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METHODS FOR EVALUATING WETLAND CONDITION

#10 Using Vegetation To Assess Environmental Conditions in Wetlands

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#10 Using Vegetation To Assess Environmental Conditions in Wetlands

Major Contributors

Department of Biology, Kenyon College
Siobhan Fennessy

Minnesota Pollution Control Agency
Mark Gernes

Ohio Environmental Protection Agency
John Mack

Penn State Cooperative Wetlands Center
Denice Heller Wardrop

Prepared jointly by:

The U.S. Environmental Protection Agency
Health and Ecological Criteria Division (Office of Science and Technology)

and

Wetlands Division (Office of Wetlands, Oceans, and Watersheds)

Notice

The material in this document has been subjected to U.S. Environmental Protection Agency (EPA) technical review and has been approved for publication as an EPA document. The information contained herein is offered to the reader as a review of the "state of the science" concerning wetland bioassessment and nutrient enrichment and is not intended to be prescriptive guidance or firm advice. Mention of trade names, products or services does not convey, and should not be interpreted as conveying official EPA approval, endorsement, or recommendation.

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http://www.epa.gov/ost/standards

http://www.epa.gov/owow/wetlands/bawwg

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Foreword

In 1999, the U.S. Environmental Protection Agency (EPA) began work on this series of reports entitled *Methods for Evaluating Wetland Condition*. The purpose of these reports is to help States and Tribes develop methods to evaluate (1) the overall ecological condition of wetlands using biological assessments and (2) nutrient enrichment of wetlands, which is one of the primary stressors damaging wetlands in many parts of the country. This information is intended to serve as a starting point for States and Tribes to eventually establish biological and nutrient water quality criteria specifically refined for wetland waterbodies.

This purpose was to be accomplished by providing a series of "state of the science" modules concerning wetland bioassessment as well as the nutrient enrichment of wetlands. The individual module format was used instead of one large publication to facilitate the addition of other reports as wetland science progresses and wetlands are further incorporated into water quality programs. Also, this modular approach allows EPA to revise reports without having to reprint them all. A list of the inaugural set of 20 modules can be found at the end of this section.

This series of reports is the product of a collaborative effort between EPA's Health and Ecological Criteria Division of the Office of Science and Technology (OST) and the Wetlands Division of the Office of Wetlands, Oceans and Watersheds (OWOW). The reports were initiated with the support and oversight of Thomas J. Danielson (OWOW), Amanda K. Parker and Susan K. Jackson (OST), and seen to completion by Douglas G. Hoskins (OWOW) and Ifeyinwa F. Davis (OST). EPA relied heavily on the input, recommendations, and energy of three panels of experts, which unfortunately have too many members to list individually:

- Biological Assessment of Wetlands Workgroup
- New England Biological Assessment of Wetlands Workgroup
- Wetlands Nutrient Criteria Workgroup

More information about biological and nutrient criteria is available at the following EPA website:

http://www.epa.gov/ost/standards

More information about wetland biological assessments is available at the following EPA website:

http://www.epa.gov/owow/wetlands/bawwg

List of "Methods for Evaluating Wetland Condition" Modules

Module #	Module Title
1	Introduction to Wetland Biological Assessment
2	Introduction to Wetland Nutrient Assessment
3	The State of Wetland Science
4	Study Design for Monitoring Wetlands
5	Administrative Framework for the Implementation of a Wetland Bioassessment Program
6	Developing Metrics and Indexes of Biological Integrity
7	Wetlands Classification
8	Volunteers and Wetland Biomonitoring
9	Developing an Invertebrate Index of Biological Integrity for Wetlands
10	Using Vegetation to Assess Environmental Conditions in Wetlands
11	Using Algae to Assess Environmental Conditions in Wetlands
12	Using amphibians in Bioassessments of Wetlands
13	Biological Assessment Methods for Birds
14	Wetland Bioassessment Case Studies
15	Bioassessment Methods for Fish
16	Vegetation-Based Indicators of Wetland Nutrient Enrichment
17	Land-Use Characterization for Nutrient and Sediment Risk Assessment
18	Biogeochemical Indicators
19	Nutrient Load Estimation
20	Sustainable Nutrient Loading

SUMMARY

Vegetation has been shown to be a sensitive measure of anthropogenic impacts to wetland ecosystems. As such it can serve as a means to evaluate best management practices, assess restoration and mitigation projects, prioritize wetland-related resource management decisions, and establish aquatic life use standards for wetlands. The basic steps necessary for developing a vegetation-based wetland biological assessment and monitoring program are relatively straightforward, but their simplicity belies their effectiveness. By building upon such monitoring tools, we will be able to more fully incorporate wetlands into water quality assessment programs.

PURPOSE

The purpose of this module is to introduce the scientific basis for using wetland vegetation to assess the biological integrity of wetlands, review methods for sampling vegetation communities, discuss the techniques by which biological metrics are developed, and present examples of metrics and indices that have been used successfully. We discuss here how the composition of the plant community and the predictable changes that result from human activities can act as sensitive indicators of the biological integrity of wetland ecosystems. This information has many potential applications including conducting an inventory, monitoring the status and trends of wetland ecosystems, performing an impact assessment, and setting goals for and/or monitoring mitigation and restoration projects.

BACKGROUND

Vegetation is perhaps the most conspicuous feature of wetland ecosystems and has been used extensively as an indicator of the presence of wetlands themselves, their boundaries, and as a basis for many wetland classification schemes. Wetland plants are commonly defined as those "growing in water or on a substrate that is at least periodically deficient in oxygen as a result of excessive water content" (Cowardin et al. 1979). This term includes both herbaceous (vascular and nonvascular) and woody species. Wetland plants may be floating, floating-leaved, submerged, or emergent and may complete their life cycle in still or flowing water, or on inundated or noninundated hydric soils (Cronk and Fennessy 2001).

One key to understanding why plants are considered "one of the best indicators of the factors that shape wetlands within their landscape" (Bedford 1996), is to understand the contributions they make to wetland ecosystems more generally. These contributions include (Wiegleb 1988, Mitsch and Gosselink 2000):

- Wetland vegetation is at the base of the food chain and, as such, is a primary pathway for energy flow in the system. Through the photosynthetic process, plants link the inorganic environment with the biotic one. Primary production (or plant biomass production) in wetlands varies, but some herbaceous wetlands have extremely high levels of productivity, rivaling those of tropical rain forests.
- Wetland vegetation provides critical habitat structure for other taxonomic groups, such as epiphytic bacteria, phytoplankton, and some species of algae, periphyton, macroinvertebrates, amphibians, and fish. The composition and diversity of the plant community influences diversity in these other taxonomic groups.
- Strong links exist between vegetation and wetland water chemistry. Plants remove nutrients through uptake and accumulation in tissues, but they also act as a nutrient pump by moving compounds from the sediment and into the water column. The ability of vegetation to improve water quality through the uptake of nutrients, metals, and other contaminants is well docu-

mented (e.g., Gersberg et al. 1986, Reddy et al. 1989, Peverly et al. 1995, Rai et al. 1995, Tanner et al. 1995).

- Vegetation influences the hydrology and sediment regime through processes such as sediment and shoreline stabilization, or by modifying currents and helping to desynchronize flood peaks.

Plants as Indicators

Plants are excellent indicators of wetland condition for many reasons including their relatively high levels of species richness, rapid growth rates, and direct response to environmental change. Many human-related alterations to the environment that act to degrade wetland ecosystems cause shifts in plant community composition that can be quantified easily. Individual species show differential tolerance to a wide array of stressors. Thus as environmental conditions vary, community composition shifts in response. Plant communities have been shown to change in response to hydrologic alterations (e.g., Gosselink and Turner 1978, van der Valk 1981, Spence 1982, Squires and van der Valk 1992, Wilcox 1995), nutrient enrichment (e.g., Pip 1984, Kadlec and Bevis 1990, Templer et al. 1998, Craft and Richardson 1998), sediment loading and turbidity (e.g., van der Valk 1981, 1986, Sager et al. 1998, Wardrop and Brooks 1998), and metals and other pollutants. These patterns can be interpreted and used to diagnose wetland impacts. Because they represent a diverse assemblage of species with different adaptations, ecological tolerances, and life history strategies, the composition of the plant community can reflect (often with great sensitivity) the biological integrity of the wetland.

A wetland's hydrologic regime can be thought of as a master variable with respect to the structure (e.g., species richness) and function (e.g., primary production) of the plant community, and much research has been done on the links between hydrology and plant community dynamics (Mitsch and Gosselink 2000). Factors related to the hydrologic regime that affect wetland plants include water depth (Spence 1982, Grace and Wetzel 1982, 1998), water chemistry (Ewel 1984, Pip 1984, Rey Benayas et al. 1990, Rey Benayas and Scheiner 1993) and flow rates (Westlake 1967, Lugo et al. 1988, Nilsson 1987, Carr et al. 1997). As hydrology changes, other environmental conditions change as well. Thus, hydrology influences community composition and productivity by influencing the availability of nutrients (Neill 1990), soil characteristics (Barko and Smart 1978, 1983), and the deposition of sediments (Barko and Smart 1979).

Water quality also has a strong bearing on community structure (Grootjans et al. 1998, Rey Benayas et al. 1990, Rey Benayas and Scheiner 1993). Fens, for example, tend to be high in calcium and magnesium bicarbonates with circumneutral pH (Wilcox et al. 1986). Bogs, on the other hand, depend solely on precipitation for their water supply and tend to be nutrient poor and of low pH. Plants adapted to bog conditions often exhibit a number of mechanisms that serve to conserve or help acquire nutrients, including evergreen leaves, carnivory, or nitrogen fixation.

Advantages of Using Vegetation in Biological Assessment

Wetland plants, both vascular and nonvascular, are commonplace, and they exist in sufficient richness to provide clear and robust signals of human disturbance. They have been used effectively to distinguish environmental stressors including hydrologic alterations, excessive siltation, nutrient enrichment, and other types of human disturbance (van der Valk 1981, Moore and Keddy 1989,

Galatowitsch 1993, Wilcox 1995, Kantrud and Newton 1996, Stromberg et al. 1996, Philippi et al. 1998). Vegetation is useful to evaluate wetland integrity because:

- Plants are found in all wetlands.
- Plants are primarily immobile (save for a few free-floating species). Because they reflect the temporal, spatial, chemical, physical, and biological dynamics of a system, they can indicate any long-term, chronic stress it undergoes.
- Plant taxonomy is well known, and excellent field guides are available for all regions.

Experienced field biologists can identify genus or species relatively easily because:

- A great diversity of species exists with differing responses to human disturbance.
- Ecological tolerances are known for many species, and thus changes in community composition might be used to diagnose the stressor responsible. For example, plant responses to changing hydrology are reasonably predictable (see above).
- Sampling techniques are well developed and extensively documented.
- Similar sampling techniques can be used in both freshwater and saltwater systems.
- Functionally or structurally based vegetation guilds have been proposed for some regions.

Despite the many advantages to developing biological assessment techniques based on vegetation, limitations should be recognized:

- A lag may occur in the response time to stressors, particularly in long-lived species. When this is the case the species present may not be indicative of the stressors present and/or the overall biological integrity.
- Plant identification to species level can be laborious, or restricted to narrow periods during the field season. Several assemblages, such as the grasses and sedges, may be particularly difficult to identify to species. Concern is sometimes expressed about the skill that good field botany requires. However, with a modest amount of training, most species in a given class of wetland can be easily learned, or the art of keying out species can be learned.
- Sampling techniques for some assemblages, such as the submerged species, can be difficult; thus it is possible to miss or erroneously sample a group of species that could provide strong signals on the condition of a site.
- Vegetation sampling is generally limited to the growing season.
- Research or literature on plant species responses to specific stressors is not well developed. Adamus and Gonyaw (2000) estimate that only 17% of all wetland plant species have been the subject of studies that detail their response to specific stressors, although the general tolerance of many species to human change to the environment is more well known.

Considerations For Sampling Design

A sound framework for developing biological indicators based on wetland vegetation should include several key components.

Objectives of the Project

The vegetation community changes seasonally, and these patterns can differ among wetland types. Standardized field methods must be tested and re-

fined to ensure that a consistent sampling effort is made at each site. Consideration must be given to the type of data that will be collected (species inventory, cover, stem counts, etc.), the sampling window (i.e., the seasonal period) that will be used to characterize the vegetation, the sampling technique that will be employed, the number of samples that will be collected, and retention of voucher specimens. The same considerations apply to any methods that will be performed subsequent to field surveys either in the laboratory or the office. Projects may be designed to develop or test metrics that are sensitive to specific stressors such as hydrologic alteration or nutrient enrichment. In this case wetlands that vary in their degree of impact should be included. This approach allows for hypothesis testing, i.e., whether the conditions at a site differ significantly from those found in a population of reference wetlands (see Module 11 for further examples).

