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Plant Functional Group Composition in Tallgrass Prairie: Development of a Rapid Assessment Method for Measuring Vegetation Integrity

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ABSTRACT

Monitoring of plant communities is critical for identifying trends and assessing the impact of management. Current methods of ecological monitoring typically involve collection of species-level data and expertise in plant identification, procedures that can be time-consuming and costly. Because many agencies rely largely on volunteer labor, a rapid assessment index is needed that is both effective and designed for volunteers to use. Such an index would allow for frequent monitoring between more intense monitoring events and for quick assessment of sites. A method of assessing prairie site quality using plant functional groups was developed and tested against species-level indices for 15 prairie remnants and plantings ranging widely in quality to determine whether functional group information could be useful for constructing a rapid assessment index. Significant correlations were found between the functional group index and all species-level indices tested. The index also differentiated between high-quality remnants and plantings. If this simplified index provides meaningful information, it might be a useful tool for evaluation of management and restoration progress when time and expertise are limited. Observed differences in functional composition between plantings and remnants might also serve as a guide for improving habitat reconstructions.

INTRODUCTION

The purpose of this study is to expand upon a rapid assessment method for measuring vegetation quality of prairies based on plant functional group density (FGD) (Taft 2002) and to test it by comparing FGD to prairies representing a range of integrity. In addition, FGD is compared to habitat quality indices calculated from species-level data at these sites representing a wide range of habitat quality to compare degree of explained variance among sites using the various functional group and species-level indices. If FGD provides a rapid, and ecologically meaningful estimate of habitat integrity, monitoring functional groups potentially can be accomplished with volunteers and other non-specialists and greatly expanding the capacity for adaptive management based on site-level trend data.

<u>The Tallgrass Prairie: Degradation and Restoration</u>

The tallgrass prairie of the midwestern United States, once an expansive and biologically diverse grassland, is now a critically endangered ecosystem in need of management to prevent further degradation and loss of species, and restoration to remedy the loss. Much of the prairie has been converted to agricultural usage because of its rich soils and manageable terrain. In Illinois, about 60 percent of which was once prairie, only about 0.01 percent of the original area of prairie remains in relatively undisturbed condition (White 1978). The Illinois Natural Areas Inventory found 83 percent of high quality prairies in the state to be smaller than 10 acres and 30 percent less than one acre (White 1978, Robertson et al. 1997). Remnant sites are rarely pristine; they are no longer subjected to historic disturbance regimes, such as periodic fires and grazing by bison, and many have been degraded by post-settlement disturbances such as soil scraping and heavy grazing (Taft 1995). These prairies are often infested with exotic weeds that can take advantage of disturbance and may out-compete and displace native species (Zavaleta and Hulvey 2004). Their small size and isolation renders them especially vulnerable to physical and genetic degradation. Although few prairie species in Illinois are in danger of extinction, many are at risk of extirpation from the state (Taft 1995). Due to previous and ongoing habitat loss and degradation in tallgrass prairies, it is critical these natural communities be evaluated using indices that provide meaningful information toward their protection and restoration.

Indices of Floristic Quality

Monitoring these communities over time facilitates identification of trends, which will ultimately help land managers decide on methods for maintaining and improving sites. The importance of evaluating vegetation trends in landscapes that are largely disturbed and fragmented by human land use has led to the development of many methods for assessing plant community integrity. Common assessment tools that have been used to evaluate prairie communities in Illinois include Illinois Natural Areas Inventory (INAI) grades (White 1978), Floristic Quality Assessment (FQA, Swink and Wilhelm 1994), and Species Richness Index (SRI) and the related Native Species Index (NRI) (Bowles and Jones 1999, Bowles et al. 2000). All these measures attempt to characterize habitat quality using floristic data, and, in some cases, frequency or percent cover of particular species or categories of species judged to be important indicators of community characteristics.

INAI Grades **-** The Illinois Natural Areas Inventory (White 1978) seeks to identify high-quality natural areas throughout the state. Methods were developed during the 1970s for evaluating the natural quality of specific sites based on community structure and composition (White 1978, Robertson 2001). Background information about sites was gathered, and aerial surveys were conducted to identify potential natural areas, followed by ground surveys at likely sites (White 1978). Railroad prairie sites were first surveyed for signs of major disturbance (e.g. soil grading), then the following observations were made about plant communities: presence of characteristic prairie species, presence of rare, disturbance-intolerant species, presence and relative abundance of species that increase with disturbance, and total species diversity (White 1978). A similar procedure was followed at cemetery prairies, but without aerial surveys. Species lists were compiled for potential qualifying cemetery prairies and species were grouped into five categories ranging from weedy native species to conservative prairie plants. These categories were assigned scores and the final tallies provided an indication which sites merited additional surveys (White 1978).

Independent of this scoring method, the INAI established a grading system assigning site grades ranging from “A” to “E”, with high-quality remnants of natural communities with little disturbance graded A or B, degraded communities graded C or D, and grade E representing severely disturbed sites with little or none of the original community remaining. Only sites judged to be high-quality (graded “A” or “B”) qualify for the inventory’s Category 1 designation, so sites not on the list can be assumed to fall into the “degraded” category (grades “C” and below) in this study. Inventory sites are continually re-evaluated, and new sites have been nominated for inclusion on the inventory since the 1978 survey (IDNR Natural Heritage Database 2006).

