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# Vegetation Height and Quality of Original and Reconstructed Tallgrass Prairies

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ABSTRACT.—To quantitatively compare vegetation height of original and restored prairies, and to explore the relationship between quality and vegetation height, we measured visual obstruction, the tallest nearby stem and vertical structure (density of stems at 50, 100 and 150 cm heights) in six remnant, six reconstructed tallgrass prairies and two former pastures. Reconstructed prairies in the Chicago, IL, region included two that were planted and four that were seeded. There were significant differences among sites within the four prairie types for all measures of structure. Type accounted for 39%, 41% and 40% of the variation in visual obstruction (VO), tallest nearby stem (LT) and the graminoid stem density at 1.0 m, respectively. Fields dominated by agricultural grasses had the lowest mean heights, VO = 32 cm, LT = 71 cm. Remnant original prairies had a mean VO of 44 cm and an LT of 130 cm. Planted reconstructed prairies had a mean VO of 54 cm and an LT of 125 cm, while seeded reconstructed prairies were significantly taller, VO = 86 cm and LT = 174 cm, and denser at the 1.0 m height than the other types. Original prairie had mean stem densities of 13 grasses and 4 forbs $m^{-2}$ at 1.0 m. Seeded reconstructions had 50 grass and 5 forb stems $m^{-2}$ at 1.0 m, so the seeded restorations taller, thicker and grassier than remnants of original prairie. Subjective and species richness estimates of prairie quality were highly positively correlated with one another, as were most of the height and density variables. In both original prairies and seeded reconstructions, shorter prairies have higher quality.

## INTRODUCTION

Each type of vegetation has its own characteristic height and vertical structure (Barbour *et al.*, 1999; Brokaw and Lent, 1999). Prairies have been portrayed as oceans of grass taller than a man on horseback (*e.g.,* Greenberg, 2002; Jones and Cushman, 2004), but we have not observed such heights on remnant Illinois prairies. Our casual observations suggested that reconstructed prairies are taller and grassier than regional remnants. This study investigates variation in vegetation height in remnants of original and reconstructed prairies within part of the eastern tallgrass prairie region. A primary goal was to produce quantitative information about vegetation height to determine if reconstructed prairies are taller than remnants of original prairie. While most reconstructions are planted by broadcasting seed, some have been planted with seedlings by hand. We asked if these alternative methods of prairie reconstruction led to height differences. Finally, for comparison, vegetation height of the locally most common grassland type, old-field, was measured. Vegetation height and height structure were measured with three methods and the correlations among alternative ways were calculated to make inferences about the best way to measure prairie height. Measurement of stem density at a specified height had separate counts for graminoids, forbs and woody stems so that the density of these different types could be compared among sites. Implicit in the observation that reconstructions are taller is the idea that height and quality are negatively related. Therefore, we calculated metrics of site quality based on the number

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TABLE 1.—The prairies studied: name, location, Type and age

| Name | Abb. | County | State | Latitude | Longitude | Type[a] | Age[b] |
|---|---|---|---|---|---|---|---|
| Berkeley Prairie | BYP | Lake | IL | N42.180 | W87.839 | O | na |
| Chicago Ridge Prairie | CR | Cook | IL | N41.701 | W87.770 | O | na |
| Gensberg-Markham | GM | Cook | IL | N41.605 | W87.690 | O | na |
| Wadsworth Prairie | WW | Lake | IL | N42.433 | W87.931 | O | na |
| West Chicago Prairie | WC | DuPage | IL | N41.891 | W88.231 | O | na |
| James Woodworth Prairie | JWP | Cook | IL | N42.060 | W87.842 | O | na |
| Horlock Hill | HH | Kane | IL | N41.920 | W88.348 | PR | 30 |
| Schulenberg Prairie | MA | DuPage | IL | N41.813 | W88.093 | PR | 40 |
| Buffalo Creek | BC | Lake | IL | N42.159 | W87.994 | F | 12 |
| Burnidge Prairie | BP | Kane | IL | N42.069 | W88.368 | F | 6 |
| Fermilab | FL | DuPage | IL | N41.843 | W88.266 | SR | 17 |
| Kankakee Sands | KS | Newton | IN | N41.061 | W87.429 | SR | 3 |
| Nelson Lake Marsh | NLM | Kane | IL | N41.828 | W88.384 | SR | 5 |
| Pratt's Wayne Woods | PWW | DuPage | IL | N41.972 | W88.240 | SR | 5 |

[a] O = remnant original prairie, PR = planted-with-plants reconstruction, F = old field, SR = seeded reconstruction

[b] Age in years, provided by site manager

and frequency of species we observed. Correlations among the quality variables evaluate the consistency of different measures of quality. Though we expected a negative correlation between height and quality based on the observation that remnants of original prairie are shorter than reconstructions, we also examined the correlations within remnant sites and within seeded reconstructions to determine if shorter reconstructions have more species and if shorter original prairies have more species than taller prairies of the Type.

