Proceedings of The Academy of Natural Sciences of Philadelphia 144: 240-253, 1993

Using Plants as Indicators of Wetland

RALPH W. TINER

U.S. Fish and Wildlife Service, Newton Corner, MA 02158

ABSTRACT.—Many types of wetlands are characterized by distinct plant communities, so vegetation can be used to easily identify these wetlands. Plant communities of drier wetlands, in particular temporarily flooded and seasonally saturated types, are often represented by plants that grow at least equally well in uplands and wetlands. This makes it extremely difficult, if not impossible, to simply use vegetation to identify these wetlands. Moreover, the upper boundaries of wetlands in areas of low topographic relief usually have a plant community containing both wetland and terrestrial species. These two situations require that other factors be considered to positively identify these areas as wetlands. This paper discusses the use of plants for wetland identification and how certain soil properties can be used to help make more difficult wetland determinations. It also addresses the impracticality of using specific hydrologic requirements to identify and even define wetlands. Finally, a new approach to wetland identification—*the Primary Indicators Approach*—is introduced. This method is an attempt to use only properties that are unique to wetlands for their identification, in marked contrast to the Federal government's three-parameter or three-criteria approach.

Certain plants and plant communities have been used to indicate the presence of wetlands. These wet habitats occur along the natural soil moisture gradient between permanently flooded deepwater areas and dryland. Wetlands are found in certain landscape positions: (1) low-lying areas subject to periodic flooding (e.g. along rivers and estuaries), (2) gentle slopes in areas of groundwater discharge (springs and seepage slopes) or surface water runoff (drainageways), (3) isolated depressions surrounded by uplands where surface water collects (e.g. ponds, lakes, kettle holes, potholes, playas, and vernal pools), (4) broad, relatively flat areas lacking drainage outlets (e.g. interstream divides and permafrost muskegs), and (5) flat or sloping areas adjacent to northern bogs and subject to paludification ("swamping" or "bogging"). Wetland hydrologic conditions vary from permanent inundation by shallow water or permanent soil saturation to periodic inundation or soil saturation. As soil wetness decreases, plant composition gradually changes from a more typical wetland community to a transitional community where typical wetland plants intermix with mesic species, making wetland identification challenging and by plants alone most difficult and somewhat arbitrary.

The varied hydrologic regimes associated with wetlands create a diverse set of environmental conditions that require different degrees of adaptation or tolerance of wetness by plants. Ecologists have traditionally described certain plant species and communities as characteristic of wetlands. Recent attention on wetlands has focused on determining the boundaries of wetlands for regulatory purposes. Today it is critical to know the limits of wetlands on individual parcels of land, since many activities (e.g. dredging or filling) require federal or state permits before commencing work. Because "hydrophytic vegetation" is a major determinant of federally regulated wetlands and is the chief determinant for regulation in some states (e.g. Massachusetts), it has become increasingly important to know which plants are, in fact, wetland indicators. The purpose of this paper is to discuss the concept of hydrophytic vegetation as it relates to wetland identification and delineation and the limitations of using plants for such assessment. In addition, recommendations on the use of plants or soils for wetland detection are presented along with some comments on the practicality of using hydrology to define the limits of wetlands. This paper is adapted in part from a more extensive treatment of the subject of hydrophytes (Tiner 1991a).

WHAT IS A WETLAND PLANT?

Plants growing in wetlands and water are technically called "hydrophytes." Most of the plants that grow in wetlands do not grow strictly in water or very wet soils, but also grow in terrestrial habitats. Many of these species are more common on the latter sites, but have populations that tolerate varying degrees of soil wetness. Unfortunately, due to the lack of distinctive morphological differences, individuals of these wetland populations can only be recognized as hydrophytes when associated with more typical hydrophytic species or after identification of hydric soils (i.e. anaerobic soils due to excessive wetness) and other signs of wetland hydrology at a given location (see Tiner 1991a for a detailed discussion of the concept of a hydrophyte).

Wetlands are mostly represented by self-supporting vascular plants that emerge from shallow water or grow in periodically flooded or saturated soils, but they also include many aquatic species (e.g. water lilies, pondweeds, and algae). Some common species that only occur in wetlands and water are presented in Table 1. Plants living in periodically inundated or saturated soils are not, however, restricted to these obligate wetland species, but also include many other species that grow in wetlands and nonwetlands to varying degrees.

For use in identifying wetlands, a national list of vascular plant species that occur in wetlands has been developed by the U.S. Fish and Wildlife Service with cooperation from other Federal agencies (Reed 1988). Because the affinity for wetlands varies considerably among plant species, the list was divided into four "wetland

Table 1. Examples of obligate hydrophytes that are widespread or particularly common in certain wetland types in the United States. Genera listed contain all or mostly obligates (Tiner 1991a).

AQUATICS. *Azolla* spp. (Mosquito-ferns). *Brasenia schreberi* (Water-shield). *Elodea* spp. (Water-weeds). *Isoetes* spp. (Quillworts). *Lemna* spp. (Duckweeds). *Myriophyllum* spp. (Water-milfoils). *Najas* spp. (Naiads). *Nuphar* spp. (Pond Lilies). *Nymphaea* spp. (Water Lilies). *Potamogeton* spp. (Pondweeds). *Proserpinaca* spp. (Mermaid-weeds). *Ruppia maritima* (Widgeon-grass). *Thalassia testudinum* (Turtle-grass). *Utricularia* spp. (Bladderworts). *Vallisneria americana* (Wild Celery). *Zannichellia palustris* (Horned Pond-weed). *Zostera marina* (Eel-grass).

EMERGENTS (HERBS). *Alisma* spp. (Water-plantains). *Calla palustris* (Wild Calla). *Caltha palustris* (Marsh Marigold). *Carex aquatilis* (Water Sedge). *Carex stricta* (Tussock Sedge). *Cicuta maculata* (Water Hemlock). *Decodon verticillatus* (Water-willow). *Drosera* spp. (Sundews). *Dulichium arundinaceum* (Three-way Sedge). *Eleocharis* spp. (Spike-rushes). *Eriophorum* spp. (Cotton-grasses). *Glyceria* spp. (Manna Grasses). *Iris versicolor* (Blue Flag). *Juncus canadensis* (Canada Rush). *Juncus roemerianus* (Black Needlerush). *Leersia oryzoides* (Rice Cutgrass). *Lindernia dubia* (Water Pimpernel). *Osmunda regalis* (Royal Fern). *Peltandra virginica* (Arrow Arum). *Polygonum hydropiperoides* (Water Pepper). *Polygonum sagittatum* (Arrow-leaved Tearthumb). *Pontederia cordata* (Pickerelweed). *Sagittaria* spp. (Arrowheads). *Salicornia virginica* (Perennial Glasswort). *Scirpus americanus* (Olney's Three-square). *Scirpus atrovirens* (Green Bulrush). *Scirpus validus* (Soft-stemmed Bulrush). *Sium suave* (Water Parsnip). *Solidago patula* (Rough-leaved Goldenrod). *Solidago uliginosa* (Bog Goldenrod). *Spartina alterniflora* (Smooth Cordgrass). *Symplocarpus foetidus* (Skunk Cabbage). *Triglochin* spp. (Arrow-grasses). *Typha* spp. (Cattails). *Woodwardia virginica* (Virginia Chain Fern). *Xyris* spp. (Yellow-eyed Grasses). *Zizania aquatica* (Wild Rice).