Floristic Quality Assessment **-** Floristic Quality Assessment (FQA) (Swink and Wilhelm 1994, Taft et al. 1997) is a method of estimating floristic integrity that incorporates species composition for index calculation. A basic assumption of FQA is that species differ in their tolerance to disturbance and disturbance types, and that occurrences and relative abundance of particular plant species can serve as indicators of habitat integrity. To apply FQA throughout Illinois, a Coefficient of Conservatism (CC) value (an integer on a scale from 0 to 10) was assigned to each native species in the state (Taft et al. 1997). The CC value represents observed patterns of species occurrence in plant communities and a level of confidence that a particular species can be found in intact native plant community remnants. This system of ranking taxa assumes species do not contribute equally to community integrity (Taft et al. 1997, Taft et al. 2006). The average CC value for a species assemblage can be used to estimate the site's quality (Mean C) and provides an area independent metric, with the exception of some very small sites. An index weighted by species composition, the floristic quality index (FQI), is the product of Mean C and the square root of total species richness. Species richness can be calculated from sample data or plotless site survey data (Wilhelm 1977; Swink and Wilhelm 1979, 1994; Taft et al. 1997). The resulting value estimates the degree to which a site represents a remnant natural community (Swink and Wilhelm 1979, 1994). Site area and habitat heterogeneity, however, if very different among sites, may influence FQI such that a large degraded site can have a higher value than a small high-quality remnant (Taft et al. 1997). Very large sites or sites with several different types of habitat are likely to contain more species than very small or homogenous sites.

Species Richness and Native Richness Indices **-** Another measure of floristic integrity developed by Bowles and Jones et al. (2000, 2006) assumes diversity patterns at different scales change as habitats are degraded or restored. It uses species richness (based on presence-absence data) at two spatial scales, quadrat and transect, to calculate a single index. The Species Richness Index (SRI) is the product of mean species density (quadrat scale) and the square root of total species richness at scale of transect (typically with 20 sample quadrats), combining native and non-native species. Native Richness Index (NRI) is calculated only using native species. The difference between SRI and NRI can be used to give an estimate of the proportion non-native species contribute to the overall index at a site.

However, indices based solely on patterns of species richness might not provide the most accurate measure of site quality and might not confer stability or a high level of ecological functioning to a community (Schwartz et al. 2000, Taft et al. 2006). Intact natural communities and degraded sites might have similar levels of species richness, but differ in composition and evenness.

Need for a New Index

The practicality of these methods has some limitations. Vegetation monitoring typically is carried out at the species level and in some cases includes estimates of percent cover for individual species. This approach provides an accurate picture of vegetation structure and composition but its practice requires expertise in plant identification and can take a great deal of time. Because many conservation organizations depend on volunteer efforts at conservation areas, and because volunteers (and many biologists) lack the requisite species identification skills, a rapid assessment method would be especially valuable if it could be used by non-experts.

Previous research suggests plant functional groups, such as warm and cool season grasses, sedges, nitrogen-fixing legumes, forbs, and hemi-parasites, can be useful in constructing an effective rapid assessment method for site evaluation (Taft 2002). With a limited amount of training, volunteers and biologists (non-specialists) effectively could use such an index because it requires only categorical knowledge of plants rather than species-level identification. A simple yet ecologically sensitive monitoring method using functional groups might, therefore, would be a valuable tool for conservation agencies.

Plant Functional Groups - Plant functional groups are categories of species with shared attributes and may be constructed based on traits such as morphological or physiological characteristics, ecological roles, resource use, or response to disturbance (Symstad 2003). Diversity in functional characteristics of species, rather than number of species alone, may serve as an important indicator of community integrity and ecological functioning (Hooper and Vitousek 1997, Tilman et al. 1997, Mason et al. 2003).

Lavorel et al. (1997) state that functional groups (or types) can be defined in relation to “either the contribution of species to ecosystem processes ... or to the response of species to changes in environmental variables.” Contributions to ecosystem processes could include primary production or nitrogen capture and retention, while environmental variables might include climate change or disturbance.

Species that are grouped together based on one of these two measures, however, might not form a similar group when classified using the other measure (Skarpe 1996, Walker et al. 1999). To clarify the definition of a functional group, the term “functional response group” can be used to refer to a group of species that respond to a given environmental change in a similar manner, with no implication of their role in ecosystem functioning, and the term “functional effect group” can refer to a group of species that play a similar role in a certain ecosystem function, with no implication of how they respond to a disturbance (Landsberg 1999, Symstad 2003). Thus functional group composition could vary greatly depending on how the classification is made. In the functional groupings defined in the present study, by including groups based on photosynthetic pathway, nitrogen fixation, growth form, and life history, we combine examples of functional response and functional effect groupings.

METHODS

Study Questions

This research expands upon a previous study (Taft 2002) where a rapid assessment method for measuring vegetation quality of prairies was developed based on plant functional group density (FGD). A major goal of the current research was to refine the method and test it by addressing the following questions.

Question A: What is the relationship between site FGD and values for other indices of floristic quality?

Hypotheses and Predictions: If functional group density is an accurate predictor of site quality, then its values should correlate closely across sites with those obtained using other metrics. Furthermore, FGD should show a stronger correlation with indices that are weighted by importance of particular species than with those that simply consider the number of species a site contains, because the latter can be biased by the presence of non-native taxa.

Method of Testing: FGD and values of other metrics, including both weighted indices and traditional direct measures, were calculated at multiple sites. Species-level metrics included MeanC, FQI, NRI, SRI, native species richness, dominance, evenness, and Shannon-Weiner diversity (Whittaker 1975). Correlation analysis was used to determine the relationship between FGD and values obtained using other indices.

Question B: Can the method distinguish between remnant sites of differing quality?