## METHODS

*Study sites.*—We sampled six remnant prairies (symbolized by O for remnant of original to avoid confusion with restored or reconstructed), three in Cook County and one each in Lake, DuPage and Kane counties. All are level mesic prairies and Illinois Natural Area Inventory sites (four are Illinois Nature Preserves). The reconstructed prairies were divided into two classes based on whether they were seeded reconstructions (SR) or planted with growing plants (PR). The only two PR prairies larger than 0.5 ha within 50 km of Chicago, the Schulenberg Prairie at the Morton Arboretum and Horlock Hill in Kane County, were studied. Seeded prairie reconstructions included the Fermilab (Sluis, 2002), the large Kankakee Sands project of the Nature Conservancy in Indiana, and others selected from lists generated by natural area managers in DuPage, Kane and Lake counties who also suggested the old-field (F) sites. Only prairies whose planting dates were known were studied. The name of each site and its location (county, state, latitude/longitude), the Type of grassland and its age (if reconstructed) are given in Table 1.

*Sampling scheme.*—To generate 15 sampling points without having seen the area, we assumed that each site had a "normal" access point. The first sampling point was 20 m from the access point and at least 20 m from any edge. From the first sample point, a transect with five points, 10 m apart, was established parallel to the long axis of the preserve. Two similar transects that were parallel to the first and 15 m apart completed our sample of 15 points.

*Vegetation height structure measurements.*—Sampling occurred during August and September in 2002 when vegetation was at or near its maximum height. Vegetation height structure is the vertical structure of vegetation, the amount of leaves, stems and other organs in terms of their height above the ground (Campbell and Norman, 1989). In this study, the stems of graminoid, forb and woody plants were counted at 50, 100 and 150 cm above the ground to estimate stem densities at these heights. Frequently, rather than provide details of structure, a single height is measured to represent the structure. In grasslands, the visual obstruction (VO) height estimated with a "Robel pole" (Robel *et al.*, 1970) is a way to estimate the height at which light becomes rapidly attenuated. The tallest nearby stem (Jurik and Kliebenstein, 2000; Lane *et al.*, 2000; Keer and Zedler, 2002) is also used as an estimate of vegetation height. The stem density estimates and the two estimators of vegetation height were made at the same points enabling us to compare these alternative estimators of vegetation height.

At each of the 15 sample points, three readings of visual obstruction height (VO) were taken with a 'Robel' pole (1 inch PVC pipe 2 m tall with bright colored tape 1 cm wide every 5 cm). Each VO reading was taken from a distance of 4 m and a height of 1 m as recommended by Robel *et al.* (1970). The VO reading was the highest half-decimeter on the pole that was completely obstructed by vegetation (Higgins *et al.*, 2002). The three readings at a point were taken from a right angles to the transect and from "behind" the transect. At each sample point, the species that blocked a view of at least part of the pole were recorded. Swink and Wilhelm (1994) was the taxonomic authority used.

The tallest nearby stem was called the "local tall" (LT) and was defined as the tallest stem that was within about 30 cm of the Robel pole at each sampling point. Stalks that naturally bent into the zone were included. The Robel pole was used to measure the height of the "local tall" individual to the nearest 5 cm. The LT species was also recorded.

To more fully describe the height structure of prairies, the density of graminoid, forb, woody and dead stems was estimated at three different heights, 50, 100 and 150 cm. The number of 'hits' of each stem type was counted as a rod parallel to the ground was rotated through 360 degrees. We found it most convenient to have a separate pole and rod for each height. The lengths of the rods were 23 cm on the 50 cm pole and 53 cm on the 100 and 150 cm poles. The density estimate was the number of stems of a class divided by the area swept by the rod. All density estimates were expressed as stems per square meter.

*Vegetation quality.*—The benchmark of high quality is an 'undisturbed' remnant. Quality is considered an attribute of the site in aggregate. Remnants of original prairie are expected have more native species and greater quality than reconstructions. Some prairie species regarded as indicators of high quality (Swink and Wilhelm, 1994) grow less than 50 cm tall, *e.g., Gentiana puberulenta* and *Sporobolus heterolepis.* In our experience, short species are in low abundance or absent from most reconstructions, possibly due to shading by the tall dominant grasses. This motivated us to estimate site quality. Site quality was measured using four variables based on the species recorded in VO and LT measurements and by subjective ranking. The first variable measuring quality was named visual obstruction species richness, VO-SR, the total number of species recorded during VO measurements at the site. The second variable, visual obstruction native species richness, VO-NSR, excluded non-native species from that count. The third and fourth quality variables used the LT species, namely, the species richness of the local tall species, LT-SR and the Shannon–Wiener diversity measure (Krebs, 1999) based on the frequency of LT species, LT-$H'$. The subjective evaluation (done by Nyberg) ranked the sites from 1 (low) to 14 (highest quality). The evaluation encompassed a greater area than the sample points and is asserted to reflect the presence of characteristic and/or special native plants and animals and the 'naturalness' of patchiness.

