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Developing an approach for assessing the functions of wetlands

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Abstract

We present a five-step proposal for developing an approach to assess the functions of wetland ecosystems. The first step is to classify wetlands based on hydrogeomorphic (HGM) properties. The major properties are geomorphic setting, the sources of water supplying the wetland, and the hydrodynamics of water within the wetland. By first grouping wetlands into HGM classes with shared properties, assessments can be tailored to address the functions most relevant to each HGM class. Step two is to define the relationship between HGM properties and the functions; the goal is to select functions that are linked, clearly and logically, to wetland HGM properties, and that have hydrologic, geomorphic, and ecological significance on site or off site. This step is critical because it represents the scientific basis for the presence of the function. The linkage between HGM properties and wetland functions can be improved with new research findings. The third step is to develop functional profiles for each wetland class. Profiles can range from descriptive narrative of a single site to detailed multivariate data sets for numerous sites. The fourth step is to develop a scale for expressing functions by using indicators and profiles from the reference wetlands; these must be developed for each wetland class in order to serve as benchmarks for the HGM classes. Reference wetlands should include the full range of natural and human-induced variations due to stress and disturbance. The final step is to develop the assessment methodology itself. The assessment relies on indicators to reveal the likelihood that the functions being evaluated are present in the wetland and depends upon reference populations to scale the assessment. Reference wetlands are critical also to the setting of goals for compensatory mitigation. The task of goal-setting is greatly simplified because reference wetlands become a standard for which goals can be chosen and success can be measured.

INTRODUCTION

The premise of this paper is that the assessment of wetland functions can be simplified by stratifying the procedure into discrete steps. Here, we give the rationale for each of these steps, and the assessment procedure as a whole. The assessment approach was developed with the goal of providing a tool for wetland regulatory programs in the United States. However, there is nothing inherent in the approach that limits its use to the United States or to regulatory applications. Rather, it is anticipated that it will be useful in any country in the context of planning, management, educational, or regulatory activities involving wetland resources. A parallel effort is being developed in Europe by an international team (Maltby et al., 1994).

The approach is being developed as part of an ongoing project supported under the Wetlands Research Program at the US Army Engineer Waterways Experiment Station. A conceptual and organizational framework for the project is described in a report by Smith (1993). Development of the approach was initiated in 1991 at a workshop attended by approximately 40 scientists who discussed various alternatives for assessing the functions of wetlands. One of the alternatives discussed was based on the fundamental hydrogeomorphic (HGM) properties of wetlands. The eventual outcome of these discussions was a HGM classification of wetlands (Brinson, 1993a) that serves as the basis for the present assessment approach. This paper focuses on the philosophy and rationale for the assessment approach rather than the mechanics of an assessment method for implementing the approach. Fundamental to this rationale is the use of "reference wetlands" which represent a collection of sites of a specific wetland class that can be used for developing the upper and lower boundaries of functioning within the class.

The five steps in the assessment approach are to: (1) classify wetlands according to HGM properties, (2) make connections between the properties of each wetland class and the ecological functions that they perform based on logic and research results, (3) develop functional profiles for each wetland class, (4) choose reference wetlands that represent the range of both natural and human-imposed stresses and disturbances, and (5) design the assessment method using indicators calibrated to reference wetlands. Each step is discussed below.

THE ASSESSMENT APPROACH

Step 1: Classifying Wetlands Based on Hydrogeomorphic Properties

In the context of assessing the functioning of wetlands, the purpose of classifying them is to identify wetland groups that exhibit a relatively narrow range of variation in the properties that fundamentally influence how wetlands function. Narrowing the range of variation makes the task of developing assessment methods more manageable, and significantly reduces the time and effort required to conduct an assessment.

The HGM classification (Brinson, 1993a) uses first principles of geomorphology, hydrology, and hydrodynamics to separate wetlands into functional classes at a gross level, and serves as an organizing principle for the development of an assessment method. As with any classification there is the need to strike a balance between what is considered too general to provide useful information, or too specific to allow broad application on a national or regional scale. In this respect, the HGM classification is hierarchical and modular so it can be easily modified for different geographic regions or scales.

