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MONITORING TALLGRASS PRAIRIE RESTORATION PERFORMANCE USING FLORISTIC QUALITY ASSESSMENT

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ABSTRACT. Floristic Quality Assessment (FQA), a tool that allows botanists to quickly and effectively determine a site's natural quality, has primarily been used to identify and rank areas of remnant natural quality. In this study FQA was employed for long-term monitoring of the Upland Prairie, an ecological restoration project in Grant County, Indiana. In 1993, the year of planting, permanent transects were established to monitor community development as well as the effects of nitrogen enrichment and intermittent seasonal flooding. FQA was applied to species cover data collected nine times from 1993 through 2006. Analysis revealed that mean conservatism (MC) and floristic quality index (FQI) values rose with increasing site age as species dominance shifted from native and exotic weeds to native prairie grasses and forbs. Quadrat level metrics were more valuable for elucidating trends because transect level metrics were easily affected by slight differences in species composition year to year. FQA monitoring confirmed the impact of nitrogen enrichment reported in previous, intensive studies of the site. Areas prone to intermittent flooding scored lower MC and FQI scores because flooding inhibited the establishment of most prairie species. Mean wetness scores for these transects indicated that the vegetation was more representative of a wet meadow than mesic tallgrass prairie. This research determined that FQA is a useful, cost-effective tool for examining trends and responses to treatments and disturbances in prairie restorations.

Keywords: Floristic quality index, prairie restoration, coefficient of conservatism, vegetation monitoring, succession

Prior to the establishment of European agriculture on the Great Plains, prairie was the dominant biome in the United States, covering much of the expanse from western Ohio to the Rockies and from southern Canada to Texas (Samson & Knopf 1994). Within the last 200 years, tallgrass prairie of the eastern part of the prairie biome has experienced losses greater than that of any other major ecosystem in this country—as much as 82% in Kansas and over 99% in Indiana, Illinois, Iowa, North Dakota, and Wisconsin. These losses are due largely to cultural practices including agriculture, control or elimination of native grazers, and prolonged fire suppression (Howe 1994; Samson & Knopf 1994).

Efforts to restore tallgrass prairies began in the late 1930s at the University of Wisconsin-Madison Arboretum (Cottam & Wilson 1966; Sperry 1982). Today, numerous small restorations, ranging from less than a hectare to several dozen, have been initiated by conservation organizations, schools creating natural areas, and homeowners replacing lawn with tallgrass prairie. Large scale restorations, such as the 200 ha site at Fermi National Accelerator Laboratory near Chicago, Illinois (Sluis 2002) and 400 ha at Prophetstown State Park, Indiana (Dick 2007), have also been attempted. Restorations, large and small, serve as sites for ecological research, places of beauty, and habitat for wildlife. As with any type of restoration, proactive management to ensure long-term success is a must. In this context, a need has arisen for a standardized method for monitoring the progression of restoration quality over time – one that can alert managers to potential problems, responses to management treatments, and overall quality. Floristic Quality Assessment (FQA), developed by Swink & Wilhelm (1979, 1994) and originally referred to as the Natural Areas Rating Index (NARI), is a standardized method used to evaluate the natural quality of a site. This methodology began in the Chicago region and has since been adapted for use in Missouri (Ladd 1993), Michigan (Herman et al. 1996), Illinois (Taft et al. 1997), North Dakota and South Dakota (Northern Great Plains Floristic Quality Assessment Panel 2001), Wisconsin (Bernthal 2003), Ohio (Andreas et al. 2003), Indiana (Rothrock 2004; Rothrock & Homoya 2005), and southern Ontario (Oldham et al. 1995).

FQA is based on the premise that individual plant species display varying degrees of "conservatism" or fidelity to presettlement community types and varying degrees of tolerance to habitat disturbance (Swink & Wilhelm 1994). Based upon these ecological properties, each native plant species in the flora of a region or state is assigned a coefficient of conservatism (C) ranging from 0–10. Species that frequently occur in habitats associated with human disturbance are given values at or near zero, while those requiring less-disturbed habitats receive higher values. Non-native species receive a null value or, if used in numerical metrics, a zero (Fennessy et al. 1998; Bourdaghs et al. 2006).

Application of C values to basic ecological sampling data can provide several convenient metrics for estimating habitat quality. The mean C (MC) gives an overall picture of site natural quality (Wilhelm & Masters 2000). The floristic quality index (FQI), defined as as MC $\times \sqrt{number \cdot of \cdot species}$, includes a measure of species richness in addition to their quality (Swink & Wilhelm 1994). From the same data set, other metrics of floristic interest can be calculated, including species richness, guild diversity, relative importance, the number and percent of rare and non-native (or exotic) species, and wetness characteristics.

Swink & Wilhelm (1994) identified four common applications of FQA: identification of natural areas; facilitation of comparisons among sites, regardless of community type; long-term monitoring of remnant natural area quality; and monitoring of habitat restorations, including *de novo* restorations. Coefficients of conservatism and the FQA method have been validated for identifying natural areas and comparing quality among sites, including prairies, forests, and wetlands (Young 1994; Fennessy et al. 1998; Lopez & Fennessy 2002; Mushet et al. 2002; Cohen et al. 2004; Herman 2005; Rothrock & Homoya 2005; Bourdaghs et al. 2006; Jog et al. 2006).