SHRUBS. *Andromeda polifolia* (Bog Laurel). *Betula pumila* (Bog Birch). *Cephalanthus occidentalis* (Buttonbush). *Forestiera acuminata* (Swamp Privet). *Lonicera oblongifolia* (Swamp Fly-honeysuckle). *Myrica gale* (Sweet Gale). *Rhizophora mangle* (Red Mangrove). *Rosa palustris* (Swamp Rose). *Salix sericea* (Silky Willow). *Vaccinium macrocarpon* (Large Cranberry).

TREES. *Carya aquatica* (Water Hickory). *Chamaecyparis thyoides* (Atlantic White Cedar). *Fraxinus profunda* (Pumpkin Ash). *Gleditsia aquatica* (Water Locust). *Nyssa aquatica* (Water Gum). *Planera aquatica* (Planer-tree). *Quercus lyrata* (Overcup Oak). *Taxodium distichum* (Bald Cypress).

Table 2. Wetland indicator categories of plant species that occur in wetlands, under natural conditions (Reed 1988).

Wetland Indicator Category	Estimated Probability of Occurrence in Wetlands	Estimated Probability of Occurrence in Nonwetlands
Obligate Wetland (OBL)	>99% of the time	< 1% of the time
Facultative Wetland (FACW)	67-99% of the time	1-33% of the time
Facultative (FAC)	34-66% of the time	34-66% of the time
Facultative Upland (FACU)	1-33% of the time	67-99% of the time

Note: Plant species that almost always occur in nonwetlands (>99% of the time) are considered upland plants. Also, in assigning indicator categories to individual plant species, a plus or a minus was added as appropriate; a plus after the category (e.g. FAC+) indicates that the species occurs in the higher portion of the range in wetlands (e.g. 51-66% of the time), whereas a minus (e.g. FAC-) indicates the lower portion of the range (e.g. 49-34%).

indicator categories" based on differences in expected frequency of occurrence in wetlands: (1) obligate wetland (OBL), (2) facultative wetland (FACW), (3) facultative (FAC), and (4) facultative upland (FACU) (Table 2).

Most wetland scientists recognize both OBL and FACW species as hydrophytic and indicators of wetlands because they are more often associated with wetlands than nonwetlands. The FAC and FACU species should be simply regarded as potentially hydrophytic, since they are known to occur in wetlands with some frequency. In some parts of the country, a plant species may not be as good an indicator as it is in others (Table 3). The national list reflects this variation by including wetland indicator categories for plant species in 13 different geographic regions. To facilitate use of the list across the country, the national list has been divided into 13 separate regional lists. Intraregional differences exist in some species, but such assessment was beyond the purpose of the original list.

The national list of wetland plants contains 6,728 species out of a total of approximately 22,500 vascular plant species that exist within all habitats in the United States and its territories and possessions (Reed 1988). Only 31% of the nation's flora occur often enough in wetlands to be on the list. Although the list is lengthy, it does not contain the majority of U.S. plant species, which are virtually intolerant of flooding or prolonged soil saturation during the growing season. Only 27% of the national wetland plant list is represented by OBL species (Tiner 1991a). The majority of listed species, therefore, grow in both wetlands and nonwetlands to different extents.

FAC species, by definition, have essentially no affinity for wetlands or nonwetlands and, therefore, are not indicative of either. They have broad ecological amplitudes or narrower habitat requirements centered around wetland borders (e.g. rich moist soils). FAC species may be found with nearly equal frequency in both habitats, yet they are often the dominant plants in many wetlands. The use of FAC species as "wetland plants" has created considerable debate as witnessed by the preamble (Issues Section) of the proposed 1991 revisions to the federal wetland delineation manual (56 Federal Register 40446-40480, August 14, 1991). Some people claim that these species are not wetland plants, while others disagree. This debate is largely semantic, since most people should agree that the presence of these species *alone* (without considering the rest of the plant community and usually soils and hydrology) does not indicate wetland or nonwetland. The controversy is centered on how these species should be used in applying the so-called "50-percent rule" for determining whether a given plant community is hydrophytic (e.g. is more than 50 percent of the community or the dominants represented by hydrophytic species?). The 1989 Federal wetland delineation manual considers FAC species as potential hydrophytes, since a predominance of these plants does not alone establish an area as wetland but requires examination of the soil and hydrology before the area is identified as wetland or nonwetland. This is the foundation of the three-criteria approach to wetland identification where criteria for hydrophytic vegetation, hydric soil, and wetland hydrology must be

Table 3. Examples of species with recognized varieties occurring in different habitats. Range in wetland indicator status in its U.S. distribution based on Reed (1988). Habitat data from Fernald (1950) and Gleason and Cronquist (1963).

Species (Common Name)	Variety	National Range of Indicator Status	Habitat
Acer rubrum			
(Red Maple)	*rubrum*	FAC	swamps, alluvial soils, and moist soil
(Swamp Red Maple)	*drummondii*	OBL to FACW	deep swamps
(Trident-leaved Red Maple)	*trilobum*	OBL to FACW+	forested wetlands
Andropogon virginicus			
(Broom-sedge)	*virginicus*	FACU to FAC	dry open soils, thin woods, etc.
	glaucus	not designated	dry sandy pine barrens
	tetrastachyus	not designated	dry sands, rocks, and pinelands
	glaucopsis	not designated	savannas, wet pineland, and swamps
	hirsutior	not designated	river-swamps, savannas, and marshes
Celtis laevigata			
(Sugarberry)	*laevigata*	FACW to UPL	bottomlands and low woods
	smallii	not designated	bottomlands and low woods
	texana	not designated	bluffs, rocky slopes, dry woods, etc.
Fagus grandifolia			
(American Beech)	*grandifolia*	FACU	rich upland soils
	*caroliniana**	FAC+	moist or wet lowland soils, especially on or near the coastal plain
Nyssa sylvatica			
(Black Gum)	*sylvatica*	FAC	low acid woods, swamps, and shores
(Swamp Tupelo)	*biflora*	OBL to FACW+	inundated swamps and damp sands
	caroliniana	not designated	chiefly on uplands of the interior
Panicum virgatum			
(Switchgrass)	*virgatum*	FACW to FAC	dry or moist sandy soils, and shores
	spissum	not designated	gravelly or sandy fresh to brackish shores and swamps
Quercus falcata			
(Southern Red Oak)	*falcata*	FACU to FACU-	moist to dry woods
(Cherrybark Oak)	*pagodaefolia*	FACW to FAC+	chiefly on bottomlands or near streams

*Designated as FAC+ only in the Northeast, while this variety also occurs in the Southeast, Midwest, and South Plains (Texas and Oklahoma).

verified to make a wetland determination (Federal Interagency Committee for Wetland Delineation 1989). It recognizes the transitional nature of plant composition along the soil moisture gradient and requires that other features be evaluated to separate wetland from nonwetland.

