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Comparison of three vegetation monitoring methods: Their relative utility for ecological assessment and monitoring

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ABSTRACT

Vegetation cover and composition are two indicators commonly used to monitor terrestrial ecosystems. These indicators are currently quantified with a number of different methods. The interchangeability and relative benefits of different methods have been widely discussed in the literature, but there are few published comparisons that address multiple criteria across a broad range of grass- and shrub-dominated communities, while keeping sampling effort (time) approximately constant. This study compared the utility of three field sampling methods for ecological assessment and monitoring: line-point intercept, grid-point intercept, and ocular estimates. The criteria used include: (1) interchangeability of data, (2) precision, (3) cost, and (4) value of each method based on its potential to generate multiple indicators. Foliar cover by species was measured for each method in five plant communities in the Chihuahuan Desert. Line- and grid-point intercept provide similar estimates of species richness which were lower than those based on ocular estimates. There were no differences in the precision of the number of species detected. Estimates of foliar cover with line- and grid-point intercept were similar and significantly higher than those based on ocular estimates. Precision of cover estimates with line-point intercept was higher than for ocular estimates. Time requirements for the three methods were similar, despite the fact that the point-based methods included cover estimates for all canopy layers and the soil surface, while the ocular estimates included only the top canopy layer. Results suggest that point-based methods provide interchangeable data with higher precision than ocular estimates. Moreover these methods can be used to generate a much greater number of indicators that are more directly applicable to a variety of monitoring objectives, including soil erosion and wildlife habitat.

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1. Introduction

A primary objective of many ecological monitoring programs is to detect changes in ecosystem functions and processes (National Research Council, 1994; Heinz Center, 2002; Niemi and McDonald, 2004). Vegetation cover and composition are two of the most commonly used groups of indicators in many terrestrial ecosystems. These indicators have been correlated with a large number of ecosystem services including biodiversity and soil and water conservation, habitat for wildlife, food and fiber production (National Research Council, 2000; Millenium Ecosystem Assessment, 2003). They are commonly used to evaluate land degradation and recovery, and the success of restoration projects.

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A large number of methods are currently used to quantify various forms of these indicators (Bonham, 1989; Elzinga et al., 2001) and a large number of datasets already exist that include them for tens of thousands of sites in the US (Spaeth et al., 2003; http://fia.fs.fed.us/library/field-guides-methods-proc/version 4.0). A number of new proposals would require a significant expansion in the spatial and temporal extent of this type of data (e.g., National Research Council, 1994; Heinz Center, 2002). While many of these initiatives will rely on new remote sensing technologies and analyses, including high resolution aerial photography (Laliberte et al., 2007), ground-based measurements will continue to be used for both calibration and local monitoring.

Despite the widespread interest in vegetation cover and composition indicators, there have been few successful attempts to standardize them so that they can be compared across space and time. These differences persist within and among agencies in the United States and throughout the world. For example the term 'vegetation cover' is commonly used to refer to both 'canopy cover' or the proportion of the soil surface included within the (variably defined) perimeter of any plant canopy, and 'foliar cover', which includes only those parts of the soil surface that are covered by a plant part (Bonham, 1989). While a diversity of measurement and reporting standards is often required by the scientific community in order to address specific research objectives at the local level, this same diversity has limited attempts to synthesize data to address regional, national, and international policy and management issues.

The lack of consensus on vegetation cover and composition monitoring protocols can be attributed to a number of factors, including personal and institutional traditions, and the fact that the optimal method varies with the relative importance of different monitoring objectives. It is also due to the relative paucity of studies that have systematically compared different methods in order to determine (1) which methods generate data that are statistically identical, or that can be systematically converted (interchangeability), (2) the level of precision that can be achieved at a particular cost, and (3) the number and value of different indicators that can be generated with each method. With a few exceptions (see reviews in Elzinga et al., 2001), most of the published comparisons have focused on the ability of these methods to measure indicators related to biodiversity, such as diversity of native plant species, detection of exotic species, and monitoring of rare species (Stohlgren et al., 1995, 1998; Campbell et al., 2002; Leis et al., 2003; Prosser et al., 2003). The detection of plant species through accumulation curves is another issue that has been discussed in a number of papers (Stohlgren et al., 1995, 1998). These discussions provide relevant information about the utility of sampling methods for preservation of biological diversity. With a few exceptions, however (e.g., Sykes et al., 1983; Stohlgren et al., 1995, 1998), most of the studies have focused on just one or two plant communities and there are few studies from arid environments.