Four broad geomorphic settings are recognized in the classification: riverine, depressional, fringe (coastal), and extensive peatlands. Wetlands may potentially receive three sources of water: precipitation, overland flow, and groundwater discharge. Three hydrodynamic categories embody the strength and principal directions of flow: vertical fluctuation, unidirectional horizontal flow, and bidirectional horizontal flow. While the number of variables in the classification may seem daunting, the classification procedure can be condensed into simple narrative statements. For example, "Wetland 'A' is classified as depressional, lacks channeled inflows and outflows, and depends primarily on snowmelt within its small drainage basin for site water balance during the growing season". This description provides the essence of a limited range of depressional wetlands while giving useful specific information on water sources and hydrodynamics. In practice, reference wetlands are to be developed (Step 3) in order to supply more detailed descriptions and quantitative data to characterize each wetland class.

Step 2: Defining the Relationship Between Hydrogeomorphic Properties and the Functions of Wetlands

The traditional approach to assessing the functions of wetlands is to begin with a generic list of wetland functions (Conservation Foundation, 1988; Larson and Mazzarese, 1994) and then look for evidence that the wetland under consideration does indeed perform the functions. For example, if a wetland has permanent standing water, is connected to a larger body of water, and has interspersion of both emergent and submerged vegetation, it will likely support fish populations, and thus be determined to have a high probability of aquatic food web support. This approach has several problems not the least of which is its inefficiency owing to the fact that each newly assessed wetland must be tested against the full range of conditions that potentially occurs in all wetland classes. However, more importantly, a generic series of questions fails to explicitly define the relationship between properties of the wetland and the functions it is supposed to be performing. This 'black box' approach makes it difficult for the user to understand, learn from, or question the assumed relationships between wetland properties and functions. In fact, such procedures can be applied without ever acknowledging the wetland class and associated attributes.

An alternative approach is to logically induce which functions a wetland is likely to perform by examining hydrogeomorphic and other fundamental properties. A great deal of information about how a wetland functions can be derived from knowing the source of the water supplying a wetland and the climatic conditions in which it exists. For example, in mesic climates where the dominant water source of a wetland may be overbank flooding, a wetland is likely to provide sediment retention and rapid biogeochemical cycling because sediments and nutrients are carried to the wetland surface from the stream channel by overbank flooding. Table 1 provides more examples of this procedure from the HGM classification (Brinson, 1993a), and illustrates them for several commonly occurring combinations of climatic setting and water source. For each of these combinations, probable functions are identified in Table 1, Column 4 along with the rationale stating why the wetland is likely to perform the function. Of course in actual practice, the brief statements in Table 1 can be expanded by developing supplemental information along with literature citations of relevant studies.

The open and explicit nature of this approach has several benefits. First, the logical sequence of linking fundamental properties with functions encourages the user to learn and understand relationships between ecosystem properties and function. Another benefit is the scientific credibility gained through an open process of peer review of the assessment itself. The approach effectively thwarts any tendency to assume that a function exists when, in fact, it may not, or to attribute functioning when documentation of its presence is scanty or lacking. By displaying the logic and tracing the origin of functions, the assessment procedure is open for review and improvement through incorporation of new scientific evidence, and the addition or deletion functions. Additionally, there can be no hidden agenda in the assessment if it is open for modification and peer review. This reduces the potential for misuse.

Extensive data sets are not necessary to establish the relationship between fundamental properties of a wetland and the functions it performs. With the establishment of reference wetlands (Step

3, next) in which functions have already been evaluated, the site being evaluated is compared to the reference group of the same class. This avoids the need to establish an arbitrary scale for ranking; the scale is defined by the variation within the reference population itself. In other cases, the simple logic of cause and effect is sufficient to establish the presence or absence of specific functions. For example: Why are floodplain wetlands important to riverine fish populations? Reasons might include that seasonal flooding of the wetland allows fish to move from the channel to the floodplain wetland for feeding, spawning, and predator avoidance. Many wetlands lack this property. Why can't ombrotrophic bogs act as traps for fluvial sources of sediment? Because their water source comes only from precipitation which is devoid of fluvial sediments. Other wetland classes may receive loadings of sediments from more than one source. Why do estuarine fringe wetlands exhibit such strong zonation? Because twice daily tides serve as an organizing force. For this reason, successful creation of wetlands in tidal environments must have accurately controlled surface elevations. Although each of these answers is self evident, there is a tendency to skip over these fundamentals that may require explanation and documentation should the assessment be challenged.

