Sampling Techniques Influence Understory Plant Trajectories After Restoration: An Example from Ponderosa Pine Restoration

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Abstract

Although there is no one correct technique for sampling vegetation, the sampling design chosen may greatly influence the conclusions researchers can draw from restoration treatments. Considerations when designing vegetation sampling protocol include determining what sampling attributes to measure, the size and shape of the sampling plot, the number of replicates and their location within the study area, and the frequency of sampling. We installed 20 point-intercept transects (50-m long), 8 belt transects (10 × 50 m), 10 adapted Daubenmire transects (four 0.5 × 2-m plots), and 4 modified-Whittaker plots (20 × 50 m with smaller nested plots) in treatment and control units to measure understory herbaceous response in a forest restoration experiment that tested different treatments. Point-intercept transects on average recorded at least twice as much plant cover as did adapted Daubenmire transects and modified-Whittaker plots taken at the same location for all control and treatment units. Point-intercept transects

and adapted Daubenmire plots on average captured fewer rare and exotic species in the control and treatment units in comparison with the belt transects and modified-Whittaker plots. Modified-Whittaker plots captured the highest species richness in all units. Early successional understory response to restoration treatments was likely masked by the response of the herbaceous community to yearly climatic variation (dry vs. wet years). Species richness and abundance were higher in wet years than dry years for all control and treatment units. Our results illustrate that sampling techniques can greatly influence perceptions of understory plant trajectories and therefore the interpretation of whether restoration goals have been achieved. In addition, our results suggest that restoration monitoring needs to be conducted for a sufficient length of time so that restoration treatment responses can be detected.

Key words: forest ecology, herbaceous, methodology, monitoring, plant community dynamics, succession.

Introduction

Ecological monitoring is a major component of numerous ecological restoration projects. Monitoring is the repetition of measurements over time for the purpose of quantifying change (MacDonald 1991), providing information about plant populations, community processes, and management techniques (Sutter 1996). Monitoring is often the tool used to define "success" in restoration projects and provides the justification for restoration treatments by being able to quantify restoration treatment effects (Sauer 1998). As a result choosing an appropriate monitoring design that is compatible with the restoration project goals is crucial to the evaluation of any ecological restoration treatment.

Numerous vegetation sampling techniques are outlined in sampling textbooks (Mueller-Dombois & Ellenberg 1974; Krebs 1989; Kent & Coker 1994; and Barbour et al. 1999) and in the scientific literature (Stohlgren et al. 1995a;

Etchberger & Krausman 1997; Stohlgren et al. 1998) for quantifying different plant community attributes. Determining the sampling technique that is most appropriate for restoration monitoring goals, however, can be difficult because there is no one "correct" sampling technique applicable to all study designs. First, restorationists need to determine what type of plant community attributes must be measured to quantify restoration goals. Some frequently measured plant community attributes in restoration monitoring include species composition, richness, cover, density, frequency, and productivity. Second, restorationists need to make decisions about plot size and shape and the frequency and location of measurements (Stohlgren 1994). Finally, Sutter (1996) outlined four criteria of monitoring techniques that must be met to reliably and precisely detect change: (1) Data need to have a known and acceptable level of precision; (2) data sampling techniques need to be repeatable; (3) data need to be collected for a long enough time to capture responses to treatments; and (4) techniques need to be feasible, realistic, and inexpensive enough to be maintained long term. In addition, monitoring techniques need to be adaptable so that new variables that were not anticipated at the beginning of the study can be incorporated into the existing monitoring protocol.

Currently, extensive efforts are underway to restore

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ponderosa pine forests across the western United States. Ponderosa pine restoration aims to reverse the degradation caused by historical land management practices of heavy grazing, intensive logging of old-growth trees, and fire suppression. Ponderosa pine forests are driven by a vital ecological attribute—fire. Before Euro-American settlement low-intensity surface fires carried by the herbaceous understory were prevalent every 2–20 years in southwestern ponderosa pine forests and played a major role in regulating the structure, composition, and stability of these ecosystems (Fulé et al. 1997). A major goal of ponderosa pine restoration is restoring ecosystem structure and function within a range of natural variability. Two major components of ponderosa pine restoration are the reduction of high tree densities through tree thinning and the reintegration of the natural disturbance regime through prescribed burning.

Increasing species diversity and abundance of the native herbaceous understory is a major element to restoring ecosystem structure in southwest ponderosa pine systems (Covington et al. 1997). It is therefore important to have a monitoring sampling technique that will reliably and precisely detect change in the herbaceous understory of ponderosa pine forests where restoration treatments have been conducted. In particular, early detection of exotic and rare species in restoration treatment areas is fundamental to assessing the success of restoration projects because exotics can be problematic and rare natives are often given special management attention. In addition, quantifying changes in overall herbaceous abundance is important in ponderosa pine restoration because a productive understory is necessary to carry natural or prescribed low-intensity fires that are integral to restoring these communities. As a result we determined that species richness and species abundance were the two most important plant community attributes to monitor so that we could quantify whether restoration goals for the herbaceous understory in southwestern ponderosa pine forests were achieved.

We were concerned that different monitoring sampling techniques that quantify species richness and abundance and different sampling sizes would result in inconsistent data and that these results would affect our ability to detect change in the herbaceous understory response to restoration treatments. The specific objectives of this study were to (1) compare four sampling techniques with equal sample sizes to quantify changes in herbaceous species richness and abundance in control and restoration treatment units, (2) compare four sampling techniques with unequal sample sizes in the same experimental setting, and (3) determine the effect of yearly climatic variation on the ability of different sampling techniques to detect change in response to restoration treatments.

Methods

Experimental Design

We established three blocks of four different treatments during the summer of 1998 within an approximate 688-ha area of the Fort Valley Experimental Forest and adjacent Coconino National Forest (35°16′00″N, 111°44′00″W). Each treatment unit was approximately 16 ha. Treatment units within each block were randomly assigned one of two treatments: no thinning nor burning (control) or thinning to a low level of trees more similar to the forest density before settlement and prescribed burning at a later date (Fig. 1).

