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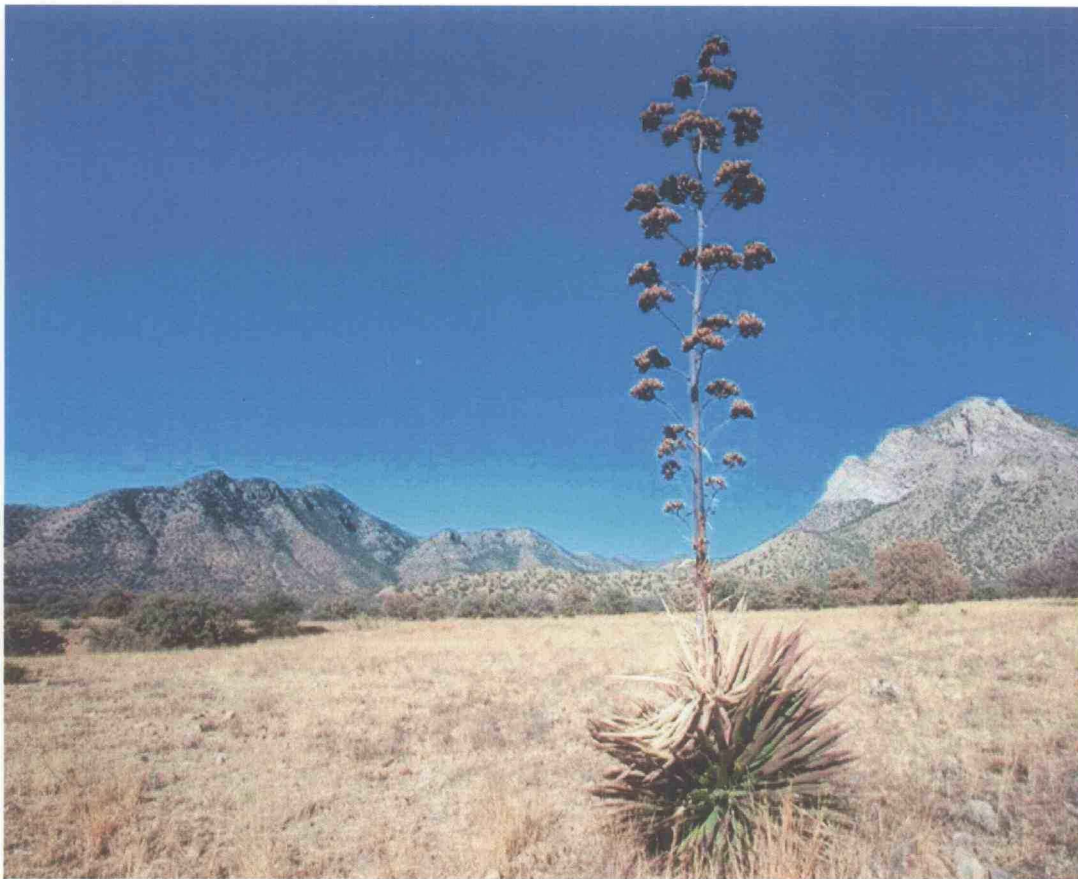
Intermountain Region
Sonoran Desert Network
Tucson, Arizona



A Comparison of Vegetation Sampling Techniques for Long-Term Monitoring

DSCESU Final Report for Quantifying Plant Communities at Coronado National Memorial

June 2005



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Introduction

Knowing the condition of natural resources in national parks is fundamental to the National Park Service's (NPS) ability to manage park resources "unimpaired for the enjoyment of future generations". NPS, under the NPS Organic Act, is legally mandated to monitor natural resources. To meet this mandate, NPS has instituted an Inventory & Monitoring Program (I&M) in order to assess the long-term ecological condition of park units, evaluate resource response to management actions, and facilitate effective resource management (SODN 2004).

Natural resource monitoring offers site-specific information needed to understand and identify change in complex, variable, and imperfectly understood natural systems and to determine whether observed changes are within natural levels of variability or may be indicators of unwanted human influences. Thus, monitoring provides a basis for understanding and identifying meaningful change in natural systems. Monitoring data help to define the normal limits of natural variation in park resources and provide a basis for understanding observed changes; monitoring results may also be used to determine what constitutes impairment and to identify the need for change in management practices. Understanding the dynamic nature of park ecosystems and the consequences of human activities is essential for management decision-making aimed to maintain, enhance, or restore the ecological integrity of park ecosystems and to avoid, minimize, or mitigate threats to these systems (SODN 2004).

Thus the primary objective of the NPS I&M program is to monitor long-term trends in key resources or "vital signs", and to use monitoring results to improve and refine park management for the benefit of the resource. One of the most important vital signs identified by NPS I&M is vegetation. Vegetation is a critical component of an ecosystem as it plays a vital role in ecosystem processes at many spatial and temporal scales. Vegetation is a base measure of the structural and functional components of ecosystems. Additionally, vegetation dynamics can be indicators of processes, productivity trends, and ecosystem interactions that can be otherwise difficult to monitor. Community composition can offer great insight into subtle shifts in nutrient availability, disturbance, and climatic conditions.