The objective of this study was to compare three commonly used vegetation monitoring methods (line-point intercept, grid-point intercept, and ocular estimates) in five different plant communities, with respect to (1) interchangeability of the data, (2) precision, (3) cost, and (4) value of each method relative to its potential to generate multiple indicators. In order to effectively address criteria 1, 2 and 4, we attempted to keep cost (3) approximately constant across all methods. We included point-based methods and ocular estimates because, in one form or another, at least one of them is applied by virtually every organization in the world today that is collecting ground-based monitoring data. Both line and quadrat-based point methods were included to specifically test the hypothesis that data collected in the same plot using these two methods are interchangeable. For simplicity, we have focused our analysis on just two key indicators, species richness and foliar cover. These indicators are frequently used to monitor biodiversity and ecosystem functioning, respectively.

2. Methods

2.1. Study sites

This study was conducted in the Jornada Basin, which is located approximately 37 km north-east of Las Cruces, New Mexico, USA. The climate of the basin is semiarid with a mean annual precipitation over 80 years (1916–1995) of 248 mm. The mean monthly temperature ranges from 3.8 °C in January to 26.1 °C in July (Hochstrasser et al., 2002). Plant communities are dominated by grasses such as *Bouteloua eriopoda* Torrey (Torrey) or *Pleuraphis mutica* Buckley, shrubs such as *Larrea tridentata* (Sess. & Moc.) Cov. or *Prosopis glandulosa* Torrey, or by combinations of shrubs, succulents, and grasses (Cox et al., 2006).

Field sampling was conducted in sites previously selected by the Jornada Basin Long Term Ecological Research program to investigate the spatial and temporal patterns of aboveground net primary production (Huenneke et al., 2001). These sites are located in five plant communities: (1) Black grama grasslands. These grasslands are dominated by black grama (*Bouteloua eriopoda*), a C_4 stoloniferous grass, together with C_4 perennial bunchgrasses including *Sporobolus* spp. and *Aristida* spp. The community also includes scattered woody and succulent species 0.3–2.0 m in height, including the sub-shrub *Gutierrezia microcephala* (DC). Gray, the shrub *Ephedra trifurca* Torrey, and the succulent *Yucca elata* Engelm. Scattered 0.5–1.0 m tall creosotebush (*Larrea tridentata*) and mesquite (*Prosopis glandulosa*) shrubs are invasive to this plant community and appeared in the study plots. (2) Creosotebush shrublands. Tall (0.75–1.5 m) creosotebush dominates this community. Subdominants include other shrubs, and sub-shrubs and C_4 perennial grasses including *Muhlenbergia porteri* Scribn., a grass which often grows under creosotebush canopies. (3) Mesquite shrublands. These shrublands occupy former black grama grasslands on sandy soils, and include remnants of that plant community. In this environment, mesquite creates coppice dunes 0.5–4.0 m in diameter, and 0.25–2.0 m in height. The size depends on soil depth and the shrub age. (4) Tarbush shrublands. Tarbush (*Flourensia cernua* DC) is the sole dominant of this plant community at all three sites. One or more perennial C_4 grass species including *Pleuraphis mutica*, *Scleropogon brevifolius* Phil, and *Muhlenbergia porteri* occur as a subdominant on at least one of the three plots. (5) Tobosa grasslands. These are dominated by tobosa (*Pleuraphis mutica*), a short-statured C_4 grass that retains its wiry leaves for up to several years. Subdominants include *Panicum obtusum* Kunth and *Scleropogon brevifolius*. All five plant communities also include annual forbs. Cover of these species is highly variable in time and space (Huenneke et al., 2002) and was relatively high, particularly in the black grama grassland community, during the year data collection was completed for this study. Three sites were selected for each plant community, for a total of 15 sites.

