ANALYSIS OF PILOT DATA: "SOIL STRUCTURE AND STABILITY" IN BIGHORN CANYON NATIONAL RECREATION AREA

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INTRODUCTION

Soils are critical to healthy ecosystem functioning because they control water storage and nutrient cycling. They also provide habitat for plants, animals, fungi, and microbes. If these functions are disrupted, it can take decades for them to recover. For these reasons, soil structure and stability was designated a “vital sign” in Bighorn Canyon National Recreation Area (BICA) by the Greater Yellowstone Network, which is a unit of the National Park Service (NPS) Inventory and Monitoring (I&M) program (www.GreaterYellowstoneScience.org).

Soils in BICA have been disturbed both by modern-day wild horse grazing and by widespread domestic livestock grazing prior to 1967, when the national recreation area was established. Even though the Bureau of Land Management is the agency responsible for managing the wild horses, twenty-one percent of the Pryor Mountain Wild Horse Range (PMWHR) is within the area manged by the NPS. In addition to wild horse grazing, BICA continues to allow limited cattle grazing adjacent to the main road through the south district, and there are two small pastures in the north end of the south district. As a result of these disturbances, plant communities in the BICA (NPS) portion of the PMWHR bear only a 44% similarity to baseline data collected in 1981 and 67% are in a downward trend (Ricketts et al. 2004). Thirty-one percent of the area is experiencing severe soil erosion; bare soil cover ranges from 22% to 74% of the surface area; and biological soil-crust cover ranges from 0 to 5% (Ricketts et al. 2004). By comparison, biological crust cover in the Horseshoe Bend area, which has been excluded from grazing since 1967, ranges from 11 to 30% (Ricketts 2004). A recent NRCS rangeland-health assessment indicated that the PMWHR unit exhibits “moderate-to-extreme departure” from historic conditions (Ricketts et al. 2004).

This report describes the results from a pilot study of soil structure and stability in Bighorn Canyon National Recreation Area (BICA). The pilot study was designed by Elizabeth Crowe during 2004 – 2005 and field work was conducted by NPS staff during the summers of 2007 and 2008. The analyses presented here will aid in the design of a long-term Inventory and Monitoring protocol for BICA. The monitoring objectives of this protocol are: (1) to detect changes in the frequency of various biotic and abiotic soil cover types, and (2) to detect changes in soil aggregate stability.

METHODS

Study Design and Field Methods

The pilot study was conducted in the south district of BICA. A detailed site description can be found in Crowe (2005). Monitoring sites were selected with a stratified random design based on eight ecological types (strata) that were defined according to aspects of soil chemistry and texture. During the pilot study, sites from only three of the eight ecological types were visited. These three site types were designated: “Silty Limy” (SILI), “Sandstone Shallow” (SASH), and “Silty Surface” (SISU). Each of the three ecological types was represented by 20 study sites (60 total sites). Half of the sites (10 for each ecological type) were located inside the PMWHR, and half (10 from each ecological type) were located outside the horse range. This design was chosen because it separates the effects of horse grazing (inside the PMWHR) from long-term trends due to other factors such as climate change (measured outside the PMWHR).

Frequencies (% cover) of 5 cover types (rock, bare soil, plant litter, basal vegetation, and moss-lichen) were measured using a point - intercept method on 3 30m transects in each site. Soil aggregate stability was measured using the methods of Herrick et al. (2005). Soil samples were submitted for laboratory analyses of soil texture (size fraction) and chemistry. Detailed methods appear in Crowe (2005).

Validation of the Sampling Frame

The lab results were used to validate the stratification that was used for site selection. Using criteria specified in the draft monitoring protocol (Crowe 2005), a site was rejected if:

- it had a 15% or greater difference in sand or clay content than the average of the remainder of samples in that ecological type;
- it had a 40% or greater difference in silt content than the average of the remainder of samples in that ecological type; or
- it had a 20% or greater difference in gypsum or calcium carbonate concentration (g/kg dry-weight soil) than the average of the remainder of samples in that ecological type.

Statistical Analysis

The draft monitoring protocol (Crowe 2005) specifies the types of contrasts that should be made on the pilot data. The following statistical tests were used to make those contrasts:

(1) When nominal variables are expressed as percentages, chi-squared tests were used whenever possible. For example, chi-squared tests were used to determine whether the frequencies of soil cover types (rock, bare soil, plant litter, basal vegetation, and moss-lichen) were independent of ecological type, horse activity, or both combined.

