Grazing, Rest, and Biological Soil Crust in Canyons of the Ancients National Monument

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INTRODUCTION

Retaining or restoring biological soil crust can be a challenge to land management agencies in the arid Southwest. Biological soil crusts ("biocrusts") are biotic layers found on the surface and upper centimeters of soil in semi-arid, arid, and desert regions. Biocrusts are diverse aggregations of cyanobacteria, various soil bacteria, mosses, and/or lichens. Biocrusts can improve water infiltration, protect vulnerable soils from erosion, and support vascular plant germination and recruitment (Belnap 2003, Bowker et al. 2008). In addition many species of cyanobacteria fix nitrogen (Belnap 2002). While it is clear that biocrusts are vulnerable to trampling, for instance by cattle (Belnap et al. 2001), less is known about the nature or rate of recovery following cessation of trampling (some recent studies include Muscha and Hild 2006, Jimenez Aguilar et al. 2009, Gomez et al. 2012, Concostrina-Zubiri et al. 2014 and a review of earlier studies by Warren and Eldridge 2003). Efforts to preserve or restore biocrusts is an issue of particular importance amid climate change, which may degrade biological soil crusts in a manner similar to, and thus cumulative with, trampling (Ferrenberg, et al. 2015) or slow growth and recovery of biocrusts because of drier conditions (Jimenez Aguilar et al. 2009).

In arid regions biocrusts can be very abundant and are influential to the ecosystem. In natural conditions, "biological soil crusts often cover all soil spaces not occupied by trees, grasses or shrubs and can comprise 70% of the living ground cover" (Rosentreter et al. 2007).

Canyon of the Ancients National Monument (CANM), in southwestern Colorado, has a long history of livestock use (since the late 1800's) and over 90% of the 164,000-acre National Monument has ongoing livestock grazing (BLM 2013). A fenced exclosure was built within the Flodine Park Allotment of CANM in 1963, excluding livestock grazing in a 1.9-acre area. In the surrounding area of that allotment, authorized grazing ceased in 2005, 11 years prior to this 2016 study, Some livestock producers have requested that the BLM once again authorize cattle grazing in Flodine Park and Yellow Jacket allotments (October 21, 2015 Scoping notice). Hamilton Mesa allotment, adjacent to Flodine Park allotment, has authorized livestock grazing. We used these three areas to evaluate impacts of livestock use on biocrusts, as well as recovery of biocrusts after livestock use is discontinued. In addition, we considered soils as a factor, since all three of the areas with different livestock histories include some of the same two soil types.

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Light cyanobacterial crusts have generally not been included in biocrust surveys on public lands in the West, but we evaluated the abundance of light cyanobacteria crust because it is the first biocrust component to recover following disturbance or elimination of biocrusts, and forms a base on which later seral biocrust components (dark cyanobacteria, moss and lichen) establish (Rosentreter et al. 2007). As a base for further biocrust development, light cyanobacteria is an indicator of how quickly biocrusts on particular soils can begin to recover from trampling, erosion, fire, or other disturbances that have damaged or eliminated biocrusts.

BACKGROUND

Biological soil crusts are complex communities that typically include more than one of the following: bryophytes, cyanobacteria, lichens, fungi, algae, and soil bacteria that are present in the upper few centimeters of soil. Biocrusts are commonly found in arid systems and are especially important for soil stabilization in these ecosystems that have patchy vegetation.

In the Colorado Plateau, and other cold desert systems, the common light cyanobacterial species is *Microcoleus vaginatus*. This species produces filaments that are surrounded by a sticky gelatinous sheath that binds soil particles together and creates a surface crust that prevents erosion and creates pathways for infiltration of water (Rosentreter et al. 2007). As succession proceeds, smaller (single-cell) cyanobacteria, such as *Nostoc*, develop on top of the soil (Jimenez Aguilar et al. 2009). These later successional species are referred to as “dark cyanobacteria” because of the UV-protective pigments which give them a darker color (Belnap et al. 2008). Dark cyanobacterial crusts have nitrogen-fixing capabilities and are better able to bind soil particles than light cyanobacteria crusts. In the Colorado Plateau, well-developed dark cyanobacterial crusts produce pinnacles that have greater soil surface area, which slows surface water runoff and helps facilitate water infiltration.

Finally, as succession proceeds, lichens and mosses colonize biocrusts and provide additional benefits to the ecosystem. Some lichens, such as the genus *Collema*, are prolific nitrogen fixers. Mosses are not nitrogen fixers but they can increase soil moisture content and thus facilitate seed germination. The exotic cheatgrass (*Bromus tectorum*) establishes more on disturbed biocrusts than undisturbed biocrusts (Warren and Eldridge 2003). Biocrusts limit germination of exotic species with large seeds such as cheatgrass because these species do not have the self-burial mechanisms that many native large seeds have or the pattern of being buried (cached) by rodents (Belnap et al. 2001). Later successional biocrusts (pinnacled dark cyanobacterial crusts, lichens, mosses) also decrease erosion and add even greater roughness and surface area which can promote infiltration.

Soils, Biocrusts and Grazing

Trampling by livestock as well as vehicles and humans can damage or eliminate biological soil crusts. Without these crusts, soil erosion and dust generation increase and moisture retention declines. This increases vulnerability to invasion by annual plants. The dust from desert soils not protected by biocrust is capable of travelling great distances, for instance to mountain snowpacks where the dust darkens the snow, absorbing sunlight, and thus accelerating snowmelt (Neff et al. 2008).

Biocrusts and Climate Change

Biocrusts are negatively impacted by climate change due to their sensitivity to microclimatic changes such as temperature increases and precipitation changes. In a ten-year experiment in southeastern Utah, Ferrenberg, et al. (2015) found that increased temperature and precipitation alterations, which are observed and predicted for climate change, resulted in increases in early seral biocrusts (light cyanobacterial crusts) and declines in moss and lichens. The authors noted that these impacts from climate change were similar to impacts associated with trampling (one of their experiment's treatments). In addition, increased CO_2 levels may favor annual grasses such as invasive cheatgrass, which can reduce available space for biocrusts (Belnap 2003). Cheatgrass litter has been shown to reduce biocrust photosynthetic capacity for some biocrusts (Serpe et al 2013).