FACU species (plants that are typically found in nonwetlands) may also be common in wetlands and may even characterize certain wetland types (e.g. hemlock swamps). This creates a serious perception problem when attempting to characterize plant species as hydrophytes or wetland plants. Many people, especially the general public, may have difficulty understanding that FACU species can be hydrophytes, since as a species they are usually typical upland plants. We must remember that plants did not evolve to become a FACU or other indicator species; this designation is purely the product of our attempt to use plants as indicators of wet-

Table 4. Plant adaptations or responses to flooding and waterlogging (Tiner 1991a).

Morphological Adaptations/Responses

Stem hypertrophy (e.g. buttressed tree trunks)
Large air-filled cavities in center (stele) of roots and stems
Aerenchyma tissue in roots and other plant parts
Hollow stems
Shallow root systems
Adventitious roots
Pneumatophores (e.g. cypress knees)
Swollen, loosely packed root nodules
Lignification and suberization (thickening) of root
Soil water roots
Succulent roots
Aerial root-tips
Hypertrophied (enlarged) lenticels
Relatively pervious cambium (in woody species)
Heterophylly (e.g. submerged vs. emergent leaves on same plant)
Succulent leaves

Physiological Adaptations/Responses

Transport of oxygen to roots from lenticels and/or leaves (as often evidenced by oxidized rhizospheres)
Anaerobic respiration
Increased ethylene production
Reduction of nitrate to nitrous oxide and nitrogen gas
Malate production and accumulation
Reoxidation of NADH
Metabolic adaptations

Other Adaptations/Responses

Seed germination under water
Viviparous seeds
Root regeneration (e.g. adventitious roots)
Growth dormancy (during flooding)
Elongation of stem or petioles
Root elongation
Additional cell wall structures in epidermis or cortex
Root mycorrhizae near upper soil surface
Expansion of coleoptiles (in grasses)
Change in direction of root or stem growth (horizontal or upward)
Long-lived seeds
Breaking of dormancy of stem buds (may produce multiple stems or trunks)

lands. Only a small portion of the world's higher plants have successfully made the transition back to a fully aquatic existence, despite the origin of the land plants from aquatic algae over 400 million years ago (Davy et al. 1990). Evolution is still occurring and land plants are continuing to adapt to life in wetlands and water. Consequently, scientists have long recognized that certain populations of FACU species have successfully adapted to wetland environments (see following section and Table 5 for additional discussion).

WETLAND ECOTYPES

At the species level, plants do not have exactly the same environmental requirements and individual populations may differ in their tolerance of degrees of wetness. It has long been recognized that a given plant species may include ecotypes—a population or group of populations having certain genetically-based morphological and/or physiological characters, but usually prevented from natural interbreeding by ecological barriers (Turesson 1922a, 1922b, 1925; Barbour et al. 1980). Recognizing the existence of wetland ecotypes, races, varieties, subspecies, and other variants or simply acknowledging wide wetness tolerances of plant species should make it easier to understand that a subset of the continental population of a FACU species is typically adapted for life and actually thriving in periodically waterlogged soils.

For many plant species, subspecies or varieties that are found in different habitats or with a restricted distribution are recognized (Table 3). In some cases, these varieties have been assigned a different indicator status, especially when their habitats are wetter than the typical species. Because of their morphological differences, they may be useful for identifying wetlands.

Besides the known difference in varietal habitat preferences, individuals of FACU and other species growing in wetlands can be examined for morphological, physiological and/or other adaptations to flooding or soil saturation (Table 4). Such study may reveal wetland ecotypes: morphological adaptations are particularly useful for this, but may require considerable technical expertise. Some plants may be typically shallow-rooted or have adaptable root systems that favor establishment in wetlands. Red maple (*Acer rubrum*) has an adaptable root system: in swamps, it develops numerous shallow lateral roots to help avoid anaerobic stress, whereas in dry uplands, a deep tap-root is formed (Kramer 1949). Consequently, this species occurs with nearly equal frequency in both wetlands and nonwetlands. Eastern hemlock (*Tsuga canadensis*) is a relatively shallow-rooted plant that dominates certain swamps in the Northeast (Huenneke 1982, Niering 1953, Tiner 1989). Shallow root systems in other plants also help them survive and flourish in wetlands. This may be an individual plant's response to a wet environment. Timing of germination and the environmental conditions that follow may be crucial to the development of this adaptation.

Responses of woody and herbaceous plants to flooding and soil saturation have received considerable attention (Crawford 1983, Gill 1970, Hook 1984, Hook and Scholtens 1978, Hook et al. 1988, Jackson and Drew 1984, Kozlowski 1984, Teskey and Hinckley 1978; Whitlow and Harris 1979), but our knowledge is far from complete on this subject. We do know that a plant's response to flooding may be quite different than its response to waterlogging. For example, red ash (*Fraxinus pennsylvanica*) was determined to be more flood-tolerant than eastern cottonwood (*Populus deltoides*) (Hosner 1958), yet the latter was more tolerant of soil saturation (Hosner 1959). Caution must therefore be exer-

Table 5. Examples of common FACU species found in wetlands in the Northeast; most may be dominant species in certain wetland types.