Hypotheses and Predictions: If functional group density is an accurate predictor of site quality, then it should reveal differences between remnant sites judged to differ in quality based on INAI criteria. Sites considered to be high quality (A/B) should differ from those considered to be low quality (C and below).

Method of Testing: Due to the inherent subjectivity of INAI grades, sites fell within a range of values identifying them as either high-quality (A/B) or degraded (C and below) for this analysis. Remnants not qualifying for the INAI were assumed to be grade C and below. An ANOVA with a Tukey post-hoc test was used to determine whether FGD values differed significantly between high and low-quality sites.

Question C: Can the method distinguish between remnant sites and restorations?

Hypotheses and predictions: If functional group density is an accurate predictor of site quality, then it should reveal differences between remnant and planted prairies (which are assumed to be lower quality than remnant sites). If a key characteristic of plantings is the lack of particular functional groups present in remnant prairies, then an index based on functional group density should clearly and consistently distinguish between remnant and planted sites of varying quality.

Method of Testing: ANOVA with a Tukey post-hoc test was used to determine whether FGD values differ significantly between restorations and remnant prairies.

Additional Analysis:

Multivariate analysis using Canonical Correspondence Analysis (CANOCO ver. 4.5; ter Braak and Smilauer 2002) was used to determine how much of the variation in the data could be attributed to FGD compared with other indices . For the Canonical Correspondence Analysis (CCA), the 100 top-ranking species based on importance values from the 30 transects were selected with scaling set for inter-species distances. These top-ranking species comprise 90% of the sum importance value for all recorded species (n = 272). Statistical significance of fitting CCA axes to the relationship depicted between the species and Functional Group Density scores was tested using a global permutation test (Monte Carlo) with 1,000 iterations. Forward selection of the external variables tested with Monte Carlo permutations also was used in determining statistical significance for each bioindex singly (marginal effects) and in order of additionally explained variance (conditional effects).

Index Development

Assignment of Functional Groups - The functional groups used in this study include the following:

- Native sedge
- Native C_3 grass
- Native C_4 grass
- Native perennial forb
- Native annual/biennial forb
- Native annual nitrogen fixer
- Native perennial nitrogen fixer
- Native hemi-parasite
- Native woody
- Alien woody
- Alien forb
- Alien grass

These functional groups were chosen following previous work (Taft 2002) and represent functional groups commonly used to characterize tallgrass prairie. Most of these groups are easily recognizable based on morphology, and those that are not (e.g. annual/biennial forb) contain few species, which may be taught on a site-by-site basis. The category “annual native N-fixer” was created to separate conservative and weedy legumes. The “native woody” functional group was intended primarily as a tool for management, to indicate where woody encroachment might be occurring. N-fixing shrubs native to the prairie, such as *Amorpha canescens* and *Ceanothus americanus*, were therefore placed with priority in the “native perennial N-fixers” category.

Index Calculation - Three indices were calculated for each transect sampled:

- **Native functional group density (FGD):** Count native functional groups occurring in a transect segment, averaged for transect
- **Percent FGD:** Percent native functional groups occurring in a transect segment, averaged for transect.
- **Mean FGD:** Σ [(Average density score for each native functional group) x (frequency of native functional group occurrence)] - Σ [(Average density score for each alien functional group) x (frequency of alien functional group occurrence)]

Mean FGD was predicted to be the most sensitive because it included both frequency and density measures, and included information for alien species.

Vegetation Sampling Methods

Site Selection - Sites chosen for the study included 16 prairies in central and north-central Illinois, divided into three categories: high quality remnant (n = 6), degraded remnant (n = 5), and planting (n = 5). Two transects were sampled at each site except two high-quality remnants along U.S. Route 66 were sampled with just a single transect.

HIGH-QUALITY REMNANTS - Sites considered high quality were those listed as Category 1 INAI sites graded as A or B quality (exception noted below). The high-quality sites chosen for this study include the following prairies:

Cayuga Prairie: This site occurs along the Illinois Central Gulf Railroad corridor parallel to US Rt. 66 in Livingston County, on the east side of the RR tracks just north of Cayuga, IL. This site appears to be unmanaged. One transect was sampled.

Rt. 66 Site #3: One transect was sampled in RR prairie along US Rt. 66 just north of Dwight, IL. This site originally was intended for the category "degraded remnant"; however, based on species level data, it was comparable to other high-quality sites so was included as a high-quality site despite not being listed on the INAI. This small, unmanaged site may not meet the INAI size criterion for prairies (0.25 acres).

Loda Cemetery Prairie: This 3.4-acre site is a high-quality mesic black-soil cemetery prairie just north of Loda, IL in Iroquois County. It was listed as a Category 1 site on the original INAI (White 1978), and was dedicated a nature preserve in 1983 (McFall and Karnes 1995). Loda Cemetery Prairie is managed with periodic burns and exotic species control efforts.

Prospect Cemetery Prairie: This site is a 4-acre mesic black-soil cemetery prairie just south of Paxton, IL, in Ford County. It was listed as a category 1 site in the INAI (White 1978) and was dedicated as a nature preserve in 1976 (McFall and Karnes 1995). Prospect Cemetery Prairie is managed with periodic burns and exotic species control efforts.

Weston Cemetery Prairie: This site is a 3.2-acre mesic black-soil cemetery prairie in McLean County 0.5 mile east of Weston, just north of Hwy. 24. It was listed as a category 1 site on the INAI (White 1978) and dedicated as a nature preserve in 1972 (McFall and Karnes 1995). Weston Cemetery Prairie is managed with periodic burns and exotic species control efforts.