In ecological monitoring and restoration, FQA allows rapid and objective assessment of changes in floristic quality from year to year and the effectiveness of various management plans. The use of FQA in monitoring is increasing, particularly in wetland restorations where there is a legal necessity for monitoring wetland mitigation (Streever 1999; NRC 2000). Mean C has been shown to consistently reflect site natural quality in restorations and natural areas (Francis et al. 2000; Mushet et al. 2002; Rooney & Rogers 2002; Cohen et al. 2004; Herman 2005; Jog et al. 2006). A positive correlation between FQI and site age has been found, as well as a negative correlation between FQI and disturbance levels for natural and restored ecosystems (Fennessy et al. 1998; Lopez & Fennessy 2002; Mushet et al. 2002; Herman 2005; Jog et al. 2006).

In an effort to ascertain the effects of prairie restoration techniques, researchers have employed a variety of analytical measurements. Some of these include soil measurements such as nitrogen content, total carbon content, and soil organic matter (Brye et al. 2002). Other measurements focus on plant productivity (above- and below-ground net primary productivity) (Brye et al. 2002). Species frequency (Cottam & Wilson 1966; Copeland et al. 2002), cover (Kindscher & Tieszen 1998), species richness (Copeland et al. 2002; Sluis 2002), and cover and density of guilds (Kindscher & Tieszen 1998; Rothrock & Squiers 2003) are plant metrics that have been employed. For some of these parameters, including those measuring soil changes, data may be difficult to interpret or there may not be a baseline for comparison (Brye et al. 2002). All of these measurements may be appropriate for ecological studies of prairie quality, but some are too laborious and expensive for routine restoration monitoring.

The goal of this study was to determine if FQA can reveal trends and changes in the quality of a tallgrass restoration, specifically the Upland Prairie. It contrasts with most previous FQA studies (e.g., Lopez & Fennessy 2002; Mushet et al. 2002; Bourdaghs et al. 2006) in that this is a longitudinal study (covering a 13-year period) based upon the resampling of permanent monitoring plots. Data were available for tracking changes in floristic quality as the restoration developed as well as the effects of three variables—degradation due to nitrogen enrichment, recovery after cessation of nitrogen enrichment, and vegetative responses to intermittent flooding.

METHODS

Study site.—The Upland Prairie Restoration (N40°27.2′, W85°0′), located in Upland, Grant

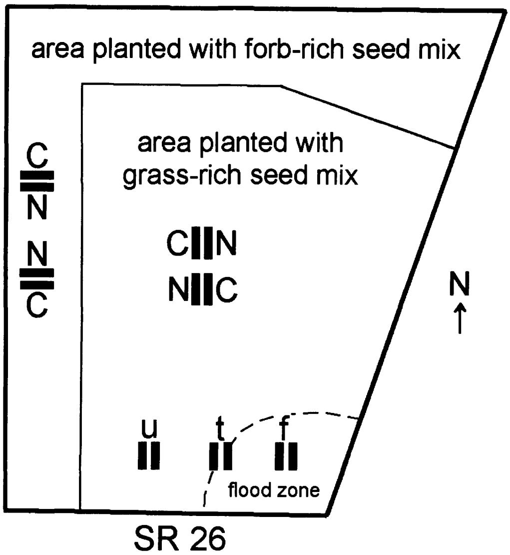


Figure 1.—Map of the Upland Prairie restoration showing transect locations. C = control transects; N = transects enriched with nitrogen fertilizer, 1993–1997; f = transects located within a flood zone; t = transects at transition between flood to upland zones; u = upland transects outside of flood zone.

County, Indiana, is a 10 ha (25 acre) tallgrass prairie restoration. Historically, this site was used for agriculture, first for row crops and later for pasture. In April 1993, the vegetation was treated with Round-up® herbicide (glyphosate – produced by Monsanto Company). In early June the ground was tilled, disked, and planted with cold-stratified, hand-collected prairie seeds of regional genotypes gathered from prairie fragments across western Indiana and eastern Illinois. After 13 years, the restoration has successfully matured to a stable community structure (Rothrock & Squiers 2003).

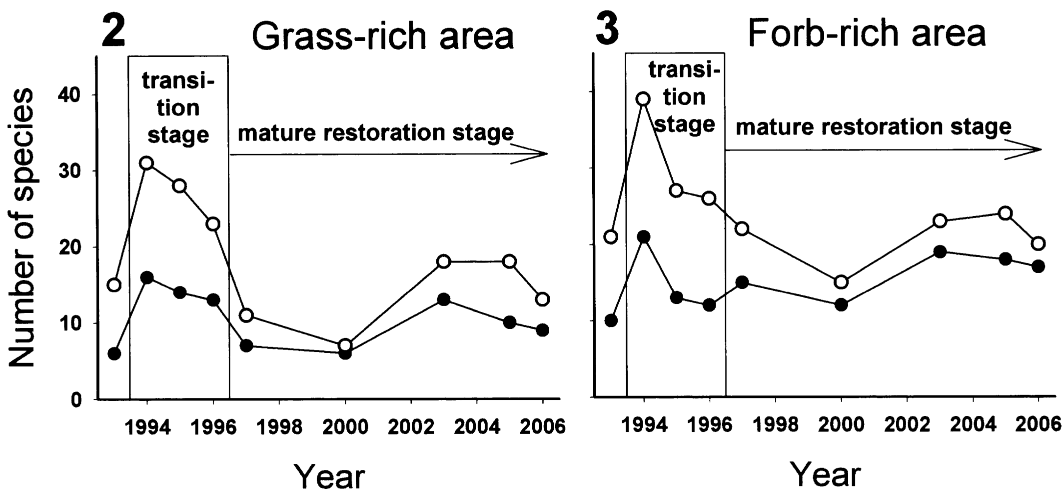
Prior to seed germination, permanent monitoring transects were established throughout the restoration site (Fig. 1). Paired control and nitrogen-treated transects, 17 × 5 m transects were placed near the middle of the site in a flat area at the bottom of an east-facing slope (Rothrock & Squiers 2003). Here the seed mix contained predominantly prairie grasses (<10% forb content). Additional paired transects were placed near the western edge of the field on the well-drained east-facing slope. The seed mix planted in this area contained 20% forbs and 80% prairie grasses. In the nitrogen-treated transects 46% urea was spread at a rate of 40 g/m^2 each April from 1993 to 1997.

