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Comparison of rangeland vegetation sampling techniques in the Central Grasslands

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Abstract

Maintaining native plant diversity, detecting exotic species, and monitoring rare species are becoming important objectives in rangeland conservation. Four rangeland vegetation sampling techniques were compared to see how well they captured local plant diversity. The methods tested included the commonly used Parker transects, Daubenmire transects as modified by the USDA Forest Service, a new transect and "large quadrat" design proposed by the USDA Agricultural Research Service, and the Modified-Whittaker multi-scale vegetation plot. The 4 methods were superimposed in shortgrass steppe, mixed grass prairie, northern mixed prairie, and tallgrass prairie in the Central Grasslands of the United States with 4 replicates in each prairie type. Analysis of variance tests showed significant method effects and prairie type effects, but no significant method × type interactions for total species richness, the number of native species, the number of species with less than 1% cover, and the time required for sampling. The methods behaved similarly in each prairie type under a wide variety of grazing regimes. The Parker, large quadrat, and Daubenmire transects significantly underestimated the total species richness and the number of native species in each prairie type, and the number of species with less than 1% cover in all but the tallgrass prairie type. The transect techniques also consistently missed half the exotic species, including noxious weeds, in each prairie type. The Modified-Whittaker method, which included an exhaustive search for plant species in a 20 x 50 m plot, served as the baseline for species richness comparisons. For all prairie types, the Modified-Whittaker plot captured an average of 42.9 (± 2.4; 1 S.E.) plant species per site compared to 15.9 (± 1.3), 18.9 (± 1.2), and 22.8 (± 1.6) plant species per site using the Parker, large quadrat, and Daubenmire transect methods, respectively. The 4 methods captured most of the dominant species at each site and thus produced similar results for total foliar cover and soil cover. The detection and measurement of exotic plant species were greatly enhanced by using ten 1 m^2 subplots in a multi-scale sampling design and searching a larger area (1,000 m^2) at each site. Even with 4 replicate sites, the transect methods usually captured, and thus would monitor, 36 to 66% of the plant species at each site. To evaluate the status and trends of common, rare, and exotic plant species at local, regional, and national scales, innovative, multi-scale methods must replace the commonly used transect methods of the past.

Key Words: multi-scale vegetation sampling design, species richness, transect methods, exotic and rare species detection

Over the past 30 to 40 years, 2 of the common rangeland sampling methods used by many scientists and range conservationists were Parker transects (Parker 1951) and Daubenmire transects (Daubenmire 1959). Federal agencies were quick to adopt the Parker and Daubenmire methods, often modifying them for various reasons, and they are still in use today in many areas (Brady et al. 1991, Coughenour et al. 1991, USDA Forest Service 1996). However, there are 3 reasons why it is now time to reevaluate rangeland sampling methods. First, ecological paradigms have changed. Most vegetation sampling methods have focussed on describing perceived homogenous communities (Tansley and Chipp 1926, Daubenmire 1968, Mueller-Dombois and Ellenberg 1974). Heterogenous areas (Collins 1987, Whicker and Detling 1988, Coffin and Laurenroth 1990, Archer 1994), ecotones (Gosz 1991), and the cumulative area of rare habitats (Stohlgren et al. 1997c) may dominate many rangelands, yet these areas have been largely ignored in vegetation measurement. Transects placed in homogeneous areas may artificially reduce the variance in biomass, foliar cover, and species richness measurements due to spatial autocorrelation effects (Fortin et al. 1989). Second, rangeland conservation objectives have changed. Important priorities for rangeland conservation now include maintaining native plant diversity, detecting exotic species, and monitoring rare species (Mack 1981, U.S. GAO 1991, National Research Council 1994, Joern and Keeler 1995, Randall 1996). Third, rangeland inventory and monitoring needs have increased in the face of decreasing funding to monitor rangelands (National Research Council 1994). Sampling techniques must be more cost-efficient and information rich than in the past. The objective of this study was to compare commonly used or proposed rangeland vegetation sampling techniques using the same metrics (e.g., the numbers of native and exotic plants species, foliar cover, percent bare ground) with adequate replication in shortgrass steppe, mixed grass prairie, north-

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ern mixed prairie, and tallgrass prairie in the Central Grasslands. A vegetation sampling design used recently in the mountains and plains was included (Stohlgren et al. 1995, 1997a).

Study Areas and Methods

The study included 4 study prairie types (Fig. 1): shortgrass steppe at the Central Plains Experimental Range, Nunn, Colorado; mixed grass prairie at the High Plains Experiment Station, Cheyenne, Wyo.; northern mixed prairie in Wind Cave National Park, S. D; and tallgrass prairie in Pipestone National Monument, Minn. (Table 1). Except for the tallgrass prairie which had no grazing, we randomly selected 4 sample sites, or replicates, in each prairie type that encompassed various grazing intensities from heavily grazed to ungrazed sites (Table 1). In the shortgrass steppe type, all sites were subjected to grazing although Site 3 was part of an exclosure opened to grazing in 1990. In the mixed grass prairie type, Sites 1 and 3 were grazed season-long (June–October), Site 2 had no grazing (exclosure), and Site 4 received rotationally heavy grazing. In the northern mixed prairie type, all sites were grazed by native ungulates (bison, deer, and elk). In the tallgrass prairie type, all sites were prescribed burned on a 3 to 4-year cycle. Sites 1 and 2 were considered the best representation of tallgrass prairie in the Monument and were prescribed burned in spring 1995. Site 3 was burned in spring 1996, and Site 4 was sod-seeded to a mix of native grasses in 1993, 1994, and 1995. At each sampling site we superimposed the 4 rangeland sampling techniques described below.