The vegetation at the study site consists of pure ponderosa pine (*Pinus ponderosa* Dougl. ex Laws.) stands, which contain a few large (>37.5 cm) yellow-barked ponderosa pine trees intermixed with numerous small black-barked ponderosa pine trees. Perennial grasses such as squirreltail (*Elymus elymoides*), mountain muhly (*Muhlenbergia montana*), Arizona fescue (*Festuca arizonica*), sedges (e.g., *Carex geophila*), and numerous forbs (*Antennaria* sp., *Cirsium* sp., *Lupinus argenteus*, *Solidago* sp.) dominate the understory. Soils are moderately well-drained clay and clay loams that are of volcanic origin (Covington et al. 1997). Annual precipitation ranges from 43 to 64 cm with an average of 50 cm in the Flagstaff area (Shubert 1974). Precipitation patterns follow scattered snowfall and rain during the winter months and a pronounced drought in May and June, followed by frequent monsoon rains in July and August (Vose & White 1991). Daily mean temperatures range from −5 to 17°C (Sackett 1980).

Field Sampling

Four different vegetation monitoring techniques were established in the three control units and the three replicate treatment units. The original monitoring sampling design consisted of 20 systematically located permanent plots on a grid system within each unit. All vegetation sampling techniques were overlaid on this grid system. The four sampling techniques consisted of the point-intercept method, an adapted Daubenmire transect, a belt transect, and a modified-Whittaker plot. We chose the first three sampling techniques because they are traditional sampling techniques that are well established and commonly used in monitoring vegetation. We chose the modified-Whittaker plot design because recent studies have illustrated that it is more robust at capturing species diversity than traditional sampling techniques (Stohlgren et al. 1998). Four randomly located plots on the 20-plot grid system were chosen in each unit for a direct paired comparison of the four techniques, hereafter referred to as the paired sampling technique comparisons.

In addition, we compared the four techniques based on the total area sampled for each method, hereafter referred to as the unpaired sampling technique comparisons. For this comparison the number of sampling plots in each unit was as follows: 20 point-intercept transects, 10 Daubenmire transects, 8 belt transects, and 4 modified-Whittaker plots. We used 20 point-intercept transects for each unit because this was the original sampling protocol for the study. We used 10 Daubenmire transects so that the average area recorded for plant foliar cover (40 m²) was the

Figure 1. Examples of the tree density, fuel loads, and understory vegetation in a thinned treatment unit (photo on top) and an uncut/unburned control unit (photo on bottom).

same between this technique and the 4 modified-Whittaker plots within each unit. Finally, we used eight belt transects so that the average area recorded for species composition (4,000 m^2) was the same between this technique and the four modified-Whittaker plots within each unit. For both the paired and unpaired sampling techniques we recorded the amount of time it took to survey the vegetation, which did not include the time to set up the plots. We collected this information so that we could determine the cost of the different sampling techniques in comparison with the amount of data we collected (e.g., species richness).

General vegetation and site characteristic data were also collected to determine restoration treatment affects on other community attributes. Overstory tree data were collected in 400-m^2 circular plots centered on the plot center of each point-intercept transect. Tree species and diameter at breast height (1.37 m) were recorded for all live and dead trees greater than 1.37 m in height. Tree canopy cover was determined by recording the presence or absence of tree canopy from a vertical projection at 30-cm intervals along the 50-m point-intercept transect. We used a 15-m planar transect located in a random direction from

the plot center to measure forest floor litter and duff depths. Every 1.5 m, litter and duff were recorded following guidelines outlined in Brown (1974).

Point-Intercept Transect. The point-intercept method uses a 50-m transect laid parallel to the environmental gradient. The primary objective of the point-intercept transect is to quantify plant foliar frequency, as a surrogate for plant cover/abundance (Buckner 1985). Every 30 cm along the transect, for a total of 166 point measurements, plant and substrate (litter, rock, wood, or bare mineral soil) was recorded using a point that varied between 5 and 10 mm. For all plant hits the species was identified and its height recorded. Plant abundance was determined by dividing the number of first plant hits by 166 points. Individual species abundance was determined by dividing the number of individual species' hits by the total number of plant hits.

Daubenmire Transect. One adapted Daubenmire transect consisting of four 0.5 × 2-m plots was overlaid on each line-intercept transect. Plots were located at 10, 20, 30, and 40 m alternating to the left and right of the transect. The main objective of the Daubenmire transect is to quantify plant foliar cover of most species in an area (Stohlgren et al. 1998). Daubenmire plant cover classes (e.g., 0–5, 5–25, 25–50%, etc.) were not used because they tend to overestimate species cover because the smallest size class averages cover to be 2.5% per species. Instead, for each plot we estimated the percent cover of each species to the nearest quarter percent using cardboard cutouts of known sizes as visual guides. Ocular estimation of plant cover is a commonly used method for determining plant dominance, succession, and treatment response in vegetation analysis (Hatton et al. 1986). The estimates can total more than 100% because percent cover was estimated independently for each species and independent of canopy position. Individual species abundance was determined by averaging the species' abundance in the four plots/transect. The percent cover of litter, rock, wood, and bare mineral soil was also determined for each plot.

Belt Transect. A 10 × 50-m belt transect was centered over each 50-m line-intercept transect. The primary objective of the belt transect is to obtain a species list of the area (Kent & Coker 1994). All herbaceous and shrub species within the belt were recorded. We did not record any plant cover or substrate data.

Modified-Whittaker Plot. We placed the modified-Whittaker plot (Stohlgren et al. 1995b) to the left of the line-intercept transect at 0 meters. The modified-Whittaker plot is a 20 × 50-m nested plot design consisting of 10 1-m^2 plots with detailed plant and substrate information (6 systematically arranged around the inside of the 1,000-m^2 plot perimeter and 4 systematically arranged around the outside of the 100-m^2 perimeter), two 10-m^2 plots (in diagonally opposite corners of the plot), one 100-m^2 plot (in plot center), and

one 1,000-m^2 plot that documents species composition. The main objectives of the modified-Whittaker plot are to quantify plant foliar cover and height for most species at an area, provide cover and frequency data that has low spatial autocorrelation, and develop species-area curves based on the nested design to predict the number of species in a larger area (Stohlgren et al. 1995b). Within each 0.5×2-m plot (1 m^2) species cover was estimated using the ocular estimate method to the nearest quarter percent similar to the methodology described for the adapted Daubenmire transects. Individual species abundance was determined by averaging the species' abundance of the 10 1-m^2 plots per a modified-Whittaker plot. In addition, mean plant height and different substrate covers were also documented for each 1-m^2 plot.