Step 3: Developing Functional Profiles

Once the connection between hydrogeomorphic properties and functions of wetlands has been established, the significance of functioning can be articulated from ecological, hydrological, and other perspectives. These perspectives can be summarized in "functional profiles" for wetlands that have been assessed. A functional profile is a body of descriptive information that characterizes a functional wetland class or a single wetland. For example, wetlands that provide sediment retention and rapid biogeochemical cycling are ecologically significant because they help to maintain high primary productivity and complex habitat structure of the wetland ecosystem (Table 1, Row beginning with "overland (surface) transport", Column 5).

The availability of time, resources, and information will limit the completeness of functional profiles for both classes and specific sites. At minimum, one must develop a profile on a small reference population as a basis for the scaling of functions within a class (see next step), but also the profile must provide the basis for comparison between the reference population and a new site undergoing assessment. With continued progress and experience in conducting assessments, the information collected during the assessment procedure can become a significant database on soils, plant species, hydrology, topography, and other information for a particular HGM class. By combining this information with what can be gleaned from the literature, a more comprehensive functional profile could be developed for HGM wetland classes within a specific locality or region. For example, one riparian forest site in an arid region may have been studied for bird habitat, another for sediment retention, and yet another for flood-water storage. By combining the information from a number of field sites representative of a wetland class, it is possible to develop a composite functional profile much like the community profiles that the U.S. Fish and Wildlife Service has published for many wetland ecosystems such as mangroves (Odum et al., 1982), pocosins (Sharitz and Gibbons, 1982), Atlantic white cedar swamps (Laderman, 1989), irregularly flooded salt marshes (Stout, 1984), tidal freshwater marshes (Odum et al., 1984), tidal marshes of Pacific Northwest (Seliskar and Gallagher, 1983), prairie basin wetlands, (Kantrud et al., 1989), and others.

Step 4: Developing Scales for Function Using Reference Wetlands

Determining where a specific wetland falls along the scale of function requires a method for estimating or quantifying the properties of the wetland that determine how it functions. The ability to identify the position of a wetland on a scale of functioning is difficult but fundamental. In contrast

TABLE 1

Different combinations of water sources for wetlands, and their linkages to functions of ecological and geomorphic significance

Examples of water source[1] (climatic setting)	Qualitative scale[2]	Quantitative estimates[3]	Examples of functions[4]	Significance of function or characters maintained[5]
Precipitation (humid climate)	Precipitation dominates site water balance and water supply to plant community under poorly drained topography.	Precipitation approaches or exceeds PET during growing season so waterlogging is maintained.	Water table drawdown is rare; conducive for peat accumulation which further retards drainage. Paludification is promoted.	Biogenic landscape isolates mineral soil from access by plants; low primary production eventually results.[6]
Overland (surface) transport from overbank flow (mesic climate)	Discharge exceeds bankfull channel capacity at least annually.	Duration and frequency of overbank flow to floodplain can be inferred from hydrographs and floodplain elevation.	Overbank flow contributes to both flashy hydroperiod and vertical accretion of sediments; provides optimal conditions for rapid biogeochemical cycling and nutrient availability.	Conditions maintained for high primary productivity and complex habitat structure.
Groundwater discharge to wetland (mesic climate)	Seeps occur at bases of hillslopes or below breaks in slope, and along edges of streams and lakes.	Hydraulic head of groundwater increases in elevation with distance from the wetland. Substrate permeable enough to allow flows.	Groundwater supplies nutrients, renews water, and flushes potential growth inhibitors.	Conditions conducive for stable plant community of high productivity. Peat accumulation possible leading to fen formation.[7]
Both groundwater discharge and, during infrequent flood flows, overland transport from upstream.	Non-atmospheric sources greatly exceed supply from precipitation.	Precipitation << PET during growing season.	High water tables are maintained by continuous inputs from groundwater sources and by intermittent catchment supplies from upstream.	Water sources support vegetative complexity and habitat not found water stressed uplands due to arid climate.[8]

TABLE 1 (*continued*)

Examples of water source[1] (climatic setting)	Qualitative scale[2]	Quantitative estimates[3]	Examples of functions[4]	Significance of function or characters maintained[5]
All three sources but precipitation is minor (subhumid to semiarid)	Alternate drought and wet periods produce decade long cycles of water table fluctuations.	Precipitation < PET. Site water balance dependent on snowmelt just before growing season	High water levels due to decade long cycle in precipitation; cycles in combination with animal grazing causes extremes in plant biomass standing stock.	Primary production high when water is abundant; high decomposition during drawdown prevents peat accumulation. Hydrology and life history of plants interact to control biodiversity.[9]

[1] Five examples in four climatic settings are represented by dominance of only one water source (first three) and combinations of sources (last two). The subsurface source of groundwater for riverine wetlands originates from an upland recharge area and passes through an aquifer before it discharges to the alluvial fill of the floodplain. Water sources to the floodplain surface include overbank flow from the channel during floods and unchannelized overland runoff from the adjacent upland. Climates are approximated by the following relationships: humid climate, rain > potential evapotranspiration (PET); mesic climate, rain = PET; arid climates, rain << PET.