The Parker transects were 30.48 m (100 feet) long (Fig. 2) and placed perpendicular to the environmental gradient with the primary objective to assess frequency, as a surrogate for foliar–cover/dominance, of plant species in an area (Parker 1951). Readings of plant species or bare ground were made through a 1.9 cm diameter ring at 30.5 cm (1 foot) intervals along transects. Three Parker transects per sample site were placed 25 m apart and produced 300 points per sample site and 1,200 points per prairie type.

One Daubenmire transect bisected each sampling site parallel to the environmental gradient (Fig. 2). The primary objective of the Daubenmire transect is to accurately quantify the foliar cover of most plant species at a site. The transects were 30.48 m (100 feet) long with 20 $\times$ 50 cm quadrats set at 1.67 m (5 foot) intervals (Daubenmire 1959; as modified by the USDA Forest Service 1996). Daubenmire (1959) did not specify the number of replicate transects required for the task, but showed that 40 quadrats (placed 0.5 m apart) were adequate for many vegetation types. Two transects of 20 quadrats each are recommended for each vegetation type. Four modified-Daubenmire transects, henceforth called Daubenmire transects, were established in each prairie type resulting in 80 quadrat readings. Daubenmire (1959) and the USDA Forest Service (1996) recommend the use of foliar cover classes (e.g., 0 to 5, 5 to 25, 25 to 50%, etc.) to reduce the variance among observers. For spatial and temporal trend analysis, these cover classes may be too broad, particularly if most species are less than 1% cover. To be consistent with the quadrat and Parker methods, the foliar cover of each species and bare ground were recorded to the nearest percent in each quadrat.

A variety of rangeland ecological condition sampling methods for vegetation and soils are being considered for use by the USDA Agricultural Research Service (Herrick et al. 1996). One proposed transect and quadrat technique, which was termed the large quadrat transect method, was designed for grass/herbaceous vegetation (details provided by W. Whitford, Environmental Protection Agency, pers. comm. June 1996). The method uses a larger quadrat (0.5 $\times$ 1.0 m) than the Daubenmire quadrat (20 $\times$ 50 cm). Similar to the Daubenmire transect, the primary objective of the large quadrat transect is to accurately quantify the foliar cover of most plant species at a site. One, 100-m long large quadrat transect was located in the center of each sample site parallel to the environmental gradient (Fig. 2). Five 0.5 $\times$ 1.0 m quadrats were placed randomly along alternate sides of the transect. The quadrat contained a decimeter grid of nylon string. Foliar cover for each species and bare ground were estimated to the nearest percent. Four large quadrat transects per prairie type resulted in 20 quadrat readings per prairie type.

One multi-scale Modified-Whittaker plot was established at each sample site. The Modified-Whittaker plot was 20 $\times$ 50 m (1,000 m^2), placed with the long axis along the environmental gradient (Stohlgren et al. 1995). Nested in each plot were ten 0.5 $\times$ 2 m (1 m^2) subplots systematically spaced along the inside border, two 2 $\times$ 5 m (10 m^2) subplots in alternate corners, and a 5 $\times$ 20 m (100 m^2) subplot in the

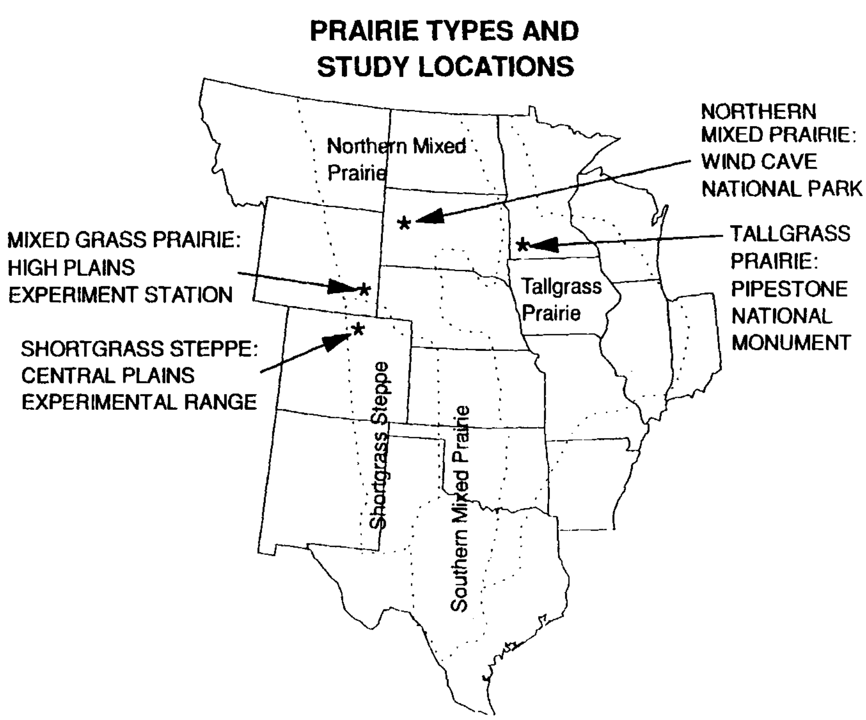

Fig. 1. Study areas and prairie types.

Table 1. Study locations, sample sites, prairie type, grazing regime, and Universal Transverse Mercator coordinates and elevation from a global positioning system (10 to 40 m accuracy).