Wetland Classification

Because the composition of wetland plant communities varies by wetland type (class), it is necessary to group "like-kind" wetlands into classes that are structurally and functionally similar. In this way natural variability is reduced, making detection of human-induced variability easier. This leads to more meaningful comparisons between wetlands and creates a more sensitive tool for decisionmakers. There are several well-established wetland classification schemes, including the hydrogeomorphic (HGM) approach (Brinson 1993), which has proven to be useful in classifying wetlands for biological assessment (e.g., Fennessy et al. 1998b), as has the classification system employed in the National Wetland Inventory (Cowardin et al. 1979). Ecoregions have also been used to classify wetlands for vegetation analysis (Omernik 1987). (See Module 7 for further discussion on wetland classification.)

Define the Reference Condition

A crucial component of a biological assessment program is the careful selection of least-impacted reference sites. Reference sites are wetlands of the same class that define the best possible condition for that class. Reference sites serve as the standard against which other sites are judged (Yoder and Rankin 1993, Karr and Chu 1999).

Select Wetlands that Represent the Full Range of Human Disturbance

In addition to reference sites, other sites should be selected to represent the full range of human disturbance for each wetland class. This makes it possible to evaluate the response of the wetland plant community to increasing "doses" of human activity (i.e., construct a dose-response curve) (Karr and Chu 1999). There is currently no standard method to quantify human disturbance at a site, so many projects have relied on surrogate measures such as percent impervious surface (Richter and Azous 1994) or percent agricultural land use in the watershed. If assessing plant community response to nutrient enrichment is the objective, potential metrics can be tested against individual environmental measures such as soil phosphorus content or turbidity of the water column. Another approach is development of a qualitative index of human disturbance based on dominant land use surrounding the wetland, buffer characteristics, and the degree of hydrologic alteration to the site (Figure 1) (Fennessy et al. 1998a, Lopez and Fennessy in press). The criteria for judging whether a site is least or most impacted are, in part, subjective, but there are several standardized, semiquantitative checklists for evaluating human disturbance at different wetlands. These include the Ohio Rapid Assessment Method (Ohio EPA 2000) and a "Stressor Checklist" developed for wetlands in Pennsylvania (Wardrop and Brooks, personal communication). Both techniques provide a means to standardize the evaluation of human impact.

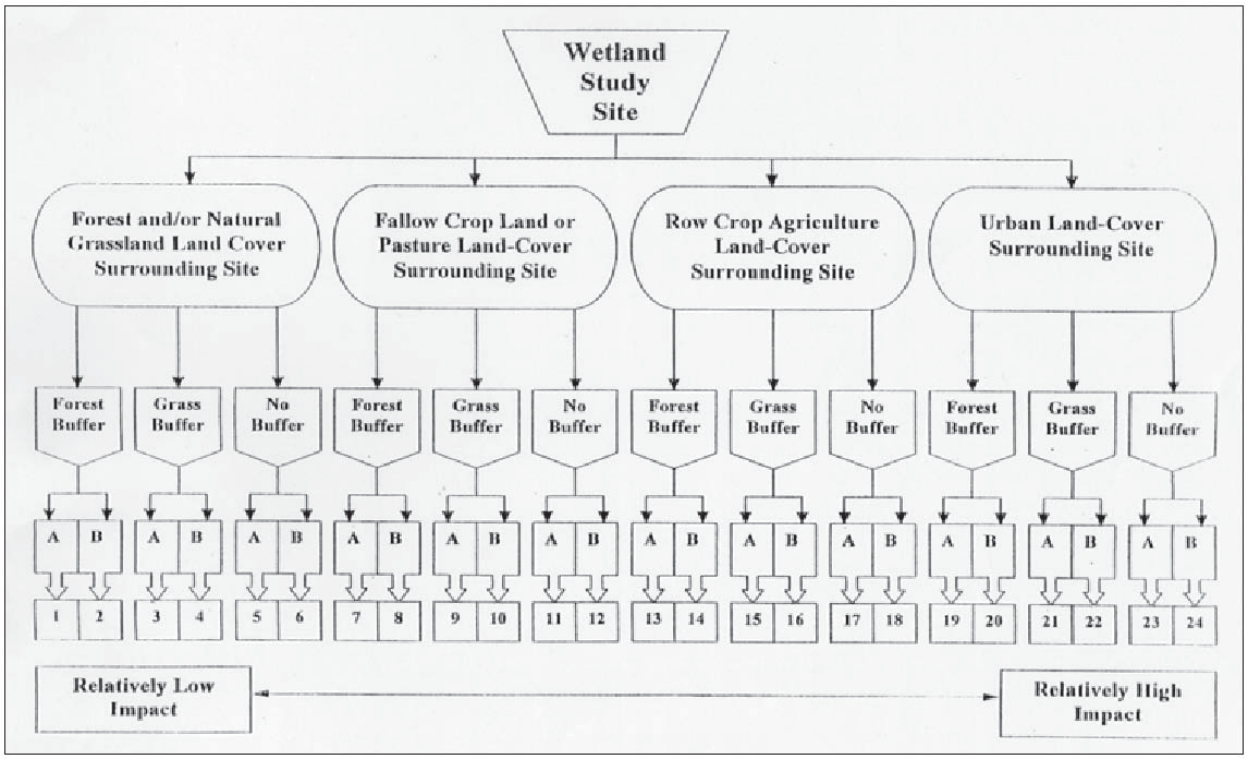

FIGURE 1: THREE-TIERED FLOW DIAGRAM USED TO RANK WETLANDS ALONG A GRADIENT OF HUMAN DISTURBANCE.

Tier 1 indicates the land cover that surrounds a site, Tier 2 indicates the type and extent of vegetated buffer that encompasses a wetland, and Tier 3 indicates either little direct hydrologic modification (denoted "A") or human modified hydrology ("B") in a wetland. Numerical ranks are displayed in squares at the bottom of the flow diagram (Fennessy et al. 1998b, Lopez and Fennessy, in press).

ESTABLISH STANDARD SAMPLING METHODS

Standardized field methods must be adopted, tested, and refined to ensure that an equal and consistent sampling effort is made at each site (discussed in detail below).

CHOICE OF METRICS

Karr and Chu (1999) have said that "a bewildering variety of biological attributes can be measured, but only a few provide useful signals about the impact of human activities." Not all attributes will show a consistent response to human disturbance; those that do have been termed "metrics." Certain attributes of wetland plant communities have been shown to vary consistently and systematically with human disturbance. Detailed examples will be discussed below.

FIELD METHODS

Vegetation sampling techniques vary greatly depending on the goals of the project and the wetlands included in the study. In general, sampling methods should be designed for wetland type, project scope, season, funding, and other constraining factors. Major concerns include ease of use, cost, reproducibility of results, and quality assurance/quality control protocols. The sampling technique should adequately represent site heterogene-

ity. Data requirements, level of sampling effort, and types of ancillary data collected all hinge on the goals of the study and the anticipated uses of the results (biocriteria development, setting goals for mitigation wetlands, monitoring wetland condition, etc). In addition, the development of any biological assessment tools will likely be the effort of a team of people with various areas of expertise and experience. We recommend that interdisciplinary crews conduct biological assessment during both the planning and data collection phases if at all possible.

Organizing Data Collection

There are several essential steps in developing vegetation-based bioassessment protocols. These include (1) decisions about the frequency and intensity of sampling, (2) site reconnaissance, and (3) decisions about the sampling technique(s) that will be used in the field.

Timing and Intensity of Sampling

Sampling season

The establishment of a standard sampling window will help ensure that representative results are obtained at each site and that valid comparisons can be made between different wetlands. Wetland plants pose a challenge in terms of their identification and because different species reach maturity or flower at different times during the growing season. Thus, some species may be present but cannot be identified because of a lack of flowing parts (a critical feature used in identification). Members of Asteraceae (e.g., *Aster* sp. [asters]), which tend to bloom late in the growing season, are a classic example. Temporal variability in the plant community is a function of geographic location and the class of wetland ecosystem being studied. Any decision will involve trade-offs because no one sampling period will be able to capture all species. Setting an index period that corresponds to the peak maturity of the community as a whole is generally considered most appropriate, particularly if the goal is to assess a wetland in a single visit. Interestingly, three States that have established index periods have arrived at nearly the same period. These include Minnesota (June 15–August 15), Ohio (June 15–August 30), and Pennsylvania (June 15–August 15).

Forested wetlands appear to be less sensitive in terms of when the vegetation is surveyed. For example, in the southeastern States, the changes that occur in the plant community over the growing season are relatively minor (see Module 16: Vegetation-Based Indicators of Wetland Nutrient Enrichment). In this case, it may be desirable to coordinate vegetation sampling periods with the sampling period for other assemblages.

Number of survey plots

In any study, the number of plots to sample is an important consideration. The appropriate number can be determined by plotting species numbers (or the cover of a given species) as a function of the number of quadrats sampled and then identifying where species richness "levels off." Daubenmire (1959) systematically investigated how sampling effort affects the number of species recorded at a site and found a point of diminishing returns was reached when 40 quadrats had been sampled. In the initial 10 quadrats some species were underrepresented whereas others were overrepresented. At the point where 30 to 40 quadrats had been sampled, the data had leveled off, and increasing the sample size to 50 quadrats did not give any additional information. Another recommendation is that a total of 1% of the total wetland area be sampled (Krebs 1999). One method to accomplish this, which several States have adopted, is use of releve techniques. Releve plots can adequately represent the vegetation of a site with a single large plot (e.g., 100 m^2). Regardless of the method selected, tradeoffs regarding sampling effort must be made in light of the time and resources available.

Site Reconnaissance

Before in-depth field sampling begins, general information should be collected on the landscape setting of the site, its hydrologic features, and other general characteristics. Many valuable observations can be made from the edges of the wetland that will describe obvious stressors such as hydrologic alterations (berms, culverts), or the extent of vegetation cover and the characteristics of any buffer areas. Buffer areas are typically defined as the 100 m of land surrounding the wetland boundary (Magee et al. 1993). Land use and/or the dominant vegetation communities within the buffer should be recorded. Depending on the goals of the project it may be desirable to collect samples to quantify characteristics of the buffer.

Inspecting the topography and landscape features that surround the site can provide much information on the context of a site. There are also many characteristics that can be recorded about the wetland itself, including its shape and approximate size, the general distribution of wetland vegetation and open water, interspersion of plant communities, the type of buffer, hydrological features including surface water inflows or outflows, and human-made water control structures.

Choice of Vegetation Field Sampling Methods

Below are examples of vegetation sampling protocols that can integrate the above considerations of plot locations, shape, size, and number, and that have been used successfully in wetland bioassessment projects.

Standard releve (Braun-Blanquet) for emergent vegetation

The releve approach has been adapted from Mueller-Dombois and Ellenberg (1974). Prior to sampling, each wetland is evaluated briefly for overall community structure. A 100 m^2 plot is established in a typical or "representative" location within the emergent plant community. Plants in the plot are inventoried and the cover class (abundance) of each plant taxon is estimated using cover classes (Almendinger 1987). Similar sampling effort can also be made in the floating or submerged community zones when they are present and wading is possible.

This sampling technique is easy to apply and practical, taking a field-trained botanist with an assistant typically 2 hours or less to complete per site. An advantage (or disadvantage, depending on one's view) is fact that sampling is restricted to the dominant vegetation community represented at the site. One negative side is that it is not very data intensive for spatially heterogeneous or complex communities. In some cases it may be desirable to collect samples across all communities present. This can be done using multiple releve plots, although this is more difficult and time-consuming.

The required equipment includes two 50-m measuring tapes, four corner markers or posts (8-foot rebar works well), a clipboard with data forms, and plant collecting materials. Data gathered in the releve plot can be augmented with a more complete list of taxa occurring at the entire site, for example, as collected by a walk-through (care should be taken in this case as sampling effort can vary depending on the investigator). A modification of the releve method has been adopted in Ohio (see Appendix A).

Transect sampling

There are numerous variations on the use of transects for sampling vegetation in herbaceous, shrub-scrub, or wooded wetlands. The location of transects within a wetland can be determined in several ways. One approach is to locate them either randomly (using a random numbers table for example) or systematically (e.g., located at fixed in-

tervals) perpendicular to a baseline. Baselines are generally established just outside the wetland parallel to its longest axis (Figure 2). Transect locations can also be determined using a stratified random design in which different portions of the site are targeted for sampling to ensure that the habitat complexity of the wetland is represented, but within those zones transects are located randomly. Transects may be a single line, or a belted transect can be used in which data are recorded in a zone extending on either side of the line (often to a distance of 1 m). Often a transect line is used in combination with quadrats placed at random or regular intervals along the line.