Species	Wetland Types	References
Picea rubens (Red Spruce)	bogs in glaciated regions and in the Appalachians	Tiner (1988); Brooks et al. (1987)
Pinus rigida (Pitch Pine)	lowlands in New Jersey Pine Barrens; bogs	Ledig and Little (1979); Little (1959)
Pinus strobus (Eastern White Pine)	sandy forested wetlands in eastern and central U.S.; bogs	Huenneke (1982); Tiner (1988, 1991c)
Tsuga canadensis (Eastern Hemlock)	mucky swamps in glaciated areas	Huenneke (1982); Niering (1953); Tiner (1989, 1991c)
Fagus grandifolia (American Beech)	temporarily flooded forested wetlands, chiefly along Atlantic Coastal Plain	Tiner (1988)
Fraxinus americana (White Ash)	forested wetlands	Golet et al. (1990); Magee (1981); Tiner (1985a)
Prunus serotina (Black Cherry)	temporarily flooded forested wetlands along floodplains	Tiner (1988)
Liriodendron tulipifera (Tulip Poplar)	forested wetlands along Atlantic Coastal Plain	Niering (1953); Tiner (1985a, 1985b, 1988)
Quercus alba (White Oak)	forested wetlands along Atlantic Coastal Plain	personal observations; C. Rhodes and M. Slattery (pers. comm.)
Ilex opaca (American Holly)	forested wetlands along Atlantic Coastal Plain	Tiner (1988)
Aralia nudicaulis (Wild Sarsaparilla)	temporarily flooded red maple swamps in New England	personal observations
Mitchella repens (Partridgeberry)	temporarily flooded or seasonally saturated forested wetlands (mostly evergreen)	Tiner (1988)
Parthenocissus quinquefolia (Virginia Creeper)	shrub and forested wetlands	Tiner (1988)

cised in extrapolating results of flood tolerance studies and concluding that one species is more water-tolerant than another. Of additional significance in using plants to identify wetlands is that distinct populations with genotypic or phenotypic differences in flooding tolerance may exist (Gill 1970, Crawford and Tyler 1969). Keeley (1979) recognized upland, swamp, and floodplain phenotypes of black gum (*Nyssa sylvatica*) in the Southeast. The upland plants were very intolerant of flooding, the swamp plants highly flood-tolerant, and the floodplain plants had intermediate tolerances. Considering only the species level, therefore, is usually not enough for determining what constitutes a wetland plant.

All FACU species have been observed in wetlands, so they may be viewed as "potential hydrophytes." The national list of wetland plant species includes about 1,400 FACU species (21% of the list) (Tiner 1991a). Some prominent examples of these species that characterize certain wetlands the Northeast are listed in Table 5. They illustrate that individuals of species more characteristic of uplands have successfully adapted to and thrive in wetland environments. While some hydrophytic individuals may have distinctive morphological adaptations, most do not and they can only be recognized when associated with typical hydrophytes or after determining that hydric soils and signs of wetland hydrology are present at the site.

FACTORS AFFECTING PLANT DISTRIBUTION

The occurrence of a plant species on the landscape can be drastically changed by human activities or natural processes. This further complicates the potential use of plants to identify wetlands.

The distribution and abundance of many plants have been significantly impacted by forestry practices, agricultural activities, urban development, drainage projects, pollution, and other human-induced actions. Planted crops, either agricultural or silvicultural, provide little information on the types of plants that would naturally grow in an area. For example, at the time of this country's settlement, in southern New England, white pine was probably only abundant in swamps and moist sandy flats and on exposed ridges due to its susceptibility to fire (Bromley 1935). Today, with silvicultural plantings and the suppression of forest fires, the species grows on many better drained sites where it probably did not naturally occur. Consequently, the present distribution of eastern white pine is largely a result of human activities. Without knowing something about the history of this pine and human intervention, one might think that it was always more abundant on New England uplands. Areas that are annually tilled and planted with row crops offer only limited information on the current wetness of the site. The success of exotic annual weeds associated with agriculture has further complicated the interpretation of vegetation as indicators of wetland.

Natural events may similarly affect the distribution of plants in wetlands. For example, long-term droughts significantly affect the plant composition of the wetlands. During these extended dry periods, FACU annuals and even perennials may colonize and dominate wetlands. In fact, this is the rule and not the exception in emergent wetlands in semiarid and arid regions. Plants are known to be rapid colonizers and in many respects are better indicators of the short-term hydrologic conditions than the long-term hydrology. Fire is also another major natural factor in changing plant composition. Major changes in regional climates can profoundly alter vegetation patterns on the landscape and eliminate existing wetlands or create new wetlands, depending on whether the climate becomes more arid or more humid, respectively.

Wetland delineators must be particularly mindful of these situations or else risk misjudging a plant species' ecological significance or misinterpreting the significance of the existing plant community in assessing an area's wetness. The 20th century landscape can be a most confounding ecological expression to decipher.

INDIVIDUALISTIC CONCEPT OF A HYDROPHYTE

The current concept of a hydrophyte for wetland identification recognizes that "hydrophytes" are individual plants or populations of a plant species growing in water or in, at least periodically saturated, anaerobic soils (Tiner 1991a). While the 1989 federal wetland manual characterizes hydrophytic vegetation as a plant community where more than 50 percent of the dominant species from all vegetative strata are OBL, FACW, and/or FAC, it recognizes that not all hydrophytic plant communities meet this condition since FACU species may dominate certain wetlands (Federal Interagency Committee for Wetland Delineation 1989). These communities are handled as "problem area wetlands" and require that hydric soils and wetland hydrology be confirmed before characterizing such communities as hydrophytic vegetation. This procedure, in effect, recognizes the existence of wetland ecotypes, races, varieties, etc. of FACU species or that such species have considerable ecological amplitude or wetness tolerance, and permits their use to meet the hydrophytic vegetation criterion for identifying wetlands. The "individualistic" concept of a hydrophyte recognizes that plant species may exhibit considerable plasticity or ecological amplitude in their adaptations to wet environments. Thus, this concept is not bound to the species level in plant taxonomy, but allows, for example, wetland variants of FACU species to be classified as hydrophytes.

USING SPECIFIC PLANTS AND SOILS TO IDENTIFY WETLANDS

Over the past 25 years, the use of plant species to identify wetlands has evolved from one approach (used by state regulatory agencies) where the predominance of "wetland plant species" was the chief determinant of wetland and its boundaries to the current approach (used by Federal agencies and some states) where vegetation is used in concert with soil and hydrologic characteristics to identify and delineate wetlands. The former approach is still useful for identifying the wetter wetlands (e.g. salt marshes, inland marshes, shrub bogs, and cypress-tupelo swamps) where OBL species predominate or in areas where OBL species form a significant element of the plant community, but a more broad-based approach incorporating soil properties is required to accurately define the limits of the variety of wetlands found throughout the United States along the soil moisture gradient. The existence of wetland ecotypes lacking distinguishing morphological characteristics to separate them from the typical species, the current limits of our knowlege on these ecotypes, and the broad ecological amplitude or wide wetness tolerance of many species complicates the use of plants to identify and elineate wetlands. Consequently, evaluation of soil properties and consideration of hydrologic conditions (at least, whether the area is significantly drained or not) are essential to accurate wetland identification and delineation in many areas. So, if plants alone are not the answer to defining or delineating all vegetated wetlands, how then can plants and soils be used to accomplish this objective?