Study Location	Prairie Type	Sample Site	Grazing Regime	Location Coordinates Northing	Easting	Elevation
				---------- (m) ----------		
Cheyenne High Plains Experimental Station	Mixed	1	Light, season long grazing	4562573	512572	1977
Cheyenne, Wyoming	Grass	2	Exclosed from grazing	4562665	512734	1933
	Prairie	3	Heavy, season long grazing	4562348	511042	1918
		4	Eight paddock heavily stocked rotational grazing	4562496	510587	1947
Central Plains Experimental Range	Short	1	All plots not protected are subject to grazing by	4521543	524604	1666
Nunn, Colorado	Grass	2	cattle, prairie dogs, and pronghorns.	4521466	524466	1627
	Steppe	3		4521711	524424	1711
		4		4521856	525430	1573
Wind Cave National Park	Northern	1	Lightly grazed, native ungulates	4825001	621607	1379
Hot Springs, South Dakota	Mixed	2	Heavily grazed, native ungulates	4828864	630579	1165
	Grass	3	Heavily grazed, native ungulates	4828769	630565	1116
		4	Lightly grazed, native ungulates	4824979	621831	1317
Pipestone National Monument	Tallgrass	1	All sites are not grazed, but they are prescribe	4876377	714378	530
Pipestone, Minnesota	Prairie	2	burned at 3 to 4 year cycles, and site 4 was	4876505	714425	468
		3	seeded with native grasses in 1993, 1994, and	4876643	714540	520
		4	1995.	4876760	714066	472

plot center. Foliar cover and height for each species and bare ground were estimated to the nearest percent in the ten 1-m^2 subplots, and cumulative plant species were noted in the 10-m^2 subplots, the 100-m^2 subplots, and the 1,000-m^2 plots.

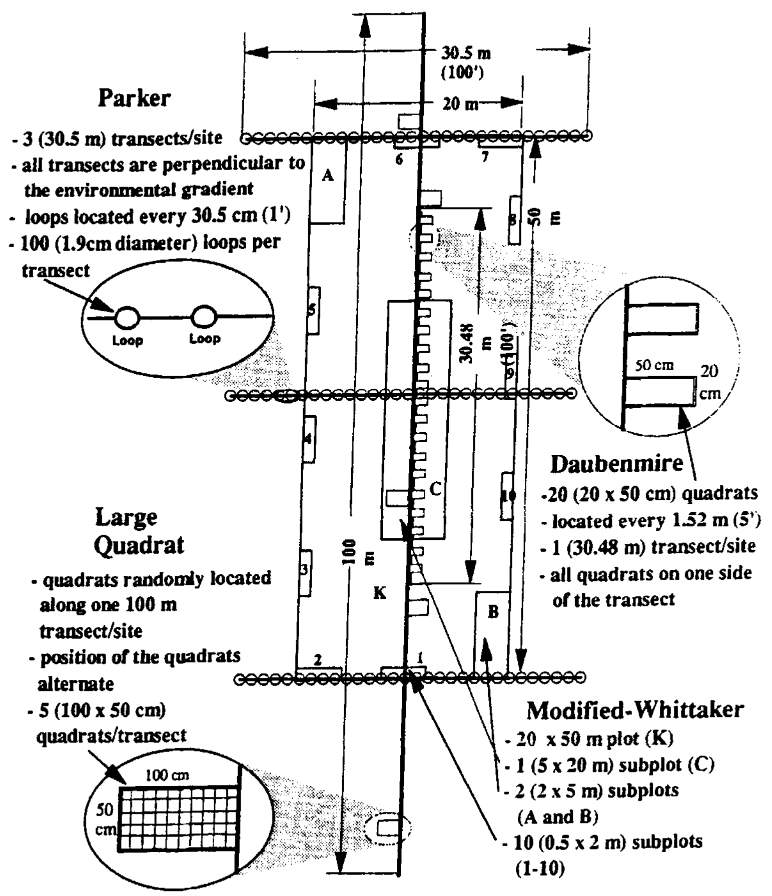

Fig. 2. Layout of plots, quadrats, and transects at each sample site, with 4 sample sites per prairie type.

Ancillary data recorded for each plot included: location and elevation from a global positioning system, slope, and aspect. The primary objectives of the Modified-Whittaker nested design are to: (1) accurately quantify the mean and variance of foliar cover and height of most plant species at a site; (2) provide cover and frequency data less influenced by spatial autocorrelation; and (3) develop species-area curves (i.e., based on species richness at 4 spatial scales) to predict the number of native and exotic species in a larger area (Stohlgren et al. 1995, 1997a).

At each sample site in each prairie type, the order of the 4 methods was staggered and the time required to collect data using each technique was recorded to assess cost efficiency relative to the amount of information gained. Each site was sampled as close to the peak biomass as possible. The shortgrass steppe was sampled from 1 to 3 July 1996; the mixed grass prairie from 25 to 27 June 1996; the northern mixed prairie from 10 to 13 July 1996; and the tallgrass prairie from 24 to 27 July 1996. Plant species that could not be identified in the field were collected and identified at the herbarium at Colorado State University. One hundred fifty six of the 1,704 plant specimens encountered, 9.1% of the total specimens, could not be identified to species due to phenological stage or to missing flower parts, so the numbers of native plus exotic species do not always equal the total number of species.

Statistical Analysis

For each prairie type, we used one-way analysis of variance (ANOVA) to test for method effects on total species richness, the number of native and exotic species, the number of species with less than 1% cover, total foliar cover, total bare ground, and the time required for each sampling method with 4 sites per prairie type. The total species found in the 20 × 50 m Modified-Whittaker plot was used to assess the completeness of the various transect methods. Only the 1-m^2 subplots in the Modified-Whittaker plots were used to compare percent foliar cover and bare ground with transect technique results. Data from the 4 prairie types were pooled and two-way ANOVA was used to test for method effects, prairie type effects, method × type interactions for different vegetation characteristics, and the time required for each sampling method. Whenever ANOVA results showed a significant effect ($P < 0.05$; with no significant interaction), Tukey's HSD test was used to determine significant differences among means (Day and Quinn 1989).