Data can be collected along the transects using several techniques:

- All vegetation in each quadrat is sampled (see section on quadrats below).
- The line-intercept method is frequently used. In this technique, the transect line is thought of as a vertical plane that is perpendicular to the ground. All plant canopies projecting through the plane (over the line) are counted. The total decimal fraction of the line covered by each species and multiplied by 100 is equal to its percent cover (Barbour et al. 1987). Total cover can be more than 100% using this technique.

Quadrat methods

Many possible sampling schemes are available for sampling using quadrats, and there are variations appropriate for all vegetation types. Often, communities or stands are selected subjectively, but then sampled using randomly located quadrats (stratified random technique). Common variations include (Barbour et al. 1987):

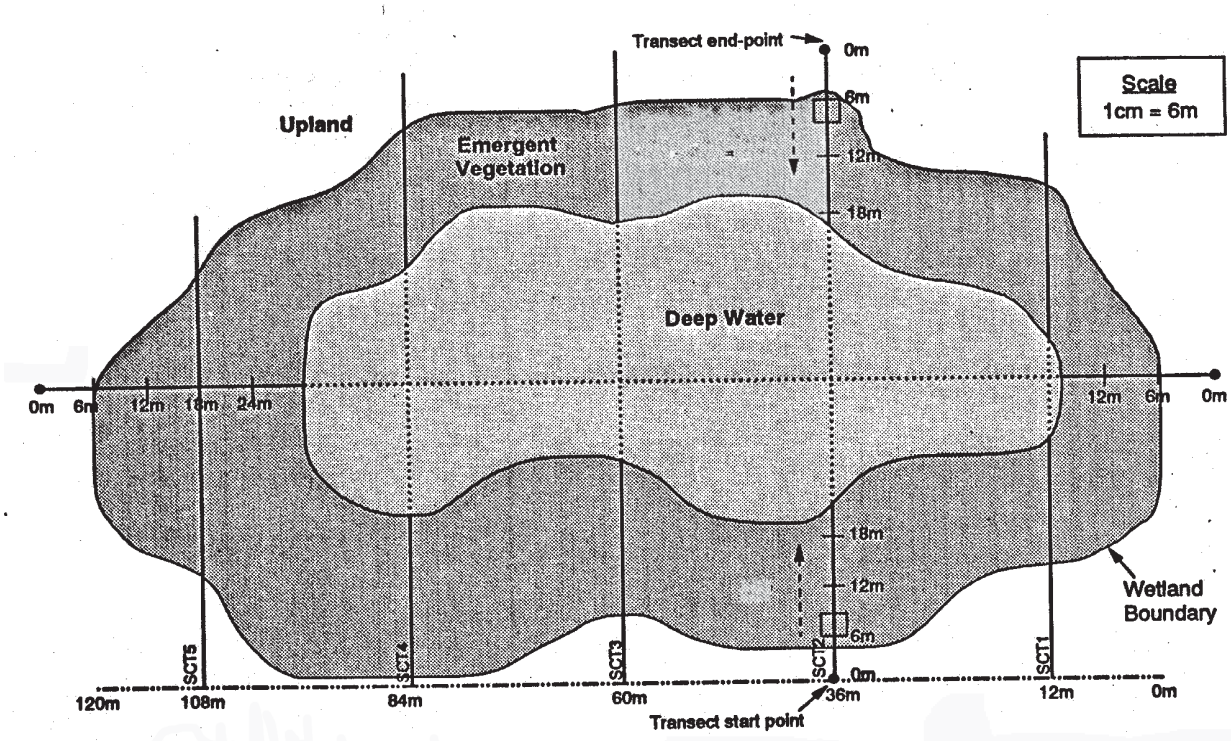

Figure 2: Example of how transects might be established in a wetland. In this case a baseline is established along the long axis of the site, and transects can be run both parallel and perpendicular to this axis.

- Locating quadrats in a completely random fashion
- Locating quadrats in a restricted or stratified random manner (stratified random sampling). This is often based on the plant community types that are present. Placing quadrats randomly within the various community types helps ensure that habitat heterogeneity will be adequately represented.

Quadrat size, shape, and number: Many methodological studies have been conducted to determine the precision and accuracy of different quadrat types (Krebs 1999). For surveying herbaceous plant communities, there are two primary issues regarding shape: edge effects and habitat heterogeneity. Many studies have found that long, narrow rectangles work best because this shape tends to cross more patches (i.e., cover more habitat heterogeneity) and therefore tends to pick up more species. Square and round quadrats have been reported to be less accurate because less heterogeneity is encompassed. However, sampling accuracy tends to decrease as quadrat shape lengthens because of edge effects. The longer the perimeter of a quadrat, the greater the necessity for any field personnel to make subjective decisions about whether a plant near the edge is "in" or not. This kind of decisionmaking leads to possible counting errors, and results can vary greatly between individuals. In light of this concern, round quadrats are considered by many to be the most accurate because this shape has the smallest perimeter:area ratio (Krebs 1999).

The appropriate quadrat size also varies with the goals of data collection. If the goal is to collect cover data, then quadrats may be small. If data on plant numbers are required, then the decision about quadrat size is a critical one. Although there are no fixed rules, several recommendations can be derived from the literature (analysis from Krebs 1999):

- Use a quadrat that is at least twice as large as the average canopy spread of the largest species (Greig-Smith 1964).
- Use a quadrat size that will include only one or two species (Daubenmire 1968).
- Use a size that allows the most common species to occur in more than 80% of all quadrat.

Sampling Considerations Specific to Forested Wetlands

For herbaceous plants, quadrats of 1 m^2 or 10 m × 10 m have most commonly been used. For woody plants, plots of at least 10 m × 10 m are used. The forestry literature recommends 400-1,000 m^2 as a minimum area to adequately characterize eastern forest communities (Peet et al. 1998). A number of sampling techniques work well for trees and shrubs in forested systems, many of which are plotless methods. These are generally called distance methods because they are based on distances between:

- Random individuals (trees or shrubs) and their nearest neighbors
- Random points and the nearest organism(s) (Krebs 1999)

Point-quarter method

The point-quarter method is a distance technique commonly used in forestry studies. A series of random points is selected, generally along a transect line, with the limitation that points should be far enough apart such that the same individual is not measured twice at two successive points. The area around each random point is divided into four 90° quadrants, and the distance to the nearest tree is measured in each (Figure 3). In this way four point-to-tree distances are measured at each random point (Krebs 1999). These data can be used to calcu-

late an unbiased estimate of population density as follows:

$$N_p = 4(4n - 1)/pi \sum (r^2_{ij})$$

where N_p = the estimate of population density, n = number of random points, pi = 3.14159, and (r^2_{ij}) = distance from random point i to the nearest organism in quadrant j (j = 1, 2, 3, 4; i = 1,...,n).

The variance of the population density can be calculated as follows:

$$\text{Variance } (N_p) = N_p{}^2/(4n - 2)$$

Standard error is expressed as:

$$\text{Standard error of } N_p = [(\text{variance of } N_p)/4n]^{1/2}$$

Each tree is identified by species, and diameter at breast height (DBH) is measured. This method is easy and efficient when site conditions allow one to quickly divide the area around the random points into four equal quadrants. The primary criticism of this method is that because only four trees are measured at each point, the number of individuals sampled is often too low to truly represent large populations.

Bitterlich variable plot method

This is a forestry technique that can be used to calculate basal area only. The advantage of this method is that it is extremely fast and has been used widely in forestry studies. Sampling is done using a sighting device (either a stick with a crosspiece at one end, or a prism). The stick is held horizontally with the crosspiece at the far end and the viewer slowly turns in a complete circle. Each tree whose trunk is seen in the line of sight is tallied and identified by species if its trunk size exceeds the width of the crosspiece; all other tress are ignored. Total basal area (m^2 Ha^{-1}) for each species is then calculated as the number of trees of that species divided by 2. Plot size is variable in this method because the plot radius is not fixed.

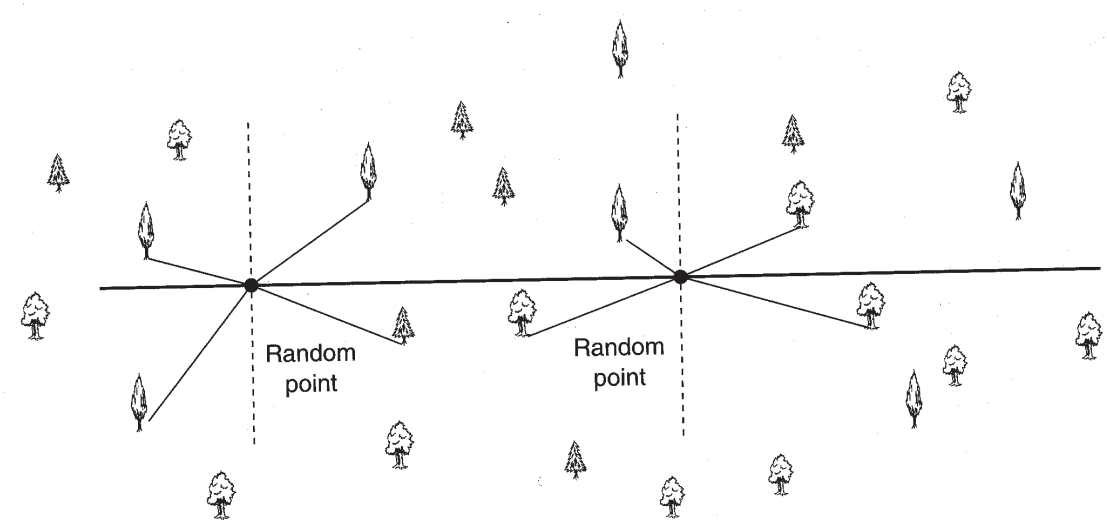

Figure 3: Example of point-quarter sampling at two randomly selected forest locations. In each case, the shortest point-to-tree distance is measured in each of the four quadrants.

Collection of Ancillary Data to Characterize Environmental Conditions

Some physical and chemical data on the site should be collected in order to interpret and understand vegetation data. The need for information on the hydrology and soils of the system, for example, is a primary reason why many wetland assessment teams are made up of individuals from several different disciplines. Some States are developing methods for assessing wetland functions on the basis of wetland HGM (Smith et al. 1995). Data on composition of wetland plant communities can be used to assist HGM determinations of wetland function, and conversely, HGM data can be invaluable in bioassessment to organize sampling and interpret the influence of hydrogromorphic factors on wetland plant communities. Some examples of hydrological indicators that might be included are:

- Presence of any surface water inflows and outflows
- Other indicators of wetland hydrology such as water marks, stained leaves, sediment deposits, or soil saturation in top 30 cm (see wetland delineation manual, ACOE 1987)
- Collection of water samples for analysis. If your system is seasonally flooded and water chemistry data are required, this must be taken into account when developing the sampling design. It may be necessary to sample water chemistry at different times than the vegetation. Parameters to analyze might include pH, dissolved oxygen, conductivity, total phosphorus, soluble reactive phosphorus, nitrogen (nitrate, ammonia, and total Kjehldahl N), total suspended solids, turbidity, metals (in some instances), and total organic carbon. Percent salinity is an additional variable to measure in saline wetlands.

Soils can be easily characterized using a standard soil probe. Some examples of soil data that might be gathered are:

- Thickness of the organic horizon
- Soil texture
- Organic matter content
- Munsell soil color
- Presence of mottles, their size and color, and presence of oxidized root channels

Depending on the study goals, it may also be necessary to collect soil samples for laboratory analysis. Standard analysis generally include pH, percent organic matter, and nutrients or perhaps metals. Total phosphorus is often a good indicator of human disturbance and/or the deposition of heavy sediment loads.

Vouchers and QA/QC

The rigor of QA/QC requirements should be appropriate to the goals of the study and the intended use of the results. Requirements that are appropriate for a "pilot" study whose purpose is to identify promising metrics may not be as rigorous as those of a full-blown regional study whose purpose is to provide statistical estimates with known confidence limits regarding the numbers (or proportion) of wetlands that are degraded. Depending on project goals and budget, consider including the following:

- Collect all species that are unknown and return them to the lab for identification. We recommend pressing plants in the field to ensure the quality of the samples and allow their preservation as voucher specimens (e.g., in herbaria) if that becomes desirable.
- Because of their difficult taxonomy, we recommend collecting all but the most common sedges (e.g., *Carex* sp.), grasses, and rushes.
- Confirm unknown species with local university herbaria or other botanical experts.
- Generally, err on the side of conservatism; overcollect rather than undercollect.