[2] Further description of spatial and temporal patterns of water source.

[3] Climatic records allow calculation of PET from the empirical formula (Holdridge et al., 1971): mean annual biotemperature × 58.93 = PET in mm, where mean annual biotemperature is the average of all values > 0°C. For wetland conditions to be maintained in climates where PET > rain, alternative sources of water (groundwater and surface water flow) are necessary.

[4] Other functions may exist; those listed serve only as examples.

[5] Information in this column represents on-site and off-site effects of the functions, and are used for development of profiles (Step 3). Considerable latitude can be taken in interpreting functions, but the effects should be founded on strong logic or documented by research results.

[6] Moore and Bellamy (1974).

[7] Roulet (1990).

[8] Brinson (1990).

[9] van der Valk (1981).

to the descriptive data that is incorporated into profiles (previous step), scaling will rely largely on indicators of function that can be observed in the field, or derived from other data sources. For example, salinity of water can be used to identify water source and related functions in wetlands as disparate as estuarine fringe (sea water source) and prairie potholes (groundwater source). In the former, salinity 'indicates' a connection with the ocean along with such attendant functions as nurseries for estuarine dependent and resident fish. In prairie potholes, high salinity 'indicates' a groundwater source and absence of a surface outflow (i.e., the salinity accumulates by evaporation). Consequently, species composition of aquatic organisms not only will be constrained by their tolerance to salinity, but the potential for repopulation of the pothole after local extinctions is limited because it lacks surface water connections for migration and recolonization by aquatic organisms. Such interpretations of salinity in the prairie pothole example would be valuable for ranking the functioning of the wetland as habitat for zooplankton and macroinvertebrate species (Kantrud et al., 1989).

Much progress is needed to work out acceptable protocols for developing reference wetland populations. These include (a) deciding what parameters can be measured efficiently and with enough precision to meet the needs of the assessment, (b) determining the kinds of data needed for developing reference populations and the minimal data requirements for an assessment, and (c) choosing who will decide what constitutes an adequate assemblage of reference wetlands. Existing sources are available that can provide guidance in making progress in reference wetland development (White et al., 1989; Technical Riparian Work Group, 1992).

Ultimately, society, through some economic or political decision-making processes, will choose which wetlands and functions to protect. For example, in the USA, the Clean Water Act did not originally include the term wetland. However, it quickly became obvious that in certain cultural settings it would be difficult, if not impossible, to "protect and maintain the .... integrity of the Nation's waters" without some effort to regulate activities in wetlands. One of the implications of "internalizing" the scale of function is that as wetlands, and the functions they perform, are better understood, policy choices may be made on the expanded scientific information base. For example, policy makers may choose to offer incentives that disproportionately protect relatively small headwater riparian wetlands that are critical for their role in improving water quality per unit area (Brinson, 1993b), while large expanses of floodplain forests or river swamps along high order streams may be deemed more important for maintaining fisheries and endangered species.

The importance of reference wetland populations to the credibility and defensibility of assessment efforts cannot be overemphasized. Reference wetlands are the real life documentation of the relationship between disturbance and function. As such, they are natural laboratories for learning and should contribute not only to an improved understanding of wetland functioning, but to better application of science into the realm of regulation and resource allocation.

As design templates, reference wetlands can provide "targets" for creation and restoration activities. There is no need to develop complex and detailed design criteria that specify the number of trees to plant, the species composition of the plant community, or slope and hydroperiod of the wetland surface. Rather, the species composition, cover, density, and other properties of the reference wetlands of a given class can serve as the goals for mitigation.