*Statistical analysis.*—Calculations, *e.g.,* means, variance, stem density, *t*-tests and correlations, were done in EXCEL spreadsheets. Prior to the ANOVA analysis, we determined that the slopes of the log mean versus log standard deviation for VO and LT were not significantly

TABLE 2.—Species composition and height attributes

| Site | Type | VO Mean[a] | LT Mean[a] | VO top species[b,c] | LT top species[b,d] | VO native grass[e] | LT native grass[f] |
|---|---|---|---|---|---|---|---|
| BYP | O | 30 | 99 | ANDGER (14) | ANDGER (6) | 1.07 | 40 |
| CR | O | 25 | 128 | ANDGER (10) | ANDGER (8) | 1.67 | 80 |
| GM | O | 35 | 118 | ANDGER (12) | ANDGER (6) | 1.40 | 47 |
| JWP | O | 47 | 108 | SILTER (5) | HELGRO (3) | 0.53 | 20 |
| WC | O | 66 | 153 | SOLCAN (15) | SORNUT (5) | 0.40 | 40 |
| WW | O | 61 | 175 | ANDGER (14) | ANDGER (11) | 1.07 | 80 |
| HH | PR | 56 | 136 | SOLRIG (13) | ANDGER (6) | 0.60 | 40 |
| MA | PR | 52 | 113 | ANDGER (8) | ANDGER (5) | 0.67 | 40 |
| BC | F | 26 | 67 | CORVAR (11) | CORVAR (3) | 0.33 | 13 |
| BP | F | 39 | 75 | AGRALA (8) | SOLCAN (7) | 0.00 | 0 |
| FL | SR | 101 | 195 | ANDGER (11) | ANDGER (9) | 1.00 | 82 |
| KS | SR | 73 | 138 | ASTNOV (15) | PANVIR (7) | 1.60 | 67 |
| NLM | SR | 62 | 154 | ANDGER (11) | ANDGER (7) | 1.60 | 87 |
| PWW | SR | 99 | 201 | ANDGER (15) | ANDGER (12) | 1.87 | 87 |

[a] Mean in centimeters

[b] Species abbreviations are first three letters of genus flowed by first three letters of specific epithet. Numbers in parentheses represent the number out of 15 point with the exception of FL which is out of 11 points

[c] Species contributing most often to VO at that site

[d] Most frequent species of the LT

[e] Average number of native grass species contributing to VO per point

[f] Percentage of LT species that were native grasses

different from zero, so we used untransformed data (Krebs, 1999) in the ANOVA (SAS Institute, 1985). Grassland Type was considered a fixed effect; Sites within Type and points within Sites were considered random effects.

## RESULTS

*Height differences among sites and types.*—The grand mean visual obstruction (VO) height was 54 cm, with the 14 site VO means ranging from 25 cm at Chicago Ridge to 101 cm at Fermilab (Table 2). A nested ANOVA of the VO values (using all four Types) indicated that 39% of the VO variation was attributable to Type, 24% was among Sites within Type, 18% was attributable to Points within the same Site and 20% of the variation was error ($s = \pm 0.14$ m for multiple measurements at the same point). The effect of grassland Type was significant ($F_{3,\,10} = 6.2$, $P < 0.05$) when tested over Sites (within Type). The effect of Site was significant ($F_{10,\,192} = 15.1$, $P < 0.001$) when tested over Points (within Site). Additionally, the points (within a site) were significantly different ($F_{192,\,412} = 3.78$, $P < 0.001$).

Old fields (F) had the shortest VO mean 32 cm. Remnants of original prairies (O) had the next lowest mean, 44 ± 13 cm, and planted prairie reconstructions (PR) had a mean of 54 ± 3 cm. Seeded prairie reconstructions (SR) had a VO mean of 84 ± 19 cm, almost twice that of the remnant tallgrass prairies. A *t*-test comparing O prairies and SR prairies found the difference between them to be significant ($P = 0.015$) and the Duncan grouping in the ANOVA also indicated that remnants had significantly shorter VO than seeded reconstructions.