Considerable attention has been focused on quantifying the species diversity and composition of plant communities and relating these parameters to successional processes and functional mechanisms (Wedin 1995). However, there is increasing evidence that the diversity of community *types* across landscapes may be more important at broader scales (See Turner 2001 for a review). This may be nowhere more relevant than in the Sonoran Desert, where relatively fine-scale variations in topography, soils, and aspect (and the ensuing microclimates these combinations produce) result in divergent biomes ranging from true desert to mixed conifer forest within the space of a few kilometers or less (Dimmitt 2000).

Several studies have attempted compared various methods for sampling vegetation characteristics (Stohlgren et al. 1998, Carlsson et al. 2005). In general, the point intercept method has been shown to be the faster of the two methods, however the more time intensive quadrat methods often yield more species, thus giving researchers a more accurate picture of the local flora. Point intercept methods have also been shown to underestimate diversity in grassland systems (Sorrells and Glenn 1991, Leis et al. 2003). In an intensive study comparing line transect

methods (Parker method) versus quadrat methods (Daubenmire method) across four grassland types, Stohlgren et al. (1998) found that both methods identified approximately 58% of the species known to be present within the study units and the variability from type to type was highly variable. The authors point out that each method also has inherent flaws that detract from the overall goals of monitoring. Because each method was based along a line transect, a high degree of spatial autocorrelation is expected. Line transects also tend to miss small patches of high species richness, which are common in heterogeneous landscapes, and thus artificially reduce species richness within an area, therefore they are more suited to homogenous landscapes. Additionally, if detection of rare or exotic species is a concern, these methods may fail to provide the necessary information (Stohlgren et al. 1998).

Given the financial and time constraints faced by many land managers and researchers, choosing the most cost and time efficient method which yields the most information is of primary concern to those monitoring landscapes. Through the use of multivariate ordination techniques and traditional statistical methods, we hope to meet two primary objectives with this research. With vegetation cover data collected using two unique sampling methods from six NPS park units, we will test for differences in (1) species composition and (2) diversity indices as were recorded by the two distinctive methods. The results from this research can be used to inform NPS I&M managers as they develop vegetation sampling protocol; additionally, other land management agencies and researchers interested

Study Locations

Located in the Sonoran Desert and Apache Highlands Ecoregions, SODN park ecosystems range from low-elevation desert scrub to high-elevation conifer forests. Grasslands, tree savannas, shrub savannas, shrublands, wooded shrublands, woodlands and forests are all apparent, though each vegetation formation appears to be comprised of similar species. Monitoring based on floristics alone may therefore miss crucial structural and physiognomic features of key vegetation types. Vegetation monitoring at community and landscape levels must incorporate both compositional and physiognomic measurements to be effective. Unfortunately, there are few instances where both components have been simultaneously measured (Elzinga et al. 1998). Furthermore, nearly all techniques are formation specific (e.g., grasslands vs. forests, etc.); as the distributions of these formations may change over time, methods that allow direct quantitative comparisons across formations are required.

Objectives

1. Compare and contrast quantitatively some of the leading field techniques (see methods) for measuring vegetation communities in the field.
2. Document the vegetation types and their distributions currently present at Coronado National Memorial. This will serve as baseline data for designing Vital Signs Monitoring protocols as Sonoran Desert Network Parks, and provide ground data for a vegetation map being developed in a complementary study.↘

Methods

Study Areas

This study focuses on vegetation composition of 6 Sonoran Desert Network park units: Coronado National Memorial, Montezuma Castle and Montezuma Well, Tonto National Monument, Tumacacori National Historical Park and Tuzigoot National Monument. These parks are representative of the vegetation types found in most of the network's 11 parks, but do not include plots in ponderosa pine or mixed conifer forests.

Coronado National Memorial

Located in Southeastern Arizona on the U.S./Mexico border, Coronado National Memorial (CNM) commemorates the travels of Spanish explorer Francisco Vázquez de Coronado. Occupying 4,750 acres at southern edge of the Huachuca Mountains, CNM contains Montezuma Canyon watershed, which drains into the San Pedro River to the east. Elevations at the memorial range from 1470-2385 meters. Vegetation at the memorial ranges from open grassland (native and invasive) at the lower elevations, riparian forests, oak woodlands and pine-oak forests at the upper elevations.

Montezuma Castle National Monument

Montezuma Castle National Monument consists of two distinct park units: Montezuma Castle National Monument-Castle Unit (MCCU), a complex of cliff dwellings established by the Sinagua Indians over 600 years ago, and Montezuma Castle National Monument-Well Unit (MCWU) a limestone sinkhole. The 840 acre monument is located on Beaver Creek in the Verde valley north of Phoenix, with elevation ranges from 980m at the creek bottom to 1112m above the well. Climatologically, the area is characterized by mild winters and hot summers, where temperatures can exceed 100 F. The precipitation regime in the area is bimodal, ranging from 10 to 65 cm, with an average of ~30.5 cm. With contributions from the riparian area around Beaver Creek, the monument exhibits highly diverse plant life: over 379 species of plant and 15 plant associations. During the prehistoric period the native vegetation was highly disturbed by irrigation and extensive agriculture undertaken by Hohokam and Sinagua communities.