Discrete use of reference wetland populations eliminates the need to consider "opportunity" and "effectiveness" as necessary conditions for high rankings of some functions. Opportunity refers to whether a function can be carried out logistically. For example, a wetland immediately downstream from a reservoir lacks the opportunity to retain sediments because they settle out instead in the reservoir. Effectiveness refers to the magnitude or scale of a function often without upper limits being defined. Using a variation of the same example, a wetland tens of kilometers downstream from the reservoir would be more effective in retaining sediments than the one immediately downstream. It has been demonstrated, for example, that riparian zones in forested landscapes of east Tennessee are not strong sinks for nitrogen and phosphorus (Mulholland, 1992) as they are where loading rates are increased many-fold by agricultural activity (Peterjohn and Correll, 1984). To rank the riparian wetland in the agricultural landscape as higher in nutrient removal functioning than the one in a forested landscape is to miss the point of using reference wetlands. First of all, the function of nutrient removal is in no way impaired in the riparian zone of the forested landscape; it is simply that the role of nutrient retention is carried out by upland forests rather than riparian ones. If one were to assess the riparian forest for its functioning, it should be compared, and the functions scaled, with other riparian forests in forested rather than agricultural landscapes. Alternatively, it could be assessed for its potential function were human activities to change the landscape from forested to a nutrient-rich agricultural setting. Both approaches, however, avoid the pitfall of using inappropriate reference wetlands as the scale for evaluation and comparison.

Step 5: Developing the Assessment Method

Completion of the previous steps provides a strong foundation on which to develop the assessment method itself. The assessment tasks include, but are not limited to: (1) acquiring maps (topographic, National Wetlands Inventory (USA), land use, etc.), soil surveys, aerial photographs, hydrologic data (discharge, water levels), water quality data, land use of the watershed, history of the project site (if for a permit application); (2) becoming acquainted with the site by walking the boundary and several traverses, (3) filling out field sheets related to developing a profile of the site (water source, hydrodynamics, vegetation cover, soil type), (4) assessing whether indicators of functioning are present, and (5) developing narrative that describes the rank of the wetland relative to the reference wetland population.

Expert opinion is probably a necessary initial ingredient for developing an assessment method for a particular region of the country. A knowledge of the literature is essential for making the link between indicators and the functions themselves. In the process of developing the assessment method, time must be allotted for testing and revising the method. Judgments must be made on the limits of extrapolation and comparison among wetland sites. One of the more difficult aspects of assessment is balancing between the desire to have more data for achieving greater confidence in the results and the expediency of completing the task.

FUTURE DIRECTIONS

At the time of this writing (mid-1993), the co-authors are about midway through the development of a method for assessing the functions of riverine wetlands. As a team, three wetland field locations have been visited to enable us to identify and define functions that are appropriate for riverine wetlands. Indicators of function are being developed, but they have not yet been tested in any systematic way. Individuals on the team have begun to develop reference populations in their geographic vicinities for their own research needs. So far, we have not encountered great difficulty in any of the steps outlined in this paper. However, the functional classification step may not require completely new efforts in geographic regions where HGM classifications have been developed already for unrelated purposes. Classes of the riverine wetlands of Georgia, USA, (Wharton, 1978) are devoid of species descriptors; the classes are mountain river, blackwater river and swamp system, blackwater branch or creek system, alluvial river and swamp system in the piedmont, alluvial river and swamp system in the coastal plain, tidewater river and swamp system, and backwater streams. Even the names are well grounded in geomorphic setting (piedmont vs. coastal plain), water source (alluvial vs blackwater), and hydrodynamics (tidewater and backwater). Consequently, for riverine wetlands of Georgia, it still would be necessary to link these classes and their HGM properties to function, but the classification step itself may already provide an adequate foundation for building a functional assessment method.

The principal challenges of the HGM approach are developing reference wetland populations and determining indicators for functions. The former will require that field visits be formalized with the consistent collection of data in order to build a data set for scaling the assessment. We are not suggesting research-level efforts; rather, descriptions of soil type and hydric characteristics, species composition of the vegetation, and projection of flooding regime are all tasks in which regulatory personnel in the USA are trained already. The use of other indicators may require additional training, but the level of effort does not seem excessive. Testing the reliability and sensitivity of indicators, however, is an area that can progress only with the help of additional research efforts.

Finally, precautions need to be taken to minimize careless misuse and to avoid intentional misuse. The initial step of classification by functional class is especially vulnerable to affecting the outcome of the procedure because the determination of functions to be assessed is made at that step. Problems are most likely to be encountered at the boundaries between functional classes. In developing the procedure, it is essential that the functions for classes also mesh at those boundaries. This recognizes the reality of the continuous nature of transitions between wetland classes.