In the 1980s, Federal regulatory agencies (Corps of Engineers — CE, and Environmental Protection Agency — EPA) developed a three-parameter approach which essentially required finding "positive indicators" of three parameters — hydrophytic vegetation, hydric soils, and wetland hydrology — to identify and delineate wetlands (Environmental Laboratory 1987; Sipple 1988). The apparent rationale for this approach was that wetlands existed only where "positive indicators" of all three parameters were found and that the upper boundary was drawn where evidence of one parameter was lacking. This approach required that some sign of wetland hydrology (other than hydrophytic vegetation and hydric soils) be present at all times of the year and that the list of hydrology indicators emphasized direct and indirect evidence of surface water (inundation) and only direct evidence of soil saturation. Consequently, the list of hydrology indicators was conspicuously lacking indirect indicators of soil saturation. In 1989, four Federal agencies (CE, EPA, Fish and Wildlife Service, and Soil Conservation Service) combined existing methodologies in developing a technical manual to identify vegetated wetlands in the U.S. entitled "Federal Manual for Identifying and Delineating Jurisdictional Wetlands" (Federal Interagency Committee for Wetland Delineation 1989). To identify vegetated wetlands potentially subject to some form of Federal regulation or policy ("jurisdiction"), the agencies adopted the general concept of the three-parameter approach and specifically defined three technical criteria — hydrophytic vegetation, hydric soils, and wetland hydrology — that would be used to identify wetlands. This three-criteria approach required verification of all three criteria, but recognized the close interrelationships between vegetation, soils, and hydrology, and the difficulty of assessing the hydrology criterion in the dry season. As a result, certain soil properties and various vegetation characteristics (e.g. buttressed stems, pneumatophores, and hypertrophied lenticels) were used to verify wetland hydrology in the absence of significant hydrologic modification. This approach has been criticized by three-parameter fundamentalists as not being a pure or strict three-criteria approach with three "independent" criteria and clearly it is not. The three-criteria or three-parameter approach will always be subject to such criticism due to the nature of wetlands and the interdependence between vegetation, soils, and hydrology. Hydrology is the only independent variable and the soils and vegetation are dependent variables reflecting the hydrologic conditions. While everyone readily admits that hydrology is the driving force creating and maintaining wetlands, hydrology (especially the actual presence of water) is the least useful parameter for wetland identification due to its dynamic nature varying daily, seasonally, and annually and the lack of long-term hydrologic data for most wetland types. Soil and vegetation of wetlands are the direct result of wetland hydrology and certain distinctive soil or vegetation characteristics should be sufficient evidence to document the occurrence of wetland *in the absence of significant drainage.* They are the product of thousands of years of hydrologic conditions, except where recent hydrologic changes have occurred. Simply stated, hydrophytes and hydric soil properties are reliable indicators of wetland or wetland hydrology provided the area has not been effectively drained. The following approach emphasizing these characteristics is offered as an alternative to the three-criteria approach. This approach is not really new, but is a refinement of traditional methods to identify wetlands, using the best features of existing methods.

THE PRIMARY INDICATORS APPROACH TO WETLAND IDENTIFICATION

Wetlands are highly varied and complex habitats subject to different hydrologic regimes, climatic conditions, soil formation processes, and geomorphologic settings across the country. Plant communities and soil properties have developed in response to these variables. Within similar geographic areas, wetlands have developed characteristics different than adjacent uplands (nonwetlands) due to the presence of water in or on top of the soil for prolonged periods during the year. The visible expression of this wetness may be evident in the plant community or in the underlying soil properties. Consequently, every wetland in its natural undrained condition should possess at least one distinctive feature that distinguishes it from the adjacent upland. The "primary indicators approach" is founded on this premise. Moreover, this approach is not really new, but is an outgrowth of traditional methods used to recognize wetlands, including the Fish and Wildlife Service's wetland classification system (Cowardin et al. 1979) which is widely recognized as the national standard for wetland classification (Mader 1991). Certain wetlands can be identified by a single feature such as a plant community dominated by OBL species (e.g. cattail marsh, buttonbush swamp, leatherleaf bog, or bald cypress swamp) or by organic soils (peats and mucks, not Folists), for example. The average citizen should be able to recognize these wetlands. Many wetlands display such obvious signs, and requiring documentation of other factors to identify these wetlands is time-consuming and of questionable utility. As long as there is no evidence of significant drainage, any area possessing one of these or other diagnostic features should be a wetland. A "primary indicator" is a single vegetation characteristic or soil property that can be reliably used to indicate the presence of wetland; it is a property that is essentially unique to wetlands. Since each primary indicator is decision-oriented, it does not have to be used in combination with other indicators. A potential list of these primary wetland indicators is presented in Table 6. The list includes both vegetation and soil indicators that verify the presence of wetland in the absence of significant signs of drainage.

From a vegetation perspective, emphasis for wetland identification is placed on OBL species and FACW species. OBL species almost always occur in wetlands (frequently of occurrence in wetlands > 99% of the time), while FACW species occur more often in wetlands than in nonwetlands (Table 2). These types of plants are the best vegetation indicators of wetland (Tiner 1991a). A plant community dominated by these species should be an obvious wetland. The presence of OBL species in lesser numbers in a plant community should also be sufficient to recognize communities dominated by facultative-type species as wetlands. The vegetation indicators presented in Table 6 represent wetlands with an excellent and readily visible plant community expression of the hydrology.

Where primary vegetation indicators of wetlands are not present, soil indicators must be relied upon to separate wetland from nonwetland. This helps avoid the confusion over

Table 6. Recommended list of primary indicators for U.S. wetlands. The presence of any of these characteristics in an area that has not been significantly drained or similarly hydrologically modified, typically indicates wetland. The upper limit of wetland is determined by the point at which none of these indicators are observed. (Note: Exceptions may occur as they do with any method and will be specified in the future as detected.

Vegetation Indicators of Wetland

V1. OBL species comprise more than 50 percent of the abundant species of the plant community. (*An abundant species is a plant species with 20 percent or more areal cover in the plant community.*)
V2. OBL *and* FACW species comprise more than 50 percent of the abundant species of the plant community.
V3. OBL species comprise at least 5 percent cover in the plant community and are evenly distributed throughout the community.
V4. One abundant plant species in the community has one or more of the following morphological adaptations: pneumatophores (knees), prop roots, hypertrophied lenticels, buttressed stems or trunks, and floating leaves. (*Note*: Some of these features may be of limited value in tropical U.S., e.g. Hawaii.)
V5. Surface encrustations of algae, usually blue-green algae, are materially present. (*Note*: This is a particularly useful indicator of drier wetlands in arid and semiarid regions.)
V6. The presence of significant patches of peat mosses (*Sphagnum* spp.) along the Gulf and Atlantic Coastal Plain. (*Note*: This may be useful elsewhere in the temperate zone.)
V7. The presence of a dominant groundcover of peat mosses (*Sphagnum* spp.) in boreal and subarctic regions.