In June 1993, shortly after the prairie was seeded with grass-rich mix (<10% forb content), flooding occurred on the southeast portion of the field. After water receded three pairs of transects were laid out—one pair in the flood zone, another in the upland zone, and a third in the transition zone.

Beginning in 1994 and continuing through 2004, the prairie was control-burned each spring to limit weed populations and woody species invasion. In 2004 a second controlled burn was administered in the fall, but none was administered in the spring of 2005. This single fall burn was an attempt to evaluate the practicality of varying the season of burn; it had to be abandoned due to limitations set by the land owner. In addition to annual fire management, noxious weeds, such as *Cirsium arvense* (L.) Scop. (field thistle), were spot-treated with Round-up® each May.

Sampling and data analysis.—Sampling was initiated in late July of 1993 (2 months after seeding) and repeated in late July or early August of 1994–1997, 2000, 2003, 2005, and 2006. The estimated percent cover of all plant species was recorded from 10 randomly-assigned 0.25 m^2 quadrats from each 17 m transect and then pooled with those from the matching transect to yield a total of 20 quadrats per treatment. The transect treatments analyzed in this study include intermittent seasonal flooding, nitrogen enrichment and recovery, and controls. A common criticism of the FQI metric is that it is affected by both sampling intensity and site size. As these two parameters increase, the number of species in the calculation may increase (Francis et al. 2000; Rooney & Rogers 2002; Matthews 2003; Ervin et al. 2005; Matthews et al. 2005; Bowles & Jones 2006). FQA can be performed on a site inventory or transect level. When used to monitor restoration quality, it is recommended that transects or a quadrat matrix be laid out and the analysis be repeated on a periodic basis (Swink & Wilhelm 1994; Wilhelm & Masters 2000). If assessment is performed in this way, FQI should not be influenced by site area or sampling intensity (Matthews et al. 2005; Jog et al. 2006).

Data analysis used *Floristic Quality Assessment Computer Programs*, Version 1.0 (Wilhelm & Masters 2000). This software permits



Figures 2, 3.—Changes in number of native species (solid circles) and total species (open circles) between 1993 and 2006. 2. Areas planted with a grass-rich seed mix; 3. Areas planted with a forb-rich seed mix. The restoration was planted in 1993; the period of 1994–1996 is a transition stage from annual weeds to native perennial species; 1997–2006 is the mature restoration stage dominated by the planted perennial prairie species.

both inventory and transect level assessment. Inventory level assessment uses a simple species checklist and was not applied in this study. For transect level analyses, the following seven metrics are generated: MC, FQI, mean wetness, species richness, guild diversity (e.g., % annual, perennial, and woody species), relative importance, and the number and percent of rare and exotic species. Mean C, FQI, mean wetness, and species richness are computed with and without exotic species and at both the transect as well as quadrat levels. For transect level metrics, MC and related metrics are based upon the roster of species observed along the transect. For quadrat level analyses, metrics are first calculated for each quadrat independently, then averaged. Thus, in quadrat level analysis, but not in transect level analysis, species frequency is important. Standard statistics (descriptive and *t*-tests) were carried out for the quadrat level analyses using Microsoft Excel 7.

The FQA metric, mean wetness, assesses whether an area is occupied primarily by hydrophytic plants. Each species in a region's flora is given a value ranging from −5 to +5 according to the probability of its occurrence in wetland areas (Wilhelm & Masters 2000). A facultative plant, one likely to occur equally in wetlands and non-wetlands, is given a value of 0. The greater the probability the plant is found in wetland areas, the more negative the value given. For example, obligate wetland plants, those with a 99% probability of occurring in wetlands, are assigned a value of −5. Conversely, those plants more likely to be found in drier habitats are assigned positive values. Upland plants, those occurring in wetlands less than 1% of the time, are assigned a value of +5 (Reed 1988; Wilhelm 1992).

RESULTS AND DISCUSSION

Floristic Quality Assessment of the Upland Prairie indicates that quality, as measured by MC and FQI, increases with age and with relaxation of nitrogen enrichment. At the same time, it decreases when intermittent flooding disrupts effective prairie establishment.

Control transects: tallgrass prairie restoration development.—The Upland Prairie Restoration was planted in 1993 with a seed mix containing 50 tallgrass prairie species of regional genotypes. Of these 50 species, 37 have established themselves. By analyzing species and cover data periodically along transects in grass- and forb-rich areas of the site, it is evident that species composition changed greatly with time. By late July of the first growing season in 1993 (Figs. 2, 3), the dominant plant guild across the restoration was non-native annuals with the grass *Setaria pumila* (Poir.) Roemer & J.A. Schultes (yellow foxtail) and the forb *Hibiscus trionum*

L. (flower-of-an-hour) being the dominant species. During the transition stage (1994–1996), that plant guild became less dominant and native perennial grasses and forbs grew in importance. By the mature restoration stage (1997–2006) *Sorghastrum nutans* (L.) Nash (Indian grass; C = 4) and *Andropogon gerardii* Vitman (big bluestem; C = 5) had become the dominant species.