Tonto National Monument

Tonto National Monument (TNM) was set aside in 1907 to protect two prehistoric Salado cliff dwellings and associated sites. The monument's 1,119 acres consists primarily of Sonoran desert upland vegetation communities, with some localized spring-fed riparian vegetation. Precipitation is bimodal, the park receives approximately 40.5 cm annually.

Tumacacori National Historical Park

Tumacacori National Historical Park (TNHP) preserves the San José de Tumacacori Mission which was established in 1691. The mission ruins of Guevavi (established in 1691) and Calabazas (established in 1756) were added to the park unit in 1990. There is currently a bill before the U.S. Congress that will expand the Mission unit by 1400% through acquisition of private lands adjacent to the Mission site and along the Santa Cruz River (SRC; Powell and

Docherty 2001). Vegetation plots for this project were collected inside the unit as well as in park extension areas. Vegetation of three units is primarily Sonoran desert riparian scrub as well as some mesic riparian communities along the SRC. Average elevation within the park is approximately 985m above sea level.

Tuzigoot National Monument

Tuzigoot National Monument (TUZNM), located 35 kilometers west of Montezuma Castle, was established in 1939 to protect Tuzigoot Pueblo, built by the Sinaguan Culture. Tuzigoot NM contains 834 legislated acres, of which only 58 are NPS owned. Tavasci Marsh, an adjacent 130-hectare wetland, has been proposed for incorporation into park boundaries. The climate and elevation of TUZNM are similar to the nearby Montezuma Castle park units. Several small riparian streams run through Tuzigoot NM, resulting in high plant diversity.

Data Collection & Field Methods

Sampling plots were randomly established at each of the six sites (CNM: $n = 33$; MCCU: $n = 15$; MCWU: $n = 5$; TNM: $n = 4$; TUZNM: $n = 15$; TNHP: $n = 20$). Each 20 x 20 m plot was divided into four 10 x 10 m subplots, each with a 10m transect running in a north/south direction in the center of the subplot. Within each subplot, vegetation was sampled using two techniques, point intercept and quadrat census (Figure 1). The center transect was used for the point intercept method. Starting at the 0.5 cm mark, a pole was placed at 1m intervals along the transect and all plants that came in contact with the pole were recorded as a "hit". Percent cover is calculated by dividing the number of hits for each plant species by the total number of points along the transect.

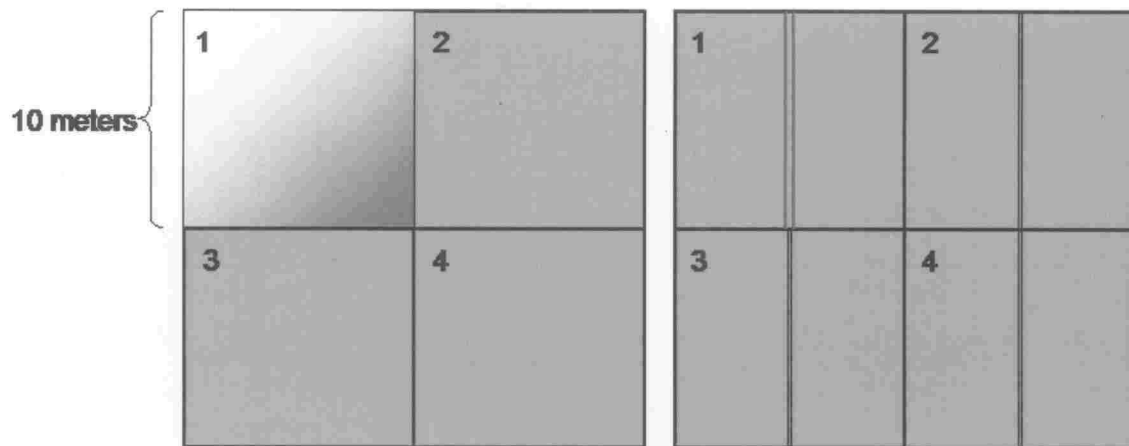


Figure 1. Plot layout for vegetation sampling in SODN park units.

The entire 10 x 10 m subplot was used in the quadrat census technique. Each species within the subplot was identified and a percent cover value class, based on the Braun-Blanquet cover classification system, was given for each species recorded within each subplot. Species identification and estimated biomass were recorded in each subplot across all sites. Percent cover value is assumed to be a good estimate of biomass and is commonly thought to be the best

possible method for assessing vegetation abundance (Carlsson et al. 2005). Over both sampling methods an additional classification was assigned to each individual plant. Three height classes, HC1: 0 – 0.5m, HC2: 0.5m – 2.0m, and HC3: > 2.0m, were used to categorize vegetation within plots. The tallest part of an individual plant was used to assign height classes and an individual plant could only fall within one of the three height classes.

Data Analysis

In total, 369 species were identified across all six sites. Each site (CNM, MCCU, MCWU, TNM, TUZNM, & TNHP) was examined separately to account for differences in vegetation that are likely to occur across such a large geographical area and diverse topography. We also divided the database for each site into the three height classes. This allowed us to examine the more subtle differences found between similar life forms and avoid many of the exaggerated differences likely to be generated when differing life forms (i.e. woody and herbaceous species) occur in the same plots. The primary matrix of each site consisted of a subset of the 369 total species (i.e. only the species identified within the plots established at each site). Sampling type, either point intercept (referred to as P on ordination graphs) or quadrat census (M), and plot name were the only factors used to create the corresponding secondary matrix.