- One approach developed in Minnesota is to establish a column on the field data sheet to indicate the level of certainty on the identification of a given species. This information can help in later data interpretation.
- If project personnel are changing, then more confirmation and vouchering will be necessary.
- Calibrate the personnel in terms of judging percent cover and species identification.
- Collect a specimen of each species if possible. These could then be donated to a local herbarium. This is especially important during the reference phase when metrics are being developed and validated.
- Collect species whose identity is uncertain in order to confirm the species using standard floras. In addition, have another person confirm the species. That way there is a more defensible record.
- Use rare-plant protocols when necessary (e.g., if there are fewer than 20 individuals of a given species, photograph them only).

One example of a quality assurance field protocol comes from Ohio EPA (Fennessy et al. 1998). In a study designed to test a vegetation-based indicator in forested riparian wetlands, a QA/QC protocol was developed to evaluate the accuracy of plant identification. In this technique, a random sample of 10% or 10 specimens (whichever was greater) of the total number of species identified at the site was collected for subsequent confirmation by a botanical expert. Prior to the vegetation survey, a random numbers table was used to generate 10, 2-digit (01, 02, etc.) nonrepeating numbers within the range of 1 to 30 (30 was the maximum value because 30 plots were sampled at each site). These numbers identified the quadrats in which quality control samples were to be collected.

Following identification of all species in the quadrat selected in step 1, a second two-digit random number within the range of the number of species found in that quadrat was generated and used to select a voucher sample. For example, if there were 10 species found in the quadrat, a number between 1 and 10 was generated. If that number was 3, then a voucher specimen of the third species encountered in that quadrat was collected. This was done even if the species selected was very common and easy to identify, such as *Typha latifolia*.

Accuracy (defined as the closeness of a measured value to the true value) was assessed by comparing the confirmed species identifications to the identification given by the field personnel such that:

% accuracy = (number of species correctly identified in field/total number confirmed)*100

Data Analysis

Vegetation-Based Metrics

Vegetation metrics can be organized into three groups based on the general level of biological organization they reflect: community-based metrics, metrics based on plant functional groups, and species-specific metrics. All should be developed on the basis of field data collection and interpretation of those data. In general, there are many more potential metrics (i.e., plant community attributes) than those that show strong biological signal. In all cases, there should be an ecological understanding as to why the metric works or does not (i.e., does it make ecological sense). Unfortunately, not all metrics are likely to work across all wetland types; therefore metrics must be tested when they are used in a new wetland class (Keddy et al. 1993).

A useful prelude to data analysis may include consulting existing information on the autecology of wetland plant species. One source of information on species-specific tolerances is the EPA's National Database of Wetland Plant Sensitivities (Adamus and Gonyaw 2000). This database documents published, species-specific assessments of plant tolerances, sensitivity, and general response to stressors, particularly nutrient enrichment and hydrologic alteration. Responses are qualified by season and plant life stage whenever such information is available. Limited information is also presented on the tolerance of plant species to increased salinity, sedimentation, and other stressors, but no attempt was made to comprehensively compile literature on those topics. The database summarizes information from more than 200 sources on 1,082 plant species (about 16% of all U.S. wetland plant species) and 450 nonwetland species that occur in the United States. Little or no information has been published for the remaining 84% of wetland plant species.

Community Metrics

Extensive ecological literature describes the changes in plant community composition in response to human disturbance. For instance, there are predictable changes in plant species diversity, as well as in the types of species that remain (Tilman 1999). Guilds or functional groups, defined as groups of species sharing certain traits predisposing them to perform similar functions or respond in similar ways to human disturbance, can be created to indicate environmental change in wetlands (Hobbs 1997). Well-known guilds in wetlands include carnivorous plants, submerged aquatic species, or species tolerant of high sediment loads (Keddy et al. 1993, Wardrop and Brooks 1998). An increase in nonnative invasive species is also considered to indicate ecosystem change that may be due, for example, to nutrient enrichment (Ehrenfeld 1983, Thompson et al. 1987). These types of biological signals can provide reliable information on the condition of the wetland.

Human activities that alter natural hydrologic regimes (changes to water quantity, water level fluctuations, or water quality) have well-documented impacts on plant communities (Ehrenfeld 1983, Vitt and Bayley 1984, Ehrenfeld and Schneider 1991, Wilcox 1995). Plant zonation patterns may shift, species tolerant of human disturbance may invade, or woody species may invade or die back as a result of drainage or flooding. Some of the responses by the plant community that occur as a result of hydrologic change include the following (from Wilcox 1995, Ehrenfeld 2000):

- Decrease in species richness
- Possible decline of mutualistic interactions, such as with pollinators or mycorrhizal fungi
- Absence of species that are sensitive to human disturbance
- Increase in the numbers and dominance of invasive and exotic species, such *as Typha angustifolia and Lythrum salicaria*
- Vegetation that is dominated by one species (monospecific) or of one structural type
- Presence of either very dense or sparse stands of vegetation (e.g., in response to water levels that were stabilized at either lower or higher than normal levels).

Floristic quality assessment index

The Floristic Quality Assessment Index (FQAI) is a vegetative community index based on the method developed for the Chicago region by Wilhelm and Ladd (1988). It has been tailored specifically to Ohio flora (Andreas and Lichvar 1995) and the flora of Michigan (Herman et al. 1996). Other States and regions are currently developing FQAI lists. The FQAI was originally designed to assess the degree of "naturalness" of an area based on the presence of ecologically conservative species. It is thought to reflect the degree of human disturbance to an area by accounting for the presence of cosmopolitan, native species, as well

as nonnative taxa. This index is capable of measuring ecosystem condition because it assigns a repeatable and quantitative value to vegetation community composition. Use of the index requires that local flora be available with coefficients of conservatism assigned to each species. These lists are finalized for some areas (e.g., Ohio, Michigan) and under development in many others (e.g., Florida).

To calculate the FQAI, a species list is compiled for the site. Then each species on the list is assigned a rating (tolerance values) of between 0 and 10 (Andreas and Lichvar 1995). A rating of 0 is given to opportunistic native invaders and nonnative species. Tolerance values of 1–10 are assigned as follows:

- Values of 1–3: applied to taxa that are widespread and do not indicate a particular community
- Values of 4–6: applied to species that are typical of a successional phase of some native community
- Values of 7–8: applied to taxa that are typical of stable or "near climax" conditions
- Values of 9–10: applied to taxa that exhibit high degrees of fidelity to a narrow set of ecological parameters.

The total species list from each wetland is used to calculate the FQAI value for each site as follows:

$$I = R/N\ (N1/2)$$

where I = the FQAI score, R = the sum of the tolerance values (C of C) for all species at the site, and N = the total number of native species.

The FQAI has been shown to respond to human disturbance (see Appendix B) as well as wetland functions such as biomass production (Figure 4) and decomposition.

Other community-based metrics that we have found useful, at least in some wetland classes are shown in Table 1. This list provides a starting point for investigating characteristics of the plant community and their response to human impacts.

Plant functional groups or guilds (also see Appendix D)

Guilds can be defined as a group of species that share similar traits or responses to human disturbance, although they may not be closely related species. There are many ways in which wetland species can be grouped on the basis of their role in ecosystem function or their response to environmental variables (Hobbs 1997, 1992). The creation of functional groups is a means to investigate environmental change at the scale of the ecosystem or landscape, and is based on the fact that set groups of species will respond in similar ways to similar types of stressors (e.g., hydrologic change, high sediment loads). The creation of functional groups then, is often based on nonphylogenetic groupings (Gitay and Noble 1997). Some suggestions defining functional groups include:

- Perennials
- Annuals
- Sediment tolerant species
- Species tolerant of hydrological alterations
- Species tolerant of elevated nutrient levels
- Use of the tolerance values ("coefficients of conservatism") provided in schemes like the FQAI to establish "very tolerant" or "very intolerant" groups
- C3 versus C4 species
- Submersed aquatic species
- Species that form persistent standing litter (see Appendix C).

Responses of the wetland plant community to landscape change (including fragmentation of habitat)

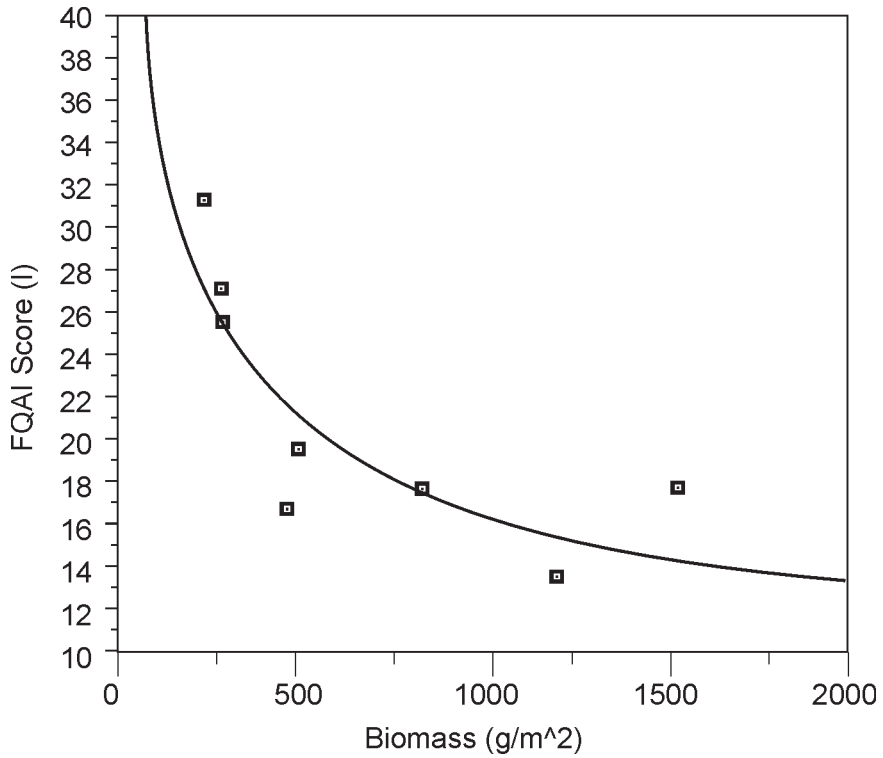

Figure 4: Relationship between FQAI scores and biomass production ($g \cdot m^2$) in eight central Ohio emergent wetlands (Fennessy et al. 1998).

have been observed in certain guilds such as submersed and emergent plant species. For example, Lopez et al. (in press) found that wetland patch size (defined as the size of the habitat fragment that contained the study wetland) and the distance to neighboring wetlands were positively correlated with the diversity of some plant guilds (e.g., submersed herbaceous plant species). The FQAI has also been shown to respond to fragmentation (Figure 4). Chapin (1991) specifically suggests using plant guilds, such as plants that live in nutrient-poor soil conditions, because particular traits might be strong indicators of a stressful environment (e.g., a slow growth rate, low photosynthetic rate, low capacity for nutrient uptake, or specific hormone levels). Chapin (1991) also reports that guilds made up of longer-lived species may be a good indicator of chronic ecosystem stress, whereas an "annual-plant guild" may be a good indicator of acute ecosystem stress. That is, relatively longer-lived wetland plants may have longer response times to environmental stressors than shorter-lived plants and may be better indicators of historic landscape change.

Species-specific attributes

Some species-specific traits also can be indicative of wetland integrity, for example:

- Dominance of an early successional species (e.g., *Salix exigua*)
- Metrics based on the health of individual plants (e.g., Miller et al. 1993).