Statistical Analyses

Multivariate analysis of variance repeated measures was used to determine the effects of different sampling techniques and time on herbaceous species richness and abundance in control and treatment units for data collected in 1999 and 2000. We used the Shapiro-Wilks test to determine whether data met the normality assumption and Leven's test if data met the homogeneity of variance assumption (Milliken & Johnson 1984). Tukey's honestly significant difference (HSD) test was used to make posthoc multiple comparisons of means between sampling techniques. Significant differences were accepted at alpha $\leq$ 0.05. PC-ORD software (MjM Software, Gleneden Beach, OR, U.S.A.) was used to determine variation in community assemblages (herbaceous species richness and abundance combined) between different sampling techniques using nonmetric multidimensional scaling (NMDS) and multi-response permutation procedures (McCune & Mefford 1999). Plant community data were relativized to the maximum before analysis to omit noise caused by very rare species and NMDS scree plots were determined to select the appropriate dimensionality in NMDS analysis.

Results

Restoration thinning treatments influenced vegetation characteristics (Fig. 1). There was a significant difference in trees per hectare and tree canopy cover between pre-

treatment and posttreatment for the thinned units (Table 1). There was no significant difference between pretreatment and posttreatment trees per hectare and tree canopy cover in the controls (no thinning/burning) (Table 1). In addition, there was no significant difference between litter and duff loads between pretreatment and posttreatment in control or thinned units (Table 1).

Paired Sampling Technique Comparisons

The four different sampling techniques that were paired for a direct comparison within the control and treated units had greater variation in species richness than plant foliar cover. The point-intercept transects recorded a significantly lower number of species for both years in the control and treatment units compared with the other three techniques (Fig. 2, A & B). The modified-Whittaker plots recorded the highest number of species of the four sampling techniques (Fig. 2, A & B). In addition, the modified-Whittaker plots recorded a significantly higher number of exotic and annual species for both years than any of the other sampling techniques (Table 2). The point-intercept transects captured the fewest exotic and annual species, followed by the Daubenmire transects and belt transects; however, these differences were not significant. There was no significant difference between the number of species recorded in the treatment units between 1999 and 2000. Similarly, there was no significant difference between the number of species recorded in the control units between 1999 and 2000. However, species richness was lower in 2000 for all the control and treatment units than in 1999 (Fig. 2, A & B). Plant foliar cover was not significantly different in the control units between the three sampling techniques for 1999 or 2000 (Fig. 3, A & B). In contrast, in the treatment units average foliar cover values were significantly higher in 1999 and 2000 using point-intercept transects than Daubenmire plots and modified-Whittaker plots (Fig. 3, A & B).

Modified-Whittaker plots took significantly longer ($p = 0.001$) on average than the other sampling techniques to survey four replicates. Modified-Whittaker plots took an average of 341 minutes for one person to survey four plots compared with 55 minutes for four point-intercept transects, 43 minutes for four Daubenmire transects, and 46 minutes for four belt transects.

Table 1. Vegetation and site characteristics for control and thinned units for pretreatment 1998 data and posttreatment 2000 data.

Variable	Pretreatment 1998		Posttreatment 2000	
	Control Stand	*Treatment Stand*	*Control Stand*	*Treatment Stand*
Trees/hectare	1,187.5 ± 307	1,043.3 ± 442.6	1,181.9 ± 302.5a	242.89 ± 31.9b
Tree canopy cover (%)	64.9 ± 5.4	58.98 ± 5.3	61.8 ± 4.6a	40 ± 2.9b
Litter load (kg/ha)	14,211.5 ± 1,508.04	14,133.76 ± 1,980.12	14,363.7 ± 1,508.04	15,625.13 ± 2,598.97
Duff load (kg/ha)	2,5127.12 ± 2,006.04	25,338.22 ± 3,266.01	25,836.25 ± 3,103.27	26,379.49 ± 3,266.01

Values are means ± SE ($n = 3$). Values indexed by a different letter are significantly different at $p \leq 0.05$ between paired control and treatment units for the same sampling year.
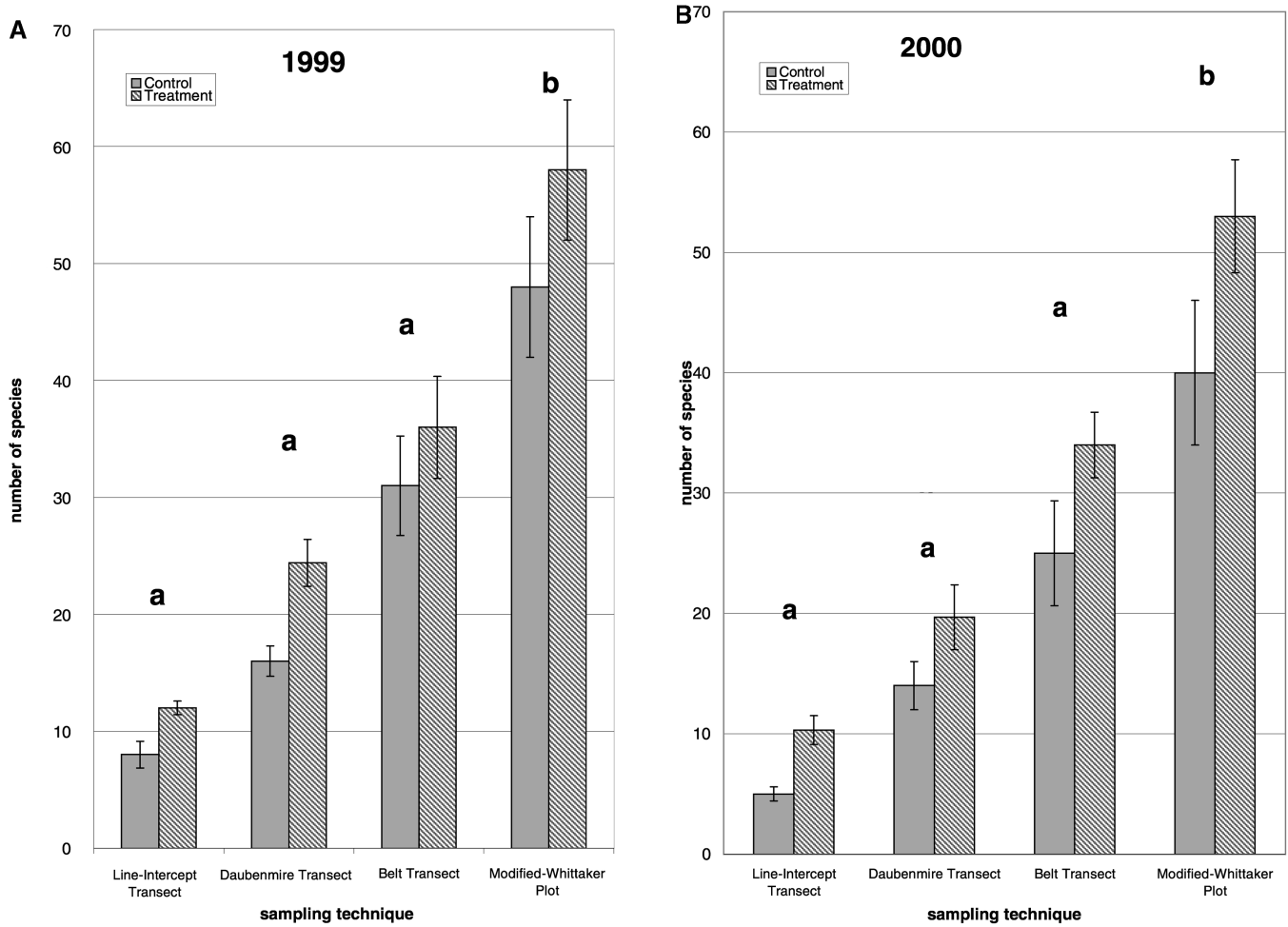
Figure 2. Total species richness for paired control and treatment plots in 1999 (A) and 2000 (B) using four different sampling techniques. Data are expressed as means (*n* = 4) ± SE. Values indexed by different letters are significantly different at *p* ≤ 0.05 as determined by Tukey's HSD test between different sampling techniques. There was no significant difference between the number of species recorded between the control and treatment plots.