Doug's Knob (Nachusa Grasslands): This prairie has soil derived primarily from weathered sandstone. Doug's Knob is a Category 1 site on the INAI, and is managed with periodic burns. Two transects were chosen at random from an established set of six.

DEGRADED REMNANTS - This category included prairies in railroad rights-of-way and degraded remnants at Nachusa Grasslands. Prairies included in this category were determined to be degraded based on presence/absence and density patterns for particular species. One of the 10 transects was considered too high-quality for the category based on species-level data, and was added to the high-quality category. To balance this change, only one high-quality transect was sampled at Cayuga Prairie, and one more railroad right-of-way transect was added to the degraded remnant category. Degraded remnant sites included the following:

Rt. 66 #2, #3, and #4: The Illinois Central Gulf Railroad runs northeast to southwest along US Rt. 66, and its right-of-way contains extensive, mostly degraded, prairie (Taft 1995b). Sampling was done at three sites near Dwight, IL. These prairies appear to be unmanaged.

Rt. 45: This site is a RR prairie along Rt. 45 just south of Paxton, IL. Prairie vegetation here has a high-quality core (known as Paxton Railroad Prairie), but transitions into weedy grasses and shrubs to the north and south. Two parallel transects were placed in the degraded portions of the prairie. Paxton Railroad Prairie is managed through invasive species control and infrequent burning.

Dot's Knob and Isabel's Knob (Nachusa Grasslands): These sites are degraded (formerly grazed) prairies. Dot's Knob occurs on soils derived primarily from weathered sandstone; Isabel's Knob occurs on soils derived primarily from glacial till and loess. Two transects were chosen at random from an established array of six parallel transects established at each site (Taft 2002; Taft et al., 2006).

RECONSTRUCTIONS (i.e., PLANTINGS) - Five plantings of varying age and quality were chosen for the study. Variation was desirable because one aim of the study was to determine whether plantings generally differ in plant functional group composition from remnants. The planting category included the following sites:

Unity East Prairie: This formerly row-cropped site is about 3 acres and occurs east of Unity East grade school one mile north of Philo in Champaign County. It was planted with prairie vegetation in May 2003. Seeds of 33 forb species and six grass species were sown with a drill. All seed was of central Illinois ecotype. The entire site was mowed in summer 2003, burned in March 2005, seeded again in April 2005, and burned again in February 2006. Weeds were controlled in summer 2005 and 2006 through hand-pulling and spot-spraying with herbicide (Solecki, pers. comm.)

Doris Westfall Prairie: This 40-acre site is located within the Forest Glen Forest Preserve in Vermillion County, near Westville, Illinois. Prior to restoration, the site was an old field stripped of its topsoil, and may have supported an open woodland at the time of settlement (Campbell and Westfall 1991, Solecki and Campbell 1997). The prairie was hand-seeded in 1972 using seed collected in local railroad rights-of-way. Hand-seeding continued through 1990, along with hand-pulling of exotic weeds (Campbell and Westfall 1991). Current management includes hand-weeding and periodic burning. The prairie was dedicated as a nature preserve in 1997 (Solecki and Campbell 1997) and currently is the only planting dedicated as a nature preserve.

Main Unit Planting (Nachusa Grasslands): This site was established in 1991 on previously plowed silt-loam soil (Taft 2002). It is managed with periodic burning and weed control.

East Heinkel Planting (Nachusa Grasslands): This site was established in 1995 on previously plowed silt-loam soil (Taft 2002). It is managed with periodic burning and weed control.

Potholes Planting (Nachusa Grasslands): This site was established in 1992 on previously plowed silt-loam soil (Taft 2002). It is managed with periodic burning and weed control.

Species-level Sampling

Arrays of six parallel transects already were established at the Nachusa sites and Prospect, Loda, and Weston cemetery prairies as part of pre-existing research efforts and recent species level data from these transects were available. Two transects were selected randomly at each site to compare with functional group data. Where no transects previously were established, two were selected randomly. Species presence and cover class values were recorded in quarter-meter-square quadrats (50 cm x 50 cm) placed every five meters on alternate sites of the transect. Most transects were 100 meters in length, but in some cases site configuration constrained transect length. Multiple transects at most sites were parallel to each other, with the exception of Rt. 66 #2 and Rt.

66 #3, where a narrow railroad right-of-way necessitated a linear end-to-end orientation for the transects.

Rapid Assessment Sampling

Functional group data were collected along the same transects established for species-level sampling. However, for plant functional group data, a one-meter-wide belt transect was utilized. Each belt was centered on the transect line and divided into five-meter segments. Within each segment, occurrence of each functional group was recorded along with the distance to first occurrence. Distance to each functional group was scored in descending rank order of meter segments (e.g., by assigning a score of 5 if the functional group was encountered in the first meter, a 4 if encountered in second meter, and 3 if encountered in the third meter, etc…).

RESULTS

Sampling for plant functional groups was much more rapid than species-level sampling using quadrats. Sampling for functional groups took approximately one hour for each transect at all sites, while a species-level transect took three to six hours.

Functional Composition Among Qualitative Categories

High-quality remnant prairies had higher average frequencies for native perennial N-fixers and hemi-parasites, and lower frequency of alien forbs than either degraded remnants or plantings (Fig. 1). Both remnant categories had higher frequencies of native sedges, native C_3 grasses and alien grasses than plantings. Plantings contained more native annual/biennial forbs than either remnant category, and more perennial native N-fixers and hemi-parasites than degraded remnants. These latter differences mostly are attributable to the Westfall Prairie planting which was unusually rich in legumes and hemi-parasites; hemi-parasites were not recorded from any other plantings. All three qualitative site categories had nearly 100 percent frequencies of native C4 grasses and native perennial forbs.