Results

Shortgrass Steppe

The 4 sampling techniques tested in the shortgrass steppe varied more in species richness characteristics than in foliar and soil cover estimates. The Modified-Whittaker plot, which included a thorough search of the four 1,000-m^2 areas, averaged 33.8 (± 3.7; 1 S.E.) plant species in this prairie type. Significantly fewer species were recorded by the Parker, large quadrat, and Daubenmire transect methods which averaged only 12.2 (± 0.9), 15.0 (± 2.1), and 17.5 (± 3.2) taxa, respectively. Accordingly, the numbers of native and exotic plant species differed among the sampling methods, with the transect methods recording about 36 to 52% of the native and exotic species at the sites. Mean foliar and soil cover did not differ significantly among sampling techniques, despite the fact that fewer species were captured by the transect methods. For a field crew of 2, the Modified-Whittaker method took about 40 to 50 minutes longer to complete than the transect methods.

Total species richness from the 4 sites in the shortgrass steppe type resulted in 17, 23, 25, and 39 plant species from the Parker, large quadrat, Daubenmire, and Modified-Whittaker methods, respectively. Two exotic species (Cypress spurge, *Euphorbia cyparissias* L., and Russian thistle, *Salsola iberica* Sen. & Pau.) detected by searching the four 0.1 ha Modified-Whittaker plots were not picked up by replicate sampling with the transect methods. At Site 1, the Daubenmire transect detected only 8 of 26 species at the site. At Site 4, the Parker transect recorded only 10 of 41 plant species, and missed 1 of the 5 dominant species at the site, hairy grama (*Bouteloua hirsuta* (H.B.L.) Lag.; Table 2).

Mixed Grass Prairie

The 4 sampling techniques tested in the mixed grass prairie also varied more in species richness characteristics than in foliar and soil cover estimates. Again, the Modified-Whittaker technique, which averaged 42.8 (± 3.1) plant species per site, recorded significantly more plant species than the Parker (13.0 ± 1.9), large quadrat (20.2 ± 0.9), and Daubenmire (26.0 ± 1.6) transect methods. Here, differences in the mean number of exotic species per site were significant at $P = 0.056$ and probably should not be dismissed as unimportant. On average, the transect methods missed 2 exotic species at each sample site. As reported for the short grass steppe, mean foliar and soil cover did not significantly differ among sampling techniques, despite the fact that fewer species were captured by the transect methods. The Modified-Whittaker method took almost 3 hours per site because: (1) half the plant species had less than 1% foliar cover each; and (2) several of them were short, well camouflaged, and difficult to find in knee-high vegetation in the 1,000-m^2 plot. The Parker transects took about half the time of the other techniques, but also recorded the fewest plant species.

Four replicates of the transect techniques did not describe the species richness of the mixed grass prairie. The methods resulted in 23, 42, 41, and 64 plant species from the Parker, large quadrat, Daubenmire, and Modified-Whittaker methods, respectively. At Site 1, the Parker transect recorded only 8 of 37 plant species present. At Site 2, the Daubenmire transect missed all 5 of the exotic species present. Exotic species recorded in the Modified-Whittaker plots but missed by the transect methods included: crested wheatgrass (*Agropyron cristatum* L.), cheatgrass (*Bromus tectorum* L.), dalmatian toadflax (*Linaria dalmatica* L.), yellow sweet clover ((*Melilotus officinalis* (L.) Lam.), and Kentucky bluegrass (*Poa pratensis* L.). The quadrat and Parker methods each missed 1 of the 5 dominant species at 2 sampling sites (Sites 1 and 4; Table 2).

Northern Mixed Prairie

Results were much the same in the northern mixed prairie. Significantly more plant species were recorded with the Modified-Whittaker technique which averaged 46.5 (± 6.5) plant species per site, while the Parker, large quadrat, and Daubenmire transect methods averaged 16.0 (± 1.5), 16.5 (± 0.9), and 21.0 (± 2.3) plant species per site, respectively. The mean number of exotic species per site was significantly different among methods, with the transect methods missing about 4 to 5 exotic species per site. Species richness, foliar cover, and soil cover were patchy due to localized prairie dog (*Cynomys* sp.) disturbance and microtopographic variability. Snowberry, *Symphorocarpus occidentalis* Hook. accounted for 42% cover in one 1-m^2 Modified-Whittaker subplot at Site 3 but was not detected by the transect methods (Table 2). Clumps of another native species, meadow rose, *Rosa blanda* Ait. averaged 5.6% cover in the 1-m^2 Modified-Whittaker subplots at Site 4 but were not detected by the transect methods. However, the Modified-Whittaker method took almost three and a half hours per site, more than twice as long as the transect techniques.

Four replicate Parker, large quadrat, and Daubenmire transects detected 38.5, 46.1, and 51.3%, respectively, of the total species richness in the northern mixed prairie study area. The Modified-Whittaker method tallied 73 plant species in the four 0.1-ha plots. Six exotic species present in the Modified-Whittaker plots but missed by the other methods were false flax (*Camelina microcarpa* Andrz. ex. DC.), Canada thistle (*Cirsium arvensis* (L) Scop.), small bindweed (*Convolvulus arvensis* L.), white horehound (*Marrubium vulgare* L.), black medic (*Medicago lupulina* L.), and yellow sweet clover.