A well-preserved biocrust community can help mitigate some climate change effects in localized soil systems via biocrusts' erosion resistance and water retention capabilities. As temperatures increase and precipitation patterns shift with climate change on the Colorado Plateau, any system that increases available water capacity and reduces erosion and dust generation warrants management attention.

The study is an effort to evaluate differences in biocrust abundance and types in relation to different grazing histories. The 53-year old exclosure, and the area with grazing that ceased 11 years prior to this study, provide a valuable opportunity to examine rate of recovery of these arid public lands amid climate change.

METHODS

Study Area

The study is located in southwest Colorado, east of the Utah border in Canyon of the Ancients National Monument (CANM). This 164,000-acre monument is under the jurisdiction of the Bureau of Land Management (BLM). The elevation of CANM is approximately 4,900-7,500 ft. The area has a combination of gently sloping land, mesas, and rugged and deeply incised canyons. The vegetation includes pinyon-juniper communities, dryland shrub communities (e.g., sagebrush and saltbush) and sparsely vegetated areas with grass (e.g., cheatgrass, alkali sacaton, galleta, salina wildrye), forbs (e.g., tansyaster, stickseed, wooly plantain), cactus and shrubs.

The study sites (map, Figs. 1a and 1b) are in a relatively low elevation (5,000-5,200 ft), dryland setting within the Monument. Each site was located on one of two soils: Uzacol-Zwicker-Claysprings Complex (hereafter "Uzacol" soil) and Claysprings soil. The Natural Resources Conservation Service (NRCS) associates these two soils with two respective Ecological Types: Clayey Saltdesert (Uzacol soil) and Mudstone/Sandstone Hills (Claysprings soils), and CANM staff use these Ecological Types and ecological site reference sheets developed by NRCS to rate ecological condition of sites within CANM. All transects were surveyed in these two soil types in the three areas with different livestock grazing histories.

Uzacol soil can be found on hills, knobs, and ridges and is composed of residuum, colluvium, and slope alluvium from Morrison Shale. This soil complex has low available water capacity. Its suitability for ungulate grazing is classified as very poor. An abundance of small surface stones in this soil type contribute to this classification. Uzacol soils are on 3 to 12 percent slopes (Ramsey 2001).

Claysprings soil is the dominant soil type for large portions of the study area. Claysprings is found on knobs and ridges and is composed of residuum from Morrison Shale. It is a very stony clay loam that has very low available water capacity and is classified as very poor for ungulate use. Claysprings soil is shallow to very shallow, well-drained, and 3 to 12 percent slopes (Ramsey 2001).

Sites with three different levels of grazing were the areas of data collection: the 53-yr site, the 11-yr site and the actively grazed site (Fig. 1a).

"53-yr Site": This 1.9-acre exclosure, also known as the Garden Exclosure, was fenced on July 29, 1963. This fence has largely prevented livestock from accessing this area for 53 years prior to the study.[4] This exclosure is within the Flodine Park Allotment, which had been grazed regularly prior to the fence being installed.

"11-yr Site": This site has not been grazed by cattle since 2005, 11 years prior to the study, although some trespass horses have frequently grazed in the allotment. This site surrounds the exclosure in the Flodine Park Allotment whose permittee ceased grazing both Flodine Park and Yellow Jacket allotments following the 2005 Environmental Assessment (EA) and Finding of No Significant Impact for the two allotments. Due to reductions in season of use and numbers of cattle specified in the EA, the permittee/ preference holder did not sign the offered permit. The Land and Water Conservation Fund subsequently purchased the permittee's base property and donated it to the BLM in 2009.

"Actively Grazed Site": This site is in the currently grazed Hamilton Mesa allotment, which has been grazed for many years.

[4] Records in the mid 1990s indicate cattle had been in the exclosure (personal communication, Garth Nelson, CANM). Grand Canyon Trust has requested documents relating to use of the exclosure by cattle.