Table 2. Total number of exotic and annual species captured in 1999 and 2000 for paired plots using different sampling techniques in the control and treatment units with similar sampling sizes.

	Line-Intercept Transect	*Daubenmire Transect*	*Belt Transect*	*Modified-Whittaker Plot*
Control plots				
Exotic 1999	0.00 ± 0.00a	0.33 ± 0.33a	1.33 ± 0.33b	2.33 ± 0.68b
Exotic 2000	0.00 ± 0.00a	0.33 ± 0.33a	0.33 ± 0.33a	2.00 ± 0.57b
Annual 1999	0.66 ± 0.33a	1.67 ± 0.33a	2.33 ± 0.33a	6.00 ± 1.52b
Annual 2000	0.00 ± 0.00 a	1.00 ± 0.58a	1.00 ± 0a	3.33 ± 0.33b
Treatment plots				
Exotic 1999	0.33 ± 0.33a	2.33 ± 1.33b	3.00 ± 1.52b	4.00 ± 0.64b
Exotic 2000	0.67 ± 0.33a	1.33 ± 0.88a	3.00 ± 1.10a	4.00 ± 0.57b
Annual 1999	0.67 ± 0.33a	3.67 ± 1.67a	6.00 ± 1.50a	10.00 ± 2.10b
Annual 2000	0.67 ± 0.33a	2.33 ± 0.88a	5.67 ± 1.40a	8.00 ± 0.58b

Values are means ± SE (*n* = 3). Number of samples within a plot: line-intercept transect *n* = 4, Daubenmire transect *n* = 4, belt transect *n* = 4, modified-Whittaker plot *n* = 4. Values indexed by different letters are significantly different at *p* ≤ 0.05 as determined by Tukey's HSD test between different sampling techniques.
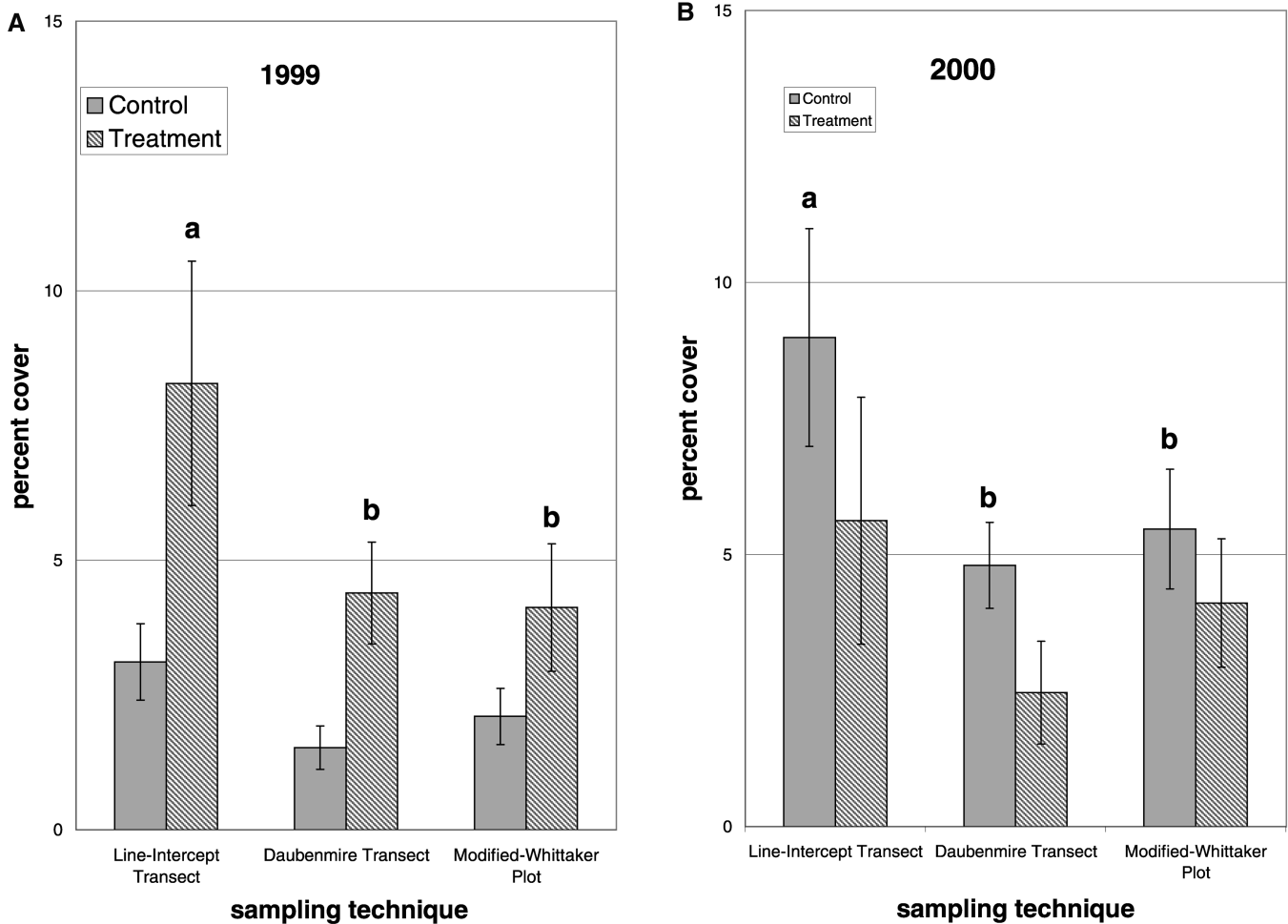
Figure 3. Total plant foliar cover for paired control and treatment plots in 1999 (A) and 2000 (B) using three different sampling techniques. Data are expressed as means ($n = 4$) $\pm$ SE. Values indexed by different letters are significantly different at $p \leq 0.05$ as determined by Tukey's HSD test between different sampling techniques. There was no significant difference between total plant foliar cover between the control and treatment plots.