REFERENCES

Brinson, M.M., 1990. Riverine forests. In: A.E. Lugo, M.M. Brinson and S. Brown (Eds), Forested Wetlands. Elsevier, Amsterdam, pp. 87–191.

Brinson, M.M., 1993a. A Hydrogeomorphic Classification for Wetlands. Wetlands Research Program Technical Report WRP-DE-4. US Army Engineers Waterways Experiment Station, Vicksburg, MS.

Brinson, M.M., 1993b. Changes in the functioning of wetlands along environmental gradients. Wetlands, 13(2): 65–74.

Conservation Foundation, 1988. Protecting America's Wetlands: an Action Agenda. The Final Report of the National Wetlands Policy Forum. The Conservation Foundation, Washington, DC, 69 pp.

Holdridge, L.R., W.C. Grenke, W.H. Hatheway, T. Liang, and J.A. Tosi Jr., 1971. Forest Environments in Tropical Life Zones. Pergamon Press, NY, 747 pp.

Kantrud, H.A., G.L. Krapu and G.A. Swanson, 1989. Prairie Basin Wetlands of the Dakotas: A Community Profile. U.S. Fish and Wildlife Service Biological Report 85(7.28), 116 pp.

Laderman, A.D., 1989. The Ecology of Atlantic White Cedar Wetlands: A Community Profile. U.S. Fish and Wildlife Service Biological Report 85(7.21), Washington, DC, 114 pp.

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

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

Moore, P.D. and D.J. Bellamy, 1974. Peatlands. Springer-Verlag, New York, 221 pp.

Mulholland, P.J., 1992. Regulation of nutrient concentrations in a temperate forest stream: Roles of upland, riparian and instream processes. Limnol. Oceanog., 37: 1512–1526.

Odum, W.E., C.C. McIvor, and T.J. Smith, 1982. The Ecology of Mangroves of South Florida: A Community Profile. FWS/OBS-81/24, U.S. Fish and Wildlife Service, Division of Biological Services, Washington, DC, 144 pp.

Odum, W.E., T.J. Smith, III, J.K. Hoover, and C.C. McIvor, 1984. The Ecology of Tidal Freshwater Marshes of the

United States East Coast: A Community Profile. FWS/OBS-84/17, U.S. Fish and Wildlife Service, Division of Biological Services, Washington, DC, 177 pp.

Peterjohn, W.T. and D.L. Correll, 1984. Nutrient dynamics in an agricultural watershed: Observations on the role of a riparian forest. Ecology, 65: 1466–1475.

Roulet, N.T., 1990. Hydrology of a headwater basin wetland: Groundwater discharge and wetland maintenance. Hydrological Processes, 4: 387–400.

Seliskar, D.M. and J.L. Gallagher, 1983. The Ecology of Tidal Marshes of The Pacific Northwest Coast; A Community Profile. FWS/OBS-82/32, U.S. Fish and Wildlife Service, Division of Biological Services, Washington, DC, 65 pp.

Sharitz, R.R. and J.W. Gibbons, 1982. The Ecology of Southeastern Shrub Bogs (Pocosins) and Carolina Bays: A Community Profile. FWS/OBS-82/04, U.S. Fish and Wildlife Service, Division of Biological Services, Washington, DC, 93 pp.

Smith, R.D., 1993. A Conceptual Framework for Assessing the Functions of Wetlands. Wetlands Research Program Technical Report WRP-DE-3. US Army Engineers Waterways Experiment Station, Vicksburg, MS.

Stout, J.P., 1984. The Ecology of Irregularly Flooded Salt Marshes of Northeastern Gulf of Mexico: A Community Profile. U.S. Fish and Wildlife Service Biological Report 85(7.1), 98 pp.

Technical Riparian Work Group, 1992. Integrated Riparian Evaluation Guide: Intermountain Region. USDA Forest Service Intermountain Region, Ogden, Utah.

van der Valk, A.G., 1981. Succession in wetlands: a Gleasonian approach. Ecology, 62: 688–696.

Wharton, C.H., 1978. The natural environments of Georgia. Georgia Department of Natural Resources, Atlanta, GA, 227 pp.

White, T.A., J.A. Allen, S.F. Mader, D.L. Mengel, D.M. Perison, and D.T. Tew (Eds), 1989. Mist: A Methodology to Classify Pre-Project Mitigation Sites and Develop Performance Standards for Construction and Restoration of Forested Wetlands. Hardwood Research Cooperative, N.C. State University, Raleigh, NC, USA.