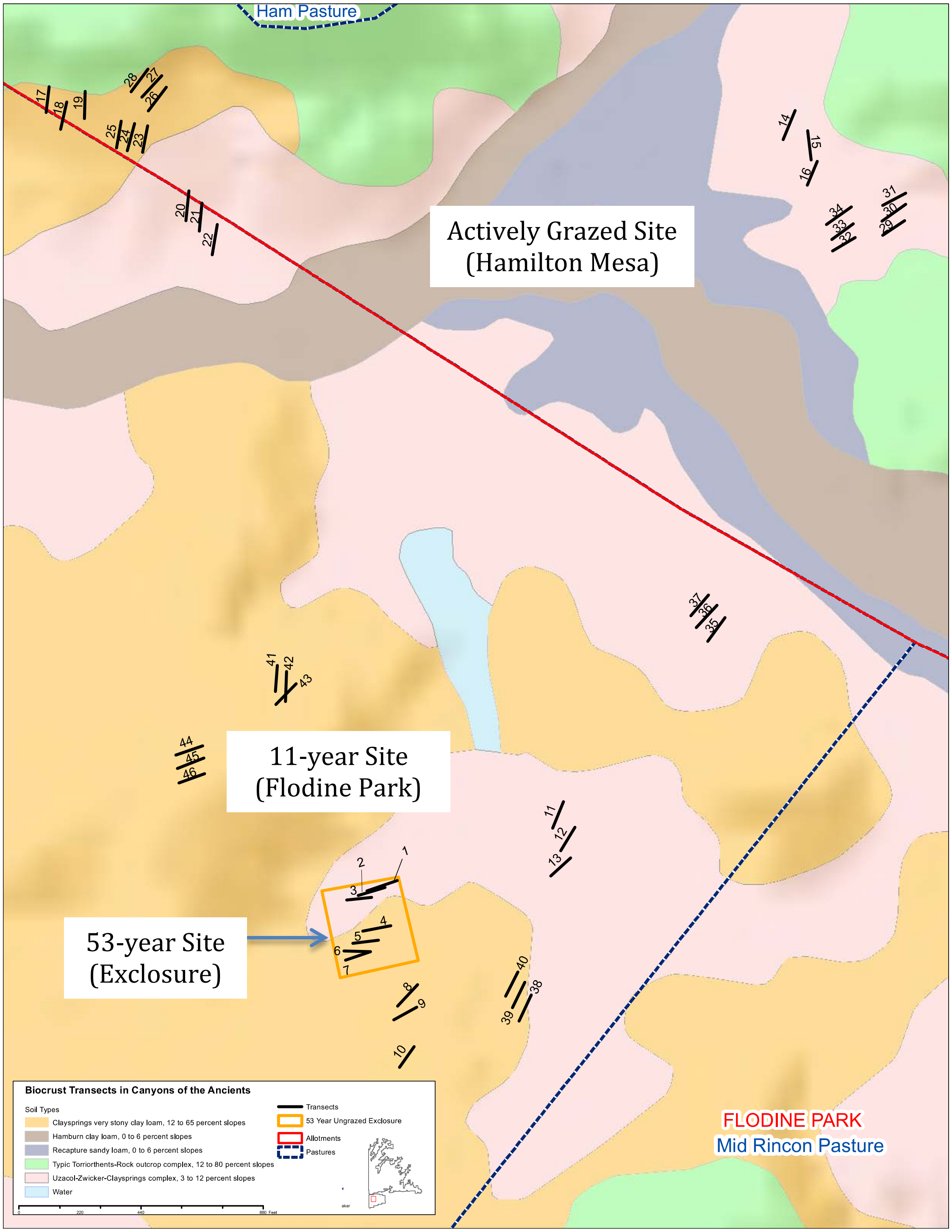

Fig. 1a. Location of sites, soil types and transects (numbered 1-46) in Canyons of the Ancients National Monument. Transects were sampled in areas with two soil types, Claysprings and Uzacol (see color code in legend), and three grazing histories (53-yr, 11-yr, and actively grazed). (Note that transects 18 and 20-22 were actually north of the allotment fence, and therefore were in the Hamilton Mesa Allotment. The error appears to be in the map shapefile provided by the Colorado BLM State Office, November 2015).

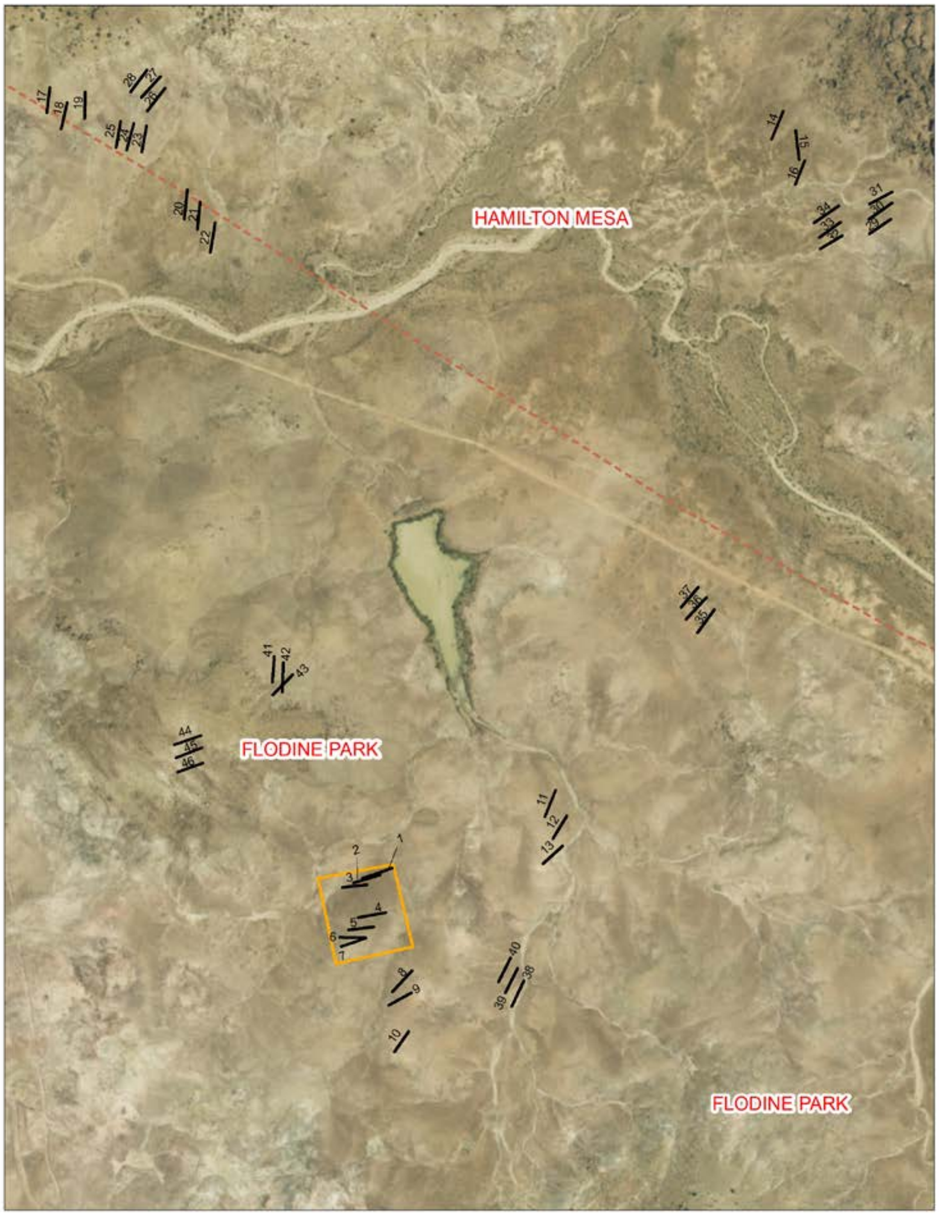

Fig. 1b. Aerial image of the study area showing the transect locations within the allotments (Hamilton Mesa = actively grazed; Flodine Park allotment had not been grazed by cattle in 11 years, and includes the 53-year exclosure, which is the square with Transects 1-7).