Tallgrass Prairie

Similar results also were found in the species-rich tallgrass prairie. The

Modified-Whittaker technique averaged 48.5 (± 3.4) plant species per site, significantly more species than the Parker, large quadrat, and Daubenmire transect methods which averaged 22.2 (± 2.1), 24.0 (± 2.5), and 26.5 (± 3.6) plant species per site, respectively. The transect methods missed about 4 to 5 exotic species per site. This was the only location where there was no significant difference in the number of species with less than 1% cover. Foliar and soil cover did not differ significantly among methods. The Modified-Whittaker method took almost 4 hours per site and the Daubenmire transects averaged 2 hours 11 minutes per site.

Four replicate Parker, large quadrat, and Daubenmire transects detected only 41, 46, and 50 plant species, respectively, while the 4 Modified-Whittaker plots tallied 77 plant species in the tallgrass prairie study area. At Site 3, the native herb, aromatic aster, *Aster oblongifolius* Nutt., which averaged 9.0% cover in the 1-m^2 Modified-Whittaker subplots and was present in 9 of 10 subplots, was not detected by the transect methods (Table 2). The Daubenmire transect contained only 16 of 41 plant species at this site. Seven exotic species in the 4 sites were not detected by the transect methods: quack grass (*Agropyron repens* L.), asparagus (*Asparagusn officinale* L.), butter-and-eggs (*Linaria vulgaris* Mill), yellow sweet clover, timothy (*Phleum pratense* L.), large goatsbeard (*Tragopogon dubius* Scop.), and red clover (*Trifolium pratense*).

All Prairie Types

Combined Results showed significant method effects and prairie type effects for all species richness characteristics, but no significant method X type interactions, except for the number of exotic species (Table 3). Thus, the methods behaved similarly in each prairie type. The Parker, large quadrat, and Daubenmire transect methods significantly underestimated the total species richness and number of native species in all prairie types, and the number of species with less than 1% cover in all but the tallgrass prairie type.

The 4 methods produced similar results for total foliar cover and soil cover (Table 3). The detection of exotic plants, especially noxious weeds, was greatly enhanced by searching the 0.1 ha plot in the multi-scale Modified-Whittaker sampling design. Even with 4 replicate sites, the transect methods usually captured less than 65% of the species richness in each prairie type.

Discussion

Sampling Designs and Species Richness Accuracy: The Plot Thickens

The transect methods were expected to capture about 70% of the plant species at a given sample site, and perhaps 80 to 90% of the plant species in a prairie type with 4 replicate sites. Daubenmire (1959) suggested that 40 plots captured, on average, 22.5 of 31.5 taxa (71.4% of the taxa) in 31 areas sampled. Even with 80 quadrats in 4 sites per prairie type, it was found, on average, that the Daubenmire transects recorded only between 55% (northern mixed prairie) and 65% (tallgrass prairie) of the species present in a prairie type (57.6% overall). At some sites, the Daubenmire transects only captured 31% (shortgrass steppe, Site 1) and 39% (tallgrass prairie, Site 3) of the plant species present. The large quadrat and Parker transects captured, on average, only 58.6 and 43.6% of the plant species recorded in a prairie type, which does not provide an accurate description of local plant species diversity.

There are 2 primary reasons why transect methods fail to capture much of the plant diversity at a site: (1) the small total sample area; and (2) the high degree of spatial autocorrelation due to the linearity of the methodology and clustering of quadrats in more localized areas. The Daubenmire transect methods sample only 2 m^2 (20 X 50 cm X 20 quadrats) at each site for information on species richness and foliar cover, and only 8 m^2 after 4 replicate transects are established. The large quadrat method covers slightly more area at 2.5 m^2 per site and 10 m^2 after 4 transects. Even with twice as many large quadrat and Daubenmire quadrats per site (i.e., similar sampling time compared to

Table 2. Comparisons of average percent cover of 5 most dominant species from representative sites using the Modified-Whittaker method.

Prairie Type (Sample Site)	Species	Native/ Exotic	Sampling Techniques: Parker	Large Quadrat	Daubenmire	Modified-Whittaker
				(%)		
Shortgrass Steppe (Site 4)*	*Bouteloua gracilis*	Native	25.4	11.8	16.0	22.5
	Opuntia polyacatha	Native	1.3	9.6	2.1	12.2
	Bouteloua hirsuta	Native	0.0	2.6	2.8	7.9
	Eriogonum effusum	Native	2.3	3.6	17.2	7.3
	Aristida longiseta	Native	5.0	4.6	8.9	6.0
Mixed Grass Prairie (Site 1)	*Bouteloua gracilis*	Native	30.9	15.2	20.6	15.9
	Koeleria pyramidata	Native	5.1	14.2	11.2	10.8
	Stipa comata	Native	2.9	0.0	2.1	7.0
	Agropyron smithii	Native	0.0	1.9	1.4	4.6
	Artemisia frigida	Native	0.7	1.9	0.8	4.2
Northern Mixed Prairie (Site 3)	*Bromus japonicus*	Exotic	4.1	22.1	3.4	14.1
	Psoralea tenuiflora	Native	1.0	6.5	17.7	13.2
	Poa pratensis	Exotic	23.7	14.8	16.2	13.1
	Symphoricarpos occidentalis	Native	0.0	0.0	0.0	4.2
	Agropyron smithii	Native	0.7	2.9	2.3	2.5
Tallgrass Prairie (Site 3)	*Bromus inermis*	Exotic	7.7	21.8	17.2	9.3
	Aster oblongifolia	Native	0.0	0.0	0.0	9.0
	Symphoricarpos occidentalis	Native	0.7	1.8	1.3	5.4
	Solidago missouriensis	Native	0.0	1.4	8.4	4.3
	Poa pratensis	Exotic	7.7	2.4	2.8	3.4

* see Table 1.