The grand mean local tall (LT) height was 133 cm and the fourteen LT means ranged from 67 cm at Buffalo Creek to 201 cm at Pratt's Wayne Woods (Table 2). Almost invariably, the LT individual was a flowering stalk, which made our LT measure similar to methods that

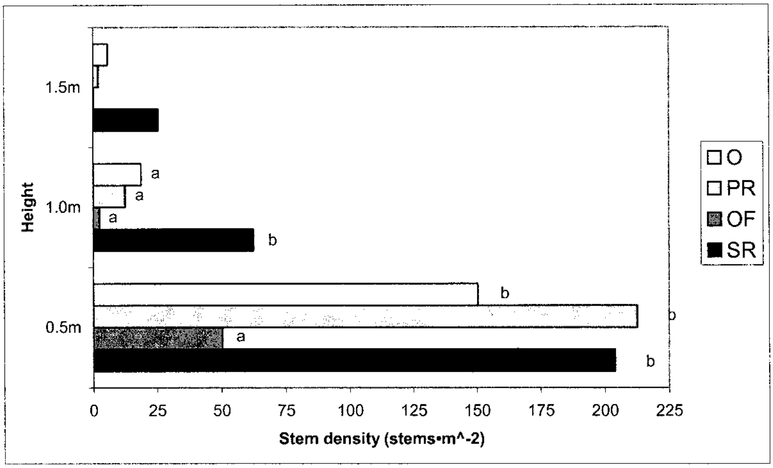



FIG. 1.—Comparison of stem densities at three different heights among prairie types. O = remnant of original prairie, PR = planted with plants reconstruction, OF = old field, SR = seeded reconstruction. Different letters represent significantly different values based on Duncan Groupings ($P < 0.05$)

measure the height of the tallest plant(s), including inflorescences, at a point or along a transect (*e.g.,* Lane *et al.*, 2000, Keer and Zedler, 2002). The nested ANOVA of the LT measurements indicated that 41% of the variation was attributable to prairie Type, 25% to Sites within Type and 34% was error (points within a site). The contrast procedure in GLM (SAS, 1985) indicated that remnant prairies were significantly taller than old fields ($P < 0.02$) and significantly shorter than seeded reconstructions ($P < 0.04$). At individual points the LT height ranged from 35 cm to 270 cm ($N = 206$).

Three species were included in the 21 measurements greater than 200 cm tall: *Andropogon gerardii* (17), *Sorghastrum nutans* (2) and *Silphium terebinthinaceum* (2), the species with the tallest individual. *Andropogon gerardii* accounted for 72 of the 206 LT points. At the seeded reconstructions the height of the *A. gerardii* averaged 197 cm ($N = 28$), significantly greater (*t*-test SR vs. O, $P < 3 \times 10^{-8}$) than the means of 145 cm ($N = 32$) at remnant prairies and 148 cm ($N = 11$) at PR prairies.

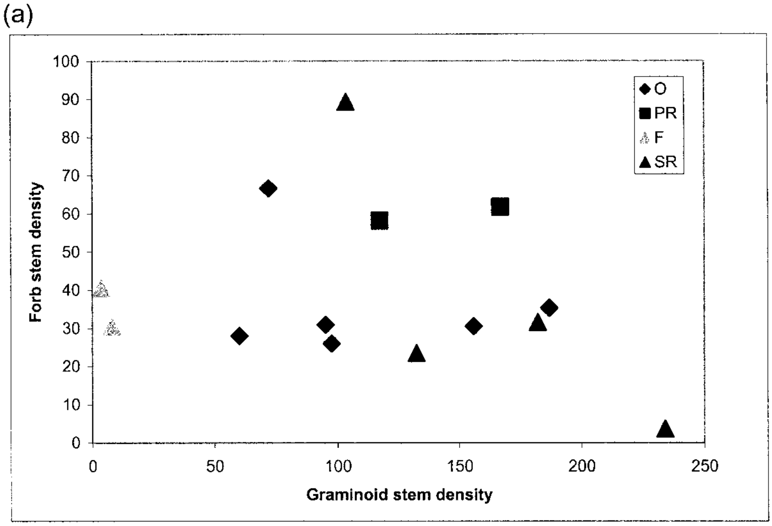
*Stem density.*—The grand mean total density of all stems was 160 $m^{-2}$ at 50 cm above the ground, 28 $m^{-2}$ at 100 cm high and 10 $m^{-2}$ at 150 cm high. The ANOVAs of the number of dead, woody, graminoid and forb stems found significant differences ($P < 0.01$) among Sites within Types for all 12 combinations of heights and vegetation types except for woody and forb stems at 150 cm (in which all sites were dominated by zeros). The number of graminoid stems was at least twice the sum of woody and forb and the analysis of the total number of stems always led to the same statistical conclusion as the analysis of graminoid stems alone (Fig. 1). At the 50 cm height, Type accounted for 18%, 0%, Site within Type 11%, 22% and Points within Site for 71%, 78% of the graminoid and forb density variation, respectively. At 100 cm, Type was 40%, 0%, Site within Type 31%, 16% and Points within Site 29%, 84% of the graminoid and forb stem density variation. At the 150 cm height, stem density variation was partitioned as17%, 0% to Type, 57%, 1% to Site and 26%, 99% to points, for graminoids and forbs, respectively. The Duncan groupings indicated that old fields had significantly fewer total stems at 50 cm than the three Types of prairies, while seeded reconstructions had significantly more total stems at 100 cm than the other grassland Types.