Transect locations

Data were collected in June and July 2016 by Lior Gross, James Kennedy, Polina Chizhof, and Alex Shoulders, interns with the Grand Canyon Trust. Multiple transects were located within each site. Data were collected along 46 transects, each 100 ft in length (Table 1). The transects were located in areas of comparable ecological type, soil type, elevation, slope and aspect. At least three transects were located within each of the two soil types, in each of the three grazing. Representative photos of these transect locations are presented in Figures 2-7.

Table 1. List of transects (numbers), and counts, where biocrust data were collected, by soil type and grazing history.

Soil	Claysprings	Claysprings	Claysprings	Uzacol	Uzacol	Uzacol
Grazing History	53-yr	11-yr	Active	53-yr	11-yr	Active
Transect Numbers	4, 5, 6, 7	8, 9, 10, 38, 39, 40, 41, 42, 43, 44, 45, 46	17, 18, 19, 23, 24, 25, 26, 27, 28	1, 2, 3	11, 12, 13, 35, 36, 37	14, 15 16, 20, 21, 22, 29, 30, 31, 32, 33, 34
Total (quantity of transects)	4	12	9	3	6	12

Sites 1-19: Initially, 100' transects were placed so there would be a set of three transects in both soil types in each of the three grazing groups. An initial 100' transect along a standard bearing was placed, then from the southeastern end of that transect, the next transect was placed about 50' perpendicular to the west and then 50' parallel to the south. It was at this point that the next 100' transect was placed. The distances between transects were altered as necessary in order to account for variability seen in the local landscape and prevent overlap with other transect sets.

Four transects were placed in the Claysprings soil type of the 19-acre 53-year exclosure in order to cover the area of the exclosure and represent the diversity present at a very small scale in this area. Three transects were placed in the Uzacol complex soil type because this section was less variable at a small scale and covered a smaller area of the exclosure than the other soil type.

A set of three transects was then placed in the upland area near the exclosure in Claysprings soil in order to capture this soil type with 11 years of recovery from active cattle grazing. Another set of three transects was placed near the exclosure in the Uzacol soil complex. These two sites were located with the guidance of Garth Nelson, BLM, who was in possession of the soil map for the area. Garth Nelson also helped us locate the plots and soil types in the active allotment. However, there was a Uzacol area that we passed through that was not represented by the existing transects for the Uzacol complex that had already been selected, so another three transects were added for that Uzacol in the active allotment.

Sites 20-46. Twenty-six additional transects were subsequently established to address the possibility the active allotment transects may not have been representative. These additional transects were located at randomly generated points in each soil type and grazing use type. Several random new Clayspring soil transects of the 11 year allotment were located on the side and top of a small mesa and several were directly at the base of small mesas, which was different than the gravelly small hills of the 11 year allotment. Finally, because the soil map was not on hand in GPS form when laying the new random transects, one of the additional random points to locate transects in the Uzacol complex of the 11 year allotments resulted in a set of three transects partially crossing into the Claysprings soil type, though they were coded as Claysprings.

The result was an uneven number of transects, so in the data analysis averages were calculated for transects and sites (Table 1). The 53-yr exclosure site had the fewest transects because it was a small area (1.9 acres); but that small area meant that these transects actually covered a large proportion of the exclosure

Fig. 2. Transect 6 in Claysprings soil of 53-yr exclosure. Toninia lichen (dark color) is visible in the center of photo on the right.

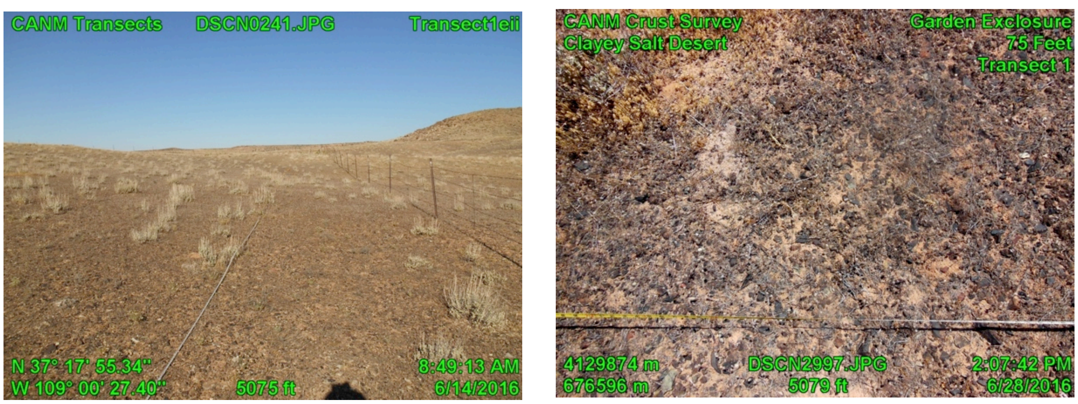

Fig. 3. Transect 1 in Uzacol soil of 53-yr exclosure.

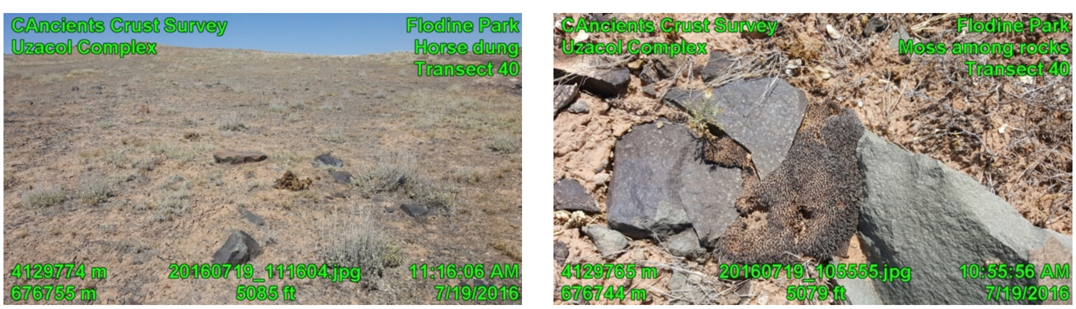

Fig. 4. Transect 40 in Claysprings soil of the 11-yr site. is visible among the rocks in the photo on the right.