Unpaired Sampling Technique Comparisons

The four different sampling techniques had significant variation for species richness and plant foliar cover within control and treated units for both years with uneven replicates of sampling techniques in each unit: 20 point-intercept transects, 10 Daubenmire transects, 8 belt transects, and 4 modified-Whittaker plots. Species richness numbers varied between the paired and unpaired sampling techniques for point-intercept transects, Daubenmire transects, and belt transects because more replicates were sampled. Similar to the paired sampling technique comparisons, the point-intercept transects recorded the lowest number of species for both 1999 and 2000 compared with the other three techniques, even with an additional 16 transects within each unit (Fig. 4, A & B). The belt transects recorded a significantly higher number of species than the previous two sampling techniques, although it was not significantly different from the modified-Whittaker plots (Fig. 4, A & B). Similar to the paired sampling technique comparisons, the line-intercept transects captured the fewest exotic and annual species, fol-

lowed by the Daubenmire transects; however, these differences were not significant (Table 3). The belt transects and modified-Whittaker plots recorded significantly more exotic and annual species than the other two sampling techniques (Table 3). For example, Dalmatian toadflax (*Linaria dalmatica* [L.] P. Mill.) was recorded in all three treatment units and one control using the belt transects and the modified-Whittaker plots but was only recorded in one treatment unit using the line-intercept transects and Daubenmire transects. Similarly, Rusby's Milkvetch (*Astragulus rusbyi* Greene) was recorded in only one treatment or control unit using the line intercept transects and Daubenmire transects. In contrast, it was found in two controls and two treatment units using the modified-Whittaker plot and in two control and one treatment unit using the belt transect. This species is listed as a threatened species by the state of Arizona. The modified-Whittaker plots offer good detection of exotic and rare species and the ability to quantify change in abundance where the belt transects only offer good detection because no cover values are recorded with belt transects.
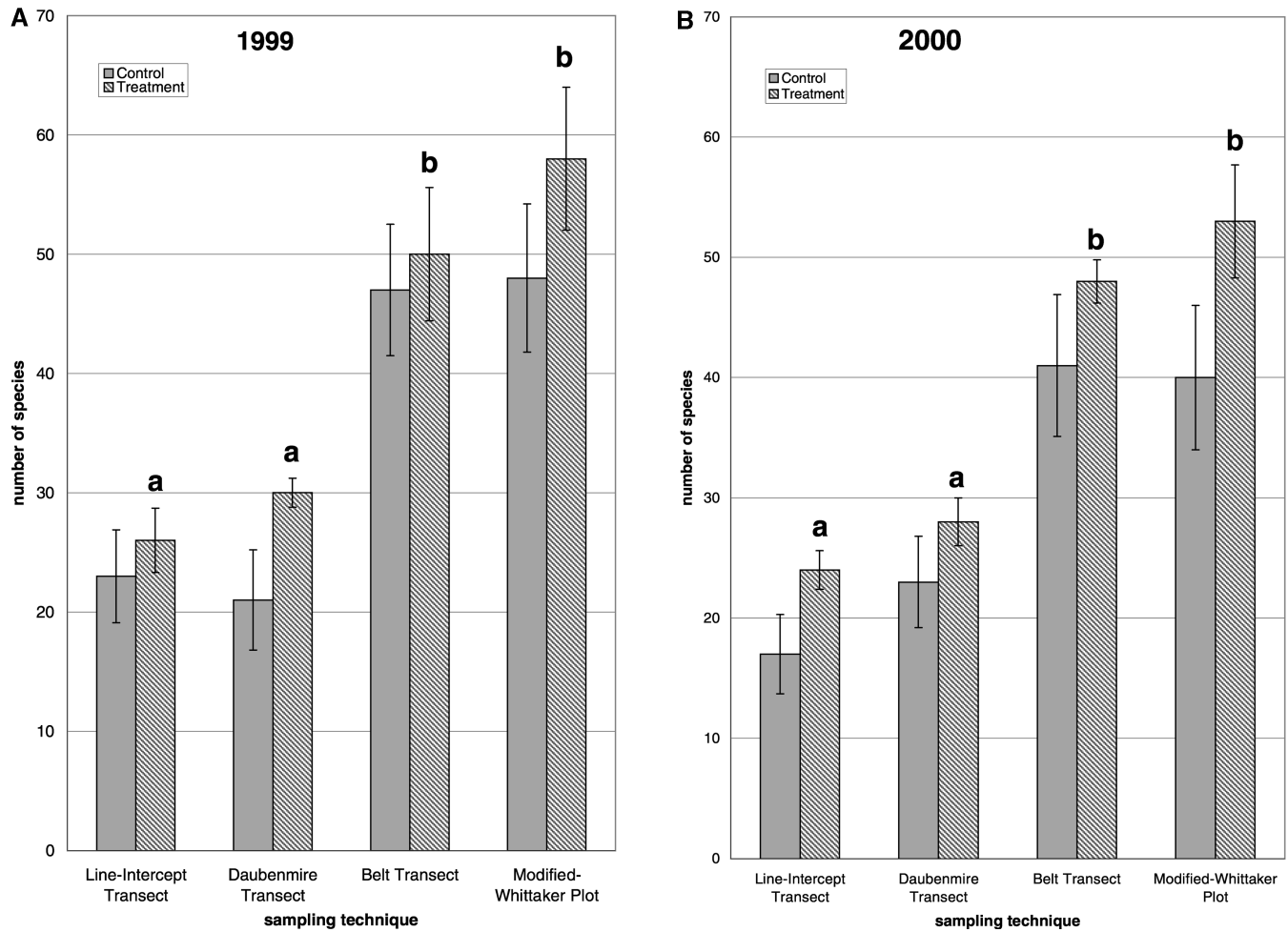
Figure 4. Total species richness for all control and treatment plots in 1999 (A) and 2000 (B) using four different sampling techniques. Data are expressed as means ($n = 20$ line-intercept transect; $n = 4$ adapted Daubenmire transects; $n = 8$ belt transects; $n = 4$ modified-Whittaker plots) $\pm$ SE. Values indexed by different letters are significantly different at $p \leq 0.05$ as determined by Tukey's HSD test between different sampling techniques. There was no significant difference between the number of species recorded between the control and treatment plots.