(2) Where the draft protocol specifies that ANOVA should be used on data expressed as percentages, an arcsine transformation has been applied before the analysis (Snedecor 1956). This resolves problems that are commonly associated with using ANOVA on frequency data. Untransformed data are presented in the tables and figures.

(3) The five original soil cover types (rock, bare soil, plant litter, basal vegetation, and moss-lichen) were merged into two classes: “biotic” and “abiotic.” This differs from the guidelines specified by the draft protocol (Crowe 2005), but it is justified for three reasons. First, merging the cover types provided enough statistical power to generate significant results. Without the re-classification, sample sizes were too low. Second, preliminary analysis determined that the five original cover types had cohesive trends within “biotic” vs. “abiotic” categories. Third, merging the original classes avoided the accumulation of Type I error that would have been associated with separate ANOVAs (specified in the draft protocol) for each of the five original classes.

***** Data from the soil aggregate stability tests were not available when this report was written**.**

RESULTS

Soil Classification of Sites

The three ecological types examined in this pilot study do not differ significantly with respect to the classification of their soils ($\chi^2 = 4.7$, df= 20, p=0.99). Taken together, sandy-loam and loam soils were found in 50 – 100% of all the study sites in all three ecological types [Sandstone shallow (SASH), Silty Limy (SILI), and Silty Surface (SILI)]. SASH sites contained the greatest diversity of soil types. Unlike the other two ecological types, SASH sites contained sand (inside the horse range) and silt-loam soils (outside the horse range) (Table 1).

Ecological Type	IN/OUT Horse Range	Sand	Silt	Sandy-Loam	Silt-Loam	Loam	Loamy-Sand
SASH	IN	30.0%	0.0%	40.0%	0.0%	10.0%	20.0%
SASH	OUT	0.0%	0.0%	50.0%	20.0%	30.0%	0.0%
SILI	IN	0.0%	0.0%	30.0%	0.0%	70.0%	0.0%
SILI	OUT	0.0%	0.0%	30.0%	0.0%	70.0%	0.0%
SISU	IN	0.0%	0.0%	80.0%	0.0%	20.0%	0.0%
SISU	OUT	0.0%	0.0%	62.5%	0.0%	37.5%	0.0%

Table 1. Soil classification of study sites visited during a pilot study of soil structure and stability in Bighorn Canyon National Recreation Area. Percentages represent the number of sites in each category that contain soils of each type.

Soil Texture Within Sites

The textural composition of soils differed among ecological types and inside vs. outside the horse range ($\chi^2 = 1367$, df= 20, $p < 0.001$). Analysis of variance (on arcsine transformed data) showed that there were significant differences between SASH sites inside vs. outside the horse range ($p < 0.05$, Fig. 1). SASH sites inside the horse range have a higher proportion of sand than SASH sites outside the range. Similarly, SASH sites inside the horse range have a lower proportion of both clay and silt than SASH sites outside the range. This effect of the horse range contributed to the difference between the overall mean of SASH (when inside vs. outside sites were pooled) and the overall means of the other two ecological types (when inside vs. outside sites were pooled). Overall, SASH sites had a greater proportion of sand and lower proportions of clay and silt than the other two ecological types (Fig. 1).