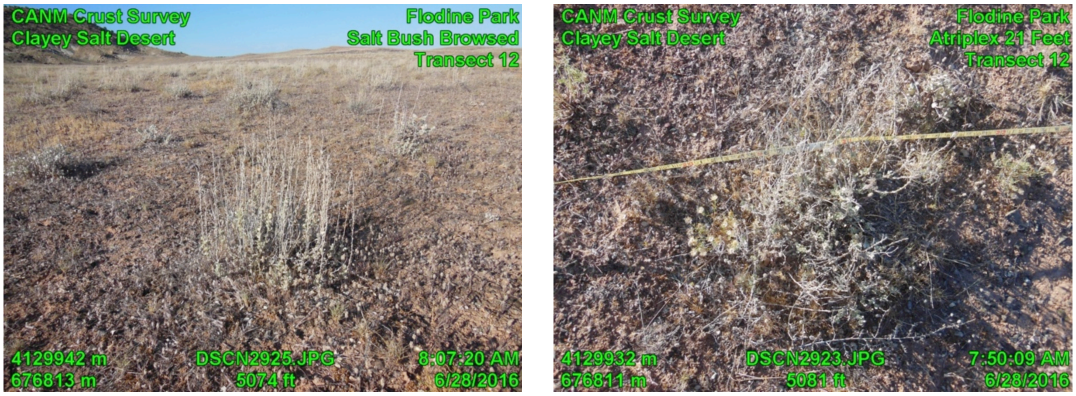

Fig. 5. Transect 12 in Uzacol soil of 11-yr site.

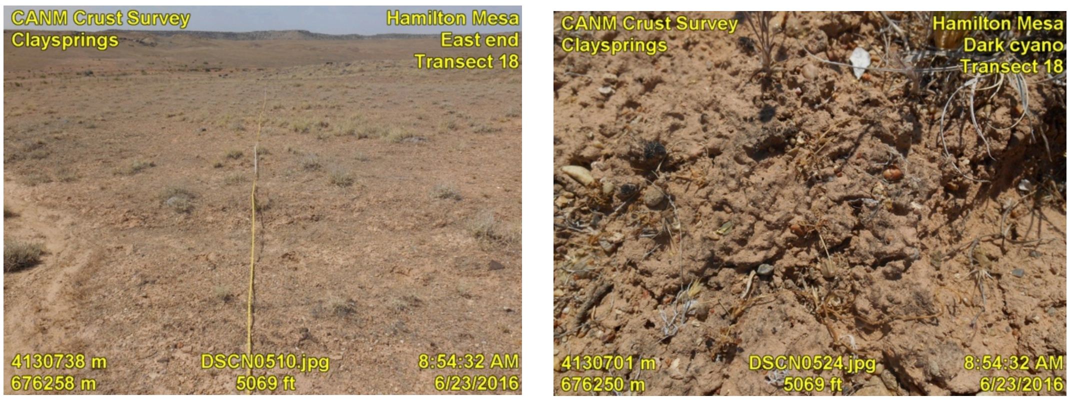

Fig. 6. Transect 18 in Claysprings soil of actively grazed site. Dark cyanobacteria are visible in the center of the right-hand photo.

Fig. 7. Transect 15 in Uzacol soil of actively grazed site. Plants and biocrust are visible in the photo on the right.

Data collection

Five types of data were collected: photos, line-point intercept for ground cover, level of development, soil aggregate stability, and biocrust species.

1. Photos. Geo-referenced photos were taken at set distances along each transect: 0, 25, 50, 75, and 100 foot points. Georeferenced macro photos were taken of each biocrust species for which a voucher specimen was collected. Additional photos were taken to illustrate site conditions (Figs. 2-7).

2. Line-point intercept for soil cover. The method used was based on the BLM's Assessment, Inventory, and Monitoring (AIM) surveys, as described on pp. 27-35 in *Monitoring Manual for Grassland, Scrubland and Savanna Ecosystems* (Herrick et al. 2015). The authors of that manual note (p. 27) that "Line-point intercept is a rapid, accurate method for quantifying soil cover, including vegetation, litter, rocks and biotic crusts. These measurements are related to wind and water erosion, water infiltration and the ability of the site to resist and recover from degradation."[5]

Along each transect, the line-point intercept method was used to record data at 2-foot intervals, resulting in 50 data points at each transect. This resulted in at least 150 points for each site. All transects were intended to be laid out parallel at a given site, according to a 110 degree bearing from the east end to the west end of the transect, however several transects inadvertently deviated from that objective (Fig. 1a).

At each 2-foot interval, a pin was lowered and a single soil cover type was recorded: biocrust type (light cyanobacteria, dark cyanobacteria, moss, or lichen), vegetation type (shrub, grass, forb), litter, bare soil, or rock. Biocrust categories were recorded as light cyanobacterial crust, dark cyanobacterial crust, moss and lichen (Belnap et al. 2001).

To determine the presence or absence of light cyanobacterial crust at each point (because the color can be indistinguishable from the soil), a small (~1 cm^2) square of soil approximately 0.5 to 1 cm thick was lifted with a small spatula and held gently between the thumb and forefinger to observe whether cyanobacterial filaments were aggregating and holding soil particles (Fig. 8). If cyanobacterial filaments were aggregating soil particles, light cyanobacteria were recorded as present.

[5] The line-point intercept method of Herrick, et al. (2015) does not include assessing light cyanobacterial crust, while this study did so.

Fig. 8. Cyanobacterial filaments that bind soil. Photo from Northern Arizona University Forest-Rangeland Soil Ecology Lab.

A point on the ground was considered available for biocrust occupancy if it was bare soil, but unavailable for biocrust if the pointer encountered rock, plant (shrub, grass, forb), or litter at the ground level. The transects used for the line-point intercept measurements resulted in the numbers of points (sample size) listed in Table 2, which were used to quantify the average cover of biocrust and bare ground. The relatively small size of the exclosure is the reason that the 53-yr site has fewer points than the other sites.

Table 2. Number of points where biocrust cover was recorded.