Soil Indicators of Wetland

S1. Organic soils (except Folists) present.
S2. Histic epipedon (e.g. organic surface layer 8-16 inches thick) present.
S3. Sulfidic material (H_2S, odor of "rotten eggs") present within 12 inches of the soil surface.
S4. Gleyed* horizon or dominant low chroma ped faces (chroma 2 or less with mottles or chroma 1 or less with or without mottles) present immediately (within 1 inch) below the surface layer (A-horizon) and within 18 inches of the soil surface.
S5. Nonsandy soils with a low chroma matrix (chroma of 2 or less) within 18 inches of the soil surface and one of the following present within 12 inches of the surface:
  a. iron and manganese concretions or nodules; or
  b. easily recognized (distinct or prominent) oxidized rhizospheres along several living roots; or
  c. low chroma mottles.
S6. Sandy soils with one of the following present:
  a. thin surface layer (1 inch or greater) of peat or muck where a leaf litter surface mat is present; or
  b. surface layer of peat or muck of any thickness where a leaf litter surface mat is absent; or
  c. surface layer (A-horizon) having a low chroma matrix (chroma 1 or less and value of 3 or less) greater than 4 inches thick; or
  d. vertical organic streaking or blotchiness within 12 inches of the surface; or
  e. easily recognized (distinct or prominent) high chroma mottles occupy at least 2 percent of a low chroma subsoil matrix within 12 inches of the surface; or
  f. organic concretions within 12 inches of the surface; or
  g. easily recognized (distinct or prominent) oxidized rhizospheres along living roots within 12 inches of the surface; or
  h. cemented layer (orstein) within 18 inches of the soil surface.
S7. Native prairie soils with a low chroma matrix (chroma of 2 or less) within 18 inches of the soil surface *and* one of the following present:
  a. thin surface layer (at least 1/4 inch thick) of peat or muck; or
  b. accumulation of iron (high chroma mottles, excluding oxidized rhizospheres) within 12 inches of the surface; or
  c. low chroma (gray-colored) matrix or mottles present immediately below the surface layer (A-horizon, mollic epipedon); or
  d. iron and manganese concretions within the surface layer (A-horizon, mollic epipedon).

(*Note*: The native prairie region extends northward from Texas to the Dakotas and adjacent Canada.)

S8. Remains of aquatic invertebrates are present within 12 inches of the soil surface in nontidal pothole-like depressions.
S9. Other regionally applicable, field-verifiable soil properties associated with prolonged seasonal high water tables.

*Gleyed colors are low chroma colors (chroma of 2 or less) formed by excessive soil wetness; other non-gleyed low chroma soils may occur due to (1) dark-colored materials (e.g. granite and phyllites), (2) human introduction of organic materials (e.g. manure) to improve soil fertility, (3) podzolization (natural soil leaching process in acid woodlands where a light-colored, often grayish E-horizon or eluvial-horizon develops below the A-horizon; these uniform light gray colors are not due to wetness).

whether FAC and FACU species "indicate" wetlands. Organic soils (excluding Folists) designate wetlands, provided the area is not significantly drained. So a stand of eastern hemlock (a FACU species) growing on an organic soil qualifies as wetland due to the nature of the soil and coincidentally these individual plants should then be recognized as hydrophytes. Properties of soils classified in the field as Typic subgroups of Aquic suborders according to "Soil Taxonomy" (Soil Survey Staff 1975; 1990) also indicate wetlands in their undrained condition since these are typical poorly and very poorly drained soils. Characteristics of these and similarly wet soils on a given site are vital to identifying wetland and separating it from nonwetland. The actual series name of the soil is not really important for field delineation of wetlands, since some series listed in "Hydric Soils of the United States" (U.S.D.A. Soil Conservation Service 1991) are only hydric in certain landscape positions (usually depressional areas, toes of slopes, or low slopes). Many, but not all, of these series are marked by a footnote on the recently published list. Based on my observations in the Northeast, any series on the list classified as a Aeric subgroup should be footnoted, but many have not been so noted, presumably because "dry phases" have not been officially designated for these series. Consequently, the actual (field-verified) soil properties that designate the Typic and similarly wet subgroups of Aquic suborders should be used to establish the presence of wetlands. In fact, these properties, which include a gleyed (low chroma due to wetness) matrix or low chroma mottles (ped faces) immediately below the A-horizon, are among the many features that reflect long-term wetness in the soil and represent the primary indicators that will most often be used to separate wetland from nonwetland, especially in areas of low topographic relief.

Following the "primary indicators approach," the boundary of a designated wetland will be located at the point at which none of the primary indicators of wetland are found. In areas of low relief, soil indicators will be the determining factor, while in areas of abrupt topographic change, vegetation indicators may be the deciding factor. The primary indicators approach to wetland identification and delineation greatly simplifies the process as compared to the three-criteria approach and makes efficient use of limited field time, yet it still requires use by a trained professional for the more difficult wetland situations.

DISTURBED AREAS

The only disturbance of major national significance that is relevant to making a wetland determination is hydrologic alteration, namely drainage. If vegetation has been removed and the hydrology of an area has not been disturbed, the soil indicators remain valid wetland indicators. If both vegetation and soils are removed, the area's hydrology should be considered significantly altered and should warrant further assessment. Areas of extensive ditching and tile drainage should be similarly treated.

In the context of evaluating significantly drained sites, such as farmland or certain managed forests, one must determine whether the area is still wet enough to function as wetland. Hydrology and functions generally vary for each wetland type, so the requirements for assessing hydrology in disturbed sites should vary with the type of "wetland" affected. For example, hydrologically altered tidal wetlands may be assessed by considering whether the area is still "periodically flooded by the tides in most years." For a hydrologically altered floodplain wetland in the eastern U.S., the hydrology requirement may be flooding for one week during the year "in most years" (i.e. more than 50 years out of 100 years) versus the requirement for a similar wetland in the arid or semiarid regions of the U.S., where flooding for one week during the "wet phase of the natural hydrologic cycle" or in "wet years" may be sufficient to still consider the area as wetland. In disturbed wetlands dependent on groundwater conditions (e.g. wet meadows, wetlands in interstream divides, wet tundra, and many depressional wetlands), saturation near the surface (within the majority of the root zone, usually within 12 inches of the surface) for one to two months or more during the year in most years may be a useful measure. Procedures for assessing the current wetness and making wetland determinations for hydrologically altered wetlands must be based on our current knowledge of wetland types in each region. Soil drainage models may be useful in these circumstances. Wetland regulatory agencies must establish practical procedures for assessing whether significantly drained "wetlands" or areas similarly hydrologically modified are still wet enough to provide wetland functions and to warrant regulation under current statutes.