Table 3. Mean (standard error) of characteristics for the various sampling techniques in all prairie types combined.[1] F-value and F-test probability (P) are given for each ANOVA.

Characteristics	Sampling Techniques Parker	Large Quadrat	Daubenmire	Modified-Whittaker	F_{type} (P)	F_{method} (P)	$F_{type\ x\ method}$ (P)
No. Total Species	15.9[a] (1.3)	18.9[a] (1.2)	22.8[a] (1.6)	42.9[b] (2.4)	9.34 (0.001)	72.45 (0.001)	0.88 (0.548)
No. Native Species	12.8[a] (1.1)	15.7[a] (1.3)	17.2[a] (1.4)	33.5[b] (1.9)	10.97 (0.001)	59.60 (0.001)	0.65 (0.747)
No. Exotic Species	1.9 (0.5)	1.7 (0.4)	2.4 (0.5)	5.5 (1.0)	72.47 (0.001)	35.47 (0.001)	3.77 (0.001)
No. Species with less than 1 Percent Cover	7.4[a] (0.9)	8.8[a] (1.0)	13.6[b] (1.4)	18.5[c] (1.6)	3.65 (0.019)	18.73 (0.001)	0.90 (0.533)
Foliar Cover Percent	53.4 (4.5)	62.0 (6.6)	50.4 (3.6)	66.1 (6.8)	4.63 (0.006)	1.98 (0.130)	0.691 (0.713)
Soil Cover Percent	19.0 (3.9)	21.0 (4.2)	26.0 (3.7)	22.3 (3.4)	0.67 (0.576)	0.53 (0.666)	0.32 (0.963)
Time (minutes)	65.5[a] (16.2)	58.4[a] (10.1)	92.9[a] (13.5)	176.2[b] (20.4)	6.22 (0.001)	15.03 (0.001)	0.38 (0.592)

[1] (ANOVA F and P, d.f. = 3, 60; Row means with dissimilar superscripts are significantly different ($P < 0.05$) using Tukey's test).

the Modified-Whittaker method; Table 3), the total area sampled would be 50 and 40%, respectively, of that sampled using the Modified-Whittaker method. The Parker transect's 1.9 cm diameter loop covers just 0.09 m^2 per site (300 points) and 0.3 m^2 (1,200 points) after 4 replicates. The ten 1-m^2 subplots in the Modified-Whittaker multi-scale design collect foliar cover data from 10 m^2 per site and 40 m^2 after 4 replicates which is 5 times the area of the Daubenmire quadrats. The 4 scales of nested subplots collect species richness information from a 1,000-m^2 area at each site, 4,000 m^2 after 4 replicates. This larger sample area is significantly more effective at describing plant species richness in heterogeneous and patchy environments.

Both Parker (1951) and Daubenmire (1959) suggested that a larger area around their transects be searched. Daubenmire (1959; page 48) mentioned in a footnote that the presence of rare species should be noted, but he did not specify the size or shape of the search area. Parker (1951) suggested searching a 45.7 × 30.5 m (150 × 100') plot to "assure a record of rare but important indicator species which may not otherwise be encountered on the transect." It is unclear what was meant by 'rare but important indicator species' although a complete taxonomic listing was not suggested. In any case, perhaps due to the increased time and taxonomic expertise needed to search the larger plot, no known examples where the "searching" part of either protocol has been adopted and consistently used (e.g., Johnston 1957, Hutchings and Holmgren 1959, Francis et al. 1972).

The second problem with transect methods is their high degree of spatial autocorrelation. Because 2 points close together are more similar than 2 points farther apart, quadrat sampling, or point sampling along the Parker, large quadrat, and Daubenmire transects tend to record redundant information among quadrats, while missing many species in the local area (Table 3). Corrections to frequency data collected with the Parker transects have been proposed (Brady et al 1991, Cook et al. 1992), but we have seen no attempts to correct for spatial autocorrelation effects on species richness. The ten 1-m^2 subplots of the Modified-Whittaker plot were arranged on the perimeter of the 20 × 50 m plot and are less influenced by spatial autocorrelation. The more widely spaced subplots averaged 28 (± 2.4) species per site, producing foliar cover data on 23% more plant species than in the Daubenmire transects. The Modified-Whittaker subplots also provide cover and frequency data that are less influenced by spatial autocorrelation (i.e., more independent replicates), which can be useful in evaluating the spread of exotic species (Stohlgren et al. 1997a). Furthermore, transects simply miss many non-linear components of the landscape (e.g., animal disturbance, micro-topographic features, and small-scale edaphic differences). Transect methods, designed under the paradigm that landscapes are dominated by homogeneous communities, may not have prepared us for sampling the heterogeneous landscapes of the Central Grasslands.

The methods could have compared in 3 ways: (1) as they are typically applied; (2) equal sample time devoted to each method; or (3) equal area sampled by each method. It was reasoned that the methods should be compared as typically applied in a given vegetation type to assess what information each of the techniques generally records in a rangeland unit, and to serve as a comparison and link to past sampling efforts. The equal time approach would have required twice as many large quadrat and Daubenmire transects and quadrats, and still would have resulted in: (1) far less sample area than the Modified-Whittaker methods, as shown above; and (2) the new transects likely would have missed many rare species and habitat patches, as shown in the data on total species per prairie type. An equal area approach would have taken 5 times longer for the Daubenmire methods and 4 times longer for the large quadrat method just for the cover and frequency data (i.e., without searching the 0.1 ha area for total species richness which took over an hour at many sites). An equal area approach with the tiny Parker loop is unrealistic. Adding a 0.1 ha search area around transect methods would take nearly as much time as the Modified-Whittaker method, but would not eliminate the problems associated with spatial autocorrelation, non-independent frequency data, and collecting cover data on fewer plant species.