Differences in composition among the grassland types were assessed by using Non-metric Multidimensional Scaling (NMS) of species cover values coupled with analysis of similarity (ANOSIM) to compare composition values obtained from both sampling techniques and to examine if there were differences across plots within a site. NMS is well suited to analyze community data that is non-normal or are on questionable scales, which is common in ecological studies. Additionally, in several comprehensive studies that have compared ordination techniques, NMS has out-performed many other ordination methods. Therefore, it can be argued that MDS is the best technique available for analyzing ecological community data, including this data set (Everitt 1978, Kenkel & Orloci 1986, Clarke 1993, Clark & Warwick 2001, McCune & Grace 2002).

Prior to performing the ordinations, we used a square root transformation of cover values to dampen the effects of dominant species. Ordination of the data was conducted using PRIMER 5.0 (Clark & Warwick 2001). Subplots containing less than 3% cover for either method were disregarded. All remaining data were then square root transformed and standardized. The Bray-Curtis coefficient of similarity was used as the distance measure for each similarity matrix. Bray-Curtis, also known as the Sorensen coefficient, was used as it has been routinely shown to provide reasonable picture of ecological communities (Clark & Warwick 2001). From these matrices, NMS ordination graphs were created from a random starting configuration. A random starting point and twenty iterations were used to create the NMS ordination graphs. Outliers, which can distort the graphical output, were removed from each graph as necessary. Removing these outliers, who generally consisted of subplots dominated by a few common or rare species, will allow us to better compare typical compositions obtained from both sampling techniques (McCune & Grace 2002). When possible, we represent the ordination in two-dimensions, however, because low stress levels is critical to useful visual representation of the data set, three-dimension graphs are used when two-dimension stress exceeds 0.2. When the ANOSIM 2-way

crossed was run on the data set, each plot, with its four corresponding subplots, was blocked to avoid issues with pseudo-replication. We then analyzed the data for differences in composition between sampling techniques and for differences in composition between plots. 999 random permutations were run to create a permutation distribution of possible R-values. The R-value is the test statistic generated in ANOSIM and its value has an absolute interpretation. The R-value always lies with a range of -1 to 1, with $R = 1$ indicating maximal separation and $R = 0$ indicating complete similarity between the units. R is very rarely less than zero and is only so in cases where inter-plot variation exceeds intra-plot variation (Clark & Warwick 2001).

In addition to the analysis described above, we also tested for differences in species richness and evenness (Shannon-Wiener Index). Matched pairs t-tests were used to determine statistical differences when data obtained from both sampling methods was available for a given subplot. Finally, one-way ANOVA was used to examine differences in richness and evenness between the census and the point intercept methods across all plots within the site. These analyses were performed using JMP v.4 (SAS Institute 2001).

Results

Coronado National Memorial

ANOSIM indicated significantly different point and census composition at height class 1 ($R = 0.08$; $p = 0.028$) and moderately significant differences at height classes 2 and 3 ($R = 0.07$; $p = 0.054$ and $R = 0.122$; $p = 0.054$, respectively). There was significant separation in composition across all plots in CNM at all height classes (Table 2, Figure 2). Matched pairs t-tests revealed significantly higher species richness in census plots when compared to point plots at HC2 ($p < 0.0001$) and HC3 ($p < 0.0001$), but significantly lower evenness in census plots at these same height classes $p = 0.016$ and $p = 0.007$, respectively). There was no significant difference in richness or evenness in HC1 (Table 1). ANOVA results point to differences in richness and evenness only seen in HC3 for both richness ($p < 0.0001$) and evenness ($p = 0.005$).

Montezuma Castle National Monument—Castle Unit

Significant differences in method composition were seen across all HCs in MCCU. ANOSIM points to clear differences in HC1 ($R = 0.34$; $p = 0.001$), HC2 ($R = 0.28$; $p = 0.001$), and HC3 ($R = 0.21$; $p = 0.019$). Additionally, differences in composition across plots were seen in all HCs as well (Table 2, Figure 3). Species richness and evenness were, in general, statistically similar with the exception of richness in HC1, which showed greater richness in census plots as compared to point plots ($p = 0.013$) in matched pairs t-tests (Table 1). This same pattern of higher richness in HC1 ($p = 0.01$) and no differences elsewhere was also detected in ANOVA results.

Montezuma Castle National Monument—Well Unit

Results from ANOSIM pointed to significant compositional differences between the two method types were seen in HC1 ($R = 0.35$; $p = 0.001$) and HC2 ($R = 0.28$; $p = 0.042$), but not HC3 ($p = 0.18$). Significant differences were seen across plots was seen in all three HCs (Table

2, Figure 3). HC3 evenness was the only category to demonstrate significant differences; census evenness was higher than point intercept evenness in both matched pairs ($p = 0.032$) and

Figure 2. NMS Ordination Graphs for three vegetation height classes at Coronado National Memorial and Montezuma Castle—Well Unit. Point intercept data are represented as blue inverted triangles, modular plot data are represented as green triangles.