Woody stems were all below 6.5 stems $m^{-2}$ at 50 cm and below 0.5 stems $m^{-2}$ at 100 cm. Many sites had all zeros for the woody count. Sites were most clearly differentiated by graminoid stem density. At 50 cm high, nine of the 14 sites had forb densities in a narrow range of 20 to 40 $m^{-2}$ (Fig. 2A). Five of the six remnant prairies fell in that range. The exception, WC, had 66-forb stems $m^{-2}$. Eleven of the 14 sites had graminoid densities between 60 and 180 stems $m^{-2}$. Both old-field sites had exceptionally low graminoid densities, while PWW was exceptionally dense at 50 cm high. At 100 cm, all remnant prairies but WW (41 $m^{-2}$) had 3 to 14 graminoid stems $m^{-2}$, while the four SRs ranged from 29 to 91 graminoid stems $m^{-2}$ (Fig. 2B). Forb densities at 100 cm high did not differ among Types.

At an average point in a remnant prairie, the median VO height was 40 cm and there was an inflorescence, split about equally between grasses and forbs near the point 123 cm tall. At 100 cm above the ground there were 13 stems of graminoids and 4 stems of forbs $m^{-2}$ and at 150 cm there were only 5 graminoid stems and half a forb stem $m^{-2}$ on an average remnant. In a set of 15 sampling points in remnant of original prairie, more than 18 different species contributed to visual obstruction. At a typical point in a seeded reconstruction the median VO was 86 cm and the nearby inflorescence was 174 cm tall. At 100 cm above the ground there were 50 stems of graminoids and 5 stems of forbs $m^{-2}$ and at 1.5 m there were 24 graminoid and 0.3 forb stems $m^{-2}$. In a set of 15 sampling points less than 14 different species contributed to visual obstruction.

*Comparison of vegetation height measures.*—VO and LT measurements yield a single value that describes something about the vegetation height structure at that point. Measuring stem density at specific heights provides a richer description. Presumably, the estimates of these different descriptors of height would correlate positively. The F sites were excluded from the correlation because our primary interest was in prairies, and we also intended to investigate the correlation of height estimates with prairie quality. The grand mean and among-prairie standard deviations of our five height variables are in Table 3A and the product moment correlation of these variables is in Table 3B. The VO mean had significant positive correlation with all four variables, explaining between 50% and 80% of the variation in the other variable. A stem density of about 80–90 $m^{-2}$ at 100 cm gives a VO height of about 100 cm (Fig. 3). All grassland Types, including old fields, seem compatible with the regression line, which explains 82% of the variation. The density of stems at 50 cm correlated significantly only with the VO mean (Table 3B), but the remaining correlations, among density at 100 and 150 cm and the LT, were all over 0.9—not surprisingly—as they all were based on the tallest plants.

*Measures of prairie quality.*—Quality was evaluated subjectively and quantitatively based on the species recorded as part of the VO and LT observations. Two measures of quality based on species recorded as contributing to VO, VO-SR and VO-NSR varied from 2 to 7 species per point and 11 to 24 and 8 to 23 per site, respectively (Table 4A). Our species richness LT quality measure, LT-SR, varied from 3 to 10 per site. The other LT quality variable, LT-H′, varied from 0.6 to 2.21 (Table 4A). None of the quality metrics has a ranking identical to the subjective ranking (Table 4A) or to each other. All the correlations among quality metrics are positive, seven of ten significantly so (Table 4B). Subjective quality correlates most highly with VO-SR and also correlates significantly to VO-NSR. The weakest correlation in the set is between subjective quality and LT species richness. VO-SR and VO-NSR correlate very highly because most of the species detected were native. VO-NSR has significant positive correlation with all the quality variables except LT-SR. The LT-SR and LT-H′ values correlate very highly with each other but less tightly with the other quality metrics (Table 4B).