2.2. Sampling methods

At each site, foliar cover data were collected along four parallel 70-m transects that were randomly located along a 70 m baseline, with a minimum of 10 m between each transect. These transects served as within-plot replicates. For the line-point intercept, foliar cover was recorded every 1 m along each transect, for a total of 70 points/transect and 280 points/site. A metal rod (1 mm diameter) was dropped from approximately 0.7 m height, and all plant species contacted by the rod were recorded (Herrick et al., 2005). Plant species were recorded only once, and no attempt was made to distinguish between live and dead leaves and stems. The top canopy hit was noted at each point to facilitate comparisons with ocular estimates, which were limited to this layer. Contacts at the soil surface level such as plant base, litter, and rock were also recorded, although they were not used to make any calculations. Foliar cover based on line- and grid-point intercept methods was estimated by dividing the total number of plant intercepts in the top canopy layer (first pin hit) by the total number of points per transect or quadrat, respectively. Foliar cover of ocular estimates was calculated by adding the foliar cover of all plant species per quadrat.

Grid-point intercepts were completed for 1-m^2 quadrats, with a 10 cm $\times$ 10 cm grid. Quadrat frames with adjustable legs were constructed with one-inch PVC pipe. Quadrats were located every 14 m on each 70-m transect, with one side parallel to the tape, for a total of 5 quadrats/transect and 20 quadrats/site. Grid-point intercepts were recorded in 16 points uniformly distributed in each quadrat, for a total of 80 points/transect and 320 points/site. Foliar cover at the grid-points was recorded in the same manner as line-point intercept (Herrick et al., 2005). Ocular estimates of foliar cover were conducted in the same 1-m^2 quadrats used for grid-point intercept. Ocular estimates were completed for each plant species to the nearest 1%. Only the top canopy layer was included in the estimates, following the lead of a number of previous studies (Floyd and Anderson, 1987; Messe and Tomich, 1992; Helm and Mead, 2003). Species with foliar cover <1% were recorded by first dividing each 10 cm $\times$ 10 cm square in which they occurred in quarters, and then counting the number of quarters occupied. Those species with foliar cover <0.25% were arbitrarily recorded as 0.1%. The time required for measurement was recorded for each method.

Data collection at all 15 sites was completed between May 25 and June 28, 2007. All methods for a particular site were collected during a 1–2 day period. In order to minimize among-observer variance, which was not addressed by this study, all measurements and observations were completed by two highly experienced field technicians in applying these methods in these plant communities. One collected line-point intercept data, while the other completed both ocular estimates and grid-point intercept methods. Ocular estimates were completed prior to the grid-point measurements. Because data collectors were familiar with nearly all species on the sites, species identification did not affect time requirements. Each observer was supported by a data recorder.

2.3. Data analysis

Species richness and foliar cover were compared for each plant community and across all communities. For community-level analyses, one-way ANOVA in which monitoring methods were considered as treatments was used. Data did not meeting the assumptions of the test were analyzed with Kruskal–Wallis tests. Across community ANOVA's were based on a randomized block design in which communities were considered as blocks and monitoring methods as treatments.

Species richness was also compared among monitoring methods by constructing species accumulation curves for each plant community. Data from all 15 sites were pooled according to plant community, generating a total of 12 transects (3 sites $\times$ 4 transects) per community. For each community, accumulation curves with 95% confidence intervals were computed using the Mao Tau estimates, in which we considered the presence/absence data for each species in each transect. Estimation of curves and confidence intervals were conducted with the program EstimateS version 7.5 (Colwell, 2005).

Relationships between foliar cover estimates obtained by each monitoring method were analyzed with Spearman's rank correlations. These correlations were conducted by considering all plant communities combined. Plant community level correlations between foliar cover estimates obtained with grid-point intercept and ocular estimates (i.e., methods conducted in 1-m^2 quadrats) were conducted using individual transects (70, 80 points or 5 quadrats) as the experimental unit.

Precision of each monitoring method was estimated by calculating the coefficient of variation for species richness and foliar cover. Data were combined for all sites and plant communities. Coefficients of variation were analyzed with likelihood ratio tests to determine whether there were significant differences among methods (Verrill and Johnson, 2007).

Cost (time) required for each method was compared across all plant communities using ANOVA and LSD multiple comparisons. Data were log-transformed to meet the underlying assumptions of the analysis. All statistical analyses were conducted with the program SPSS for Windows Release 9.0.