Comparing the techniques as typically applied may be one indication that previous rangeland monitoring may have gathered little information on rare and exotic plant species.

Data on plant species composition suggest that heterogeneity is the rule, rather than the exception in the Central Grasslands. Species overlap between sites averaged 42 to 49% for the 4 prairie types. Plant diversity in the Central Grasslands typically is spatially heterogeneous because of the underlying patchiness of nutrient rich and poor areas (Cambardella and Elliott 1993, Seastadt 1995), variations in topography along broad-scale temperature and micro-topographic moisture gradients (Coffin and Laurenroth 1989a, 1989b, Collins and Glenn 1995), patch and soil disturbances by prairie dogs, ungulates, and other animals (Polley and Collins 1984, Polley and Wallace 1986, Whicker and Detling 1988, Knight 1994), seedbank variability and chance establishment (Coffin and Laurenroth 1989b, Joern 1995), competition (Coffin and Laurenroth 1991, Nasri and Doescher 1995, Joern 1995), fire (Dix 1960, Hulbert 1969, 1988, White and Currie 1983, Whisenant and Uresk 1990), and heterogeneous herbivory (Parsons et al. 1991, Singer 1995). Temporal variation (succession, invasions, climate change) can be equally impressive (Mack 1981, Collins and Glenn 1995, Bock and Bock 1995). Larger, long-term plots and a greater sampling intensity are needed to accurately quantify spatial and temporal heterogeneity. It may be time to wean field ecologists from the fixation of sampling only homogeneous units.

Importance of Detecting Locally Rare Species

Why is it so important to detect and monitor locally rare species in rangeland sampling? First, locally rare species are a major component of plant diversity, and probably biodiversity. Almost half the plant species encountered in each prairie type had less than 1% foliar cover (Table 3). Assuming that many soil organisms and terrestrial invertebrates may be mutualistically linked to many plant species, underestimating the number of locally rare plant species may directly translate into underestimating local and regional biodiversity (Stohlgren et al. 1997b).

The second reason that detecting locally rare species is important is purely economic. Early detection of exotic species and noxious weeds (i.e., while they are less than 1 cover) is important to range management: eradication and restoration efforts are less expensive for smaller affected areas (Peters et al. 1996). The use of cover classes such as 0 to 5% and 5 to 25%, etc. (Daubenmire 1959, USDA Forest Service 1996) may be too broad to detect and monitor the spread of exotic species. Searching the 0.1 ha Modified-Whittaker plots led to the early detection of Cypress spurge and Russian thistle in the short grass steppe, and to the detection of crested wheatgrass, cheatgrass, dalmatian toadflax, yellow sweet clover, and Kentucky bluegrass in the mixed grass prairie. The rapid spread of these weeds could reduce the productivity of preferred forage and decrease native plant diversity (Rosentreter 1994). In the northern mixed prairie of Wind Cave National Park, yellow sweet clover was barely present in the corner of the Modified-Whittaker plot at Site 4, but it extended well into the surrounding landscape. This is significant because park managers consider yellow sweet clover to be one of their most invasive weeds.

In the tallgrass prairie at Pipestone National Monument (Site 3), only the Modified-Whittaker plot was able to pick up 2 native species that had been seeded by resource managers into a burned site: silver leaved psoralea (*Psoralea argophylla* L.) and purple prairie clover (*Dalea purpurea* L.). Both species were growing in large, but widely spaced patches. Detecting these species could be an indication that the seeding efforts by managers were successful.

Finding new or rare species at a site is not a primary objective of rangeland sampling, but it is exciting for conservation biologists. In the reseeded tallgrass prairie site (Site 4), a single unknown legume was detected in the 0.1 ha plot, and because there was only one individual present, it was not collected. With so little of the tallgrass ecosystem left in the U.S. (Swengel and Swengel 1995, Leach and Givnish 1996), this could have been an exciting find. In any case, as rangeland conservation objectives are modified to protect native plant diversity, manage for rare species and habitats, and monitor the spread of exotic species, it is clear that field sampling must result in a more complete picture of plant diversity than could be gained from the commonly used transect methods. Furthermore, species area curves developed from transects aligned so that they missed species rich patches, which frequently happened in this study, would greatly underestimate the number of species in a larger area (Stohlgren et al. 1995).

Cost efficiency

The old adage holds that 'you get what you pay for.' The Modified-Whittaker method took longer to complete at each site than the transect methods because larger quadrats were used and height information was collected, which along with cover data can be used to estimate biomass, and the entire 0.1 ha area was searched for species richness (Table 3). However, cost-efficiency is based on: (1) information gained per unit of time; and (2) the total amount of information gained. The number of plant species recorded per minute was similar among techniques: 0.32, 0.25, 0.24, and 0.24 species per minute for the large quadrat, Daubenmire, Modified-Whittaker, and Parker methods, respectively. The large quadrat method was higher than the other methods because it took the shortest time, and species accumulation curves rise quickly in the early stages of botanical surveys. Capturing more species becomes increasingly difficult, especially with transect methods due to spatial autocorrelation effects. In fact, an alteration to the Modified-Whittaker design is recommended to better disperse the 1 m^2 subplots throughout the plot by staggering the placement of 4 of the 10 subplots along the exterior of the 100 m^2 subplot (Fig. 3). Even with the design used, the total amount of information gained from the Modified-Whittaker plot exceeded that of the transects methods as measured by total species richness, the number of native and exotic species, the number of species with less than 1% cover (Table 3), and height data for estimates of above ground biomass.