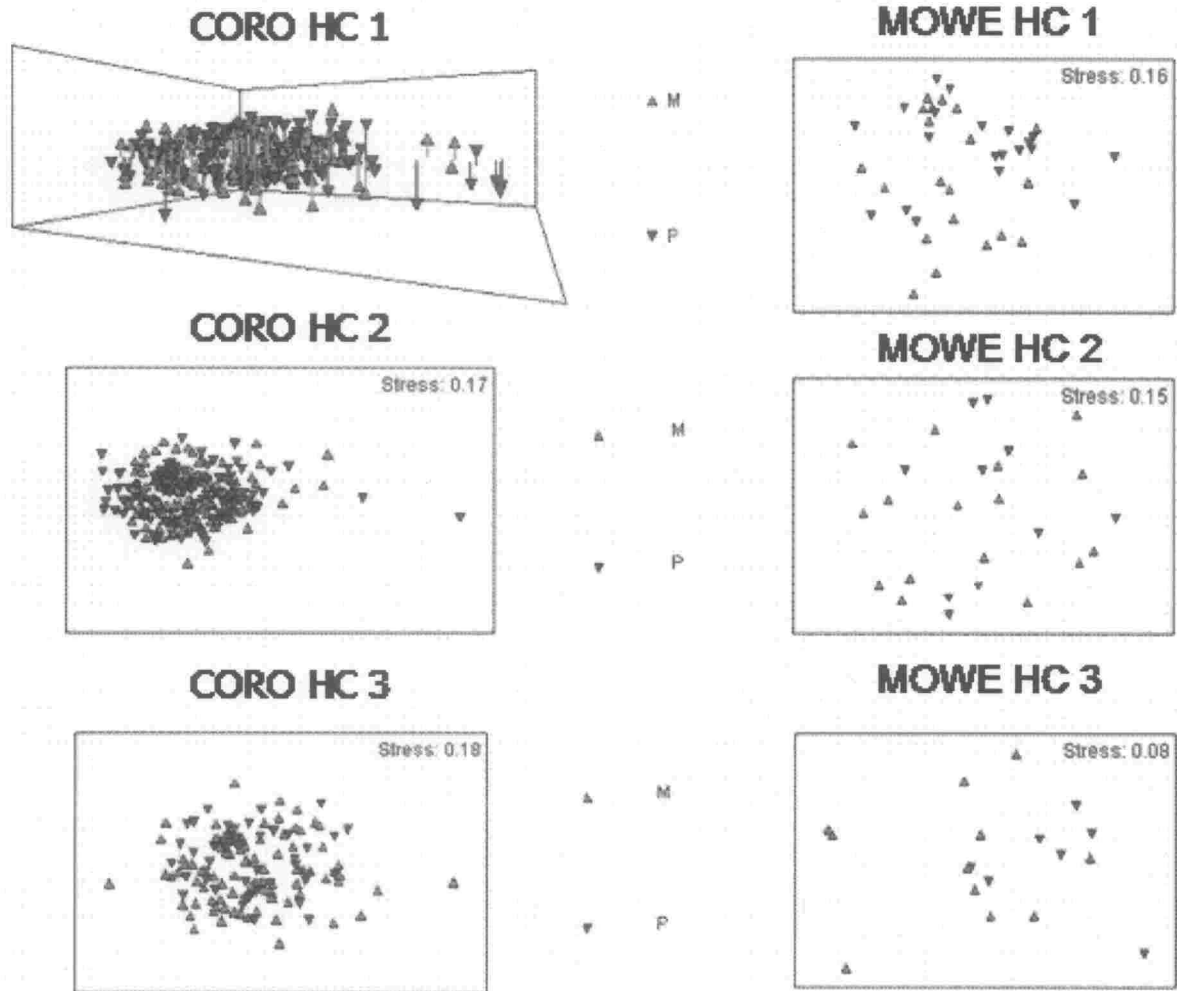
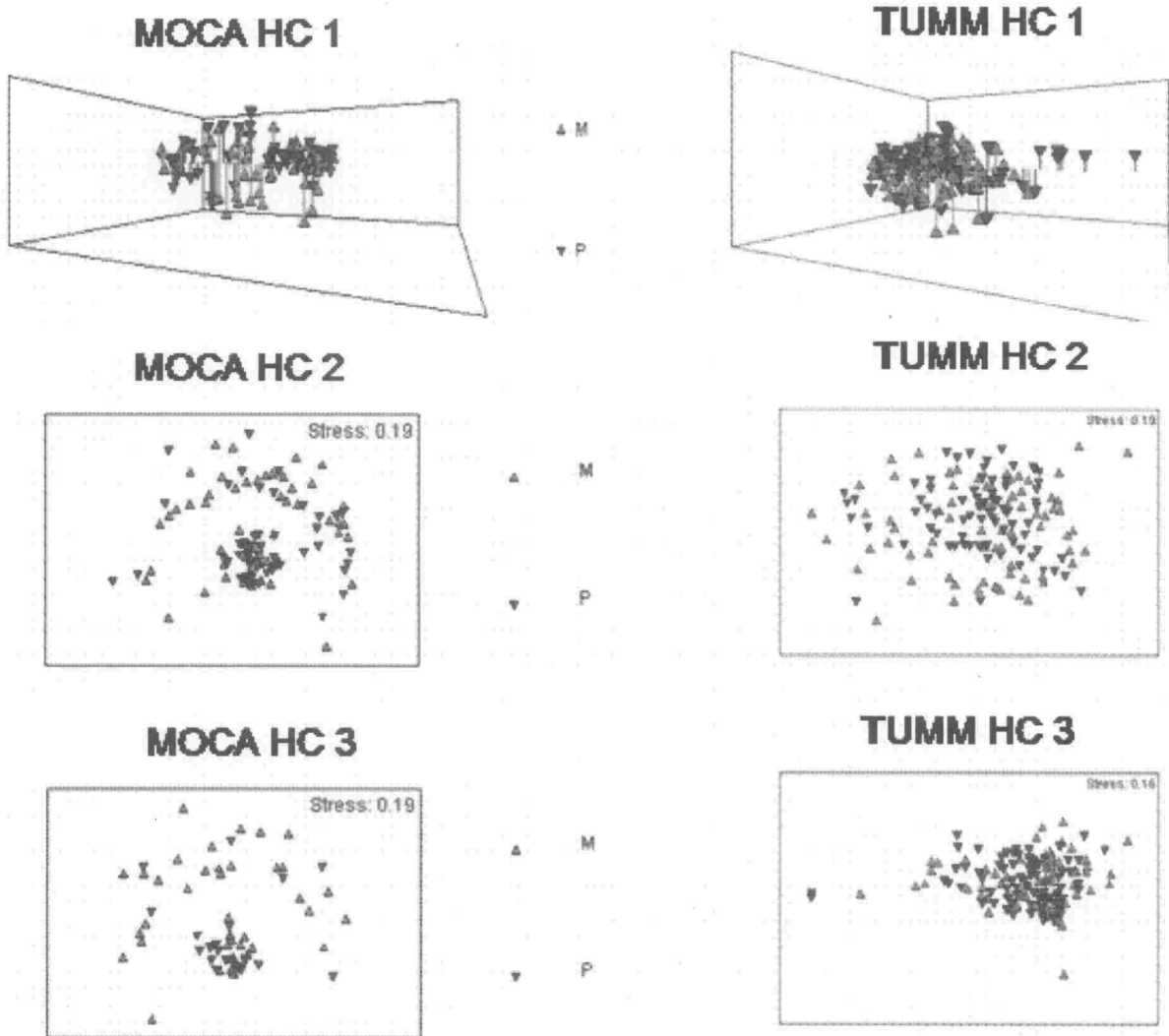