Correlation Analysis

All correlations of indices calculated with species-level data (e.g., diversity, dominance, evenness, FQI, Mean C, NRI, etc…) to Mean FGD were significant ($p < 0.05$; Figure 2; Table 1). Of the three functional group indices, mean functional group density gave the highest Pearson R values. Functional group indices correlated more closely with weighted indices (Mean C and FQI) than traditional direct measures and indices. The correlations with the best fit were between functional group mean density (FGD) and Mean C and FQI ($R = 0.74$).

ANOVA

Mean comparison of qualitative site categories - high-quality remnant, degraded remnant, and planting - with ANOVA (Figure 3a) indicated a significant difference among groups ($p = 0.01$). A Tukey post-hoc test indicated that significant pair-wise differences were found between high-quality remnants and plantings ($p = 0.013$). Differences between high-quality and degraded remnants were nearly significant ($p = 0.07$) and degraded remnants and plantings did not differ.

Because the Doris Westfall Prairie was of higher quality than the other plantings (species-level bio-indices were comparable to high-quality remnants), as a statistical exercise it was placed in the high-quality category. This resulted in significant differences not only for the overall test ($p = 0.000001$) but in all pair-wise comparisons with a Tukey post-hoc test ($p < 0.05$; Figure 3b).

Multivariate Analysis

Canonical correspondence analysis indicated Dominance, Evenness, and Mean C explained the most variation in the data, and variation explained by the functional group indices was not significant (Table 2). However, all three functional group indices were correlated with the other diversity measures (Figure 4), though they overall explain less variance than indices calculated from species-level data. Mean Functional Group Density was strongly correlated with Mean C and FQI.

DISCUSSION AND CONCLUSIONS

The results obtained from this study indicate that a rapid assessment method based on plant functional groups shows promise for estimating and monitoring floristic quality. Plant functional group comparisons between remnants and plantings highlight key differences similar to a previous study (Taft 2002). Particularly salient is the difference for sedges and native cool-season grasses, groups that have greater frequency at remnants, and annual/biennial forbs, a group with greater frequency among plantings. However, differences among qualitative sample groups varied by plant functional group. In some cases, high-quality prairies were distinct from degraded remnants and plantings (e.g., hemi-parasites and alien forbs). Hemi-parasites and native nitrogen fixers were particularly in low frequency in degraded remnants compared with high-quality remnants and plantings. However, much of this difference between degraded remnants and plantings can be attributed to the Westfall Prairie, the oldest prairie reconstruction in the study and one that has been recognized for its resemblance to high-quality remnants meriting dedication as an Illinois Nature Preserve. This site has received intensive management for 35 years (Campbell and Westfall 1991, Solecki and Campbell 1997).

Differences among sample groups in this study, particularly between plantings and high-quality remnants, suggest areas of needed improvement in planting mixtures to meet the general goal of increasing similarity of reconstructions to remnants. In particular, the establishment of greater frequency of sedges, native cool-season grasses, and hemi-parasites in prairie reconstructions will result in plantings with greater structural similarity to high-quality remnants. The data also indicate that degraded prairies typically have lower frequency of perennial nitrogen fixers and hemi-parasites compared with high-quality remnants and greater frequency of alien forbs. This supports the empirical judgment of grading criteria for the Illinois Natural Areas Inventory which typically take these factors into consideration.

As predicted a priori, Mean Functional Group Density (Mean FGD) was the plant functional group metric that was most highly correlated to indices of habitat quality calculated from species-level data. This index combines measures of frequency and density of functional groups and accounts for non-native functional groups by subtracting sum scores of non-native groups from native functional group scores. Mean FGD was most highly correlated with Mean C and FQI, indices found to explain the most variance compared with other habitat-quality indices among qualitatively different prairies (Taft et al., 2006). Mean FGD also distinguished high-quality remnants from degraded remnants and plantings and did so particularly well when the Westfall planting was included among high-quality remnants.

However, FGD metrics generally explained less variance than the indices calculated from species-level data. This is not particularly surprising since FGD indices, by distilling species-level information to categories (always fewer in number than total species richness) represent a simplification of more complex assemblages. While FGD metrics are highly correlated with reliable indicators of habitat quality, and require much less time to calculate, species-level data provide more precision. FGD would be insensitive to species-level changes where the frequency distributions of functional groups remain unchanged. This can occur with a change in diversity among members of a functional group, a factor not measured in this rapid assessment methodology.

In conclusion, FGD is recommended as a rapid-assessment monitoring technique when time and expertise are limited and Mean FGD is recommended as the index of choice. Periodically, at least once every 5-to-10 years, species-level monitoring will be needed for the most effective adaptive management and evaluation of ecological trends, particularly with regard to patterns of species composition and diversity. Mean FGD index may have application in other plant communities and should be tested for efficacy.

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Table 1. Pearson R values and corresponding P values for correlations between Functional Group Density indices and species-level metrics. All correlations are significant. P values between 0.05 and 0.0005 include upper and lower ranges.