3. Results

Ocular estimates generally detected more species than either of the point-based methods, although the significance of the results depended on the analysis method. The comparison of species richness for each plant community showed that there were no significant differences among methods, except for

Table 1 – Species richness, foliar cover, precision, and cost of the three methods in the five plant communities. Values are mean ± S.E., except for precision, for which 95% confidence intervals are listed in parentheses. Row values with the same letter are not significantly different at $p = 0.05$, based on LSD posteriori tests.

Traits	Monitoring methods			P
	Line-point intercept	Grid-point intercept	Ocular estimate	
(1) Species richness				
Black grama grasslands	25 ± 3	24 ± 4	33 ± 2	0.24
Creosotebush shrublands	18 ± 2	16 ± 1	25 ± 3	0.09
Mesquite shrublands	13 ± 2	13 ± 2	14 ± 2	0.89
Tarbush shrublands	18 ± 1^{a}	15 ± 1^{b}	23 ± 1^{c}	0.002
Tobosa grasslands	10 ± 2	9 ± 2	12 ± 1	0.61
All plant communities	17 ± 2^{a}	16 ± 2^{a}	21 ± 2^{b}	0.0002
(2) Foliar cover (%)				
Black grama grasslands	65 ± 1^{a}	62 ± 3^{a}	25 ± 1^{b}	< 0.0001
Creosotebush shrublands	38 ± 2^{a}	34 ± 5^{a}	19 ± 3^{b}	0.002
Mesquite shrublands	42 ± 3^{a}	41 ± 4^{a}	28 ± 3^{b}	0.008
Tarbush shrublands	48 ± 3^{a}	47 ± 5^{a}	30 ± 3^{b}	0.001
Tobosa grasslands	78 ± 4^{a}	85 ± 2^{a}	58 ± 4^{b}	< 0.0001
All plant communities	54 ± 2^{a}	54 ± 3^{a}	32 ± 2^{b}	< 0.0001
(3) Precision (coefficient of variation: %)				
Species richness	37 (26–64)	39 (28–68)	38 (27–66)	0.1
Foliar cover	33^{a} (28–41)	41^{ab} (34–52)	53^{b} (43–69)	0.007
(4) Cost (min/transect)[§]	23 ± 2^{a}	31 ± 3^{b}	27 ± 4^{a}	0.02

tarbush shrublands. In these shrublands ocular estimates detected more species than either of the point-based methods. The comparison across all plant communities showed that significantly more species were detected with ocular estimates than with point-based methods (Table 1).

The species accumulation curves showed that monitoring methods did not differ in the cumulative number of species per transect in each of the five plant communities. Black grama grassland was the only community in which the cumulative number of species was significantly higher for ocular estimates than line- and grid-point intercept (Fig. 1).

Foliar cover estimates with line- and grid-point intercept significantly differed from ocular estimates in each of the five plant communities and across all communities. Cover estimates obtained using line- and grid-point methods were virtually identical (Table 1).

