for the wetland subclass, (2) constructing models that depict functioning, (3) collecting relevant data from reference wetlands to scale the models, and (4) revising models based on the kinds of information that can be practically gathered during a rapid assessment procedure. The third activity necessarily overlaps with the section below.

Table 2. Tree density as a variable showing indices that correspond to reference standard sites as well as densities that depart from reference standards. Data are hypothetical and for illustration purposes only.

Model variable	Condition	Index of variable
V_{DTREE}: Tree density Definition: Number of trees >10 cm DBH	Density between 400 to 700 stems per hectare (condition of reference standard sites)	1.0
	Density between 50 and 400 or greater than 700 stems per hectare	0.5
	Density below 50 per hectare but trees not absent	0.1
	No trees are present	0

The Use of Reference Wetland Systems to Establish Reference Standards

The third and final component of the HGM approach is the use of reference wetlands to establish reference standards and scale variables to impacts. Establishing reference standards is the foundation of an assessment procedure. In most cases, reference standards are simply direct or indirect measurements of variables taken from the least altered sites. The purpose of reference is to provide stability to the assessment by 'referencing' it to real wetland locations instead of imagined, hypothetical levels of functioning with no information on the nature of specific wetland sites (Brinson and Rheinhardt, 1996).

Several reference sets for regional subclasses have been developed in the USA to date, and this experience serves as the basis for this material. Three points about reference should be emphasized: (1) the term 'reference standards' was not used in the 1994 paper although the concept of reference wetlands was central to the paper, (2) scaling of variables is an iterative processes between field measurement of reference wetlands and model development, and (3) all relevant information should be brought into the process of developing reference systems, including best professional judgement. Scaling can not be completed until data from reference wetlands are available. Several terms are useful and necessary for explaining the use of reference wetlands in functional assessment:

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

Reference domain identifies boundaries where the subclass changes geographically, possibly to a different climatic or physiographic region or a different biogeographic province. Transitions between reference domains may represent a continuum that is difficult to identify precisely. In practice, reference standards (defined below) of a particular reference domain will be dissimilar to those in another reference domain, even if the wetlands are of the same class. If they are similar, the two reference domains should be merged.

- Reference wetlands – Wetland sites within the reference domain that encompass the known variation of the subclass.

Reference wetlands are used to establish the range of functioning within the subclass. Reference wetlands may include former wetland sites for which restoration is possible and characteristics of sites derived from historic records or published data. While historic records are unlikely to provide data on variables, they may be useful for determining the condition of sites that are the least altered. The need for the term reference is to facilitate making the distinction between variation due to natural sources and variation due to impacts. In practice, 20 to 50 sites are chosen for the subclasses from within the reference domain. Typically, reference wetland sites are identified through extensive reconnaissance in the field with the aid of local experts, maps, aerial photographs, historic records, and informed judgement.

- Reference standard sites – The subset of reference wetlands from which reference standards are developed. Among all reference wetlands, reference standard sites are judged by an interdisciplinary team of local experts to be the least altered of the subclass, and hence have characteristic levels of functioning.

Characteristics of the reference standard sites (e.g., reference standards, see below) stabilize the assessment procedure by relating it to existing wetlands that are exposed to environmental conditions found within the reference domain. The choice of reference standard sites is one of the most critical and controversial components of the HGM approach. The choices will influence the outcome of all subsequent assessments. If the subclass chosen is too broad (i.e., natural variation is large, or if degraded wetlands are included in the population of reference standard sites), then the resulting assessment procedure will lack the resolution necessary for detecting significant losses in functioning. In contrast, if reference standard sites are limited to a pristine condition, either no sites will exist in most landscapes, or the low number of available sites will not be robust enough to capture the natural variation. Descriptors applied to these sites vary from 'relatively unaltered', which implies that they have been subjected only to natural disturbances with minimal anthropogenic influence, to 'pristine', a condition that is unlikely to exist except in the most remote portions of the earth. Consequently, decisions on which sites are chosen for reference standard sites are somewhat subjective. That is why consensus of an interdisciplinary team of scientists is needed for choosing reference standard sites based on scientific literature, historic accounts, data on the sites, and other sources of information.

- Reference standards – Conditions exhibited by a group of reference wetlands that correspond to characteristic levels of functioning sustainable across the suite of functions of the subclass. By definition, reference standards, when combined as variables into the logic equations as described above, receive an index score of 1.0.