FG index	**SP index**	**Pearson R**	**P lower**	**P upper**
mean FGD	nmeanC	0.711	<.0005	
mean FGD	mean C	0.741	<.0005	
mean FGD	FQI	0.739	<.0005	
mean FGD	FQInat	0.696	<.0005	
mean FGD	SRI	0.388	0.025	0.05
mean FGD	NRI	0.523	0.0025	0.005
mean FGD	N native	0.458	0.005	0.01
mean FGD	H native	0.504	0.0025	0.005
mean FGD	evenness	0.448	0.01	0.02
mean FGD	dominance	-0.536	0.001	0.002
Percent FGD	nmeanC	0.598	<.0005	
Percent FGD	meanC	0.578	<.0005	
Percent FGD	FQI	0.606	<.0005	
Percent FGD	FQInat	0.604	<.0005	
Percent FGD	SRI	0.417	0.01	0.02
Percent FGD	NRI	0.449	0.01	0.02
native FGD	nmeanC	0.593	<.0005	
native FGD	meanC	0.575	<.0005	
native FGD	FQI	0.605	<.0005	
native FGD	FQInat	0.603	<.0005	
native FGD	SRI	0.420	0.01	0.02
native FGD	NRI	0.452	0.01	0.02

Table 2. Summary results are shown of global permutation test (1,000 Monte-Carlo permutations) from Canonical Correspondence Analysis and results of forward selection of biotic variables including Functional Group Density indices (shown in red). Marginal Effects rank variables according to the variance explained singly; Conditional Effects show variation explained by the variables in the rank order of their inclusion in the model.

	Marginal Effects			**Conditional Effects**			
Variable	Var.N	Lambda1	Variable	Var.N	LambdaA	P	F
Dominance	19	0.41	Dominance	19	0.41	0.001	3.55
Hn	22	0.4	Mean C	6	0.39	0.001	3.69
N Spp	20	0.37	En	21	0.25	0.001	2.51
En	21	0.36	Hn	22	0.17	0.014	1.82
NRI	12	0.35	FQI	9	0.16	0.028	1.67
Adv Spp	2	0.35	N Spp	20	0.14	0.049	1.61
Mean C	6	0.34	NRI	12	0.15	0.057	1.49
FQI	9	0.34	Adv Spp	2	0.13	0.107	1.41
MEANFGD	15	0.25	MEANFGD	15	0.12	0.118	1.41
NATFGD	13	0.23	NATFGD	13	0.11	0.182	1.3
%NatFGD	14	0.22	%NatFGD	14	0.08	0.609	0.86

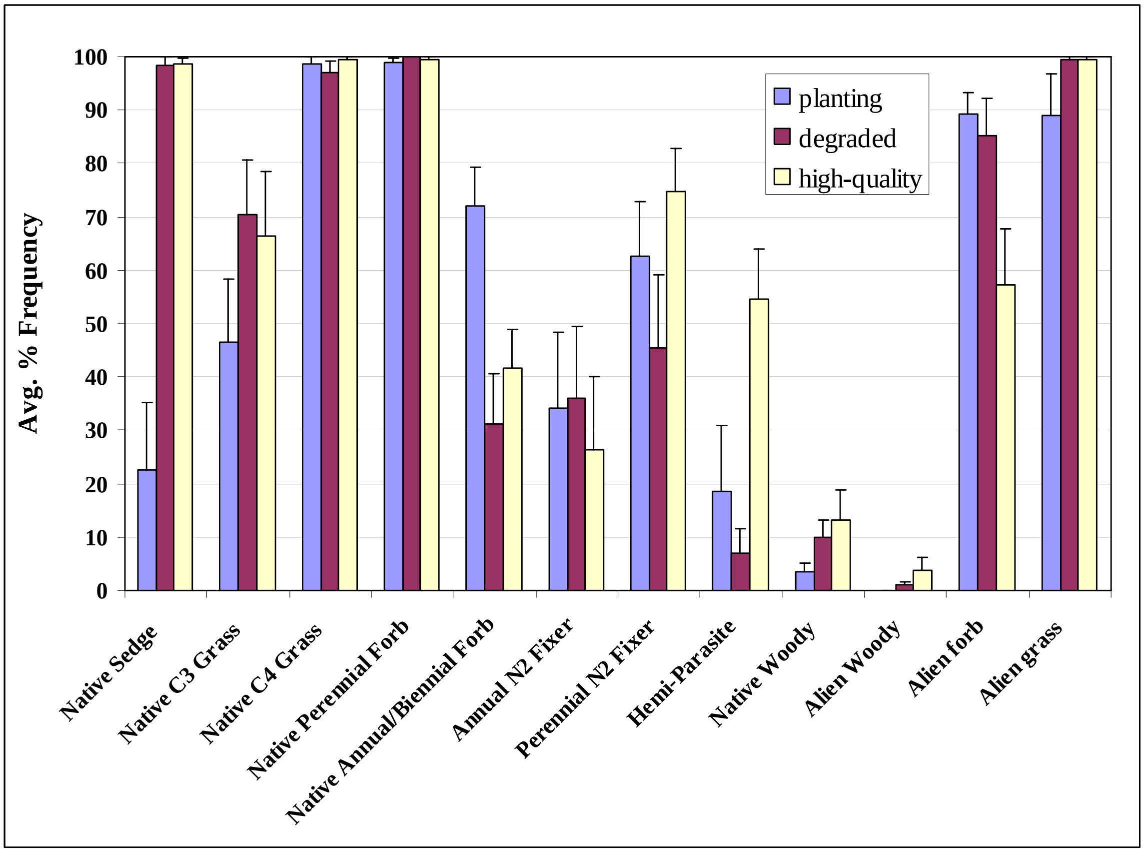

Figure 1. Average frequency of each plant functional group by site category.