Figure 3. NMS Ordination Graphs for three vegetation height classes at Montezuma Castle—Castle Unit and Tumacacori National Historic Park. Point intercept data are represented as blue inverted triangles, modular plot data are represented as green triangles.



ANOVA ($p = 0.034$) results. Richness across all HCs and evenness across HC1 and 2 showed no significant differences between method types (Table 1).

Tuzigoot National Monument

ANOSIM results show no significant separation of composition between the two method types across all three HCs (Table 2, Figure 4). Differences in composition across plots were seen in and HC2. Like MCWU, HC3 evenness (matched pairs: $p = 0.018$; ANOVA: $p = 0.017$) was the only category to exhibit significant differences; however point intercept evenness was greater than census evenness in this case (Table 1).

Tumacacori National Historic Park

There were significant differences in composition in HC1 ($R = 0.14$; $p = 0.001$), HC2 ($R = 0.18$; $p = 0.002$) and HC3 ($R = 0.14$; $p = 0.005$) when comparing the two method types in ANOSIM. Significant differences were seen across plots in all three HCs as well (Table 2, Figure 4). Differences in species richness was seen at all three HCs while no significant differences in species evenness was seen at any of the three HCs. Richness was found to be higher in HC1 census plots (matched pairs: $p < 0.0001$; ANOVA: $p = 0.0004$) and moderately higher in HC2 census plots (matched pairs: $p = 0.048$; ANOVA: $p = 0.056$), but lower in HC3 census plots (matched pairs: $p < 0.0001$; ANOVA: $p < 0.0001$; Table 1).

Tonto National Monument

Moderately significant differences in method type composition were in only in HC1 ($R = 0.14$; $p = 0.053$), while no differences were seen in HC2 and HC3 (see Table 2, Figure 4). Significant differences in composition across plots were seen in all three HCs. No differences in species richness or evenness were seen in HC1 in either matched pairs analysis or ANOVA. Richness in HC2 (matched pairs: $p = 0.015$; ANOVA: $p = 0.007$) and HC3 (matched pairs: $p = 0.001$; ANOVA: $p = 0.0003$) was significantly higher in census than in point intercept plots. Species evenness was not significantly different in HC2 but was significantly higher in point intercept plots in HC3 (matched pairs: $p = 0.028$; ANOVA: $p = 0.02$; Table 1).