Species richness varied with time and location in the restoration, but the trends in species richness were similar for the grass- and forb-rich areas (Figs.2, 3). Species richness was low during the year of planting (15 total species in the grass-rich area; 21 in the forb-rich area), but greatly increased and peaked in both areas in year two (31 total species in the grass-rich area; 39 in the forb-rich area). This increase may be due to the different management strategies employed. Prior to seeding the site in early June of 1993, the existing vegetation was treated with herbicide, tilled, and disked. These treatments limited species richness for that growing season. In year two, the site was burned in early April, allowing seedling establishment shortly thereafter. The increase in species richness in year two is largely due to the presence of previously unrecorded native and exotic weeds, not prairie species. Species richness declined for the next few growing seasons, the transition stage (Figs. 2, 3), as fewer of the lower quality species were recorded in transects. Species richness rose somewhat during the mature restoration stage (Figs. 2, 3). Ten years after establishment, the community's native species richness appeared to have stabilized with approximately 18 species in forb-rich transects.

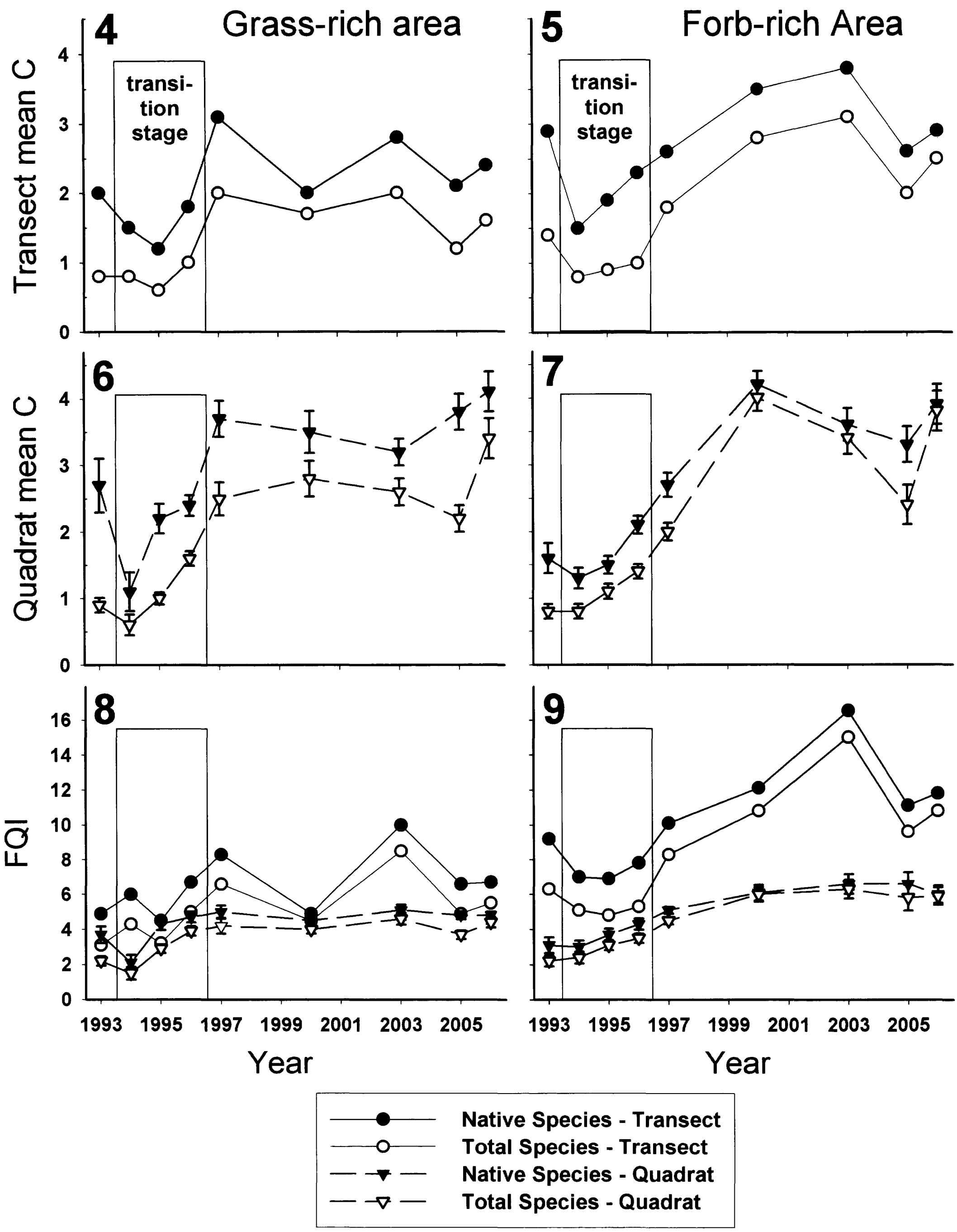
During first four season (and especially the transition stage), the numbers of exotic species were high. At their peak 15 non-native species were recorded in the grass-rich area and 18 in the forb-rich area. In mature restoration stage, the numbers of non-native species declined and remained at levels less than half that of native species. This is especially evident in the forb-rich transect where exotics comprised approximately 50% of the total species during year one, but comprised between 17 and 25% of the total in the mature stage.

The transect level MC for both the grass- and forb-rich areas demonstrated somewhat similar floristic quality changes over time (Figs. 4, 5). These changes are reflected in both the MC for native species (MC_n) and total MC (MC_t) in which exotic species are included and given conservatism values of zero. The MC_n values in year one were somewhat elevated (grass-rich MC_n = 2.0; forb-rich MC_n = 2.9), but they decreased and remained low during the transition stage. These low values were due to numerous native weeds. For example, in the forb-rich area, 60–80% of the native species had C values of 0–3 during this period.