Table 3. Total number of exotic and annual species captured in 1999 and 2000 in the control and treatment units using different sampling techniques with different sampling sizes.

	Line-Intercept Transect	Daubenmire Transect	Belt Transect	Modified-Whittaker Plot
Control plots				
Exotic 1999	0.00 ± 0.00a	0.33 ± 0.33a	2.67 ± 0.33b	2.33 ± 0.88b
Exotic 2000	0.33 ± 0.33a	0.33 ± 0.33a	1.27 ± 0.33b	2.00 ± 0.57b
Annual 1999	2.67 ± 0.88a	1.67 ± 0.33a	5.33 ± 0.88b	6.00 ± 1.52b
Annual 2000	1.00 ± 0.58a	1.00 ± 0.58a	3.00 ± 1.33b	3.33 ± 0.33b
Treatment plots				
Exotic 1999	0.67 ± 0.33a	1.33 ± 0.88a	3.67 ± 0.76b	4.00 ± 0.64b
Exotic 2000	1.00 ± 0.58a	0.67 ± 0.67a	3.67 ± 0.67b	4.00 ± 0.57b
Annual 1999	2.33 ± 0.67a	3.67 ± 0.33a	8.00 ± 3.00b	10.00 ± 2.006b
Annual 2000	2.67 ± 0.88a	3.33 ± 0.33a	7.00 ± 1.106b	8.00 ± 0.58b

Values are means $\pm$ SE ($n = 3$). Number of samples within a plot: line-intercept transect $n = 20$, Daubenmire transect $n = 10$, belt transect $n = 8$, modified-Whittaker plot $n = 4$. Values indexed by different letters are significantly different at $p \leq 0.05$ as determined by Tukey's HSD test between different sampling techniques.
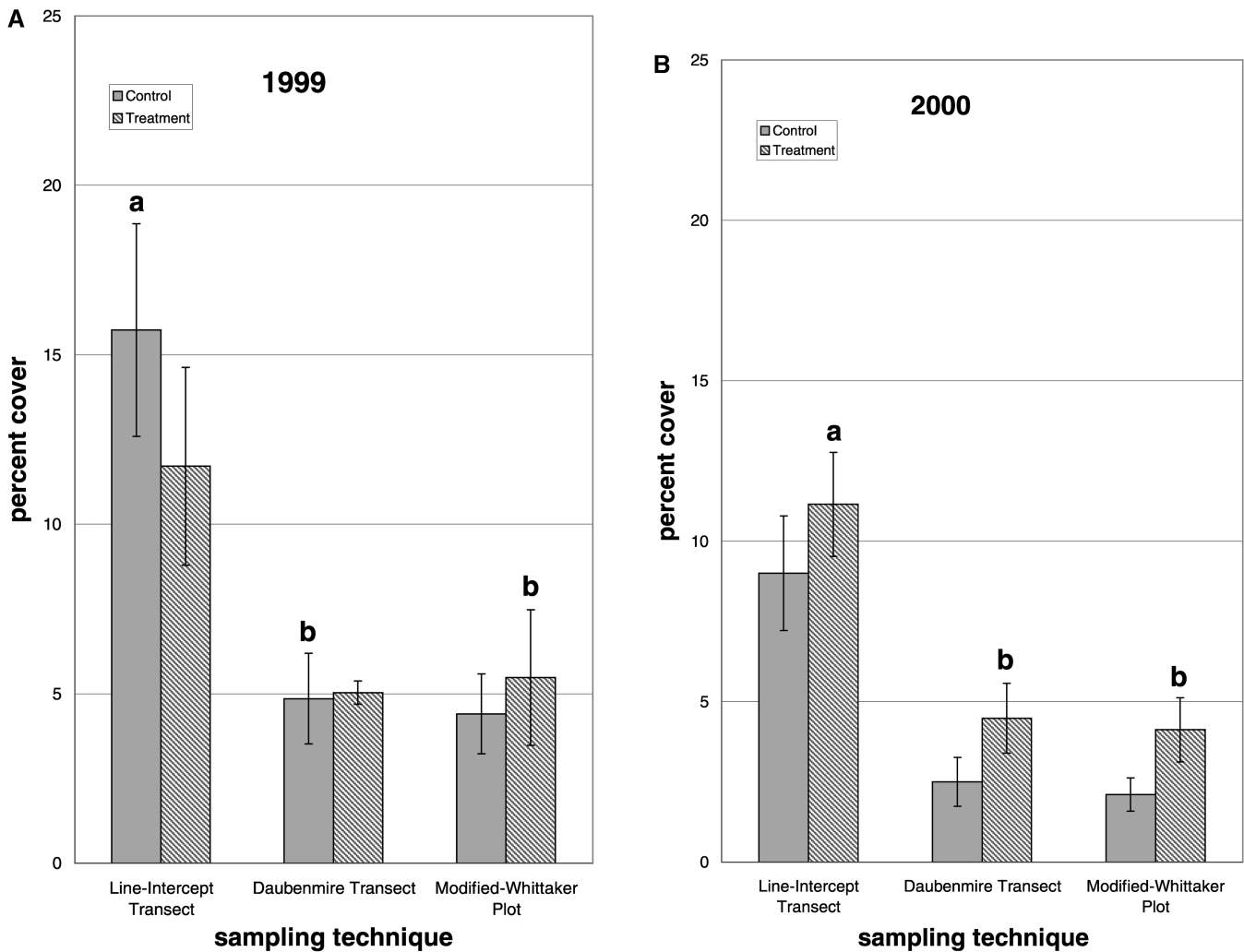
Figure 5. Total plant foliar cover for all control and treatment plots in 1999 (A) and 2000 (B) using three different sampling techniques. Data are expressed as means ($n = 20$ line-intercept transect; $n = 4$ adapted Daubenmire transects; $n = 8$ belt transects; $n = 4$ modified-Whittaker plots) ± SE. Values indexed by different letters are significantly different at $p \leq 0.05$ as determined by Tukey's HSD test between different sampling techniques. There was no significant difference between total plant foliar cover between the control and treatment plots.