Discussion

Accurately capturing the vegetation composition of the ecological community is critical to the development of a viable natural resource monitoring program. Additionally, given the limited financial resources and political pressures facing land managers and researchers, using time and cost efficient methodologies which yield the richest information is essential. The results of this research give us some preliminary suggestions as to how best to monitor low to mid elevation vegetation communities of southern Arizona. Analysis of compositional similarity demonstrated significant differences between sampling method types across all height classes in four parks (CNM, MCCU, MCWU, & TNHP) with one exception (TNHP HC3). The nearly uniform response of sampling type differences across sites indicates that there are real differences in composition generated by the unique methods. However, it should be noted that woody species tend to skew ordination results as cover values tend to be extremely high (when

Table 1. Matched Pairs t-test results fro all HCs for all six park units.

HC1								
	Census Richness	Point Richness	p-value	d.f.	Census Evenness	Point Evenness	p-value	d.f.
CORO	5.56	5.24	0.34	49	0.507	0.456	0.31	47
MOCA	7.2	5.9	0.013	49	0.384	0.425	0.31	58
MOWE	6.15	5.35	0.16	19	0.399	0.38	0.86	17
TUZI	6.5	6.23	0.49	63	0.444	0.409	0.4	62
TUMM	6.64	5.17	>0.0001	76	0.4	0.468	0.12	73
TONT	3.55	3.55	1	10	0.454	0.454	0.99	6
HC2								
	Census Richness	Point Richness	p-value	d.f.	Census Evenness	Point Evenness	p-value	d.f.
CORO	6.24	5.08	<0.0001	105	0.384	0.46	0.016	102
MOCA	5.28	5.42	0.73	49	0.43	0.43	0.99	47
MOWE	4.3	5.4	0.08	9	0.555	0.423	0.29	8
TUZI	6.7	6.52	0.7	43	0.456	0.461	0.92	42
TUMM	5.64	4.99	0.048	74	0.398	0.398	0.99	71
TONT	5.08	3.17	0.015	11	0.351	0.608	0.08	9
HC3								
	Census Richness	Point Richness	p-value	d.f.	Census Evenness	Point Evenness	p-value	d.f.
CORO	7.19	5.6	<0.0001	130	0.395	0.48	0.007	127
MOCA	5.04	4.72	0.55	24	0.347	0.315	0.7	23
MOWE	5	4.29	0.44	6	0.62	0.348	0.032	6
TUZI	7.5	6.75	0.68	3	0.149	0.375	0.018	3
TUMM	4.47	6.49	<0.0001	73	0.395	0.358	0.47	63
TONT	6.44	3.88	0.0001	15	0.282	0.499	0.028	13

Tables 2a and 2b. ANOSIM and ANOVA values for all HCs for all six park units.