Once the mature restoration stage was reached, MC_n did not fall below 2.0 (Figs. 4, 5). The grass-rich transect MC_n peaked in 1997 (MC_n = 3.1). The forb-rich MC_n increased steadily from 1995 to 2003 when it peaked at 3.8. Excluding years 2000 and 2005 (discussed below), it appears that at maturity the grass-rich area is maintaining a MC_n between 2.8 and 3.1 (Fig. 4). The forb-rich area reached maturity several years later than the grass-rich area. Its MC_n (excluding 2005) ranged from 3.5 to 3.8 (Fig. 5). MC_n is higher for the forb-rich area because the initial seed mix in this part of the restoration contained many high C value forbs in addition to the native prairie grasses.

For both the grass- and forb-rich areas MC_n decreased in 2005 (Figs. 4, 5). This was due to an increase in the number of low C value plants observed. The prairie was burned in the Fall of 2004 rather than in the spring as had been done in previous years. Annuals that had not been recorded in the prairie in several years were recorded again in 2005, including *Hibiscus trionum* and *Acalypha rhomboidea* Raf. (three-seeded mercury). With the resumption of spring burning in 2006, these annuals again disappeared from our transects.

Table 1 shows the effect that a species with a high C value located in only one quadrat may have on MC. In 1997, *Silphium laciniatum* L. (compass plant; C = 10) was recorded in one quadrat in the grass-rich area transect, but not in 2000 due to the use of randomly placed quadrats. To determine if this species omission was partially responsible for the strong reduction in native floristic quality (at the transect level) observed in 2000, the FQA analysis was run twice, once excluding and once including *Silphium laciniatum*. When the analysis included this plant in one quadrat, the transect MC_n increased by 1.1 points. Had *Silphium laciniatum* been recorded in 2000, there would not be a strong dip in the transect MC_n line graph that year (Fig. 4). Because transect level analysis



Figures 4–9.—Changes in floristic quality between 1993 and 2006 in areas planted with grass-rich (left) or with forb-rich (right) seed mixes. 4, 5. Changes in transect level MC; 6, 7. Changes in average quadrat level MC (±SE); 8, 9. Changes in FQI calculated at the transect and quadrat levels (quadrat FQI ±SE).

Table 1.—Comparison of the FQA results for the year 2000 grass-rich area control transect excluding and including *Silphium laciniatum* L. (compass plant; C=10). The plant occurred in one quadrat along the transect in 1997, but was not recorded in 2000.

FQA Metric	Excluding *Silphium laciniatum*	Including *Silphium laciniatum*
Native species	6	7
Total species	7	8
Transect MC_n	2.0	3.1
Transect MC_t	1.7	2.8
Quadrat MC_n	3.5	3.6
Quadrat MC_t	2.8	2.9

gives equal weight to every recorded species, missing one infrequent species can strongly affect MC in a restoration with limited plant diversity.

In FQA analyses, attempts have been made to weight species based on their relative frequency at a site (Cohen et al. 2004; Alix & Scribailo 2006; Bowles & Jones 2006). Quadrat level metrics is another method for incorporating species frequency into FQA analysis (Wilhelm and Masters 2000). In this method, MC and FQI are calculated for each quadrat independently; then their average across quadrats is calculated. Because each quadrat represents a data point, statistical calculations can be performed, including standard error and inference testing. When the FQA analysis was conducted for the 2000 grass-rich transect including *Silphium laciniatum*, the quadrat level MC_n rose by a value of 0.1 (Table 1). When compared to the transect level analysis in which the MC_n rose by 1.1 points, the quadrat level analysis is not strongly affected by the presence or absence of one highly conservative plant.

The quadrat level MC's (Figs. 6, 7) displayed trends similar to those observed at the transect level (Figs. 4, 5). According to *t*-test quadrat MC_n in the grass-rich area was significantly higher in year one compared to year two (P = 0.001). On the other hand, the forb-rich transect did not demonstrate a significant change during this same time period. For both areas in the prairie, floristic quality increased during the transition stage (Figs. 6, 7) reaching a high at maturity of 3.8 (grass-rich area) and 4.2 (forb-rich area).

Though the trends observed in transect and quadrat level analyses were similar, the ranges of values at maturity differ. Excluding 2005, the grass-rich area had quadrat MC_n values ranging from 3.2 to 3.7 (Fig. 6). The forb-rich area ranged between 3.6 and 4.2 (Fig. 7). These values are higher than those obtained at the transect level. At maturity many of the weed species were not occurring throughout the transects, but, in most cases, were recorded in only a few quadrats. In contrast, the prairie species, especially the grasses, were recorded in almost every quadrat.

In summary, several studies have indicated that MC consistently reflects disturbance levels and the natural quality of sites (Francis et al. 2000; Mushet et al. 2002; Rooney & Rogers 2002; Cohen et al. 2004; Herman 2005; Jog et al. 2006). In the Upland Prairie Restoration, both transect and quadrat MC values increased over time, indicating overall improvement in floristic quality as the community matured.

The trends in the prairie community's floristic quality as measured by the transect FQI values (Figs. 8, 9) are similar to those seen for the transect MC. During the first four years, transect FQI_n ranged between 4.5 and 6.7 in the grass-rich area (Fig. 8) and between 6.9 and 9.2 in the forb-rich area (Fig. 9). Once the prairie reached maturity, the maximum values attained were 10.0 and 16.5 in the grass- and forb-rich areas, respectively.