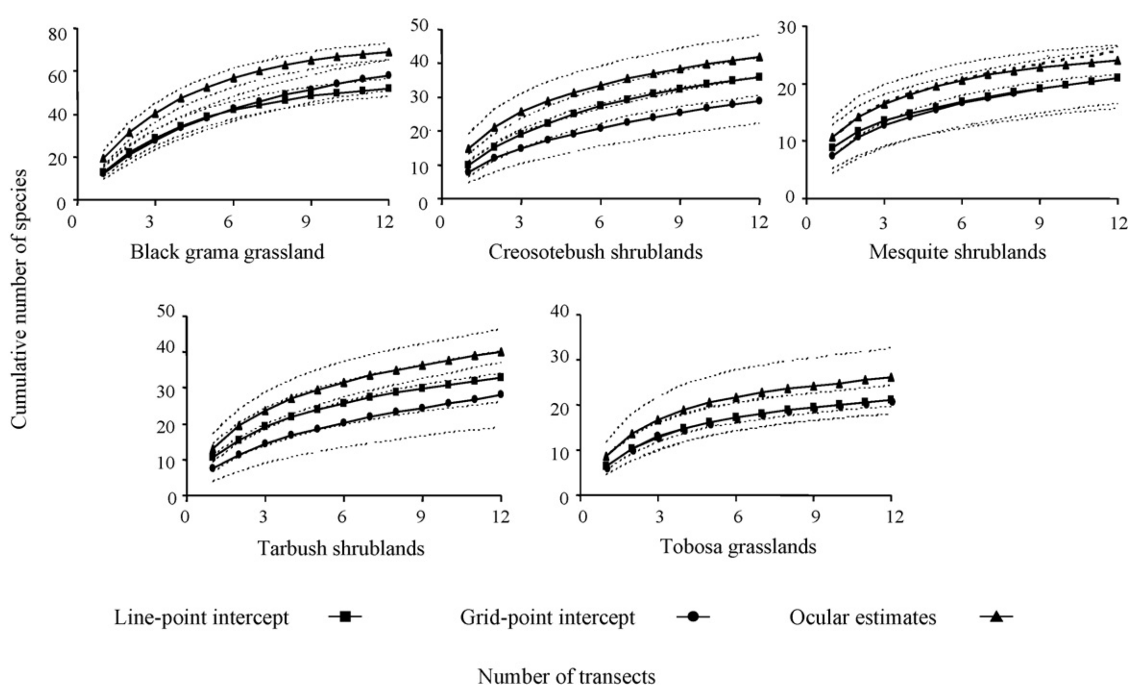

Fig. 1 – Species accumulation curves for the three monitoring methods in the five plant communities. Solid and dotted lines refer to expected values and 95% confidence intervals, respectively.

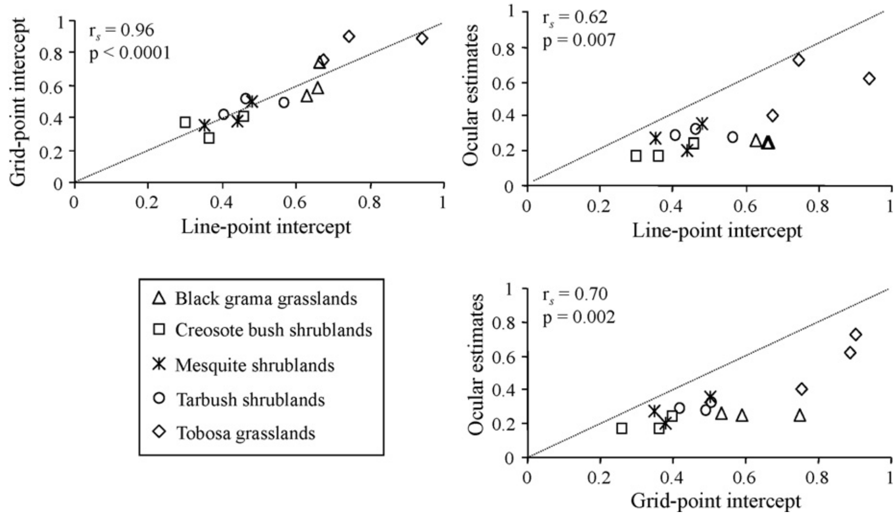

Fig. 2 – Scattergraph and Spearman's rank correlation coefficient between foliar cover (proportion: 0–1.0 scale) estimates obtained with the three monitoring methods in the five plant communities. Line (1:1) is only a visual reference for interpretation.

Cover estimates from all three methods were correlated but the correlation was much stronger for line-point and grid-point than for either of these methods with ocular estimates (Fig. 2). The relationship between grid-point intercept and ocular estimates was highly variable among plant communities and was non-significant for black grama grasslands (Fig. 3).

The coefficient of variation for species richness was similar for all three methods, but varied widely for foliar cover (Table 1). Line-point intercept had the lowest coefficient for foliar cover, followed by grid-point intercept and ocular estimates.

The time required for line-point intercept and ocular estimates was significantly lower than the time required for grid-point intercept (Table 1).