There was no significant difference between the average number of species recorded in the control between 1999 and 2000 and treatment units between 1999 and 2000. However, there was lower species richness in 2000 than 1999 for all of the control and treatment units (Fig. 4, A & B). The point-intercept transects recorded significantly higher plant foliar cover than Daubenmire transects and modified-Whittaker plots in both the control and treatment units in 1999 and 2000 (Fig. 5, A & B). Specifically, foliar cover from the point-intercept transects was more than double the average foliar cover from the Daubenmire transects and modified-Whittaker plots.

Combining species composition data along with species abundance data allowed us to test whether community assemblages varied using different sampling techniques. Herbaceous community analysis using NMDS showed significant differences in community assemblages between

the different sampling techniques that measured species richness and abundance (Fig. 6).

There was no significant difference between the average time it took for one person to survey four modified-Whittaker plots (341 minutes) in comparison with 20 point-intercept transects (321 minutes). Daubenmire transects and belt transects took significantly less ($p = 0.001$) time, with an average of 128 minutes to survey 10 Daubenmire transects and an average of 133 minutes to survey 8 belt transects for one individual.

Discussion

Species Richness

Species diversity is one of the most frequently sampled attributes in vegetation studies (Ricklefs & Schluter 1993),
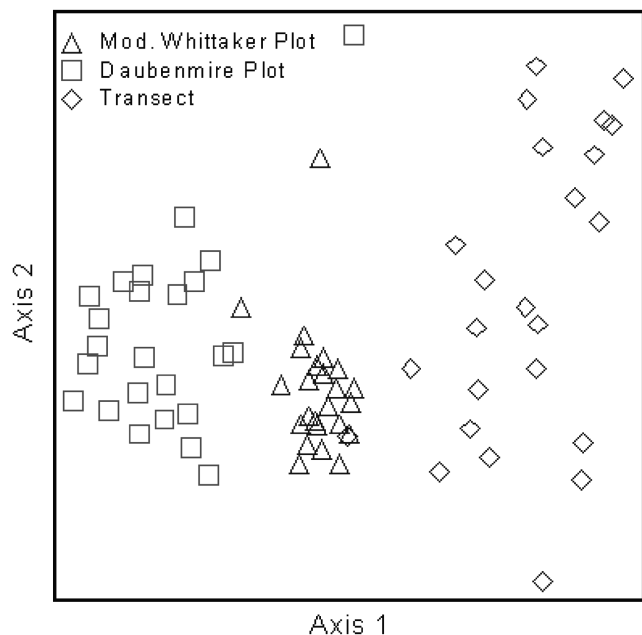
Figure 6. Ordination of plant community data for posttreatment 1999 and 2000 data determined with nonmetric multidimensional scaling (NMDS) for three different sampling techniques: point-intercept transects, Daubenmire plots, and modified-Whittaker plots. Belt transect data were not included because species abundance values were not collected for this method. Each symbol represents the plant community for a specific unit and sampling technique. Plant communities that are more similar are found closer together, and plant communities that are more dissimilar are further apart. Plant community data were relativized to the maximum before analysis to omit noise caused by very rare species and NMDS scree plots were determined to select the appropriate dimensionality in NMDS analysis.

and increasing native plant diversity is one of the most cited goals of ecological restoration (e.g., Johnson 1996; Bugg et al. 1997; Kindscher & Tieszen 1998). Species diversity is often used interchangeably with species richness. Species richness, however, is one of two components that define species diversity, the other being species evenness (Kent & Coker 1994). The value of species richness data in restoration studies is to classify species into different groups based on nativity, functional groups (e.g., nitrogen-fixers, photosynthetic pathways), and life-history traits to identify whether restoration goals are met. Understanding the appropriate scale for capturing species diversity is important because relationships between species richness and other community attributes such as productivity can be dependent on the scale of study (Grytnes 2000). For example, a recent study by Stohlgren and others (1999) found that at the 1-m^2 plot scale areas rich in species were less invaded by exotic species; however, at the 1,000-m^2 plot scale areas rich in species were the most heavily invaded by exotic species.

In our study the modified-Whittaker plot served as the baseline for species richness comparisons because it cap-

tured the most species. Assuming there is some true number of species, the method that captures the highest species richness must be closest to the "truth." The direct comparison of sampling techniques at one location supported the well-known concept that an increase in sampling area will increase species richness detection (Rapson et al. 1997). The grain (the minimal scale sampled), the extent (the farthest distance between samples), and the number of samples influence the positive relationship between species richness and area (Palmer & White 1994). In our study the point-intercept transect sampled the smallest total area (<0.1 m^2) and found the fewest species, followed by the Daubenmire transect (4 m^2), the belt transect (500 m^2) and the modified-Whittaker plot (1,000 m^2), which captured the most species. When more belt transects were added so that the sampling area was equal to the area surveyed in modified-Whittaker plots (unpaired sampling) there was no significant difference in species richness, although modified-Whittaker plots returned slightly higher numbers (species richness values between paired and unpaired tests were different because more replicated plots were sampled for unpaired tests). Other methodology comparison studies in various ecosystems have documented low species detection using point-intercept transects in comparison with other sampling techniques (Kinsinger et al. 1960; Etchberger & Krausman 1997; Stohlgren et al. 1998). A high degree of spatial autocorrelation may be one probable reason why transect methods failed to capture higher levels of species richness (Stohlgren et al. 1998).

Modified-Whittaker plots on average took five times longer for one individual to survey four plots in comparison with sampling four replicates of the other sampling techniques. Modified-Whittaker plots also captured five times as many species as the point-intercept technique for the paired sampling technique comparisons. There was no significant difference between the time it took one individual to survey four point-intercept transects, four Daubenmire transects, and four belt transects. However, Daubenmire transects captured twice as many species and belt transects captured three times as many species as the point-intercept transects. For the unpaired sampling technique comparisons there was no significant difference between the time it took one individual to survey four modified-Whittaker plots in comparison with 20 point-intercept transects, although on average the four modified-Whittaker plots captured over twice as many species as the 20 point-intercept transects. In addition, there was no significant difference between the amount of time it took to survey 10 Daubenmire transects and eight belt transects, but belt transects captured twice as many species. Finally, there was no difference between the average number of species captured using eight belt transects in comparison with four modified-Whittaker plots even though the eight belt transects took less than half the time to survey. These data illustrate how the amount of data collected is related to the time it takes to collect the data.