The quadrat level FQI values for both control transects reveal less fluctuations in quality than the transect level (Figs. 8, 9). The grass-rich quadrat level FQI_n ranged from 2.1 to 5.1 (Fig. 8). In the forb-rich area the range was between 3.0 and 6.6 (Fig. 9). Though the values do not fluctuate by more than a few FQI points, they do demonstrate a modest increase in floristic quality during the transition stage and subsequent stabilization of quality in the mature restoration stage. These floristic quality changes are due largely to alterations in species composition rather than species richness, as species dominance shifted from weedy plants, including *Ambrosia artemisiifolia* L. (common ragweed; C = 0) and *Acalypha rhomboidea*, to native prairie grasses and forbs. Transect FQI, like transect MC, can be strongly influenced by the presence or absence of one highly conservative species (Fig. 8). When *Silphium laciniatum* was included in one quadrat in the analysis of the year 2000 grass-rich transect, the transect

FQI_n rose from 4.9 to 8.3. The quadrat FQI_n only rose from 4.5 to 4.7.

In our analysis, quadrat MC was more sensitive to year-to-year changes than the quadrat FQI. For example, the forb-rich area attained a quadrat MC_n of 3.6 in 2003 and 3.3 in 2005. The quadrat FQI_n remained stable at 6.6. While MC_n did alert us that there might be reduction in floristic quality, FQI_n did not reflect this change. The reduction in MC_n was due to the reappearance of annual weeds that had not been observed in the transects since the early years of the restoration. These species disappeared with the resumption of spring burns and, as indicated by the FQI, the floristic quality of the site had not been affected strongly. As concluded by Jog et al. (2006), it is best to consider several FQA metrics, not just one.

Because quadrat level analyses are not strongly affected by the presence or absence of an extremely conservative species in one quadrat, and because several useful statistics can be calculated for the quadrat data, only quadrat level metrics will be reported in the remaining analyses.

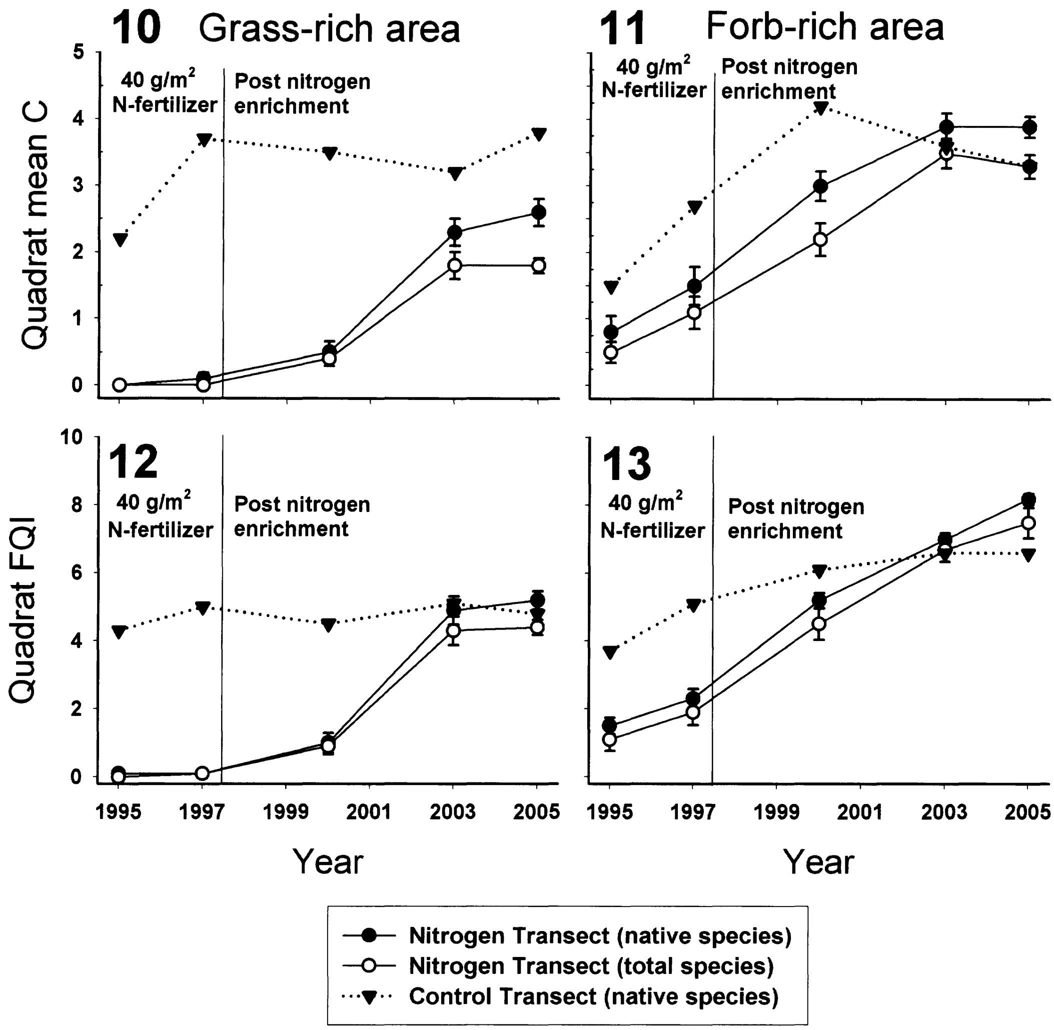
Nitrogen-enriched transects: degradation and recovery of the prairie community.—Shortly after planting in 1993 and in April of 1994–1997, nitrogen in the form of 46% urea was added at a rate of 40 g/m^2 to transects in the grass- and forb-rich areas. This practice resulted in weed dominance and inhibition of prairie species establishment, thus adversely affecting floristic quality (Rothrock & Squiers 2003). Analysis with FQA reveals the poor floristic quality of the transects during N fertilization and subsequent recovery when fertilization was discontinued (Figs. 10–13).