Data gathered with all three methods permits the generation of a number of additional quantitative indicators, some of which are listed in Table 2. Line- and grid-point intercept methods provide information on 10 of these indicators and ocular estimates addressed 5 of them. Two indicators (plant height diversity and the ratio of live to dead foliar cover) that are often generated using point-based methods, particularly to address wildlife habitat objectives, were not included in this study due to time constraints. Ocular estimates can be

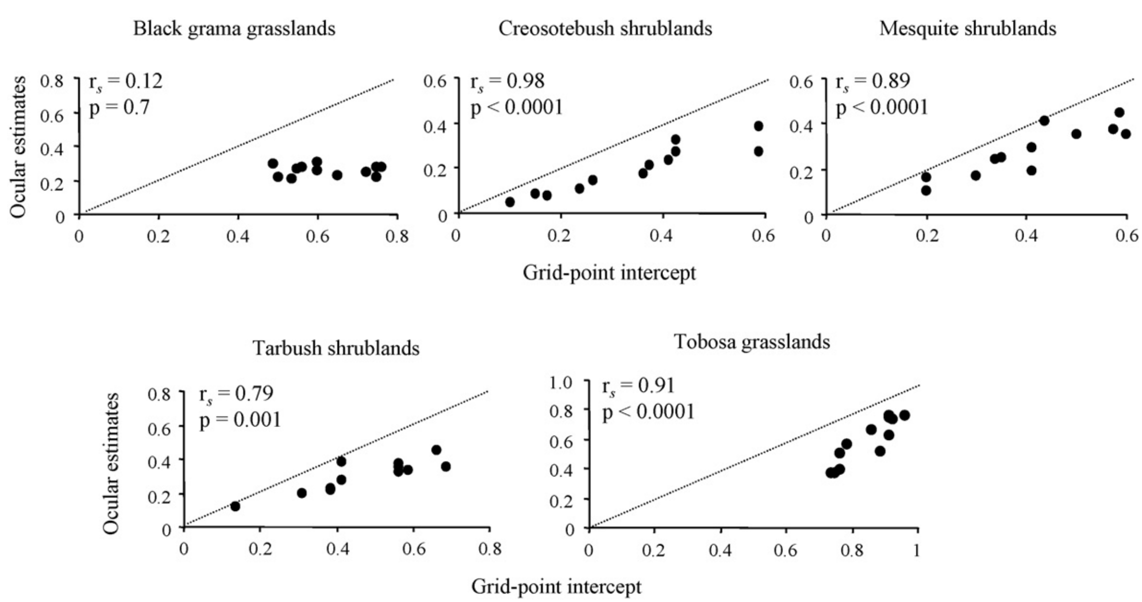

Fig. 3 – Scattergraph and Spearman's rank correlation coefficient between foliar cover estimates (proportion: 0–1.0 scale) obtained with grid-point intercept and ocular estimates in the five plant communities. Line (1:1) is only a visual reference for interpretation.

Table 2 – Quantitative indicators that can be generated with the monitoring methods compared in this study. Entries refer to indicators that can be calculated with data gathered in the field in this study (✓), not collected due to time (t) or precision (p) limitations, but are often collected in association with the method.

Indicator	Monitoring method		
	Line-point intercept	Grid-point intercept	Ocular estimate (top layer)
Species richness	✓	✓	✓
Percent foliar cover	✓	✓	✓
Percent foliar cover/species	✓	✓	✓
Percent foliar cover/invasive species	✓	✓	✓
Percent foliar cover/functional or structural group	✓	✓	✓
Ratio of total (all layers) live to dead foliar cover	t	t	t, p
Plant height diversity	t	t	t, p
Percent basal cover	✓	✓	t, p
Percent litter cover	✓	✓	t, p
Proportion of litter cover in interspaces vs. under canopies	✓	✓	t, p
Percent rock cover	✓	✓	t, p
Percent bare ground cover	✓	✓	t, p

obtained for the remaining indicators, depending on time available and precision requirements.

4. Discussion

The results showed that line- and grid-point intercept methods provide similar estimates of species richness across all plant communities, and that these were generally lower than those obtained with ocular estimates. This same tendency was also observed within each plant community, although there were no significant differences among monitoring methods, except for tarbush shrublands. The non-significant differences among methods could be due to the limited number of replicates conducted within each plant community (three sites per community). All these results support the conclusion that, at least in terms of species richness, estimates obtained with point-based methods (line- and grid-point intercept) are relatively interchangeable at the site level, whereas those obtained with ocular estimates are not. The greater power of ocular estimates to detect species is supported by other studies (Stohlgren et al., 1998; Korb et al., 2003; Leis et al., 2003; Prosser et al., 2003). The limited number of observed points (approximately 300 per site in this study) reduces the probability of detecting rare species. For this reason it has been suggested that point-based methods are not adequate to monitor biological diversity, since they are able to detect common species, but fail to capture rare species (Dethier et al., 1993; Stohlgren et al., 1998).