	Claysprings bare soil or biocrust			Uzacol bare soil or biocrust		
	53-yr	11-yr	Active	53-yr	11-yr	Active
Points	51	277	191	61	151	217

3. Level of Development. Level of Development of dark cyanobacterial crust was determined In 25x25 cm plots next to each point (every 2 ft) along transects, and presence of all species of moss and lichen was recorded. Level of Development was determined using the visual index to six categories of biological crust development of Rosentreter et al. (2007). As noted in that guide (p. 10), “Tests showed these categories are easily distinguished by both trained and untrained observers and are closely related to cyanobacterial biomass and the resistance of the soil surface to wind and water erosion.”

The number of plots where level of development was assessed (sample sizes) are listed in Table 3. The relatively small size of the exclosure is the reason that the 53-yr site has fewer samples, compared to other sites.

Table 3. Number of small plots where soil development was assessed.

	Claysprings Soil			Uzacol Soil		
	53-yr	11-yr	Active	53-yr	11-yr	Active
Plots	200	600	448	150	300	600

4. Soil aggregate stability. At 9 random locations along each 100-ft transect, soil stability was assessed using the method of Herrick et al. (2009). This method involves wetting the soil and observing how quickly and how much the soil dissolves. Herrick et al. (2009) describe the test this way:

> The soil stability test provides information about the degree of soil structural development and erosion resistance. It also reflects soil biotic integrity, because the "glue" (organic matter) that binds soil particles together must constantly be renewed by plant roots and soil organisms. This test measures the soil's stability when exposed to rapid wetting.

This test provided quantitative information to complement the visual observations of: (1) level of development; and (2) light cyanobacteria observations along the line-point intercept.

The number of soil samples (sample size) for the soil aggregate stability tests are listed in Table 4. The relatively small size of the exclosure is the reason that the 53-yr site has fewer samples compared to other sites.

Table 4. Number of samples used to evaluate soil stability.

	Claysprings Soil			Uzacol Soil		
	53-yr	11-yr	Active	53-yr	11-yr	Active
Samples	36	108	81	27	54	108

5. Biocrust species. Voucher specimens of all biological soil crust species were collected along each transect. Biological crust lichen and moss specimens were identified using the *Field Guide to Biological Soil Crusts of Western U.S. Drylands* (Rosentreter et al. 2007) and these identifications were confirmed by biological soil crust specialists including Hilda Smith at the Southwest Biological Science Center, US Geological Survey in Moab, Utah.

Vegetation types were recorded, but inexperience with plant identification resulted in limited data about plant species intercepted by the pin at ground level.

Statistics

Mixed logistic models were performed using Stata software (Statacorp 2015). The random variable in the mixed models was transect, which corrects the standard errors for the fact that observations in each transect tend to be more closely alike than those of other transects. The coefficients reported are odds ratios and the reference groups were the 53-year exclosure for the grazing regime, and Uzacol soil for the soil type. This was a two-tailed probability test, using a 95% confidence interval, with the p-values reported in the tables.

Statistical significance between proportions at different sites was calculated for the proportions and sample size (number of points or plots for a site type) using the online calculator at https://www.medcalc.org/calc/comparison_of_proportions.php. MedCalc uses the "N-1" Chi-squared test.

Statistical difference between average values at different sites was calculated for the mean, standard deviation and sample size (number of points or plots for a site type) using the online calculator at https://www.medcalc.org/calc/comparison_of_means.php.

In this study p-values ≤ 0.05 were considered statistically significant.

RESULTS

Sites had different amounts of available area where biocrust could establish. Areas where biocrust cannot establish include rock, vegetation and litter, and the average amount of such unavailable area for the sites sampled was between 48% and 75%. For most of the sites the highest cover of unavailable points was rock, followed by litter and then vegetation; the ranges in unavailable cover values were 13-41% rock, 17-27% litter and 6-26% vegetation Since those parts of the transects (with rock, vegetation and litter cover) were not available for biocrust establishment, those areas were excluded from the analyses of percent cover.

The absolute cover values for each of the sites are presented in Figures 9-14 to show the amount of available and unavailable surfaces, but subsequent figures and analyses focus on points that had the potential to have biocrust, which were bare ground, cyanobacteria, moss or lichen.

Details on sample sizes for the different sites and variables are presented in tables in the Methods section. Details on statistical significance for the different sites and variables are presented in the tables in Appendix A.

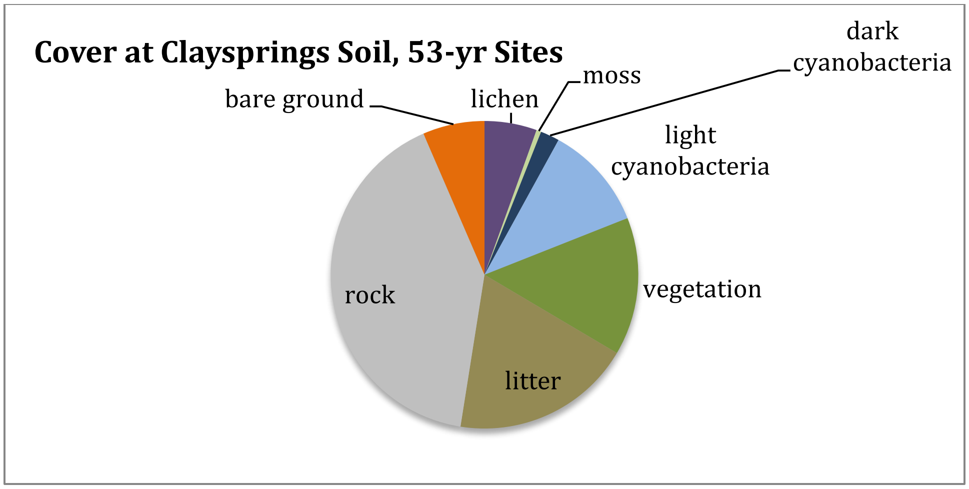

Fig. 9. Absolute cover on Claysprings soil in the 53-yr exclosure site.