In most cases, reference standards are equivalent to the measurements of variables (indexed to 1.0) from reference standard sites. The use of reference standards to scale indices of functioning is illustrated in Table 2. This table is a hypothetical example of a stem density that might be used as one variable to describe the physiognomy of a forested wetland. As shown, reference standard sites ranged between 400 and 700 stems per hectare, and thus, by definition, would be indexed to 1.0 prior to being incorporated into an equation. Lower stem densities due to thinning or other alterations would fall below 1.0, perhaps along some linear scale, or according to the categories used in Table 2. Stem densities that exceed the 700 per hectare would not score a 1.0 because they are likely representative of an altered condition. This illustrates the 'more is not necessarily better' principle of functional assessment. High stem densities are inconsistent with reference standard conditions and thus are assigned an index of less than 1.0.

Several reference standards can be established for a subclass of wetlands. Because a goal of functional assessment is to separate natural variation including natural cycles of disturbances, from alterations induced by human activity, the approach must make allowances for disturbances that sustain wetland ecosystems. In black spruce wetlands of interior Alaska, for example, unaltered conditions were identified for stand age categories of 0 to 5 years, 6 to 30 years, and greater than 30 years since burning. This allowed several temporal ecosystem states to be assessed as reference standard conditions for black spruce wetlands.

Other terms are necessary for reference (see Brinson *et al.*, 1995), especially when assessments are used for tracking the progress of restored wetlands. Restoration toward reference standards may represent the common default goal. However, policy considerations may override such goals, leading to (1) restoration to alternative wetland subclasses or (2) enhancement of selected functions.

This overview falls far short of instructing a user on how to build reference wetland data sets. Nevertheless, it is worthwhile to mention that data collection on reference sites should not be restricted to only those variables thought to be needed in building the models for the functions. Any data that are reasonably useful for describing the wetland subclass quantitatively or qualitatively should be collected on site in the building of the reference system. Two principal reasons for doing this are (1) to aid in design of restoration projects that require detail beyond that needed for conducting a functional assessment and (2) to use in updating models to make them more responsive to existing impacts and those impacts that were unanticipated.

Conclusions

Three components of the HGM approach to functional assessment of wetlands are classification by geomorphic setting, articulation of functions, and the use of wetlands to establish reference standards. While each of these is described separately above, in reality, the HGM approach integrates them into one coherent, iterative process. Once the assessment method is developed around standards possessed by the highest functioning wetlands of a subclass (e.g., reference standard sites), conducting functional assessments becomes a rapid procedure (usually completed in less than a day) for detecting changes in functioning due to anticipated alterations and restoration projects. Additional characteristics of the approach include the following:

1. The approach should be applicable to ecosystems other than wetlands. The HGM approach to functional assessment is the application of community ecology, ecosystem ecology, and related disciplines through the use of background information, a logical framework, and easily measured ecosystem features.

2. The approach does not pretend to be rigorous science. It utilizes available information and professional judgement. In so doing, we can be explicit about which components of an assessment are based on prevailing ecological paradigms, which are based on relevant data, and which require the application of professional judgement. The HGM approach identifies information gaps that could be filled with appropriate research. The HGM approach may be useful as a tool in the emerging field of watershed planning and management.

3. While the approach has been developed for detecting changes in functioning due to impacts and restoration to individual wetlands, it could be modified for other levels of detail. As a screening tool, proposed projects could be provisionally assessed in terms of which functions are most likely to be altered. As a cumulative effects procedure, changes in functions over time could be monitored at larger scales than routinely used for individual projects. To do so would require strengthening and incorporating functions that operate at landscape scales.

4. Information is being exchanged with parallel efforts on functional assessment by the European Union. The EU efforts are dealing with highly altered landscapes which may make difficult the use of reference standards as described in this paper. Alternatively, the USA effort would benefit from lessons learned for application in urbanizing areas. The two groups need to collaborate by exchanging ideas and information as parallel efforts progress.

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References

Adamus, P.R., 1983. A Method for Wetland Functional Assessment. FHWA-IP-82-24. Federal Highway Administration, Washington, District of Columbia, USA.

Adamus, P.R., Clairain, E.J., Smith, R.D. and Young, R.E., 1987. Wetland Evaluation Technique (WET) – Volume II. Operational Draft TRY-87. US Army Engineer Waterways Experiment Station, Vicksburg, Mississippi, USA.

Armentano, T.V. and Menges, E.S., 1986. Patterns of change in the carbon balance of organic soil-wetlands of the temperate zone. Journal of Ecology 74: 755–774.

Brinson, M.M., 1993a. A Hydrogeomorphic Classification for Wetlands. Technical Report WRP-DE-4. US Army Corps of Engineers Waterways Experiment Station, Vicksburg, Mississippi, USA.

Brinson, M.M., 1993b. Changes in the functioning of wetlands along environmental gradients. Wetlands 13: 65–74.