Attributes that do not seem to work

Some attributes do not give consistent, ecologically meaningful indications of wetland integrity. Although they may be worth investigating on a case-by-case basis, our experience has shown the following:

Table 1: Some potential metrics for wetland plants including how they could be scored, how they would respond to human disturbance, and geographic areas of the U.S. where they have been tested

Potential metric	Scoring methods: Number of taxa	Scoring methods: Percent cover	Predicted response to human disturbance	Where developed, tested
Alien taxa	xx	xx	increase	
Annuals	xx	zz	increase	Mid-Atlantic
Carex species	xx		decrease	MN
Clonal growth	xx	xx	increase	
Dominant species (1, 2, or 3)		xx	increase	
Decomposition (persistent standing litter)		xx	increase	MN, mid-Atlantic, New England
Dicots	xx	xx	increase (?)	MN, Ohio
Dominance of Typha (or other taxon)		xx	increase	
Early successional species	xx	xx	increase	
Facultative wetland taxa	xx	xx	variable	MN, New England
Grasslike taxa (sedges, rushes, grasses)	xx	xx	decrease	MN
Intolerant or sensitive taxa	xx		decrease	OH
Invasive taxa	xx	xx	increase	mid-Atlantic, New England
Monocarpic taxa	xx	xx	increase	MN
Monocots	xx	xx	decrease (?)	
Native taxa	xx	?	decrease	Mid-Atlantic
Nonvascular plant taxa	xx	xx	decrease	MN
Number of plant guilds (emergent, submerged, etc.)			decrease	MN
Obligate wetland taxa	xx	xx	variable	New England
Perennials	xx	zz	decrease	Mid-Atlantic
Perennial to annual species (ratio)	xx		decrease	Mid-Atlantic
Indicator species (e.g. Utricularia)			decrease	MN
Species richness	xx	xx	decrease	Mid-Atlantic, New England
Species tolerant of hydrologic change	xx		increase	
Taxa in selected families (composites, etc)	xx	xx		
Taxa richness by growth form (trees shrubs)	xx		variable	
Taxonomic composition by strata	xx	xx	decrease?	
Tolerant or insensitive taxa (opportunists)	xx	xx	increase	New England, OH
True aquatic species (floating, submerged)	xx	xx	decrease	MN, mid-Atlantic
Upland species	xx	xx	variable	mid-Atlantic
Vascular plant taxa	xx	xx	decrease	MN
Woody species	xx	xx	decrease	mid-Atlantic
Community similarity to reference			decrease	New England
Wetness	xx	xx	variable	New England
Flood tolerance	xx	xx	variable	New England (freshwater only)
Salinity tolerance	xx	xx	variable	New England (saltwater only)

Note: "?" indicates uncertainty about the response of that particular metric.

- Forest canopy species are often limited in the signal they can provide because of their relatively long response time.
- Some doubt prevails as to the utility of metrics that are based on the health of individual plants. For example, chlorosis (yellowing or turning brown) in plant leaves may indicate stress to that individual; however, this condition may also result from many naturally occurring phenomena such as aging. Quantifying individual health has worked well in other taxonomic assemblages (e.g., fish and the presence of tumors), but no clear dose-response pattern has been seen with regard to plants.
- Although there has been some interest in the potential of the wetland plant indicator status classification system developed for conducting delineations (U.S. CoE 1997) to interpret vegetation patterns, there is concern about using the indicator status to evaluate integrity. The wetland indicator status describes the probability that a given plant species will occur in wetlands. The ratings are found in the "National List of Plant Species that Occur in Wetlands" (Reed 1997, 1988); within it is a list of the indicator status of all wetland plants known to occur in U.S. wetlands. Currently about 7,000 species are on the list, each of which has been assigned an indicator status for the regions in which it occurs. Each species is assigned one of four indicator status categories based on the probability that the species will be found in a wetland. These are obligate wetland (OBL), facultative wetland (FACW), facultative (FAC), and facultative upland (FACU). Obligate species occur in wetlands more than 99% of the time, whereas facultative species are just as likely to be found in uplands (50% of the time) as in wetlands (50% of the time). Species not found on the list are considered to be obligate upland (UPL) species. The indicator status was not designed to provide information on the condition of a wetland. Many obligate (OBL) wetland species, for instance, are invasive and/or nonnative species (*Typha* sp., for example), and so do not provide an indication of "integrity" in this way.
- In general, care should be taken because metrics that are useful in one class of wetland (e.g., emergent) are not necessarily transferable to other classes.

Limitations of Current Knowledge–Research Needs

Wetland vegetation promises to be one of the best indicators for use in assessing the biological integrity of wetlands. The examples given in Appendixes A–D provide illustrations of how these techniques are currently being tested and used in different State programs. However, research on the relationship between environmental conditions and the response of different species could provide greater sensitivity and precision in detecting impairment. For instance, methods are lacking for characterizing the role of the landscape surrounding a wetland. Questions such as the effect of surrounding uplands on determining the site's condition are difficult to answer. Land use in a wetland's watershed largely determines the quantity and quality of water that enters the site, and this has obvious repercussions for the composition of biotic communities. In addition, human disturbance can be manifest at many scales; how can we assess these and begin to be truly diagnostic about the stressors that lead to a loss of biological integrity? Sampling techniques are sometimes lacking as well. For instance, small wetlands are sometimes undervalued, particularly when they occur in a mosaic of wetland patches interspersed with another habitat type. Useful techniques to evaluate wetlands in this landscape context are needed.

There are also limits on the use of methods that have already been developed (e.g., the FQAI) because we lack the information needed to apply them to wider geographic areas. There is a need to create plant response guilds and/or FQAI tolerance lists for more regions of the country. In fact, despite the vast literature on wetland vegetation, the majority of wetland plant species have not been studied at all, so there is no literature to consult on the autecology of many species. One remedy is to initiate studies on the dose-response relationship, both in the field and in the lab or greenhouse, between different plant species and different types of stressors. This would do much to provide information on species for which little is known.

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Appendix A

A Tale of Two Methods: Developing, Evaluating, and Changing Sampling Methods

John J. Mack and M. Siobhan Fennessy

The Ohio Environmental Protection Agency began evaluating vegetation sampling methods in 1996. Major concerns in selecting a sampling method were ease of use, cost, reproducibility of results, and obtaining as complete a list plant species at a wetland as possible. This last concern related to Ohio's use of a Floristic Quality Assessment Index (FQAI) (Wilhelm 199X ; Andreas and Ladd 1995) which requires a relatively complete flora of a site.

Ohio EPA sampled disturbed and undisturbed wetlands in western and central Ohio in 1996 and 1997. Initially, Ohio EPA adopted a fixed transect method with 1m^2 and 10m^2 circular nested quadrats spaced evenly along the transect. A minimum of 30 quadrats were sampled along 3 transects (30m^2 area sampled herbaceous vegetation and 300m^2 woody vegetation), with at least one transect oriented perpendicular to the other two (hereafter transect-quadrat method). In addition, plants located outside the quadrats but within a 5m wide "belt" along the transect were identified but no density or dominance information was recorded for these plants (hereafter transect-belt method). Within the quadrats, percent cover, stem counts and DBH (woody only) were recorded for each species.

As Ohio EPA IBI development advanced, it become apparent that many successful attributes were associated with measures of dominance, including percent cover and density (stems/ha). However, using the existing method, 30%–60% of the plants observed had only presence/absence data associated with them (Figure A-1). Other issues included (1) the size of the area sampled to characterize forested communities was too small. The forestry literature recommends 400-1,000 m^2 as minimum area to adequately characterize eastern forest communities (Peet et al. 1998); (2) a perceived over sampling of species at the wetland edges.

In 1999, Ohio EPA reevaluated its sampling method and adopted a flexible, multipurpose releve method used by the North Carolina Vegetation Survey (hereafter releve method) as described in Peet et al. (1997, 1998). This method can be used to sample such diverse communities as grass and forb dominated savannahs, dense shrub thickets, forest, and sparsely vegetated rock outcrops and has been used at over 3000 sites for over 10 years as part of the North Carolina Vegetation Survey. It is appropriate for most types of vegetation, flexible in intensity and time commitment, compatible with other data types from other methods, and provides information on species composition across spatial scales. It also addresses the problem that processes affecting vegetation composition differ as spatial scales increase or decrease and that vegetation typically exhibits strong autocorrelation (Peet et al. 1998). The method employs a set of 10, 10 x10m sampling units in a 20 x 50 m layout. Within the site to be surveyed, a 20 x 50 m grid is located such that the long axis of the plot is oriented to minimize the environmental heterogeneity within the plot. In effect then, the method proposed by Peet et al. incorporates the use of releves found in the Braun-Blanquet methodology in as much as the length, width, orientation, and location of the modules are qualitatively selected by the investigator based on site characteristics; however, within the modules,

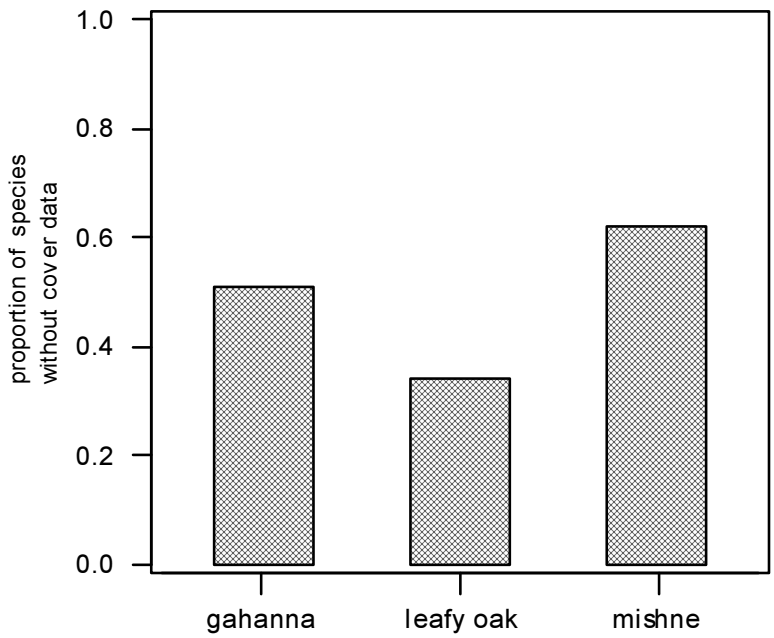

Figure A-1: Proportion of plant species that were missing dominance or density data at three wetlands resampled in 1999 using releve method as described in Peet et al. (1998).

standard quantitative floristic and forestry information is recorded, e.g. density, basal area, cover, and so on.

Ohio EPA resampled several wetlands with the new method that had previously been sampled with transect-quadrat method. These wetlands included a highly degraded emergent marsh, a sparsely vegetated vernal pool, and a floristically rich forested wetland. The releve method solved many of the problems listed above. For instance, all plants have cover or density data associated with them. However, at all three sites, the original transect-belt method had the highest species list (highest species richness) (Figure A-2); this difference was most apparent in the degraded to moderately degraded sites (Mishne and Gahanna). At the floristically rich wetland (Leafy Oak), the difference between the releve method and the transect-belt method was 11 species, or 14% of the maximum value (Figure A-2). At the highly degraded emergent marsh (Mishne), substantially greater numbers of species (80% more) were identified using the transect-quadrat and transect-belt methods than the releve method. These tended to be upland or facultative species growing in a band around the edge of the wetland. Inclusion of these plants raised the Floristic Quality Assessment Index scores for the Mishne site (Figure A-3). Species richness was 48% higher at the Gahana Woods site using the quadrat + belt method as it was using the releve method. But, at the floristically rich Leafy Oak site, the releve method performed nearly as well as the transect-belt method with regards to FQAI scores (Figure A-3). Using the quadrat only data from the transect-quadrat methods yielded very similar scores to the releve method.

A comparison of vegetation IBI scores of data from the transect-quadrat and releve methods yielded very similar results: the relative position of the wetlands sampled using both methods did not significantly change (Figure A-4).

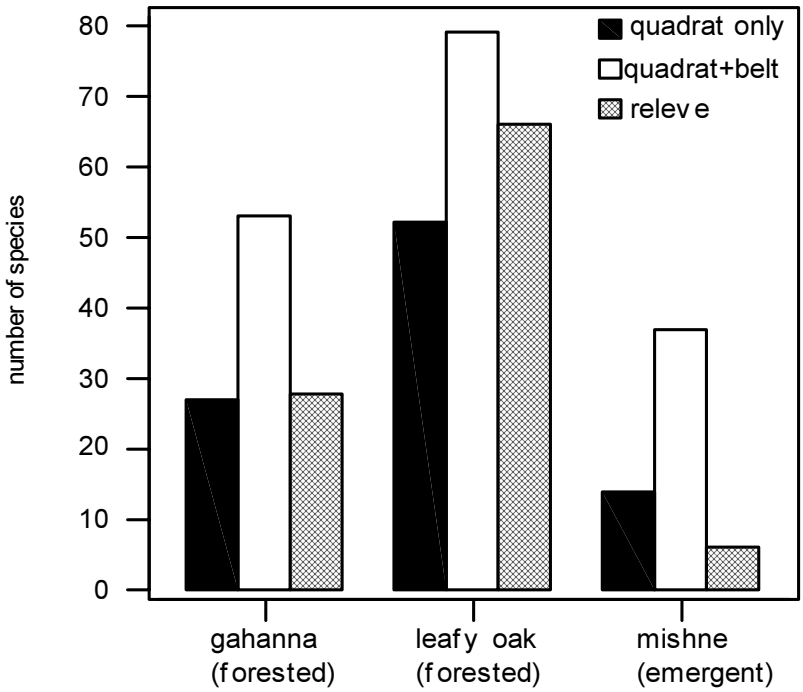

Figure A-2: Number of species found at three wetlands sampled using transect-quadrat, transect-belt, and releve methods (see text) .