Ease of use is an extremely important component of cost efficiency. Field crews found that the Modified-Whittaker technique worked well in all vegetation types. The snap-together, plastic subplot frame (0.5 × 2.0 m) was light and easy to assemble. The subplot size was able to accommodate shrubs and tallgrasses. The nested scale design has also proven effective in forested and mountainous landscapes, especially when linked to remotely sensed data (Stohlgren et al. 1997a,b,c). The 20 × 50 cm Daubenmire frame was difficult to use in shrublands, and very difficult to use in tallgrass prairie sites: with so many

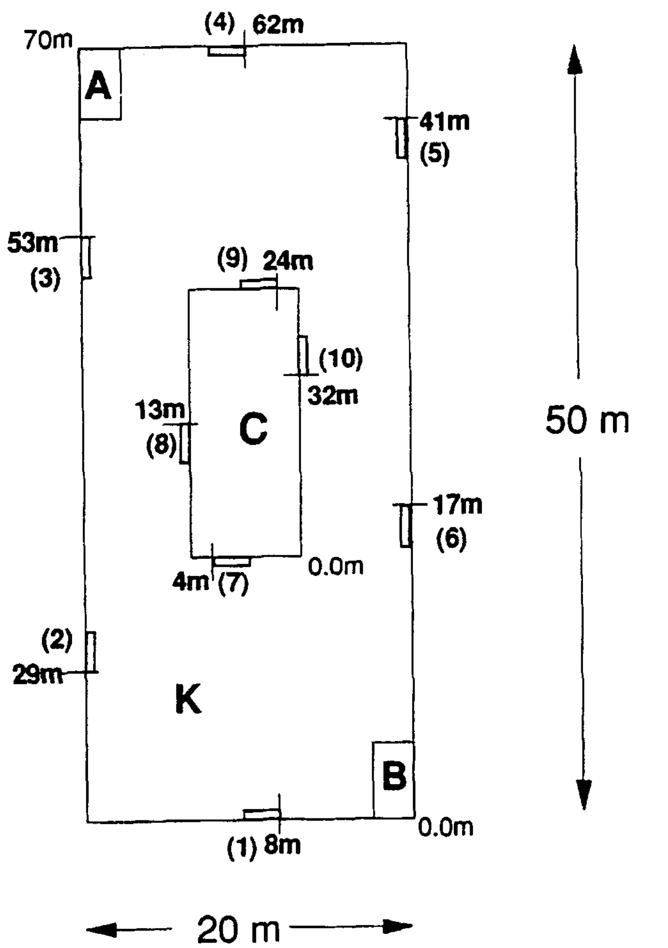

Fig. 3. Revised sampling layout for the Modified-Whittaker sampling plot. 1-m^2 subplot locations are marked along two 70-m tapes from the 0.0 m point to the 70 m point of the plot (K), and clock-wise along a 50-m tape from the 0.0 m point of the 100- m^2 subplot (C).

tall grasses and forbs overlapping the quadrat, it was difficult to get accurate cover estimates. The 0.5 × 1.0 m large quadrat also was easy to use in shortgrass but almost impossible to use in tall grass or shrub patches. Plants had to be threaded through the nylon decimeter grid, and it was difficult to get accurate readings for litter, duff, and soil. All the techniques were easy to use in shortgrass prairie. The Parker transects were fast and easy, though they did require a great deal of stooping. The Parker methods frustrated field crews who realized how many plant species the technique was missing at each sampling site.

The major factor in cost efficiency is traveling to the sites. Spending more time at each site to gain much more information may be time well spent. Multi-scale sampling techniques may provide better monitoring data on rare and exotic species, independent frequency data, and accurate species-area curves, improving the ability to extrapolate plot data to the larger, unsampled areas. Thus, despite the increased time at each site, the overall cost efficiency of sampling landscapes and regions would be improved with multi-scale sampling techniques.

Conclusion

As rangeland conservation objectives develop and adapt, so must rangeland vegetation sampling techniques. Due to the potential threats of exotic plants to rangeland productivity, increasing concern about noxious weeds, and the desire to protect native plant diversity and biodiversity, new sampling techniques will be expected to accurately quantify the status and trends of plant diversity at local, regional, and national scales. It was found that the commonly used Parker transects and Daubenmire transects, and the proposed large quadrat transect methods greatly underestimated the number of native and exotic species, and the number of species with less than 1% cover in each prairie type. The multi-scale Modified-Whittaker method, that included an exhaustive search for plant species in a 20 × 50 m area, captured significantly more plant species than replicated transect methods. The detection and measurement of exotic plants, including noxious weeds, was greatly enhanced by using a multi-scale sampling design. Even replicated transects methods were less effective than multi-scale techniques due to small sample areas, spatial autocorrelation bias, and because they tended to miss rare species and habitats.

A new and increasingly important objective of rangeland sampling is to evaluate range condition and trends at local, regional, and national scales (National Research Council 1994). The nested scale design of the Modified-Whittaker plot allows the development of species-area curves (generally, species richness = m × logArea + b) based on the average cumulative species found in the 1-m^2, 10-m^2, 100-m^2, and 1,000-m^2 subplots and plots (Stohlgren et al. 1995, 1997a, 1997b). The species area curves allow estimates of the number of native and exotic species in the larger, unsampled area. Species accumulation curves could be developed from transect data, but there is no known way to correct for bias due to spatial autocorrelation or to missed patches of high diversity. Multi-scale sampling methods may better monitor the spread of exotic species and evaluate range condition and trends at local, regional, and national scales compared to the commonly used transect methods (Kalkhan et al. 1995, Stohlgren et al. 1997a,b,c). The Modified-Whittaker design can be superimposed over existing monitoring transects to link long-term data on common species with new information on locally rare species, exotic species, and common and rare habitats.

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