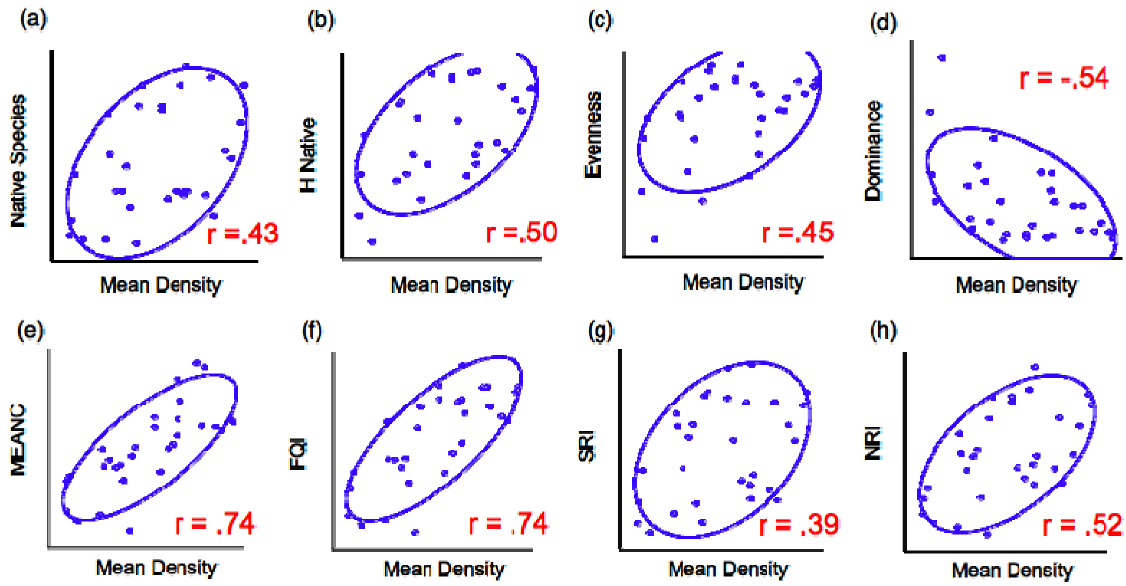

Figure 2. Correlations between Mean FGD and species-level indices: (a) native species richness, (b) Shannon-Weiner diversity (H), (c) evenness, (d) dominance, (e) mean Coefficient of Conservatism (MeanC), (f) Floristic Quality Index (FQI), (g) Species Richness Index (SRI), and (h) Native Richness Index (NRI). All correlations are significant ($p < .05$).

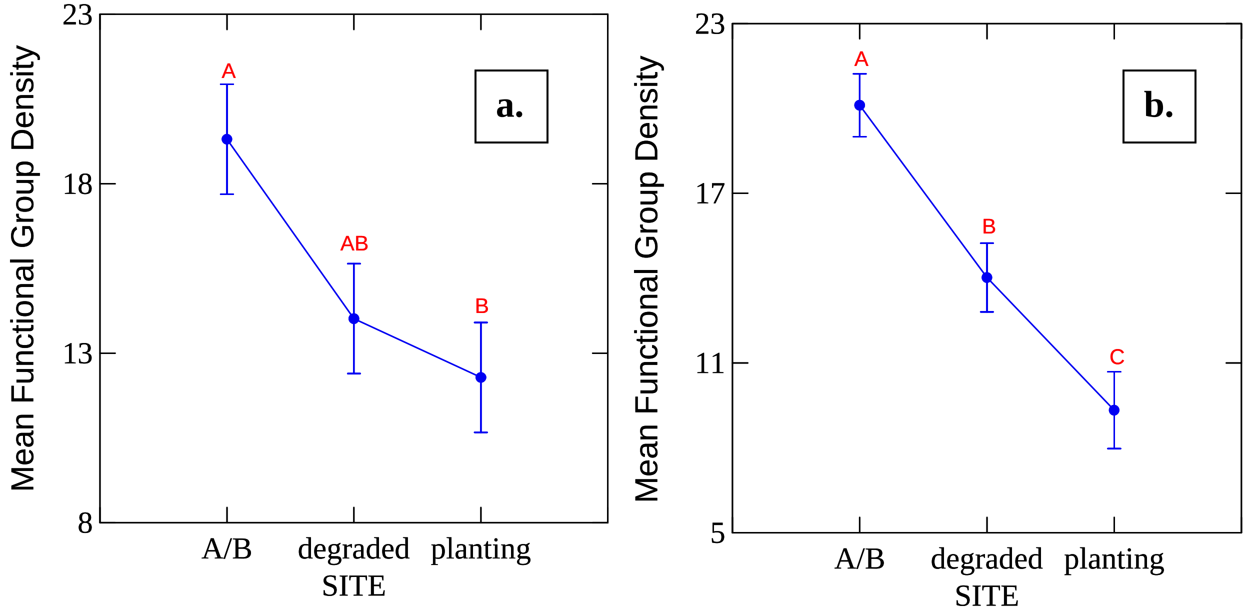

Figure 3. (a) ANOVA results show that mean functional group density distinguished between high-quality remnants (Graded A or B [A/B]) and plantings (p=.01). Significant differences among site categories are indicated by different (upper case) letters. Tukey post-hoc tests reveal that the difference between high and low-quality remnants is only marginally significant (p=.07). (b) When an especially high-quality planting was placed in the A/B category, all three categories differed significantly from each other (p < 0.00001).