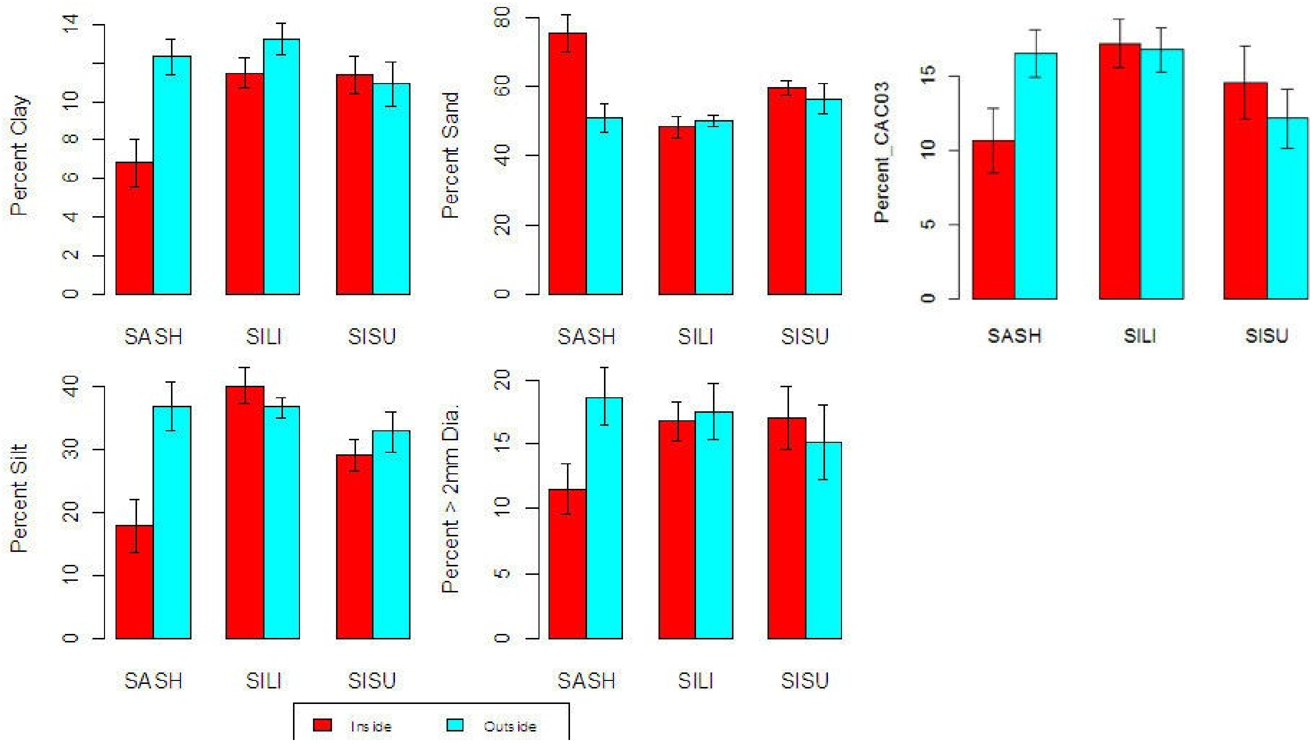

Figure 1. Soil texture of study sites visited during a pilot study of soil structure and stability in Bighorn Canyon National Recreation Area. Red bars = Inside the wild horse range. Blue Bars = outside the wild horse range. CODES: SASH = Sandstone Shallow, SISU = Silty Surface, SILI = Silty Limy ecological type. Error bars indicate one standard error of the mean.

Rejection of study sites based on criteria defined in the draft monitoring protocol

Twelve sites were rejected by the criteria defined in the draft monitoring protocol (Crowe 2005). The following sites were rejected because they had sand content that exceeded the mean of all the other sites in their ecological type by greater than 15%: ISASH 3, ISASH6, ISASH 7, ISASH 9, ISASH 10, ISILI 6, OSISU 2. The following sites were rejected because they had sand content 15% or more below the mean of the other sites in their ecological type: OSASH 5, OSASH 8, OSASH 9, OSASH 10, OSISU 6. Note that the "I" or the "O" at the beginning of each site name indicates whether it was inside or outside the horse range. No other sites met the rejection criteria for sand, clay, silt, gypsum or $CaCO_3$ content.

The sites just listed reflect the pattern seen in Fig. 1. SASH sites comprise the majority of the rejected sites, and SASH sites inside the horse range (denoted "ISASH" in the list of rejected sites) often have unacceptably high sand content. SASH sites outside the horse range (denoted "OSASH") often have unacceptably low sand content.

Dry Sieve Analysis of the Sand Fraction

Size composition of the sand fraction did not differ significantly among sites in different ecological types or inside vs. outside the horse range ($\chi^2 = 28.5$, df= 20, $p < 0.09$). SASH sites inside the horse range were dominated by the 0.105 – 0.25mm fraction, but SASH sites outside the horse range, like all the other sites in the pilot study, were dominated by the 0.045-0.105 fraction (Fig. 2).