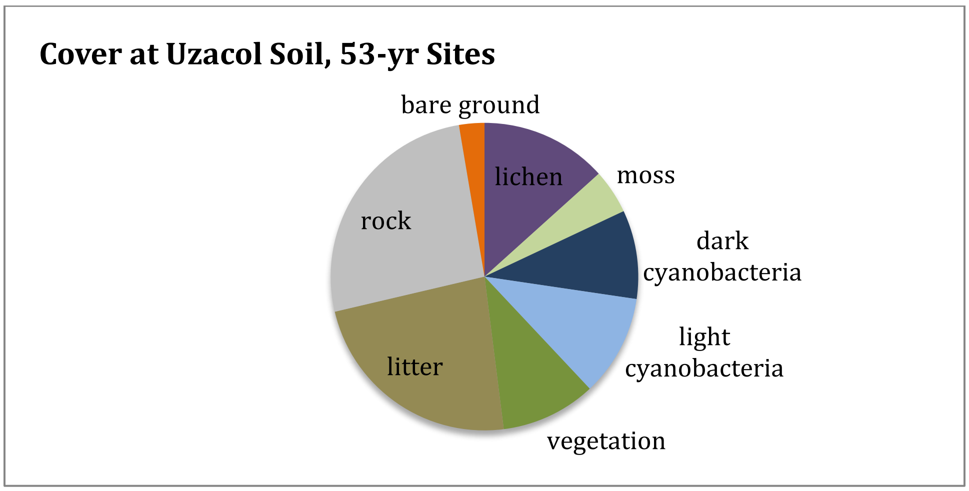

Fig. 10. Absolute cover on Uzacol soil in the 53-yr exclosure site.

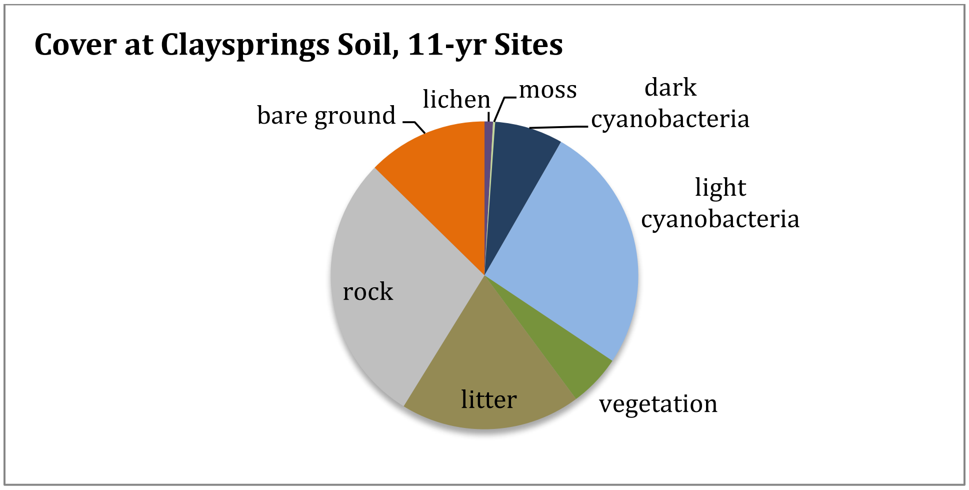

Fig. 11. Absolute cover on Claysprings soil in the 11-yr exclosure site.

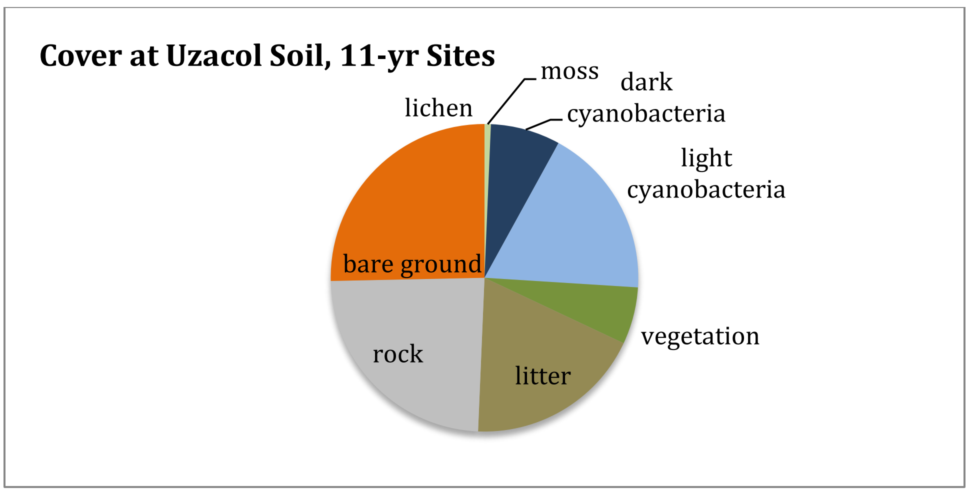

Fig. 12. Absolute cover on Uzacol soil in the 11-yr exclosure site.

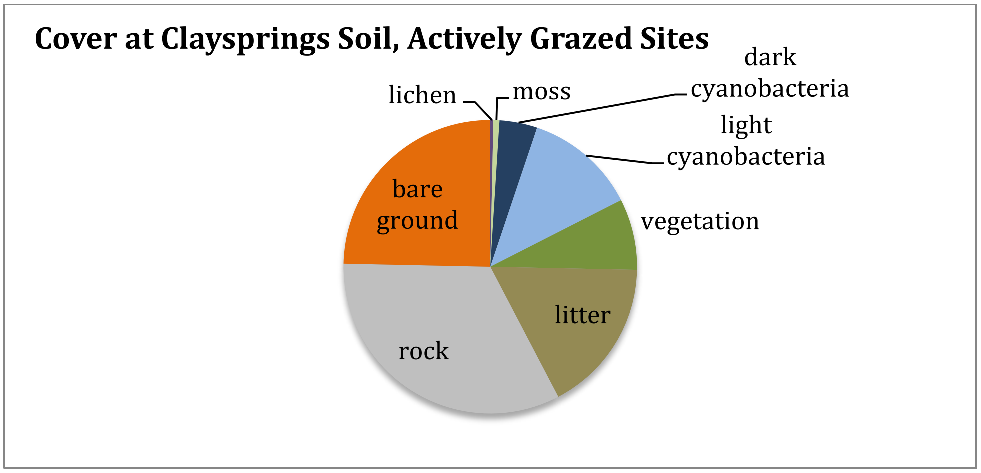

Fig. 13. Absolute cover on Claysprings soil in the actively grazed site.