While N was being applied, the highest MC_n achieved in the grass-rich transect was 0.1 (Fig. 10). In the corresponding control transect MC_n was 3.7. The N transect in the forb-rich area only reached 1.5 (Fig. 11), compared to 2.7 in the control. After cessation of N treatment, transects in both areas demonstrated rapid improvement in floristic quality.

In the grass-rich area, MC_n was 0.0 in 1995 (Fig. 10) and the dominant species were annual weeds *Persicaria pensylvanica* L. (Pennsylvania smartweed), *Ambrosia artemisiifolia*, and *Chenopodium album* (lamb's quarter). In contrast, the control transect had a MC_n of 2.2 and was dominated by *Sorghastrum nutans* and *Andropogon gerardii* as well as the annual weed *Setaria faberi* (giant foxtail). Two years after cessation of treatment, improvement was evident in the 2000 analysis (MC_n = 0.5). The highest quality was seen in 2005 when the MC_n reached 2.6 (Fig. 10). The dominant species were *Andropogon gerardii, Sorghastrum nutans,* and *Ratibida pinnata* (Vent.) Barnh (yellow coneflower), species with a C value of 4 or 5. Although the native flora in the N-enriched transect showed great improvement following cessation of N addition, it did not reach the floristic quality of the control in 2005 (MC_n = 3.8; P = 0.0006). While prairie species dominated the recovered N-enriched transect, but it also contained 11 native species with a C value of zero. Eighteen of the 20 quadrats contained at least one low quality (C = 0) species. The control transect had only five native species with a C value of zero, and nine of the 20 control quadrats contained these species.

In 1995, the forb-rich area N-enriched transect only reached a MC_n of 0.8 and a MC_t of 0.5 (Fig. 11), with *Ambrosia artemisiifolia* as the dominant species, followed by exotic and native weeds of much lower relative importance. After cessation of N addition, the vegetation recovered rapidly to achieve similar MC values as the control by 2003 (N-enriched MC_n = 3.9, MC_t = 3.5; control MC_n = 3.6, MC_t = 3.4; native species: P = 0.3; total species: P = 0.3). The floristic quality in 2005 surpassed that of the control transect (N-enriched MC_n = 3.9, MC_t = 3.3; control MC_n = 3.3, MC_t = 2.4; native species: P = 0.03; total species: P = 0.01). In these two years the dominant species were no longer weeds but prairie species such as *Andropogon gerardii, Monarda fistulosa* L. (wild bergamot; C = 3), *Ratibida pinnata*, and *Sorghastrum nutans*. The recovered N-enriched transect achieved higher MC values than the control because prairie forbs were recorded more frequently in it than in the control. In 1997, prairie grasses accounted for only 6% of the total cover in the N-enriched transect, while *Ambrosia artemisiifolia* contributed 58%. When N enrichment was terminated, *Ambrosia artemisiifolia* began to lose dominance. At that time, the prairie forbs may have been able to seed and establish themselves better than the prairie grasses.

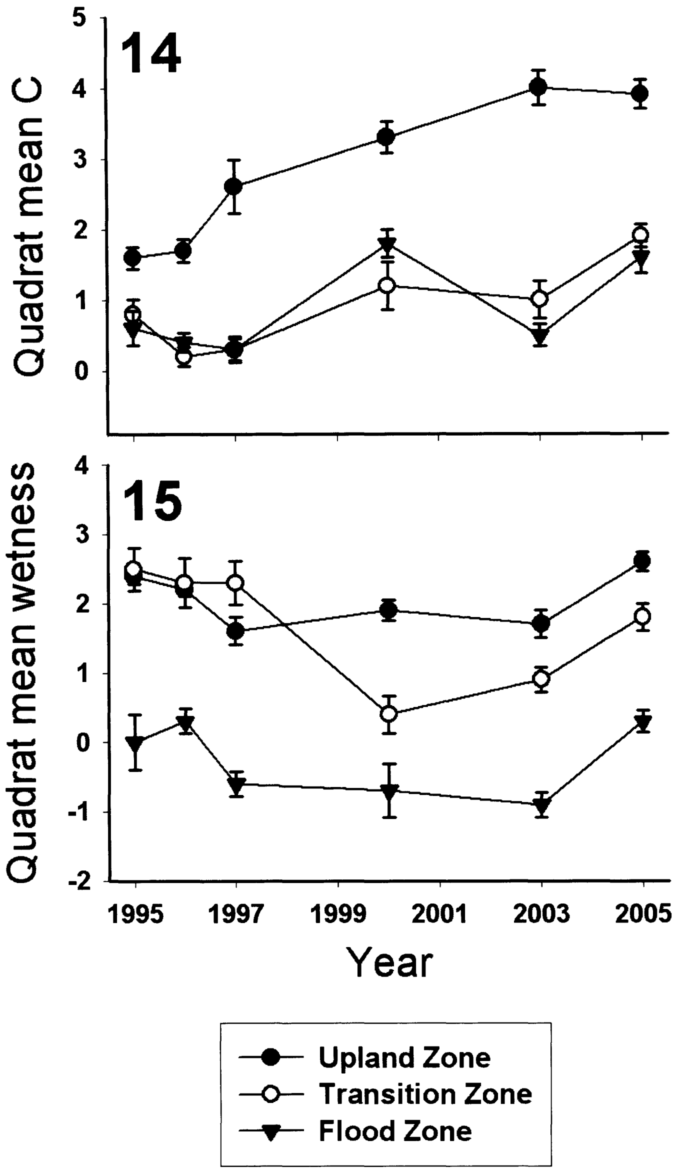
FQI trends almost mirror those seen in the MC data (Figs. 12, 13). In the grass-rich area, FQI_n ranged from 0.1 in 1995 and 1996 to 5.2