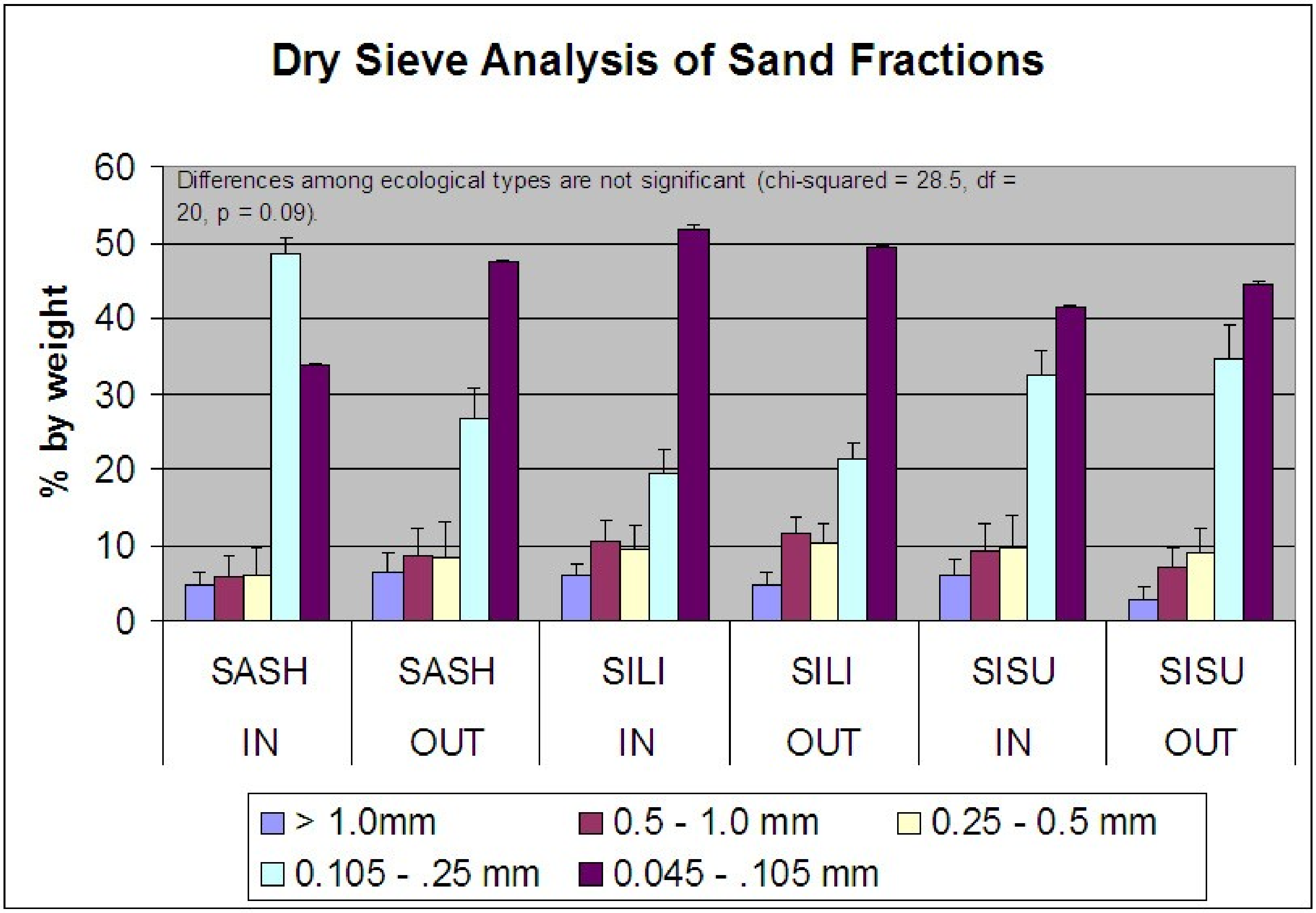

Figure 2. Dry sieve analysis of the sand fraction in sites visited during a pilot study of soil structure and stability in Bighorn Canyon National Recreation Area. "IN" and "OUT" indicate whether the sites are inside vs. outside the Pryor Mountain Wild Horse Range. Bars indicate one standard error of the mean. CODES: SASH = Sandstone Shallow, SISU = Silty Surface, SILI = Silty Limy ecological type.

Soil cover data

The soil cover data were normally distributed (Kolmogorov-Smirnov tests, $p = 0.163$ to $p = 0.2$) and had homogeneous variances (Levene's Tests, $p = .162$ to $p = 0.2$). Transformations were not required except as noted below. Figure 3 shows the distribution of the three ecological types for the variable (% biotic cover).