The analysis of the accumulation curves showed that there were no significant differences among methods in the number of species detected per unit of sampling effort. Leis et al. (2003) reported that point intercept and quadrat methods have similar rates of species accumulation in a mixed-grass prairie at Oklahoma. Our results also showed that there were only limited differences in the precision and time required to measure species richness, despite the fact that the ocular estimates were based solely on the top canopy layer, while species (and litter) at all layers were recorded with the point-based methods.

Estimates of foliar cover made with line- and grid-point intercept methods were similar and significantly different from ocular estimates. The magnitude of these differences varied across plant communities. These results suggest that point-based methods provide data that are statistically identical, whereas ocular estimates generate data that cannot be reliably interchanged with these methods, even when the same, highly trained observer completed all ocular estimates, and this same observer was also responsible for grid point-based cover. It has been suggested that point-based methods are more objective techniques that provide precise estimates of plant cover because they use pins to identify and record the number of contacts of each plant species (Bonham, 1989; Dethier et al., 1993; Elzinga et al., 2001). These estimates however can be time-consuming, which can be important when the main objective is to maximize species detection, and influenced by pin diameter and projection (Hatton et al., 1986; Stohlgren et al., 1998; Elzinga et al., 2001; Korb et al., 2003). Ocular estimates, on the other hand, are relatively rapidly obtained, but they could be biased and imprecise, since observers need to mentally integrate the foliar cover of individual plants (but see Dethier et al., 1993).

Precision of the foliar cover estimates made with point-based methods was higher, particularly for the line-point intercept method, than ocular estimates. Several studies conducted in different plant communities such as woodland vegetation and sagebrush steppes or shrublands have reported that estimates of point-based methods are more precise than ocular estimates (Hanley, 1978; Sykes et al., 1983; Floyd and Anderson, 1987; Bonham, 1989; Elzinga et al., 2001). Our results also showed that ocular estimates were poorly correlated with estimates of point-based methods. It seems that precision of ocular estimates varies depending on the composition and structure of the plant community (Figs. 2 and 3). Ocular estimates were highly correlated with estimates of grid-point intercept when plant communities were dominated by creosotebush, mesquite, and tarbush. These estimates however were poorly correlated when plant communities were dominated by tobosa or black grama grasses. Grasses have a lot of fine stems and leaves at their periphery, which might influence cover estimation. Some authors have suggested that ocular estimates can be complicated by a variety of life forms and canopy boundaries (Sykes et al., 1983; Hatton et al., 1986; Floyd and Anderson, 1987). Our study supported at least one other suggesting that ocular estimates provide more reliable estimates in shrub-dominated communities than in those dominated by herbaceous species (Floyd and Anderson, 1987).

Monitoring methods should be able to detect small changes in indicators to successfully monitor ecosystem functions and processes (Havstad and Herrick, 2003). This ability to detect small changes depends on the precision of estimates, since estimates with high precision are less variable and more repeatable (Brady et al., 1995; Elzinga et al., 2001). Moreover methods should provide information on the highest possible number of indicators in the shortest time (i.e., efficiency; Floyd and Anderson, 1987). Financial support to conduct monitoring programs is always limited therefore methods should ideally be objective, precise, and efficient (Havstad and Herrick, 2003). With these ideas on mind, we believe that ocular estimates generate maximum estimates of species richness in less time, although all three methods can generate equally precise estimates. Consequently, for monitoring changes in relative species richness, all three methods are appropriate, but for assessments of total richness, ocular estimates should be used. The best method for estimating foliar cover is line-point intercept since it provides the highest precision in the least time. Grid-point intercept generated intermediate levels of precision, probably due to the clumped distribution of the points associated with the quadrats, and takes more time than line-point intercept. Ocular estimates had the lowest precision of all sampling methods. In addition to these differences it is important to consider that point-based methods (line- and grid-point intercept) are able to potentially provide information on many more indicators than ocular estimates for a similar amount of sampling effort. Based on this information the line-point intercept method should be considered a good option for monitoring ecosystems because it is not only objective, rapid, and efficient, but it also provides interchangeable data with other point-based methods allowing comparison and standardization at different spatial and temporal scales.

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