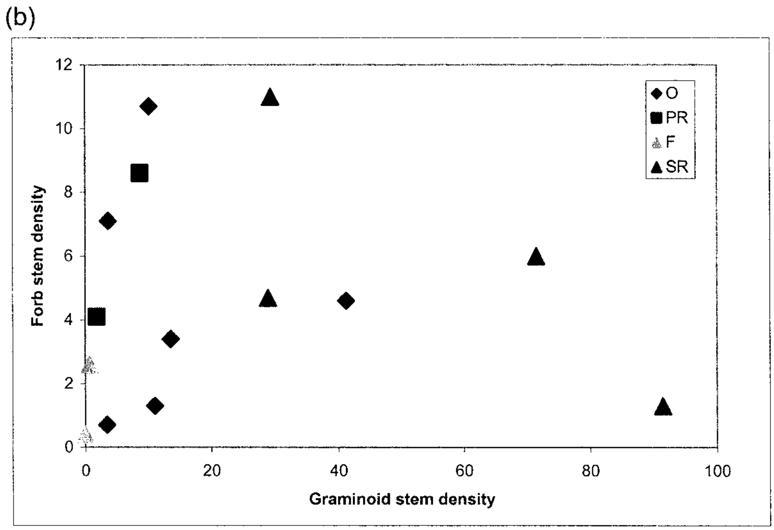




FIG. 2.—Stem densities of graminoids versus forbs (stems $m^{-2}$) at (a) 50 cm and (b) 100 cm of height. Legend shows symbols for each prairie type

Among reconstructed prairies the relationship between age (Table 1) and the quality variables (Table 4A) is confounded by the fact that all PR prairies are much older than any of the SR ones. Considering just the four SR prairies, the youngest, KS, has the highest quality in VO-NSR, LT-SR and LT-H′; therefore, age must not be necessary to increase quality. Most of these prairies (9) were burned in the previous season (Table 4A). The burnt prairies average quality on the two VO measures was higher than the unburnt ones but lower on the two LT-based measures. None of those differences were statistically significant.

*Relationships between vegetation height and quality.*—Relationships between the five vegetation

TABLE 3.—Prairie vegetation height: (a) means and (b) correlation among attributes describing height

| (a) | Mean | Standard deviation |
|---|---|---|
| VO mean[a] | 59 | 15 |
| 50 cm high total density[b] | 179 | 49 |
| 100 cm high total density[b] | 32 | 28 |
| 150 cm high total density[b] | 12 | 17 |
| Local tall height[a] | 143 | 33 |

| (b) | VO Mean | 0.5 m total density[b] | 1.0 m total density[b] | 1.5 m total density[b] | Local tall Height |
|---|---|---|---|---|---|
| VO Mean | 1.00 | 0.71* | 0.89* | 0.82* | 0.86* |
| 0.5 m total density | | 1.00 | 0.54 | 0.53 | 0.47 |
| 1.0 m total density | | | 1.00 | 0.95* | 0.93* |
| 1.5 m total density | | | | 1.00 | 0.91* |
| Local tall height | | | | | 1.00 |

[a] Values in centimeters
[b] Stems $m^{-2}$
* Significant correlation (0.05 level, > |0.58| for N = 12)

height metrics and the five prairie quality metrics was investigated using product moment correlation. All 25 correlations are negative and 20 of them are significant (Table 5). Four of the five non-significant correlations involve the density of stems at the lowest height. Subjective quality has significant negative correlation with all height measures and correlates most highly with the VO mean, which explains 70% of the variation in subjective quality. VO-SR and VO-NSR correlate negatively with all height variables, significantly so with three

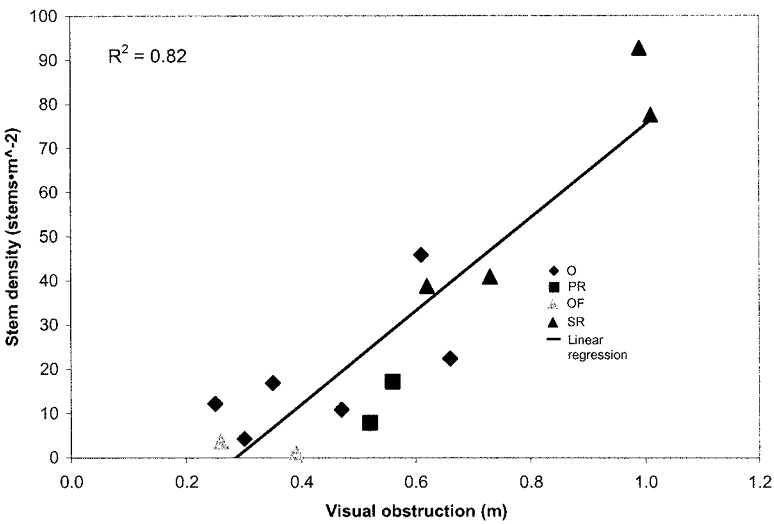



FIG. 3.—Stem density at 100 cm versus VO mean height for all fourteen prairies. Legend gives symbols for each prairie type