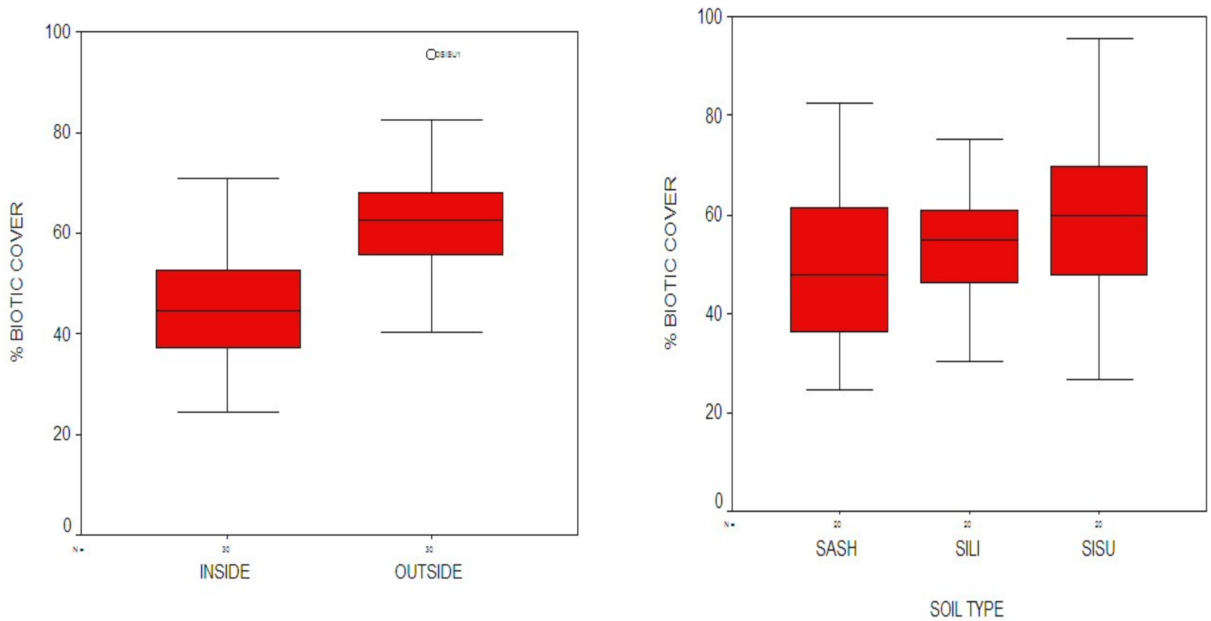

FIGURE 3. Box plots showing percent biotic cover of soils in Bighorn Canyon NRA. LEFT: Inside vs. Outside the Pryor Mountain Horse Range, RIGHT: Contrast of the three ecological types with data from inside and outside the horse range combined. CODES: SASH = Sandstone Shallow, SISU = Silty Surface, SILI = Silty Limy ecological type. Percent Biotic cover was calculated by re-coding the original data set to combine "Moss Lichen," "Litter, "and "Basal Vegetation" cover into a single field. Abiotic cover was calculating as the sum of "bare" and "rock" cover. Note that site OSISU1 has unusually high levels of biotic cover.

Outlier screening

Site OSISU 1 was flagged as an outlier, with unusually high biotic cover values. Removing this site did not change the significance of initial tests, so it has been included in the present analysis. This site should be examined for potential sources of bias during future field work.

Differences among ecological types and inside vs. outside the horse range

There was significantly higher biotic cover (litter, moss-lichen, and basal vegetation cover types combined) outside the horse range than inside the horse range (Factorial ANOVA, $F=2.86$,$df = 1,54$, $p < 0.01$) and biotic cover differed significantly among ecological types (Factorial ANOVA, $F = 4.9$, $df = 2,4$, $p = .011$). Percent biotic cover across all ecological types was 62.9% outside the horse range and 44.8% inside. SISU sites had the highest percent biotic cover overall (59.1%), SASH sites had the lowest (48.7%) and SILI sites were intermediate (53.7%) (Fig3, 4). The interaction term (ecological type X inside vs. outside) was nearly significant ($p = .066$).