Species Abundance

Increasing native herbaceous foliar cover is an important goal in many ecological restoration treatments (Covington et al. 1997; Lovich & Bainbridge 1999). Species abundance is some measure of the amount of a species in a sample (Chiarucci et al. 1999). Plant community attributes that measure species abundance include plant foliar cover, plant density, and plant frequency. Plant foliar cover is one of the most widely used abundance measurements because it is not biased by the size or distribution of individual species as plant density and plant frequency measurements can be (Floyd & Anderson 1987). Ecologists have designed numerous sampling techniques to quantify plant foliar cover. The three most commonly used techniques include the point-intercept, the line-intercept, and ocular estimation (Buckner 1985), all of which have been used in restoration studies.

Point-Intercept. It is difficult to determine a baseline for foliar cover as was done with species richness because the sampling techniques in our study produced varied results and the actual cover of individual species in the treatment units is unknown. Because one technique provides more species cover than another technique does not necessarily mean that the technique providing the higher cover is more accurate. Regardless, we can draw some general conclusions about the two sampling techniques used in this study from other published data that have compared these sampling techniques and their precision. The point-intercept transect is a very robust technique for measuring foliar cover when it is used appropriately (Brady et al. 1995). This sampling technique was designed to be limited to a "dimensionless" point where the probability of a particular species being contacted by a point is a strict function of its abundance (Buckner 1985). This requirement is often violated because of the extra time needed to sample small points with a vertical projection. Researchers have shown that the violation of point size and point projection can be minimized when an optical device with fine cross hairs is attached to a sturdy tripod.

In our study the point-intercept method recorded twice as much foliar cover as the Daubenmire transects and modified-Whittaker plots in the paired sampling technique comparisons. Point-intercept plant foliar cover values were almost three times higher than Daubenmire transect and modified-Whittaker plot values in the unpaired sampling technique comparisons. These results are consistent with other studies that have documented an overestimation of foliar cover when the point-line intercept transect technique requirements were violated (Sharp 1954; Buckner 1985; Frank & McNaughton 1990; Stohlgren et al. 1998). Goodall (1952) illustrated the large effect that point size has on cover values. For example, when measuring cover of a grass species he found that a pin diameter of 4.75 mm recorded a cover of 71%, a pin diameter of 1.84 mm recorded 66.5% cover, and pin diameter reduced to a point with almost no diameter resulted in 39% cover. Similarly, Wilson (1963) found that the error in cover estimates doubled with a doubling of the pin diameter or halving of the leaf breadth.

Our original sampling technique was designed to be consistent with the prescribed fire monitoring protocol (National Park Service 1992) currently being used across the western United States to measure herbaceous response to prescribed fire. In our study we used a point that varied between 5 and 10 mm and a point that was not controlled for vertical projection. These two violations of the point-intercept sampling technique, along with the comparison of our data with other studies that used a similar point size, suggest that our point-intercept foliar cover values overestimated the actual foliar cover. Other evidence that suggests our sampling technique overestimated cover includes a study that found systematically located points overestimated foliar cover in comparison with randomly located points along a transect (Whysong & Miller 1987) and a study that found species with small outstretched leaves such as grasses and legumes increased pin contact and therefore overestimated their cover (Glatzle et al. 1993). In our study we used systematically located points along a transect to measure cover and our vegetation was dominated by grasses and sedges.

Ocular Estimation. Visual estimation of plant cover is one of the most common measurements in plant ecology and restoration studies (Kennedy & Addison 1987). Ocular estimates are normally taken within a 1-m^2 area because one of the requirements for accuracy is that observations must be made from a vertical perspective within a bounded plot (Buckner 1985). Ocular estimates can either be estimated to the nearest predetermined percent (e.g., closest 1%) or they can be categorized into published cover classes (e.g., Daubenmire or Braun-Blanquet) (Mueller-Dombois & Ellenberg 1974). In this study we did not categorize ocular estimates into published cover classes because of the problems with overestimating cover values when ocular estimates are categorized (Hatton et al. 1986; Floyd & Anderson 1987; Stohlgren et al. 1998). Instead, we estimated cover values to the nearest quarter percent within 1-m^2 plots and used cutout visual aids of different percents as suggested by Tilman (1997) to reduce inconsistencies between observers. Even taking these measures to reduce bias in cover estimates, the mental integrations involved in ocular estimation make cover estimates inherently variable between observers, though observers experienced with the technique can be consistent within their own observations (Buckner 1985). To increase consistency in ocular estimates it has been recommended that observers practice reading cover for species before sampling begins and to periodically compare values among observers throughout the field season (Anderson & Kothmann 1982). In our study both the Daubenmire transects and the modified-Whittaker plots used ocular estimates for species cover values. In the direct comparison plots (16 1-m^2 plots for the Daubenmire transects and 40 1-m^2 plots in the modified-

Whittaker plots per a unit) there was no significant difference between foliar cover values using these two techniques in comparison with the point-intercept technique. In addition, there was no significant difference in foliar cover values between the two sampling techniques when both the Daubenmire transects and modified-Whittaker plots had 40 1-m^2 plots within each sampling unit. This consistency between the two sampling techniques, along with the known violations made using the point-intercept technique, suggests that foliar cover values using ocular estimation were more accurate than foliar cover values using the point-intercept method.

Conclusion and Recommendations

The sampling technique chosen for monitoring herbaceous species composition, richness, and foliar cover in restoration studies can greatly influence perceived understory plant trajectories after restoration treatments. Large area sampling techniques were the most effective at capturing overall species composition and rare and exotic species. Modified-Whittaker plots returned on average the highest species richness in all sampling technique comparisons and captured the most rare and exotic species. In comparison, point-intercept transects captured the fewest species. Determining the sampling technique that should be used for a particular study needs to take into consideration numerous factors such as the restoration goals, sampling attributes, level of sampling precision, and financial and personnel constraints.

Our study with 2 years posttreatment data was not conducted over a long enough timeframe to detect foliar cover change in response to restoration treatments. Change in foliar cover was likely masked by the herbaceous community response to yearly climatic variation (dry versus wet years). The year of 1999 was a wet summer (May–September) with 27.51 cm of rain in comparison to the summer of 2000, which received 11.26 cm of rain (NOAA). The average summer precipitation is 20.83 cm (NOAA). These changes in precipitation were evident in the herbaceous community with lower species richness and foliar cover in 2000 for the control and treatment units than recorded in 1999 for all units. The monitoring of the herbaceous understory in this study is part of a long-term restoration research project and will be sampled every year until 2003 and then every 5 years thereafter. Monitoring needs to be conducted for a sufficient length of time so that variables such as yearly climatic variation do not mask long-term restoration treatment responses.

Acknowledgments

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