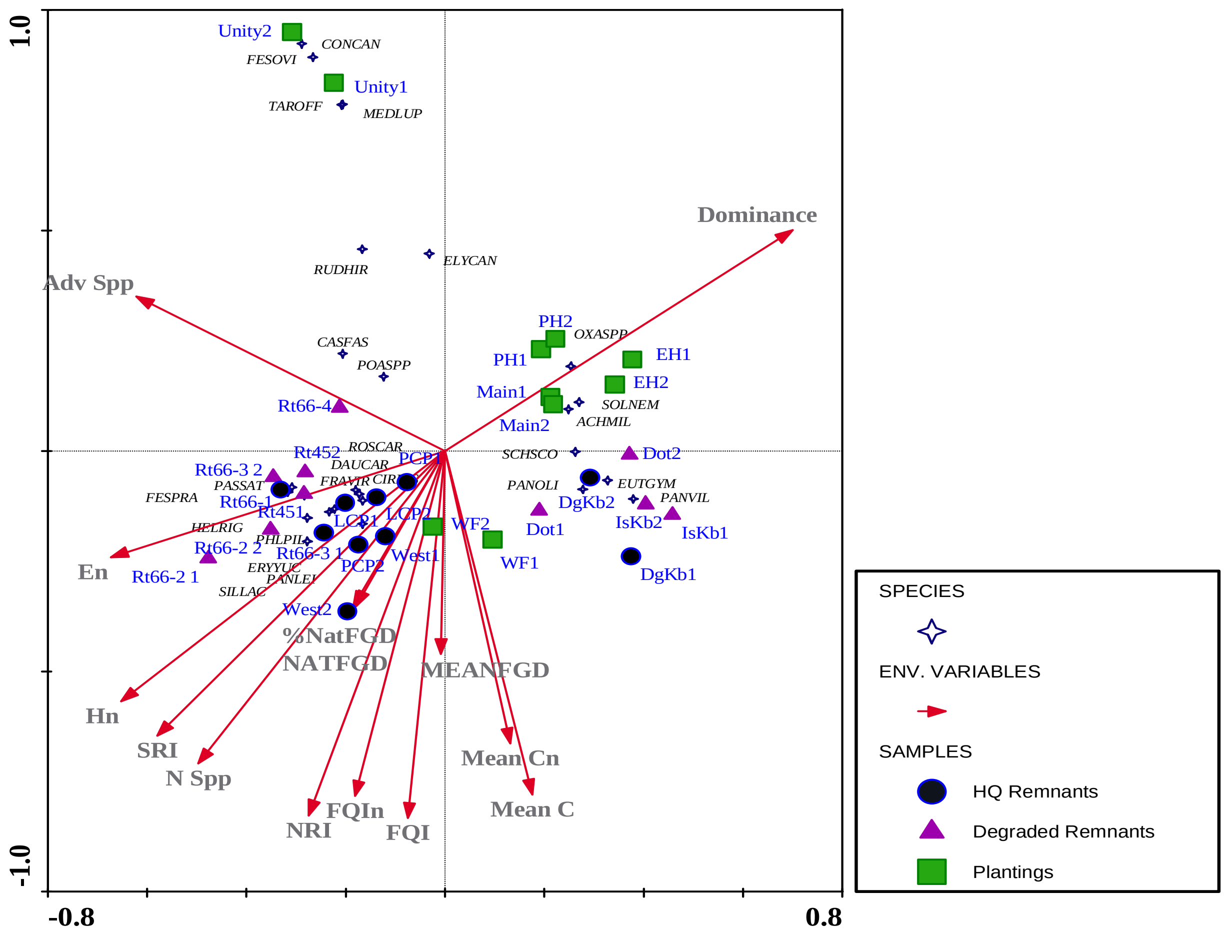

Figure 4. Canonical correspondence analysis triplot showing association of indices, sites, and species. To limit clutter in the diagram, species shown are only those that individually explain $\geq$ 25% of variance in ordination based on relative abundance patterns among sites. **Species codes**: ACHMIL – *Achillea millefolium*, CASFAS – *Cassia fasciculata*, CIRDIS – *Cirsium discolor*, CONCAN – *Conyza canadensis*, DAUCAR – *Daucus carota*, ELYCAN – *Elymus canadensis*, ERYYUC – *Eryngium yuccifolium*, EUTGYM – *Euthamia gymnospermoides*, FESOVI – *Festuca ovina*, FESPRA – *Festuca pratense*, FRAVIR – *Fragaria virginica*, HELRIG – *Helianthus rigidus*, MEDLUP – *Medicago lupulina*, OXASPP – *Oxalis* spp., PANLEI – *Dichanthelium leibergii*, PANOLI – *Dichanthelium oligosanthes*, PANVIL – *Dichanthelium villosissimum*, PASSAT – *Pastinaca sativa*, PHLPIL – *Phlox pilosa*, POASPP – *Poa* spp., ROSCAR – *Rosa carolina*, RUBHIR – *Rudbeckia hirta*, SCHSCO – *Schizachyrium scoparium*, SILLAC – *Silphium laciniatum*, SOLNEM – *Solidago nemoralis*, TAROFF – *Taraxicum officinale*. **Site Codes**: 1 and 2 refer to transect number; DgKb – Doug's Knob, Dot – Dot's Knob, EH – East Heinkle, IsKb – Isabel's Knob, LCP – Loda Cemetery Prairie, Main – Main Unit, PCP – Prospect Cemetery Prairie, PH – Potholes, Rt 45 – Route 45 Prairie, Rt 66 – Route 66 Prairies, Unity – Unity East Prairie, West – Weston Prairie, WF – Westfall Prairie. **Index Codes:** lowercase "n" indicates an index calculated with only native species; Adv Spp – Adventive Species, E – Evenness, FGD – Functional Group

Density, FQI – Floristic Quality Index, H – Diveristy, Mean C – Average Coefficient of Conservatism, N Spp – Native Species Richness, NRI – Native Richness Index, SRI – Species Richness Index.