TABLE 4.—Measures of site quality: (a) values, (b) correlation among quality metrics

| Site | Type | Subjective quality[a] | VO-SR[b] | VO-NSR[c] | LT-SR[d] | LT-H[e] | Burned[f] |
|---|---|---|---|---|---|---|---|
| a. | | | | | | | |
| BYP | O | 10 | 18 | 16 | 9 | 1.90 | N |
| CR | O | 14 | 21 | 21 | 4 | 1.14 | Y |
| GM | O | 12 | 20 | 18 | 8 | 1.81 | Y |
| JWP | O | 13 | 24 | 23 | 10 | 2.21 | Y |
| WW | O | 11 | 19 | 17 | 4 | 0.86 | Y |
| WC | O | 9 | 18 | 13 | 5 | 1.58 | Y |
| HH | PR | 7 | 20 | 20 | 5 | 1.40 | Y |
| MA | PR | 8 | 21 | 20 | 8 | 1.86 | N |
| BC | F | 1 | 14 | 9 | 10 | 2.18 | N |
| BP | F | 2 | 14 | 10 | 6 | 1.49 | N |
| FL | SR | 4 | 16 | 14 | 3 | 0.60 | Y |
| KS | SR | 6 | 15 | 15 | 6 | 1.49 | Y |
| NLM | SR | 5 | 11 | 9 | 4 | 1.08 | N |
| PWW | SR | 3 | 11 | 8 | 3 | 0.63 | Y |
| Grand mean | | | 17.7 | 15.2 | 6 | 1.44 | |
| Among site std. dev. | | | 3.78 | 4.92 | 2.42 | 0.51 | |

b.

| | Subjective quality[a] | VO-SR[b] | VO-NSR[c] | LT-SR[d] | LT-H[e] |
|---|---|---|---|---|---|
| Subjective quality | 1.00 | 0.81* | 0.75* | 0.53 | 0.56 |
| VO-SR | | 1.00 | 0.96* | 0.61* | 0.64* |
| VO-NSR | | | 1.00 | 0.58 | 0.59* |
| LT-SR | | | | 1.00 | 0.95* |
| H | | | | | 1.00 |

* Significant correlation (0.05 level, > |0.58| for N = 12)
[a] Rating of sites with 1 the lowest quality and 14 the highest
[b] Species richness of species contributing to VO
[c] Native species richness of species contributing to VO
[d] Species richness of LT species
[e] Shannon-Weaver diversity index of LT species
[f] Evidence that the prairie was burned prior to the growing season

and four of them respectively. LT-SR and LT-H′ have significant negative correlation with all height measures except density at 0.5 m. The correlation of LT-SR and LT-H′ with mean LT height is extremely strong and negative: respectively, –0.87 and –0.91 (Table 5). The correlation of height and quality measures within remnant and within SR prairies was investigated. With the reduced degrees of freedom only the LT height by LT-SR correlation was significantly negative among remnant prairies, but most (22 of the 25) height by quality correlations remained negative. Among SR prairies, three correlations of the height variables and the quality variables were significantly negative and almost all correlations (22 of 25) were negative.

## DISCUSSION

There was significant variation among Sites within Type in our measures of vegetation height, VO and LT and in the density of stems at all three heights, 50 cm, 100 cm and

TABLE 5.—Correlations between prairie vegetation height and quality metrics

| | Subjective quality | VO-SR | VO-NSR | LT-SR | H |
|---|---|---|---|---|---|
| VO Mean | −0.84* | −0.63* | −0.64* | −0.61* | −0.66* |
| LT Mean | −0.65* | −0.65* | −0.68* | −0.87* | −0.91* |
| 0.5m total density | −0.58* | −0.24 | −0.22 | −0.15 | −0.28 |
| 1.0m total density | −0.73* | −0.72* | −0.71* | −0.72* | −0.84* |
| 1.5m total density | −0.62* | −0.57 | −0.60* | −0.67* | −0.82* |

* Significant correlation (0.05 level, $> |0.58|$ for N = 12)

150 cm. This means that within a grassland Type, different sites have distinguishable vegetation heights. The differences among sites within a grassland Type may be due to species composition differences or other unknown site attributes. Despite the variation among prairies within a Type, there were significant differences among prairie Types in both measures of vegetation height and in total stem density at 50 and 100 cm. The hypothesis that prairies reconstructed by seeding are taller and have greater stem densities than remnant prairies was supported by both VO and LT heights and by direct counts determining density. Fields dominated by pasture grasses proved to be the shortest grassland Type and had the lowest stem density at all three heights. As previous observations had suggested, planted reconstructions were indistinguishable from remnant prairies using these measures of vegetation height and structure.