The three ecological types (SASH, SILI, SISU) did not differ significantly from each other with respect to the 5 original cover types (rock, bare soil, plant litter, basal vegetation, and moss-lichen) either inside the horse range ($\chi^2 = 5.76$, $df = 8$, $p = 0.68$) or outside the horse range ($\chi^2 = 7.46$, $df = 8$, $p = 0.48$). Litter was the most common cover in all ecological types (46.3% cover outside the horse range and 35.6% cover inside the range). Basal vegetation was the least common cover type (2.9% cover outside the range and 1.5% inside) (Fig. 5).

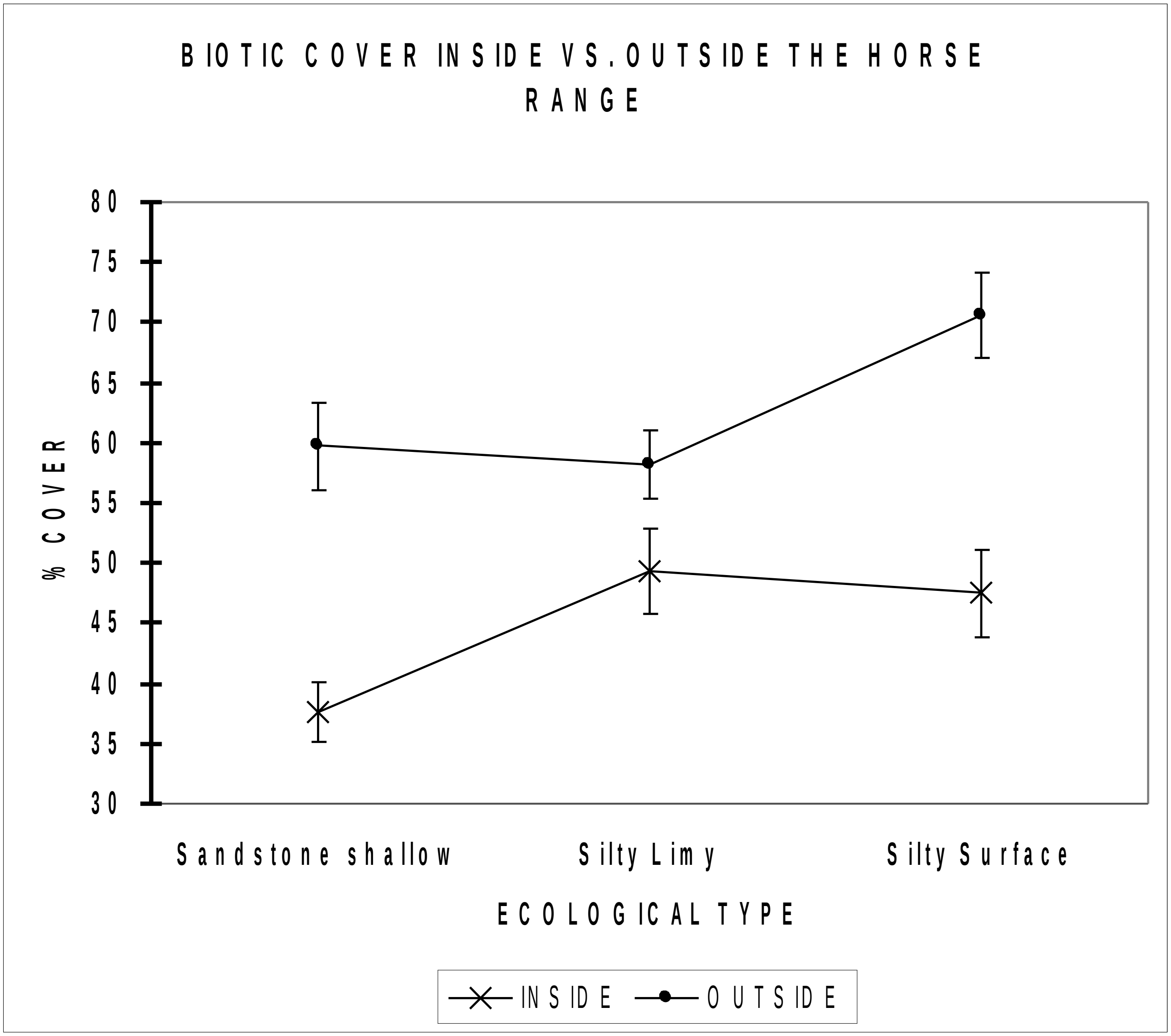

FIGURE 4. Percent biotic cover (Moss-lichen + Litter + Basal Vegetation) on three ecological types inside vs. outside the Pryor Mountain Wild Horse Range in Bighorn Canyon National Recreation Area. Bars represent one standard error of the mean.