Brinson, M.M., Hauer, F.R., Lee, L.C., Nutter, W.L., Rheinhardt, R.D., Smith, R.D. and Whigham, D., 1995. Guidebook for application of hydrogeomorphic assessments to riverine wetlands. Technical Report TR-WRP-DE-11, Waterways Experiment Station, Army Corps of Engineers, Vicksburg, Mississippi, USA.

Brinson, M.M., Kruczynski, W., Lee, L.C., Nutter, W.L., Smith, R.D. and Whigham, D.F., 1994. Developing an approach for assessing the functions of wetlands. In: Global Wetlands: Old World and New. Ed. W.J. Mitsch. pp. 615–624. Elsevier Science B.V., Amsterdam, The Netherlands.

Brinson, M.M., Nutter, W.L., Rheinhardt, R.D. and Pruitt, B., 1996. Background and recommendations for establishing reference wetlands in the Piedmont of the Carolinas and Georgia. Contract No. 3B0978TEX. US Environmental Protection Agency, National Health and Environmental Effects Laboratory, Corvallis, Oregon, USA.

Brinson, M.M. and Rheinhardt, R., 1996. The role of reference wetlands in functional assessment and mitigation. Ecological Applications 6: 69–76.

Burke, M.A. and Nutter, W.L., 1995. Channel morphology evolution and riverine wetland hydrology in the Georgia Piedmont. In: Versatility of wetlands in the agricultural landscape. Ed. K.L. Campbell. American Society of Agricultural Engineers. St Joseph, Michigan, USA.

Golet, R.C., Calhoun, A.J.K., DeRagon, W.R., Lowry, D.J. and Gold, A.J., 1993. Ecology of Red Maple Swamps in the Glaciated Northeast: A Community Profile. US Department of Interior, Fish and Wildlife Service, Biological Report 12, Washington, District of Columbia, USA.

Gosselink, J.G., Shaffer, G.P., Lee, L.C., Burdick, D.M., Childers, D.L., Leibowitz, N.C., Hamilton, S.C., Boumans, R., Cushman, D., Fields, S., Koch, M., and Visser, J.M., 1990. Landscape conservation in a forested wetland watershed. BioScience 40: 588–600.

Larson, J.S. and Mazzarese, D.B., 1994. Rapid assessment of wetlands: history and application to management. In: Global Wetlands: Old World and New. Ed. W.J. Mitsch. pp. 625–636. Elsevier Science BV, Amsterdam, The Netherlands.

Leibowitz, S.G., Abbruzzese, B., Adamus, P.R., Hughes, L.E., and Irish, J.T., 1992. A Synoptic Approach to Cumulative Impact Assessment: A Proposed Methodology. EPA/600/R-92/167. US Environmental Protection Agency, Environmental Research Laboratory, Corvallis, Oregon, USA.

Maltby, E., Hogan, D.V., Immirzi, C.P., Tellam, J.H. and van der Peijl, M.J., 1994. Building a new approach to the investigation and assessment of wetland ecosystem functioning. In Global Wetlands: Old World and New. Ed. W.J. Mitsch. pp. 637–658. Elsevier Science B.V., Amsterdam, The Netherlands.

Maltby, E., Hogan, D.V. and McInnes, R.J. (Eds), 1996. Functional analysis of European wetland ecosystems, Phase 1. Ecosystems Research Report No. 18, Final Report EC DG XII CT90-0084. Office for Official Publications of the European Communities, Luxembourg, Brussels.

Odum, W.E., Smith III, T.J., Hoover, J.K. and McIvor C.C., 1984. The Ecology of Tidal Freshwater Marshes of the United States East Coast: a Community Profile. FWS/OBS-83/17, Fish and Wildlife Service, Washington, District of Columbia, USA.

Post, R.A., 1996. Functional profile of black spruce wetlands in Alaska. US Environmental Protection Agency and Alaska Department of Fish and Game, Fairbanks, Alaska, USA.

Smith, R.D., Ammann, A., Bartoldus, C. and Brinson, M.M., 1995. An approach for assessing wetland functions using hydrogeomorphic classification, reference wetlands, and functional indices. US Army Corps of Engineers Waterways Experiment Station, Technical Report TR WRP-DE-10. Vicksburg, Mississippi, USA.

US Fish and Wildlife Service, 1981. Habitat Evaluation Procedures. FWS/DES-ESM 102, Washington, District of Columbia, USA.

Wharton, C.H., Kitchens, W.M., Pendleton, E.C. and Sipe, T.W., 1982. The Ecology of Bottomland Hardwood Swamps of the Southeast: A Community Profile. US Fish and Wildlife Service, Biological Services Program, FWS/OBS-81/37. Washington, District of Columbia, USA.

Whigham, D.F., Chitterling, C. and Palmer, B., 1988. Impacts of freshwater wetlands on water quality: a landscape perspective. Environmental Management 12: 663–671.