*Comparison of prairie attributes.*—Original prairie as seen through remnants were significantly shorter than seeded reconstructions. At an average point in a seeded reconstruction, the VO height and the nearby tallest stem was 40 cm taller than a point in a remnant. At 100 cm above the ground there were four times as many grass stems in the seeded reconstructions than there were in remnants. The grass stem count ratio was even higher at 150 cm. While remnant prairies had approximate equality of grass and forb stems, seeded reconstructions had many more graminoid than forb stems. In a set of sampling points, remnant prairie had 50% more species than seeded reconstructions contributing to visual obstruction. Other tallgrass prairie vegetation height studies also found low canopies. Fletcher and Koford (2002) measured a mean VO of 46 cm in several Iowa tallgrass remnants. Two studies conducted in South Dakota prairies measured VO means of 34 cm and 25 cm (Bakker *et al.*, 2002; Higgins *et al.*, 2002). None of our six Illinois tallgrass remnant prairies had vegetation tall enough to obscure the vision of an average human on foot, much less one on horseback. Thus, the literary image of the prairie as sward of grass taller than one's head does not apply to Illinois remnants. The literary image is likely to have been repeated based on rare circumstances that were particularly impressive and/or because it could impress a distant reader, but it is possible that remaining remnants are not representative of the original prairie.

The hand-planted reconstructions that we studied are 30 to 40 y old, much older than any of the seeded reconstructions. No one has suggested to us that either of these prairies has grown obviously shorter, so we think most of the difference is due to the construction technique rather than age. Except for having more forb stems than graminoid stems at 100 cm high, both planted reconstructions fell within the range of the six remnant prairies for the height attributes measured. Both planted reconstructions had as many species contributing to VO as remnants.

*Why do seeded and remnant prairies differ?*—What makes seeded reconstructions taller and denser and, presumably, with more aboveground biomass than reconstructions planted with plants and remnant prairie? The most obvious suggestion is that differences in species composition lead to differences in vegetation height. Seeded reconstructions have fewer species than the remnant prairies. Native species that flower in the spring are of short stature (*e.g., Comandra umbellata, Dodecatheon meadia, Hypoxis hirsuta, Lithospermum canescens, Pedicularis canadensis, Sisyrinchium albidum* and *Viola pedatifida*) and are at low density or absent from seeded reconstructions. Some spring flowering species are present in the planted reconstructions and, of course, they are present in remnants. Prairie reconstruction projects have cost considerations and the seed of many warm-season grasses is abundant and cheap. The seed of ephemeral species and most short-stature species is either expensive or not available. Thus, the conjecture that seeded reconstructions are taller because they were sown primarily with seeds of tall species is probably true, and could explain the vegetation height difference.

Our observation that individuals of a same species seem to grow taller on seeded reconstructions than on remnant prairies suggests that species composition differences will not explain all of the height difference between these grassland types. The most common local tall species, *Andropogon gerardii*, was 52 cm taller on the seeded reconstructions than on remnant prairie. One reason that species might grow shorter on remnants is that animal, fungal and microbial predators, parasites and pathogens in intact natural communities might suppress growth. Holah and Alexander (1999) found that *A. gerardii* was shorter when grown in soil in which the annual legume *Chamaecrista fasciculata* had previously been grown. They also found that *A. gerardii* grew significantly taller on soil that had been microwaved to reduce soil fungi (Holah and Alexander, 1999).

*Conclusions.*—The high correlation among VO, LT and the density of stems at 100 and 150 cm suggests that a single estimate of prairie vegetation height could be useful to describe vegetation height structure. VO is a measure of the height of the top of the bulk of the vegetation and is therefore presumably associated with the height at which there is a steep gradient of light attenuation. The quickly measured LT height was typically a constant amount above the VO height in our measurements, but LT is more sensitive than VO to the time at which the observations are made. Estimating the density of stems at any height is much more time consuming than the VO estimates. Because the Robel pole is used widely, correlates highly with biomass (Robel *et al.*, 1970; Vermeire and Gillen, 2001; Benkobi *et al.*, 2000), and with LT and stem density, VO measurement is recommended as the best single estimator of prairie vegetation height.

This study was initiated by the observation that reconstructed prairies were taller than original prairie. The consistent negative relationship of vegetation height and stem density measures with all the species richness metrics, VO-SR, VO-NSR, LT-SR and LT-H′, suggests that taller and thicker prairies have a lower species diversity, but does not tell whether the lack of plant and animal species diversity makes grasslands taller or whether the capacity of dominant grasses to grow very tall in disturbed soil reduces species diversity.

The goal of reconstruction is presumably to recreate prairie as close to the original as possible. Failure to recreate vegetation structure characteristic of original prairie may prevent the restoration of the animal community. Many investigators have found vegetation height preferences among grassland birds (*e.g.,* Wiens, 1969; Madden *et al.*, 2000; Renfrew and Ribic, 2001), which implies that vegetation height is an important characteristic for those declining species. This study shows that typical seeded reconstructions have not recreated the vegetation height structure of remnant prairies. Adjusting the species composition of the seed mix seems to be an obvious way to address both the excess height and the deficient species diversity restoration problems.

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