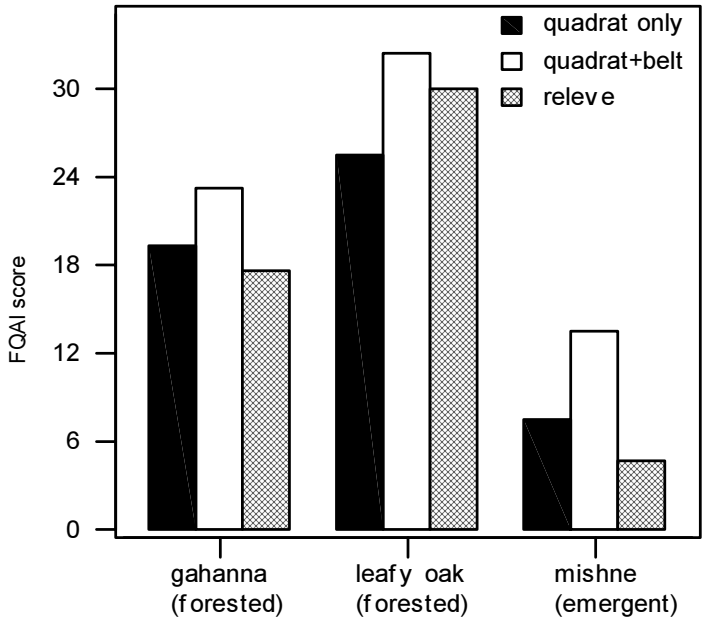

Figure A-3: Floristic Quality Assessment Index (FQAI) score at three wetlands sampled using transect-quadrat, transect-belt, and releve methods (see text for description of FQAI score and box text for description of methods).

The releve method has several advantages over transect-quadrat methods: (1) it allows for an easy qualitative stratified sampling of the dominant plant communities; (2) it provides a more complete forest inventory; (3) the quantitative data is intercomparable with other standard vegetation sampling methods; (4) it is relatively quick (1-3 sites per day with an experienced team); it is easily adaptable to unique situations and shapes of communities (the module system allows you to build up or down in plot size); (5) it provides the data for phytosociological analysis; and (6) it ensures all plants identified have dominance data associated with them.

The releve does not allow mapping of the vegetation communities like a fixed transect method would and the releves are often difficult to lay out in dense shrub communities. In addition, the flora of the wetland is somewhat less complete using the releve method, although this could be compensated for by doing a qualitative survey outside of the plot (something Ohio EPA does as a qualitative check on the appropriateness of the plot location). Cover data would again be lacking however.

In sum, both the transect-quadrat and releve methods yielded equivalent results when the data resulting from these methods was used to calculate a vegetation IBI. Thus, the conclusion may be that whatever method is selected, that it be capable of sampling with sufficient completeness such that human disturbances are detectable.

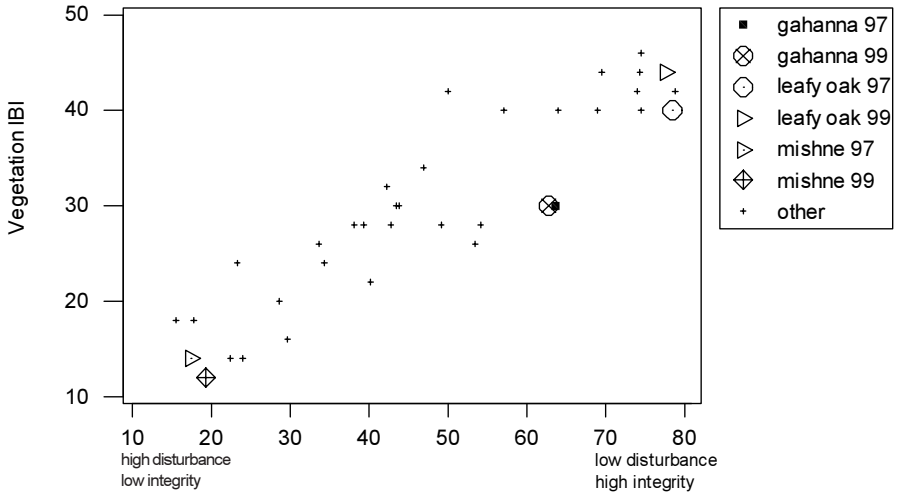

Figure A-4: Interim Vegetation Indices of Biological Integrity (IBI) scores for 45 wetlands in the Eastern Cornbelt Plains Ecoregion of Ohio. Comparison of IBI scores for three wetlands sampled using transect-quadrat and releve method. Data from Mack and Micacchion (in prep).

Appendix B

Development of Vegetation IBIs: The Ohio Experience and Lessons Learned

John J. Mack, Ohio Environmental Protection Agency

The State of Ohio has well-developed biological criteria (or biocriteria) for streams, e.g., the Invertebrate Community Index (macroinvertebrates), Index of Biological Integrity (fish), and Modified Index of Well Being (fish) (Yoder and Rankin 1995). These indices are codified in Ohio Administrative Code Chapter 3745-1. Until recently however, surface waters of the State that are jurisdictional wetlands were only generically protected under Ohio's water quality standards. On May 1, 1998, the State of Ohio adopted wetland water quality standards and a wetland antidegradation rule (OAC Rules 3745-1-50 to -54). These wetland quality standards developed narrative criteria for wetlands and created the "wetland designated use."

Ohio began development of sampling methodologies and began sampling reference wetlands for biocriteria development in 1996. To date, Ohio has sampled nearly 60 wetlands located primarily in the Eastern Cornbelt Plains Ecoregion located in central and western Ohio. This work has been funded since 1996 by several different U.S. EPA Region 5 Wetland Program Development Grants including CD995927, CD995761, CD985277, CD985276, CD985875, and CD975350.

The first two years of data laid the groundwork for standardizing sampling methodologies, classifying wetlands, identifying potential attributes, and developing metrics using vascular plants, amphibians, and macroinvertebrates. The wetlands studied have included depressional emergent, forested, and scrub-shrub wetlands, floodplain wetlands, fens, kettle lakes, and seep wetlands. The wetlands being studied span the range of condition from highly disturbed to relatively undisturbed, i.e., "reference" conditions.

Based on the results to date (see Fennessy et al. 1998a, b; Mack et al. 2000, Mack in prep.), Ohio's research supports the use of vascular plants as taxa group for wetland biocriteria (Figure B-1).

Successful attributes for emergent wetlands include floristic quality assessment index (FQAI) score (see below), ratio of shrub species to total species, numbers of *Carex* spp., numbers of *dicot* spp., numbers of plants with facultative wet (FACW) or obligate (OBL) wetland indicator status, heterogeneity (Simpson's Index), standing biomass, and relative cover of tolerant and intolerant plant species, where "tolerance" is determined by the plant's "coefficient of conservatism," which is derived from a State or regional FQAI system. In addition, for wetlands dominated by woody species, relative density of shrubs and small trees and tree size class equitability have also proved to be useful attributes.

Semiquantitative disturbance/integrity scales

Ohio EPA has had good success in developing a semiquantitative disturbance/biological integrity scale called the Ohio Rapid Assessment Method for Wetlands v. 5.0 (Mack 2001, Figure B-2). Until such time as more quantitative variables like percent impervious surface are found, this type of tool is a good candidate for the problematic x-axis in

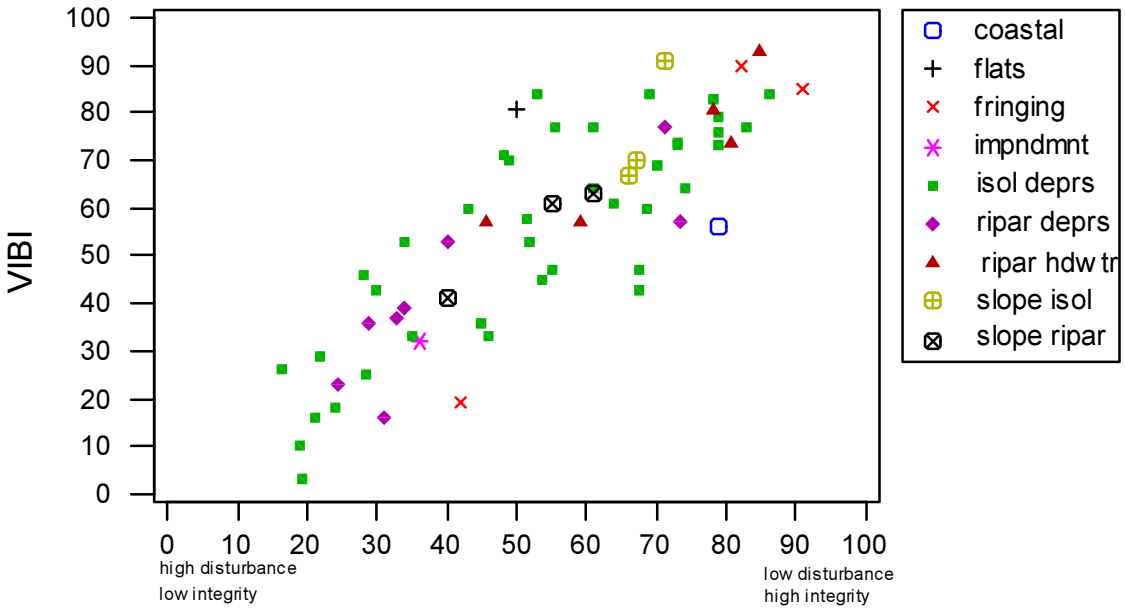

Figure B-1: Vegetation Index of Biological Integrity score by hydrogeomorphic classification for N=65 forested and emergent wetlands in the State of Ohio.

"Coastal"=Lake Erie coastal marsh, "flats"=isolated flats wetlands, "fringing"=wetlands fringing natural lake other than Lake Erie, "impoundment"=wetlands located in or formed by human impoundment, "isol depr"=isolated depressional wetland, "ripar depr"=depressional wetland located in a riparian context, "ripar hdwtr"=wetland located next to or near 1 or 2 order stream, "slope isol"=slope wetland in isolated landscape position, "slope ripar"=slope wetland in riparian landscape position.

wetland biocriteria development. See also Carlisle et al. (1999), where a similar system was used to rank levels of disturbance.

Classification

Classification is definitely an iterative process. Investigators should definitely consider a hydrogeomorphic (HGM) classification scheme if one has been developed for their region of interest, at least as a starting point. For example, shrub dominated wetlands began to emerge as a separate class only after several years of sampling. However, the experience in Ohio suggests that grosser classes based on dominant vegetation (emergent, scrub-shrub, forested, etc.) may work also. A goal of a cost-effective biocriteria program is to have the fewest classes that provide the most cost-effective feedback. With vegetation, data from Ohio are suggesting somewhat diverse wetland types may be "clumpable," since even though their floras are different at the species level, the quality/responsiveness of their unique floras to human disturbance is equivalent (Figure B-2). This is also a concern in States with high degrees of wetland loss where two few wetlands of a particular HGM class remain to analyze as a separate class.

Floristic quality assessment indexes

Ohio EPA has found that Floristic Quality Assessment Index (FQAI) scores and subscores are very successful attributes and metrics for detecting disturbance in wetlands (Figures B-4 and B-5) (see Andreas and Lichvar 1995, Herman et al. 1996, Wilhelm and Masters 1995).

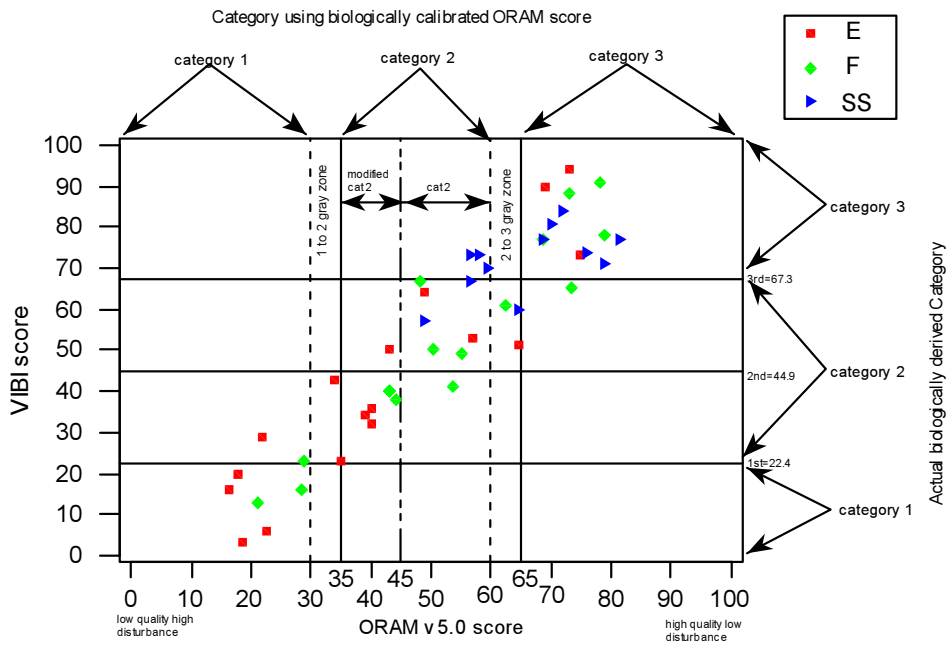

Figure B-2: Relative cover of tolerant herb and shrub stratum species for reference (least impacted) and nonreference (all other sites) of forested and emergent wetlands (N=65) for four ecological regions in the State of Ohio.