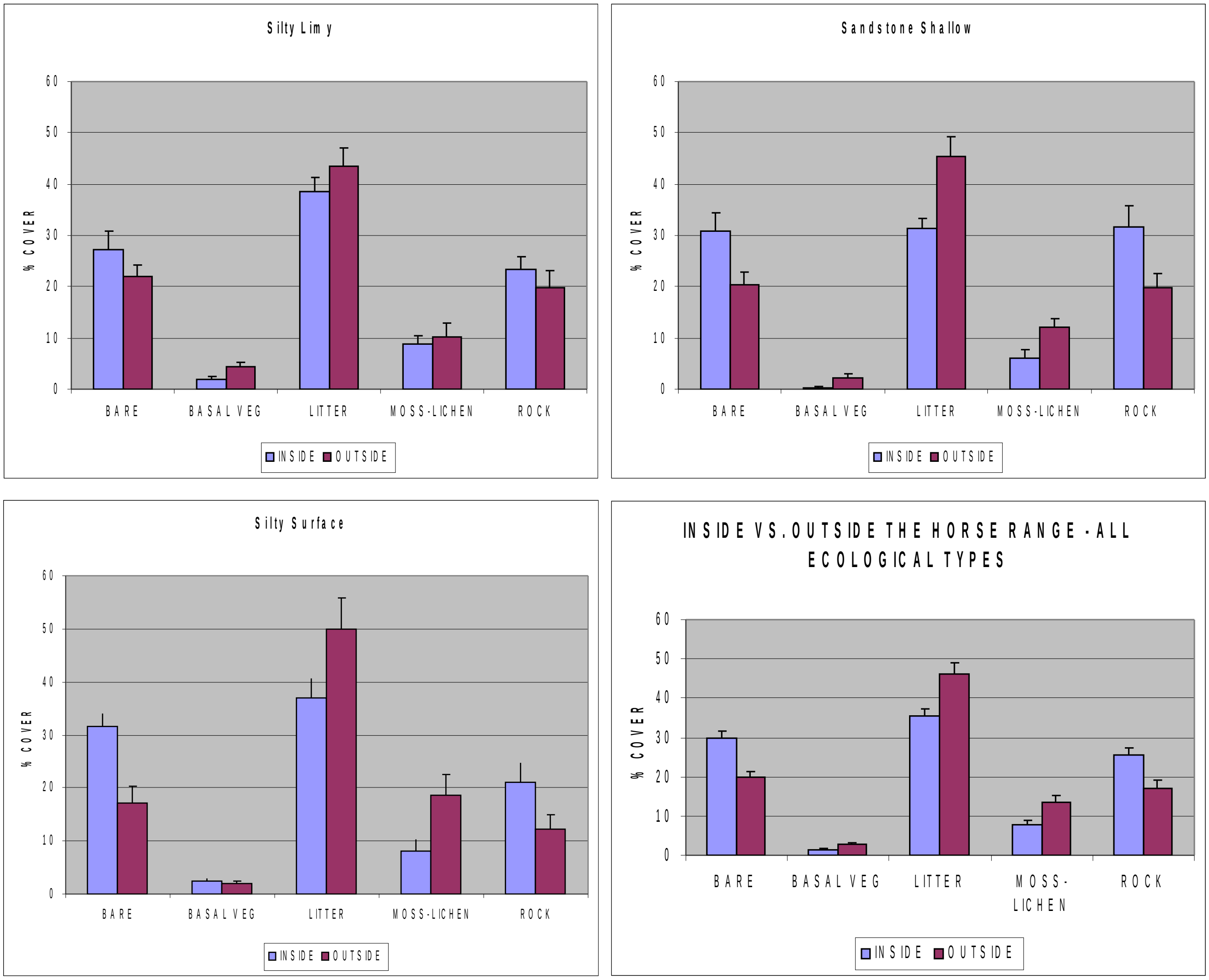

FIGURE 5. Frequencies of five soil cover types (%) inside vs. outside the Pryor Mountain Wild Horse Range in Bighorn Canyon National Recreation Area. First three panels: % cover shown separately for three ecological types. Bottom-right: All ecological types combined. Bars represent one standard error of the mean.