Figures 10–13.—Response of native species (solid circles) and total species (open circles) to nitrogen fertilization (1995–1997) and subsequent recovery when treatment ceased (1998–2005). Native species results from neighboring, untreated transects (closed triangles) are shown for comparative purposes. 10, 11. Quadrat level MC (±SE); 12, 13. Quadrat level FQI (±SE).

in 2005, the year it peaked. Unlike MC_n, FQI_n did reach that of the control in 2003 (N-enriched FQI_n = 4.9; control FQI_n = 5.1; P = 0.3). The forb-rich area FQI_n ranged from 1.5 (1995) to 8.2 (2005). FQI_n exceeded that of the control in 2005 (N-enriched FQI_n = 7.0; control FQI_n = 6.6; P = 0.03). These results demonstrate that FQI can indicate vegetative responses to detrimental management techniques. This is part of a growing body of literature in which FQI was successful in revealing vegetative responses to management strategies and human disturbances (Fennessy et al. 1998; Lopez & Fennessy 2002; Mushet et al. 2002; Herman 2005; Jog et al. 2006).

Two previous studies of the Upland Prairie Restoration have focused on floristic responses to nitrogen enrichment (Rothrock & Squiers 2003; Ross 2005). These two ecological studies involved intense sampling and analysis of the N-enriched transects. The results from analysis with FQA revealed similar floristic quality effects as the two more intense studies. All three studies showed that N enrichment resulted in dominance by weeds rather than prairie species. As described by Ross (2005), when N



Figures 14, 15.—Native vegetation responses to intermittent seasonal flooding as restoration age increases. 14. Quadrat MC (±SE); 15. Quadrat mean wetness (MW±SE).

addition ceased, the vegetation began to show signs of recovery as more prairie species became established in these transects. According to FQA, MC and FQI values were low when the N was being added, but those values increased when addition was terminated.

Flood transects: vegetative responses to intermittent seasonal flooding.—The southeastern corner of the Upland Prairie Restoration is at the bottom of an east-facing slope and is prone to short-term flooding. To examine the effects of this environmental variable on floristic quality, transects were placed in different zones along the slope. One transect was located in the flood zone, another in the upland zone, and a third in the transition zone. In June of 1993, shortly after the prairie was seeded, the flood zone transect was covered in standing water and has been flooded intermittently since then.

The upland zone transect had significantly higher quadrat MC_n values than the two lower transects and its floristic quality increased over time (Fig. 14). Prairie species dominated every year that the transect was monitored. In the transition and flood zones, native weeds dominated every year except in 1995 when exotics were dominant. These two transects had similar MC_n values in most years. The ranges of MC_n obtained in these transects were relatively small when compared to the upland zone transect which ranged from 1.6 in 1995 to 4.0 in 2003. The transition zone values ranged from a MC_n of 0.2 in 1996 to 1.9 in 2005, while the flood zone transect ranged from 0.3 in 1997 to 1.8 in 2000.

Francis et al. (2000) found that, in forest studies, mean wetness scores of native species (MW_n) correlated with soil moisture regimes. Similarly, in the Upland Prairie Restoration the MW values indicate that there were differences in moisture regimes between all three transects (Fig. 15). The quadrat MW_n of the upland zone ranged from +1.6 (1997) to +2.6 (2005). The transition zone exhibited lower MW_n values ranging from +0.4 (2000) to +2.5 (1995). The flood zone MW_n were the lowest as they ranged from −0.9 (2003) to +0.3 (1996 & 2005). All three zones showed a numerical increase in MW from 2003 to 2005. As discussed earlier, the change in burn time from spring to fall resulted in the reappearance of annual or biennial species that had not been observed in the transects in several years. Although the dominant species in 2003 and 2005 were the same, in 2005 several species with more positive MW values appeared in the flood zone. These included *Acalypha rhomboidea* (W = +3), *Gaura biennis* L. (biennial gaura; W = +4), and *Oenothera biennis* L. (common evening primrose; W = +3). The species composition in each of these transects is indicative of the moisture available. In the latter years of the restoration, the upland zone transect was dominated by typical prairie species including *Andropogon gerardii*, *Ratibida pinnata*, and *Sorghastrum nutans*, which have positive Ws. The transition zone transect was dominated by non-conservative native species such as *Solidago altissima* L. (tall goldenrod; W = +3) and facultative+ *Ambrosia trifida* L. (giant ragweed; W = −1), as well as the native prairie grass, *Andropogon gerardii*. The flood zone transect was dominated by facultative wet+ *Persicaria pensylvanica* (W = −4), *Solidago altissima*, and the exotic facultative wet+ *Phalaris arundinacea* L. (reed canary grass; W = −4). Because *Phalaris arundinacea* is an exotic, its wetness and C values were not included in the MW_{native} and MC_n calculations. However, this species is common in Indiana wet meadows (Swink & Wilhelm 1994).

It is evident that the flooding that occurred in June of 1993, soon after the prairie was seeded, prevented the establishment of many prairie species. Due to the wet conditions, the vegetation in the flood zone is becoming a wet meadow community consisting mainly of low C value species.

In summary, the Upland Prairie Restoration has been monitored for well over a decade. We have found that FQA was successful in tracking successional changes, responses to nitrogen fertilizer, and effects of flooding. Currently, work is underway to apply FQA to a sample of prairie restorations and natural prairie remnants across northern Indiana to further elucidate the potential of this technique for documenting community structure and natural quality.

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