E=emergent, F=forested, SS=scrub-shrub.

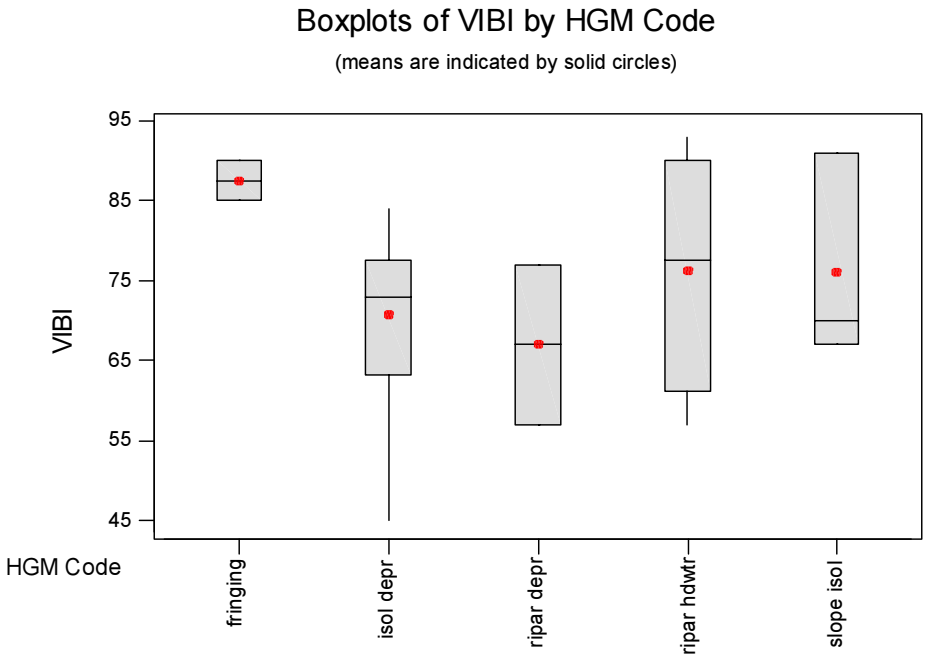

Figure B-3: Box and whisker plots of emergent and forested reference (least-impacted) wetlands (N=29).
See Figures B-5 and B-6 for HGM code descriptions.

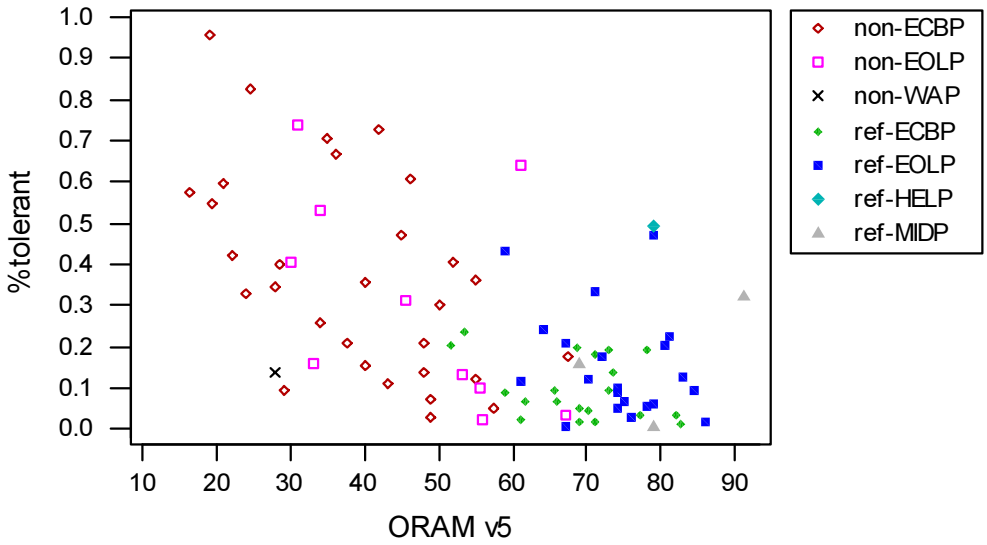

Figure B-4: Relative cover of tolerant herb and shrub stratum species for reference (least impacted) and nonreference (all other sites) of forested and emergent wetlands (N=65) for four ecological regions in the State of Ohio.

ECBP=Eastern Corn Belt Plains, EOLP=Erie-Ontario Lake Plains, HELP=Huron-Erie Lake Plains, MIDP=Michigan-Indiana Drift Plains, WAP=Western Allegheny Plateau.

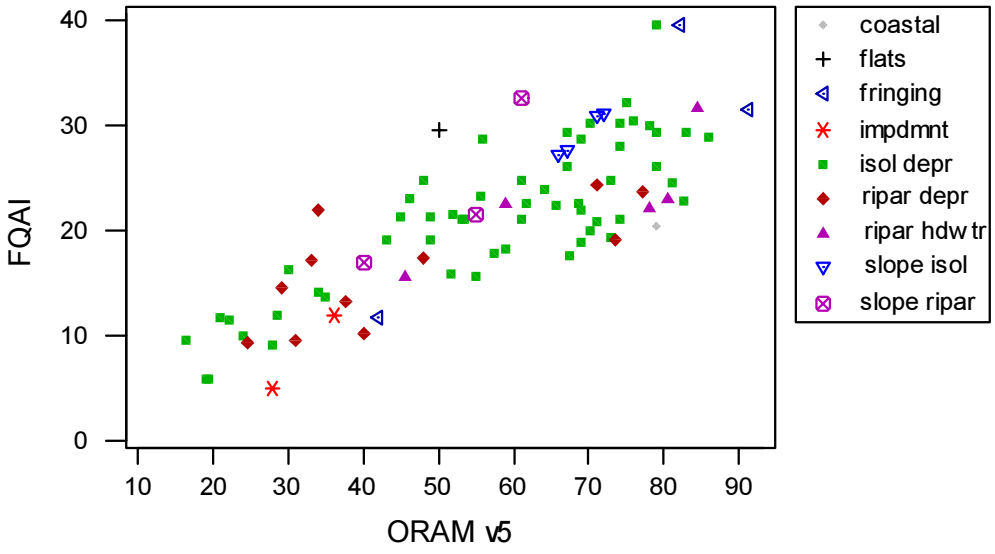

Figure B-5: FQAI score by hydrogeomorphic classification for N=65 forested and emergent wetlands in Ohio.

"coastal"=Lake Erie coastal marsh, "flats"=isolated flats wetlands, "fringing"=wetlands fringing natural lake other than Lake Erie, "impoundment"=wetlands located in or formed by human impoundment, "isol depr"=isolated depressional wetland, "ripar depr"=depressional wetland located in a riparian context, "ripar hdwtr"=wetland located next to or hear 1 or 2 order stream, "slope isol"=slope wetland in isolated landscape position, "slope ripar"=slope wetland in riparian landscape position.

Field and lab methods

After experimenting with both transect/quadrat and releve-style plot methods, Ohio has adopted a plot based method which allows for a qualitative stratification of wetland by dominant vegetation communities. This method appears flexible and adaptable to unique site conditions, provides dominance data for all species in all strata, provides data intercomparable with other common methods, is relatively easy to learn, and is relatively fast and cost-effective (up to 2 to 3 plots can be completed in a day).

Whatever sampling method is adopted, it is essential that dominance and density information (cover, basal area of trees, stems per unit area, relative cover, relative density, importance values, etc.) be collected. Many of the most successful attributes Ohio has found in developing a vegetation IBI are based on cover data of the herb and shrub layers and density data of the shrub and tree layers.

Definitely consider using cover classes in general and a class scheme that works on a doubling principle to aid in consistent inter-investigator usage. Then use the midpoints of the class for your analysis. This seemed to help with consistent usage and smoothing out the roughness in cover data.

Appendix C

Minnesota Index of Vegetative Integrity (IVI)

Mark Gernes

Minnesota intends to use its biological assessment results to report on and track wetland conditions within local watersheds. This assessment tool will be useful for evaluating best management practices for wetlands and wetland restorations, and prioritizing wetland-related resource management decisions. Minnesota also intends to develop numeric wetland biological criteria.

Minnesota has proposed 10 wetland vegetation metrics that have been combined into a multimetric "Index of Vegetative Integrity" (IVI). Two metrics focus on taxa richness, four are based on life-form guilds, two are sensitive and tolerant taxa metrics, and two are community-structure metrics. This multimetric index has been used effectively in Minnesota to assess wetland condition. A 100 m^2 releve plot method was used to sample the vegetation. All sampling was conducted in the wetland emergent vegetation zone. Additional metrics may be developed as this work progresses. Reference sites were chosen as least-impacted wetlands; stormwater runoff or agricultural activities disturbed the other sites. Scoring criteria for the metrics described below are shown in Table C-1.

1. Vascular genera metric

Rationale: The vascular genera metric expresses the richness of native genera occurring in the wetland (i.e., the number of native vascular plant genera in a 100 m^2 releve plot). Many genera have some species that are native and others that are nonnative. In these instances the genus is not excluded from the count. When all taxa within the genus are not native to Minnesota the genus is not counted. An example might be the genus *Echinochloa*, where two common wetland species occur. *Echinochloa muricata* is native whereas *E. crusgalli* is not. When plants in this genus occurred in the sampling plot but could not be identified by species, they were counted. This metric was developed for depressional wetlands, so all taxa recognized as being nonwetland taxa were excluded from the count. Species are identified as being nonwetland taxa in accordance with the Region III assignment (Reed 1988) and include those species with indicators of FAC+, FACU, and UPL. This forces the resulting count to reflect the wetland condition as opposed to the terrestrial and aquatic community edge.

Although keeping this metric at the genus level will make it accessible for less specialized biologists and simplify the sampling, whenever possible all identifications were done to the species level. Interestingly, when this metric was developed it was based on species-level identification. However, the genus-level scoring gave a stronger negative response to human disturbance. Caution should be used in applying this metric where plant diversity is naturally low. Some examples of wetland plant communities that have naturally low numbers of species are lake sedge (*Carex lacustris*), fringe communities, wild rice (*Zinnia palustris*) beds, and hardstem bulrush (*Scirpus acutus*) communities.

2. Nonvascular taxa metric

Rationale: The nonvascular taxa metric expresses the number of nonvascular taxa including liverworts, mosses, lichen taxa, and the macroscopic algae *Chara* and *Nitella*. In the Minnesota study, the maximum number of nonvascular taxa observed at any site was two (including four of the six reference sites). Six of the agriculturally impacted sites and

Table C-1: Scoring criteria for vegetation-based metrics in the Minnesota IVI. The number of sites scoring at each level is given, as are the number of least-impacted reference (ref) sites.

Vascular plant metric

Genera	Score	#Sites
>14	5	6 (3 ref)
.9-14	3	10 (3 ref)
< 9	1	10

Aquatic guild metric

Species	Score	#Sites
> 6	5	5 (4 ref)
.3-6	3	9 (2 ref)
< 3	1	12

Nonvascular plant metric

#Taxa	Score	#Sites
>1	5	6 (4 ref)
1	3	7 (2 ref)
0	1	11

Sensitive taxa metric

Sensitive species	Score	#Sites
> 4	5	3 (ref)
.1-3	3	12 (3 ref)
0	1	9

Carex cover metric

Total Carex Cove	Score	#Sites
> 3	5	6 (2 ref)
0.1 - 2.9	3	11 (4 ref)
0	1	9

Tolerant taxa metric

Tolerant Taxa	Score	#Sites
< 25%	5	4 (4 ref)
25.1 - 60%	3	12 (2 ref)
> 60%	1	10

Grasslike species metric

#Species	Score	#Sites
> 8	5	4(2 ref)
7-Feb	3	6(4 ref)
< 2	1	12

Dominance metric

Dominance	Score	#Sites
< 0.07	5	7 (3 ref)
0.08 - 0.2	3	11 (3 ref)
> 0.2	1	8

Monocarpic species metric

Cover	Score	#Sites
> 2.5	5	7 (4 ref)
2.0 - 2.49	3	11 (2 ref)
< 2.0	1	8

Persistent litter metric

Cover	Score	#Sites
< 25%	5	6 (4 ref)
25 - 75%	3	13 (2 ref)
> 75%	1	7

Note: All data were collected in 100 m^2 releve plots.

five of the stormwater sites supported no nonvascular taxa. This was not surprising. Blindow (1992) reported that charaphytes and possibly other nonvascular taxa are more sensitive to eutrophication than are angiosperms. It is likely this metric could be strengthened by improving the level of identification for the mosses, bringing them to genus.