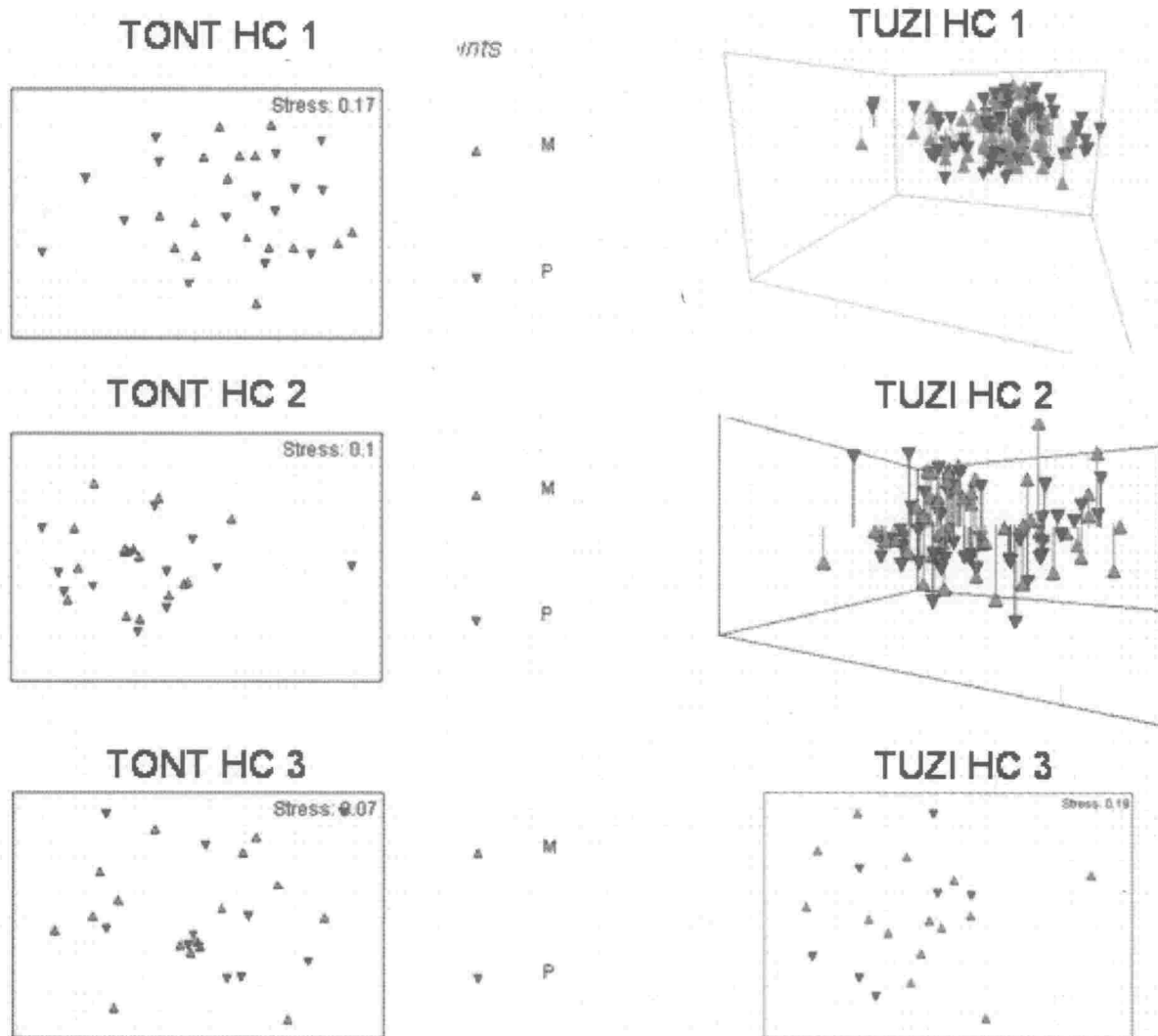
a) ANOSIM b/w types

	HC1		HC2		HC3	
	R	p-value	R	p-value	R	p-value
CORO	0.08	0.028	0.069	0.054	0.122	0.054
MOCA	0.34	0.001	0.277	0.001	0.206	0.019
MOWE	0.348	0.001	0.276	0.042	0.126	0.18
TUZI	-0.109	0.66	-0.083	0.92	0.179	0.2
TUMM	0.141	0.0001	0.176	0.002	0.143	0.005
TONT	0.139	0.053	-0.109	0.81	-0.197	0.97

b) ANOSIM b/w plots

	HC1		HC2		HC3	
	R	p-value	R	p-value	R	p-value
CORO	0.618	0.001	0.62	0.001	0.577	0.001
MOCA	0.459	0.001	0.432	0.001	0.331	0.001
MOWE	0.483	0.001	0.525	0.001	0.5	0.001
TUZI	0.453	0.001	0.297	0.001	0.371	0.015
TUMM	0.447	0.001	0.55	0.001	0.607	0.001
TONT	0.487	0.001	0.347	0.002	0.182	0.021

Figure 4. NMS Ordination Graphs for three vegetation height classes at Tonto National Monument and Tuzigoot National Monument. Point intercept data are represented as blue inverted triangles, modular plot data are represented as green triangles.



recorded as “in” a plot) or obviously quite low when absent from a plot. Therefore, extreme cover values of woody species can generate artificial differences. By eliminating plots that had low cover values ($< 3\%$) and outliers, we have attempted to control for this distortion. Yet it is still likely that it plays a role in the interpretation of the ordination results. The two other parks, TUZNM & TNM, had no differences between sampling methods at all height classes with the exception of TNM HC1. It is likely that the low number of samples in TNM ($n = 4$) contributed to the lack of significance. TUZNM had sample sizes equal to those of other parks which did have compositional differences; however, the negative global R suggests two ideas. One, data error in either collection or entry, or two, negative R values have been found in other research projects to be associated with diverse, patchy landscapes that are dominated by a wide variety of species (Chapman and Underwood 1999).

Matched pairs analysis reveals, in more detail, differences in species diversity and thus disparities in composition. In general, differences between sampling types became more obvious as height class increased. This result points towards differences in vegetation type (i.e. woody and herbaceous species) driving the distinctions in composition as reflected by ANOSIM, ANOVA, and matched pairs t-tests. Interestingly, differences in species richness are evident across all HCs and it too is likely due to life form dynamics. Richness, in general is higher in the quadrat method, which should be expected given that it's a census of the entire area. Interestingly, species evenness is only significantly different at HC3 and is greater in the point method than in the quadrat method. We suggest that the quadrat method may be picking more of the dominant species than the point method.

Differences in the sampling methodologies themselves have been demonstrated in other research projects (Stohlgren 1998, Leis et al. 2003, Carlssen et al. 2005). Point intercept yields the best results when used in low to mid elevation landscapes, which are typically desert scrub, grassland, and mixed grassland/savanna communities in southern Arizona. Point intercept is known to underestimate species richness, even when applied in optimal settings (Sorrells and Glenn 1991). Therefore, differences between the two methods should certainly be evident as height class increases. Height class three records only species that greater than 2 meters in height, thus it likely is focused on woody species.

The results of this preliminary research can be used to further refine monitoring methods and produce more conclusions results upon which monitoring protocols can be built. Future research projects should focus on increasing the sample sizes at each park, particularly parks with currently low sample size (TUZNM & MCCU), differentiating riparian dominated parks from more arid units, and inclusion of other methodologies. Modified Whittaker multi-scale plots have been shown to generate more accurate species counts at a minimal time cost. Comparing this method with both the point and census methods might prove to be beneficial in protocol selection.

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