After the limits of wetlands are identified based on technical considerations, decision-makers can develop and implement policies to regulate or protect wetlands to varying degrees. Here wetland functions and values play a dominant role.

THE IMPRACTICALITY OF USING HYDROLOGY FOR WETLAND IDENTIFICATION

The "primary indicators approach" intentionally does not include observations of water or indirect evidence of water-carried debris, water-stained leaves, or other signs of hydrology. These ephemeral signs indicate that an event is happening or has happened, but reveal little about the duration and frequency of this event — which is vital to separating wetlands from nonwetlands in a strictly hydrologic sense. These signs may at times be observed in nonwetlands. For example, the 100-year floodplain includes areas that on average are flooded briefly once in one hundred years, clearly nonwetland areas.

For practical purposes when identifying wetlands and their boundaries, it is best to rely on the visible and enduring expressions of their hydrology, that is, by their vegetation and/or soils. Recent U.S. Fish and Wildlife Service studies have further confirmed traditional scientific opinion and observations that there is an excellent correlation between "hydrophytic vegetation" and "hydric soils" for determining the presence of wetlands (Scott et al. 1989, Segalquist et al. 1990). Consequently, these features should be used to identify wetlands, in the absence of significant hydrologic modification. Requiring that areas having such vegetation and soils must also be *demonstrably wet for a specific time period* makes wetland identification unnecessarily burdensome and puts too much emphasis on a condition that is not documented in the scientific literature (Tiner 1991b). Existing wetland definitions reflect this realization and do not mention specific time periods for inundation or soil saturation. Most definitions simply state that the area must be saturated or flooded long enough to support or be capable of supporting plants adapted to saturated soils.

If the presence of water must be required to identify wetlands, then investigators must limit their work to the "wet season" or in arid and semiarid regions to "wet years." To some extent, this has been and is still done in many areas of the country for performing "perc" tests to determine site suitability for septic systems. Local water tables could be monitored annually to determine the appropriate length of the "wet season" for each year, since conditions will vary from year to year. This, too, is already in practice in some areas for validating the "perc" tests. Such monitoring and limiting wetland delineation field work to the "wet season" are, however, too costly and restrictive, and place heavy seasonal workloads on consultants and regulators alike. In some states, efforts are underway to replace the "perc" test with a procedure evaluating soil properties for evidence of a seasonal high water table.

Specific hydrologic conditions should only be considered when an area has been significantly drained or similarly modified hydrologically (e.g. reduced river flows). Altered hydrology often negates the interpretative value of vegetation and soil properties. Consequently, it may be necessary to define hydrologic conditions that can be measured or interpreted to evaluate whether the area is effectively drained or not, unless useful surrogates can be found. Regionally based wetland type-specific hydrology requirements could be used to determine whether such hydrologically disturbed areas are wetland or not.

In areas not modified to such extent, certain plant species and plant communities are still reliable indicators of wetlands, but there are many cases, especially in drier wetlands and along the margins of wetlands in areas of low topographic relief, where specific soil properties associated with prolonged seasonal high water tables are needed to recognize these wetlands and delineate their boundaries. So, soils have taken on a more prominent role in wetland delineations. At the present time, emphasis in wetland recognition and delineation should be placed on what we know best — vegetation and soils that typically reflect an area's wetness.

ACKNOWLEDGMENTS

While the ideas expressed in this paper are my own, they have evolved from interactions with many colleagues (too numerous to mention) during the past few years. I would, however, like to acknowledge the following individuals with whom I have had much significant discussion on the topic of wetland identification: Peter Fletcher, Maurice Mausbach, Charles Rhodes, Bill Sipple, Dan Smalley, Chris Smith, Billy Teels, Russ Theriot, Peter Veneman, and Bill Wilen. I also wish to thank Jim Richardson for providing information on hydric mollisols (prairie soils) and the U.S.D.A. Soil Conservation Service for providing proposed indicators of significant soil saturation used in the primary indicators approach.

LITERATURE CITED

Barbour, M. G., J. H. Burk, and W. K. Pitts. 1980. Terrestrial Plant Ecology. Benjamin/Cummings Publishing Company, Inc., Menlo Park.

Bromley, S. W. 1935. The original forest types of southern New England. Ecol. Monog. 5(1): 61-89.

Brooks, R. P., D. E. Arnold, and E. D. Bellis. 1987. Wildlife and Plant Communities of Selected Wetlands in the Pocono Region of Pennsylvania. U.S. Fish and Wildlife Service, Washington. NWRC Open File Rep. 87-02.

Cowardin, L. M., V. Carter, F. C. Golet, and E. T. LaRoe. 1979. Classification of wetlands and deepwater habitats of the United States. U.S. Fish and Wildlife SErvice, Washington. FWS/OBS-79/31.

Crawford, R. M. M. and P. D. Tyler. 1969. Oranic acid metabolism in relation to flooding tolerance in roots. J. Ecol. 57: 235-344.

Crawford, R. M. M. 1983. Root survival in flooded soils. Pages 257-283 in A. J. P. Gore, ed., Ecosystems of the World. 4A. Mires: Swamp, Bog, Fen, and Moor. General Studies. Elsevier Scientific Publishing Co., Amsterdam.

Davy, A. J., S. M. Noble, and R. P. Oliver. 1990. Genetic variation and adaptation to flooding in plants. Aquatic Botany 38: 91-108.

Environmental Laboratory. 1987. Corps of Engineers wetland delineation manual. U.S. Army Engineer Waterways Experiment Station, Vicksburg. Tech. Rpt. Y-87-1.

Federal Interagency Committee for Wetland Delineation. 1989. Federal manual for identifying and delineating jurisdictional wetlands. U.S. Army Corps of Engineers, U.S. Environmental Protection Agency, U.S. Fish and Wildlife Service, and U.S.D.A. Soil Conservation Service, Washington. Cooperative technical publication.

Fernald, M. L. 1950. Gray's Manual of Botany. American Book Company, New York.

Gill, C. J. 1970. The flooding tolerance of woody species — a review. For. Abstr. 31: 671-688.

Gleason, H. A., and A. Cronquist. 1963. Manual of Vascular Plants of Northeastern United States and Adjacent Canada. D. Van Nostrand Co., New York.

Golet, F. C., A. J. K. Calhoun, D. J. Lowry, W. R. DeRagon, and A. J. Gold. 1990. The ecology of red maple swamps in the glaciated northeastern United States: a community profile. U.S. Fish and Wildlife Service, Washington. Biol. Rep. 90. In press.