3. Carex cover metric

Rationale: The Carex cover metric was calculated by summing the cover class for all *Carex* taxa sampled in each plot. *Carex* occur as an important structural component of shallow wetland emergent plant communities. Members of the *Carex* genus are particularly common in shallow marsh and wet

meadow communities (Eggers and Reed 1997). They are known to be adversely affected by such environmental stressors as excessive siltation and hydrologic alteration and nutrient enrichment (Wilcox 1995). Field observations have demonstrated that these plants are among the most sensitive to human disturbance and among the first to either disappear from sites or be poorly recruited in most wetland restoration projects (Galatowitsch 1993).

In order to receive a score of 5 a site must support at least 25% *Carex* cover. It is interesting that two agricultural, two stormwater, and two reference sites had a score of 5 for this metric. These sites were likely influenced by groundwater that may have positively influenced the amount of *Carex* they supported.

4. Grasslike species metric

Rationale: The grasslike species metric expresses the richness of grasses (*Poaceae*), sedges (*Cyperaceae*), and rushes (*Juncaceae*). Structurally these plants are very similar and generally occupy similar niches. Only native taxa in these three families were tabulated for the grasslike species metric. This metric is important because native taxa in these plant families are frequently among the first to begin decreasing following human disturbance (Wilcox 1995). Galatowitsch (1993) reports that particularly the sedges are poorly recruited in wetland restoration projects, which suggests sedges have a relatively low ecological tolerance to stress.

There was only a moderate ($R^2 = 0.43$) linear relationship between the number of grasslike species and the gradient of human disturbance. The statistical analysis showed this metric to be one of the weaker plant metrics. However, this measure was able to distinguish the severely impaired sites from the reference sites.

5. Monocarpic species metric

Rationale: Monocarpic species flower only once in their life cycle and typically including annual and biennial species. We used a mathematical function to relate the importance of monocarpic species (using cover) at each study site. van der Valk (1981) reported that changes in water level through natural drying or inundation can result in habitat changes that facilitate the growth of monocarpic species. We calculated this metric as a sum of the monocarpic species richness and cover class values divided by the monocarpic species cover. Only native monocarpic taxa were not included because nonnative monocarpic taxa are often aggressive and could skew the response.

The monocarpic species metric responded strongly to hydrologic fluctuations. As such it would be useful to include this metric in a multimetric index to respond to signals from worst-case sites, particularly those affected by severe hydrologic fluctuations.

6. Aquatic guild metric

Rationale: This metric evaluates the number of aquatic guilds at a site. Submerged plants, either rooted or unrooted, and floating vascular plants such as the duckweeds are life-form-dependent aquatic macrophytes that comprise the aquatic guild used in this metric. The guild is adapted from Galatowitsch and McAdams (1994), who recognize six separate aquatic guilds. Four of their guilds, including "rooted submersed aquatics," "unrooted submersed aquatics," "floating perennials," and "floating annuals" were used in constructing this metric. When counting the number of aquatic guild species only native species were included. The aquatic guild taxa were expected to be most responsive to the water quality. Though the relationship between this metric and the human disturbance index was not a statistically significant linear relationship ($R^2 = 0.28$), the data show a separation of

the a priori reference sites from more than half of the degraded sites. This metric appears to be particularly important in larger or more open wetlands.

7. Sensitive taxa metric

Rationale: The sensitive taxa metric evaluates the decrease in richness of taxa that are most susceptible to human disturbance. To determine which species were sensitive, a matrix of all plant taxa sampled in the project was created by site. In this matrix the a priori reference sites were arranged along one side of the site continuum. Taxa either unique to the reference sites or those that occurred in two or more reference sites and only one impaired site were considered to be sensitive. Any nonnative species meeting these criteria were not considered to be sensitive taxa. The list of taxa considered to be sensitive included *Asclepias incarnata*, *Dulichium arundinaceum*, *Eriophorum gracile*, *Scirpus validus*, and *Iris versicolor*. Recognition of tolerant taxa was based partly on reported responses of plant species to human disturbance (Wilcox 1995, Rice and Pinkerton 1993, Weisner 1993, Squires and van der Valk 1992) as well as personal field observations in this project. All nonnative plant taxa were also considered to be tolerant. Percent tolerant species values were developed as a proportion of the number of tolerant species in a sample divided by the total number of all taxa in the sample. Possible values for this metric range from 1 to 100. Our results for this metric showed that from 11% to 100% of the taxa in the sample were tolerant. The reference wetlands clearly had proportionately fewer tolerant species than the impaired sites. This metric gave the strongest response signal out of the 10 vegetation metrics.

8. Dominance metric

Rationale: The dominance metric incorporates the distribution or concentration of cover class values relative to the taxa richness for native species within the sample. Used in this way it is similar to an expression of evenness. The formula for calculating dominance was taken from Odum (1971) and expressed as:

$$D = (n_i/N)^2$$

where n_i = the cover class for each taxa within an emergent sampling plot, and N = the sum of all cover class values for all taxa within the sampling plot.

The mathematical range of this function is between 0 and 1, with a more biologically diverse wetland scoring near 0 and more monotypic sites scoring near 1. In this study, the eight most impaired sites had higher dominance values than all the reference sites. The dominance metric is considered to be one of the moderately reliable metrics.

9. Persistent litter metric

Rationale: Persistent litter is defined as being resistant to decomposition. It does not provide as many available nutrients or as much detrital energy to drive the wetland system as does readily decomposable litter. Decomposing litter provides microhabitats and nutritional benefit for many aquatic invertebrates (Campeau et al. 1994). Scoring for the persistent litter metric was based on a sum of the abundance cover classes for plant taxa recognized as having persistent litter, including: common reed (*Phragmites*), bullrushes (*Scirpus*), smartweeds (*Polygonum*), cattails (*Typha*), and burreeds (*Sparganium*). This measure proved to be a reliable metric.

Appendix D

Tolerance Groups of Wetland Plants for Use in a Plant-Based Index of Biological Integrity

Denice Heller Wardrop and Robert P. Brooks
Penn State Cooperative Wetlands Center

In preparation for a plant-based Index of Biological Integrity (IBI), individual plant community metrics have been tested for robustness along a gradient of human disturbance in Pennsylvania wetlands. Human activities of high interest in Pennsylvania include land-use conversion to agricultural and urban uses; dominant stressors associated with these activities are hydrologic modification, sedimentation, and nutrient input. General measures of community response, such as species richness, diversity, and evenness, when taken over all wetland types, do little to establish general patterns of response to these stressors. Suitable metrics for expressing plant community responses to disturbance were not available and therefore needed to be constructed. One traditional metric is the use of functional, or tolerance, groups of organisms. Existing functional groups do not incorporate stress-resistant characteristics. For example, currently-used functional groups do not include traits that exemplify a species' germination capabilities as well as its ability for clonal growth; both traits are basic to a plant's ability to tolerate sedimentation. Tolerance groups of plants relating to sedimentation and hydrologic stress were, therefore, constructed using field data on 70 reference wetlands in Pennsylvania.

Our wetland sites were chosen to encompass six common (HGM) subclasses of Pennsylvania's five ecoregions (headwater floodplains, mainstem floodplains, slopes, riparian depressions, surface depressions, and fringing), as well as high, moderate, and low levels of impact from human activities (e.g., elevated sedimentation, nutrient loading, habitat fragmentation). Field data included presence/absence and percent cover data, resulting in more than 500 plant species represented over approximately 800 plots. Characterization of plant communities in these wetlands showed clear associations between individual species and ability to tolerate sediment. The tolerance for sedimentation in most species, however, is also dependent on other possible co-occurring stressors, such as wetting and drying cycles. HGM subclass was used as an indicator of levels of these co-occurring stressors. It was expected that the ability of a plant community or individual species to occupy space along a gradient of increasing sediment accumulation would be different for various HGM subclasses. This was borne out in shifts of some species between sediment tolerance groups within wetlands of different HGM types, or drastic reductions in the mean percent cover demonstrated between HGM subclasses. In this context, HGM classification was important in establishing the range of other co-occurring stressors, and thus provided a constrained condition for examining the effects of sedimentation. Because of the clear value of HGM classification as an organizing variable of co-occurring stressors, sediment tolerance groups were established for each HGM wetland type.

Sediment tolerance groups were established by tabulating average percent cover of individual species, when present, with sedimentation levels. Species were categorized as very tolerant, moderately tolerant, slightly tolerant, and intolerant on the basis of their association with environments of varying sedimentation. In general, species that were cat-

egorized as very tolerant or moderately tolerant increased their percent cover (dominance) over the disturbance gradient. For species that represented either end of the disturbance gradient (i.e., highly tolerant or intolerant), the appropriateness of the plant species as an ecological indicator was assessed utilizing calculation of validity and significance. Validity is a measure of how often an indicator (e.g., a particular plant species) is found with whatever it is expected to indicate (e.g., sedimentation category). This is expressed as the ratio of the number of plots where these two items occur together to the total number of plots where the indicator occurs, expressed as a percentage. Significance denotes the frequency with which the indicator and that particular object are associated. Significance is determined by expressing as a percentage the ratio of the number of plots where both occur to the total number of plots where the indicator object is found. Validity and significance were calculated for each plant species/sedimentation category combination. Plant species were sorted according to validity and significance values in each sedimentation category.

Hydrologic groups were determined in a similar fashion, utilizing well monitoring data collected by the Penn State Cooperative Wetlands Center at 27 sites. Hydrologic measures, based on water level data recorded every 6 hours, were the following:

- Median depth to water
- Percent time water level was within the top 30 cm
- Percent time upper 30 cm was saturated, inundated, or dry
- Percent time upper 10 cm was saturated, inundated, or dry

Utilizing these data, sites were assigned to one of five hydrologic groups, ranging from predominantly inundated to predominately dry. Plant data from 406 plots, with a total of 187 plant species, was used to construct the groups. Groups were established by tabulating average percent cover of individual species, when present, within each of the five hydrologic groups. Wetland plant indicator status (obligate, facultative, etc.) was an extremely poor predictor of an individual species' associated hydrologic regime. For example, species found in wetlands that were almost constantly inundated had indicator statuses ranging from obligate to facultative-upland. However, HGM classification is a suitable surrogate for hydrologic regime, suggesting that hydrologic groups can be constructed without extensive monitoring well data.

A number of reasons indicate that stressor-specific tolerance groups of plant species, constructed with field data, are an effective basis for metrics in a plant-based IBI:

- Linkages of plant species to specific stressors are well documented
- Ecological suitability of a site for an individual plant species is documented
- Field-based groups complement literature-based ones
- Field-based construction improves the diagnostic capabilities of metrics

An example of tabulation of field data for establishment of groups is presented in Figure D-1.

Legend: * 0% 1-25% 26-50% 51-75% 76-100%

Sedimentation

Lowest → Highest

Species	Cluster 1 n=16	Cluster 2 n=12	Cluster 3 n=5	Cluster 4 n=1
Sediment Tolerators				
Solidago patula		*		
Solidago uliginosa		*		
Typha latifolia		*	*	
Senecio aureus			*	
Dipsacus sylvestris		*	*	
Fragaria virginiana		*	*	
Moderately Tolerant				
Solidago sp.				*
Carex vulpinoidea				*
grass				*
Impatiens capensis				*
Erythronium americanum				*
Carex prasina				*
Phalaris arundinacea				*
Slightly Tolerant				
Carex sp.			*	*
Equisetum arvense	*		*	*
Arisaema triphyllum			*	*
Viola sp.			*	*
Thelypteris noveboracensis	*		*	*
Brachyelytrum erectum	*		*	*
Sediment Intolerant				
Mentha arvensis		*	*	*
Onoclea sensibilis		*	*	*
Cirsium arvense		*	*	*
Eupatorium maculatum		*	*	*
Boehmeria cylindrica		*	*	*
Euthamia graminifolia		*	*	*
Glecoma hederacea		*	*	*
Potentilla sp.		*	*	*
Symplocarpus foetidus		*	*	*
Asclepias syriaca		*	*	*
Lysimachia nummularia		*	*	*

Figure D-1: Sediment Tolerance Groups of Wetland Plants in Slope Wetlands of Central Pennsylvania Wetlands.