Power Analysis

Table 2 shows the sample sizes required to detect a range of changes in % biotic cover with 80% power at a significance level (alpha) of 0.05. During the pilot study, the observed difference in biotic cover inside vs. outside the horse range was 18% (62.8% outside the range and 44.8% inside). The right-most column in Table 1 shows the minimum sample size required to detect this 18% change.

			SAMPLE SIZE NEEDED TO DETECT CHANGE OF . . .				
	Ecological Type	Std. Deviation	1%	5%	10%	15%	**18%**
INSIDE THE RANGE	Sandstone Shallow	7.8	956	39	11	6	5
	Silty Limy	11.2	1970	80	21	10	8
	Silty Surface	11.7	2150	87	23	11	8
OUTSIDE THE RANGE	Sandstone Shallow	11.4	2041	83	22	11	8
	Silty Limy	9	1272	52	14	7	6
	Silty Surface	11.2	1970	80	21	10	8
COMBINED IN AND OUT	Sandstone Shallow	14.8	3440	139	36	17	12
	Silty Limy	10.9	1866	76	20	10	7
	Silty Surface	16.3	4171	168	43	20	14

Table 2. Power analysis for the variable "percent biotic cover." This composite variable was calculated as the sum of the the 3 original cover types moss-lichen, litter, and basal vegetation. Standard deviations in the third column are those observed during the pilot study.

The most conservative (largest) estimates of sample size appear in the last line of the table, in the group with the highest standard deviation (Silty Surface ecological type, combined inside and outside the horse range, standard deviation = 16.3).

DISCUSSION

Executive summary of important results

Soil structure and stability has been designated a vital sign by National Park Service (NPS) Inventory and Monitoring (I&M) Program in Bighorn Canyon National Recreation Area (BICA). The response variable chosen to measure this vital sign was frequency (% cover) of five soil cover types: rock, bare soil, plant litter, basal vegetation, and moss-lichen. Preliminary analysis (Fig. 5) of the data from the pilot study indicated that biotic cover types (basal vegetation, plant litter, moss-lichen) exhibit the same trends both inside vs. outside the Pryor Mountain Wild Horse Range (PMWHR) and among the ecological types (strata) chosen for the study design. Likewise, abiotic cover types (rock, bare soil) exhibit cohesive trends that complement those seen in the biotic classes. Merging the five original cover types into two classes (biotic and abiotic) is therefore justified, and it provides enough power for statistically significant results.

Biotic cover was 18% higher outside the Pryor Mountain Wild Horse Range (PMWHR) than inside the range. This difference was statistically significant, and a smaller sample size would have been sufficient to detect this effect (Table 2). The strata chosen for this study (ecological types based on soil structure) also exhibit significant differences in percent biotic cover (Fig. 4).

Quality of the field data

The field methods used in this pilot study have produced good quality data that are normally distributed data with few outliers. Sample sizes were adequate (Table 2). One site, OSISU1, should be re-examined for potential sources of bias. The field crew did an excellent job of collecting data under challenging conditions.

Potential modifications to the stratified-random design

There are two potential sources of bias that should be considered in the final monitoring protocol. First, total annual precipitation may be a useful covariate for percent biotic cover. BICA has a strong north-south precipitation gradient, and this coincides with one of the primary contrasts used by the pilot study, i.e., inside vs. outside the horse range. The BICA unit of the PMWHR is south of the horse-free portions of BICA. Increased precipitation has significant effects on the plant community composition (Knight et al. 1987) and these effects may in turn affect the soil structure and stability metrics used in the pilot study. Second, horse activity within the PMWHR is not uniform, but instead concentrates around BICA's perennial water sources (Ricketts et al. 2004). Linear distance from perennial water sources (on a per site basis) may be a useful covariate for percent biotic cover.

If the current, soil-type based stratification is maintained in the final protocol, the SASH ecological type should be re-examined for consistency. Data from this pilot study suggest that SASH sites inside the PMWHR differ from SASH sites outside the PMWHR with respect to soil classification (Table 1), soil texture (Fig. 1), size composition of the sand fraction (Fig. 2), and percent biotic cover (Fig. 4).

BICA has several fenced exclosures that are > 10 years old. Duplicating the current field methods within these exclosures might be a useful way to quantify the effects of horse activity on soil structure and stability. Since previous researchers have used these exclosures (Singer and Schoenecker 2000), this approach may yield trend estimates that extend back to the early 1990s.

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