Hook, D. D. 1984. Adaptations to flooding with fresh water. Chapter 8. Pages 265-294 in T. T. Kozlowski, ed. Flooding and Plant Growth. Academic Press, Inc., Orlando.

Hook, D. D., and J. R. Scholtens. 1978. Adaptations and flood tolerance of tree species. Pages 229-331 in D. D. Hook and R. M. M. Crawford, eds. Plant Life in Anaerobic Environments. Ann Arbor Sci. Publ., Ann Arbor.

Hook, D. D., W. H. McKee, Jr., H. K. Smith, J. Gregory, V. G. Burrell, Jr., M. R. DeVoe, R. E. Sojka, S. Gilbert, R. Banks, L. H. Stolzy, C. Brooks, T. D. Matthews, and T. H. Shear, eds. 1988. The Ecology and Management of Wetlands. Vol. 1: Ecology of Wetlands. Timber Press, Portland.

Hosner, J. F. 1958. The effects of complete inundation upon seedlings of six bottomland tree species. Ecology 39: 371-373.

Hosner, J. F. 1959. Survival, root and shoot growth of six bottomland tree species following flooding. J. For. 59: 927-928.

Hosner, J. F. 1960. Relative tolerance to complete inundation of fourteen bottomland tree species. For. Sci. 6: 246-251.

Huenneke, L. F. 1982. Wetland forests of Tompkins County, New York. Bull. Torrey Bot. Club 109: 51-63.

Jackson, M. B., and M. C. Drew. 1984. Effects of flooding on growth and metabolism of herbaceous plants. Chapter 3. Pages 47-128 in T. T. Kozlowski, ed. Flooding and Plant Growth. Academic Press, Inc., New York.

Keeley, J. E. 1979. Population differentiation along a flood frequency gradient: physiological adaptations to flooding in *Nyssa sylvatica*. Ecol. Monog. 49: 89-108.

Kozlowski, T. T. 1984. Responses of woody plants to flooding. Chapter 4. Pages 129-163 in T. T. Kozlowski, ed. Flooding and Plant Growth. Academic Press, Inc., New York.

Kramer, P. J. 1949. Plant and Soil Water Relationships. McGraw-Hill Book Co., Inc., New York.

Ledig, F. T., and S. Little. 1979. Pitch pine (*Pinus rigida* Mill.): ecology, physiology, and genetics. Pages 347-371 in R. T. T. Forman, ed. Pine Barrens: Ecosystem and Landscape. Academic Press, Inc., New York.

Little, S. 1959. Silvical characteristics of pitch pine (*Pinus rigida*). U.S.D.A. Forest Service, Northeastern Forest Expt. Stat., Upper Darby. Station Paper No. 119.

Mader, S. F. 1991. Forested wetlands classification and mapping: a literature review. National Council of the Paper Industry for Air and Stream Improvement, Inc., New York. Technical Bulletin No. 606.

Magee, D. W. 1981. Freshwater Wetlands. A Guide to Common Indicator Plants of the Northeast. The University of Massachusetts Press, Amherst.

Niering, W. A. 1953. The past and present vegetation of High Point State Park, New Jersey. Ecol. Monogr. 23: 127-147.

Reed, P. B. 1988. National list of plant species that occur in wetlands: 1988 national summary. U.S. Fish and Wildlife Service, Washington. Biol. Rep. 88(24).

Scott, M. L., W. L. Slauson, C. A. Segelquist, and G. T. Auble. 1989. Correspondence between vegetation and soils in wetlands and nearby uplands. Wetlands 9(1): 41-60.

Segelquist, C. A., W. L. Slauson, M. L. Scott, and G. T. Auble. 1990. Synthesis of soil-plant correspondence data from twelve wetland studies throughout the United States. U.S. Fish and Wildlife Service, Washington. Biol. Rpt. 90(19) (In press).

Sipple, W. S. 1988. Wetland identification and delineation manual. Volume I. Rationale, wetland parameters, and overview of jurisdictional approach. Revised Interim Final. U.S. Environmental Protection Agency, Office of Wetlands Protection, Washington.

Soil Survey Staff. 1975. Soil Taxonomy. A Basic System of Soil Classification and for Making and Interpreting Soil Surveys. U.S.D.A. Soil Conservation Service, Washington. Agriculture Handbook No. 436.

Soil Survey Staff. 1990. Keys to soil taxonomy. Agency for International Development and U.S.D.A. Soil Conservation Service. Soil Management Support Staff Technical Monograph No. 19, 4th edition. Virginia Poly. Tech. Inst. and State Univ., Blacksburg.

Teskey, R. O. and T. M. Hinckley. 1978. Impact of water level change on woody riparian and wetland communities. Vol. V. Northern Forest Region. U.S. Fish and Wildlife Service, Washington. FWS/OBS-78/88.

Tiner, R. W., Jr. 1985a. Wetlands of New Jersey. U.S. Fish and Wildlife Service, National Wetlands Inventory, Newton Corner.

Tiner, R. W., Jr. 1985b. Wetlands of Delaware. U.S. Fish and Wildlife Service, Newton and Delaware Dept. of Natural Resources and Environmental Control, Dover. Cooperative Publication.

Tiner, R. W., Jr. 1988. Field Guide to Nontidal Wetland Identificaton. Maryland Dept. of Natural Resources, Annapolis and U.S. Fish and Wildlife Service, Newton Corner. Cooperative publication.

Tiner, R. W. 1989. Wetlands of Rhode Island. U.S. Fish and Wildlife Service, National Wetlands Inventory, Newton Corner.

Tiner, R. W. 1991a. The concept of a hydrophyte for wetland identification. Bioscience 41(4): 236-247.

Tiner, R. W. 1991b. How wet is a wetland? Great Lakes Wetlands Newsletter 2(3): 1-4.

Tiner, R. W. 1991c. Maine wetlands and their boundaries: a guide for code enforcement officers. Maine Development of Economic and Community Development, Office of Comprehensive Planning, Augusta.

Turesson, G. 1922a. The species and the variety as ecological units. Hereditas 3: 100-113.

Turesson, G. 1922b. The genotypical response of the plant species to the habitat. Hereditas 3: 221-350.

Turesson, G. 1925. The plant species in relation to habitat and climate. Hereditas 6: 147-236.

U.S.D.A. Soil Conservation Service. 1991. Hydric soils of the United States. In cooperation with the National Technical Committee for Hydric Soils. Washington. Misc. Publ. No. 1491.

Whitlow, T. H., and R. W. Harris. 1979. Flood toleratnce in plants: a state-of-the-art review. U.S. Army Engineers Waterways Exp. Sta., Vicksburg. Tech. Rep. E-79-2.