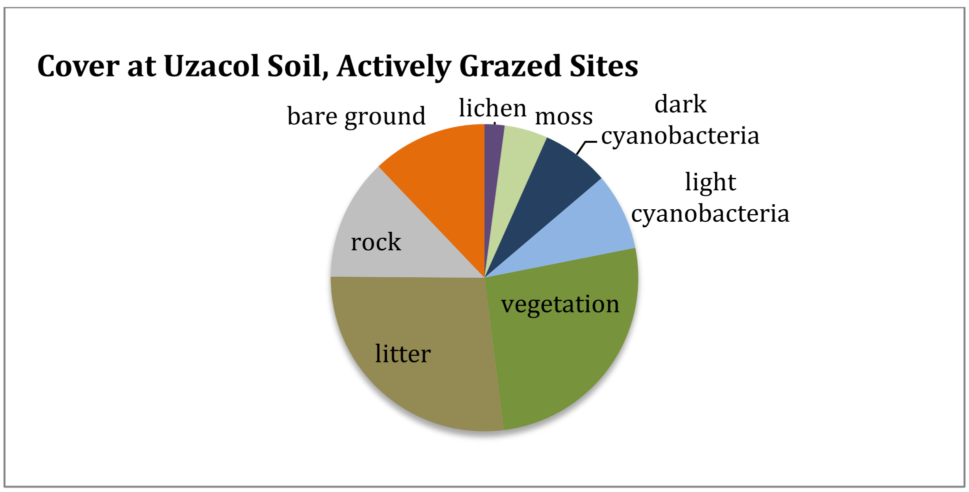

Fig. 14. Absolute cover on Uzacol soil in the actively grazed site.

Biocrust and Soil

While the focus of the study is on the presence of biocrusts on soils that have last been grazed by livestock for different periods of time, the two soils in the study differed regarding the presence of biocrust components.

Lichen, moss, and dark cyanobacteria were present with higher frequency on Uzacol soil compared to Claysprings soil. However, **lichen** was not significantly more frequent ($p = 0.649$), while **moss** was present more than twice as often on Uzacol sites; with statistical significance ($p = 0.049$). **Dark cyanobacteria** was also present more than three times as often on Uzacol sites, with statistical significance ($p = 0.004$).

In contrast, light cyanobacteria and bare soil were more frequent on Claysprings soil than Uzacol soil. **Light cyanobacteria** was not statistically more frequent ($p = 0.219$), but **bare ground** was 2.3 times as frequent on Claysprings sites, a difference that was statistically significant ($p = 0.049$).

Biocrust and Grazing

Light cyanobacteria in this paper are defined as "early seral biocrust" because they generally establish before other biocrust organisms (Jimenez Aguilar et al. 2009). After cyanobacteria establish, lichens and mosses can colonize (Rosentreter et al. 2007); therefore we use the term "mid-late seral biocrust" to group dark cyanobacteria, moss, and lichen.

Sites with different grazing histories, i.e., 53 years of livestock exclusion, 11 years of livestock exclusion (although wild horses grazed there) and actively grazed, differed in terms of biocrust presence on available soil sites, with later seral biocrust (lichen, moss, and dark cyanobacteria) generally, but not always associated with longer times since grazing (Tables 5 and 6 and Figs. 15-17; Appendix A Tables A1a-A5b).

<u>Claysprings sites</u>. Cover of lichen (a late-seral component) was significantly higher in the 53-year Claysprings sites than in the 11-year and actively grazed sites, but moss cover was not significantly different on the three sites (Table 5). Dark cyanobacteria, a mid-seral biocrust component, and light cyanobacteria, the pioneering early-seral biocrust component, were statistically highest in the 11-year site. Bare ground was statistically highest on the actively grazed sites. All of these statistical differences (Table 5; Appendix A) were significant at less than 0.04 (range was $p = 0.0001$ to 0.039).

Table 5. Claysprings soil cover types, grazing history and percent biocrust cover of available areas.

Cover Type	Percent Cover (of available areas) on Claysprings Soil		
	53-yr Site*	**11-yr Site***	**Actively Grazed***
lichen	21.6^{a}	2.9^{b}	1.0^{b}
moss	2.0^{a}	1.1^{a}	1.0^{a}
dark cyanobacteria	7.8^{ab}	14.1^{b}	7.9^{a}
light cyanobacteria	43.1^{a}	50.2^{b}	29.3^{a}
bare ground	25.5^{a}	31.8^{a}	60.7^{b}

** For each row, statistically significant differences in values are indicated by different superscript letters (e.g., a and b) based on the test for difference between proportions. In this table, all statistically significant differences were below 0.04 ($p < 0.04$).*

<u>Uzacol sites</u>. On Uzacol soils, which tend to support higher amounts of biocrust (see "Biocrust and Soil" above), sites were significantly different for fewer biocrust types, but the sites that were significantly different, were highly significantly different (i.e., $p < 0.008$). Cover of lichen was significantly greater in the 53-year sites than in the 11-year and actively grazed sites. Moss (at 4.6% cover) and dark cyanobacteria were higher on both the 53-year and actively grazed sites than the 11-year sites, though the moss difference was not statistically significant. Light cyanobacteria, as on the Claysprings soil, was highest on the 11-year sites, and bare soil was lowest at the 53-year sites (Table 6).

Table 6. Uzacol soil cover types, grazing history and percent biocrust cover of available areas.

Cover Type	Percent Cover (of available areas) on Uzacol Soil		
	53-yr Site*	**11-yr Site***	**Actively Grazed***
lichen	32.8^{a}	0.0^{c}	4.6^{b}
moss	11.5^{a}	0.7^{b}	11.5^{a}
dark cyanobacteria	23.0^{a}	19.2^{a}	24.0^{a}
light cyanobacteria	26.2^{a}	47.7^{b}	24.4^{a}
bare ground	6.6^{a}	32.5^{b}	35.5^{b}

** For each row, statistically significant ($p \leq 0.05$) differences in values are indicated by different superscript letters (e.g., a, b, or c) based on the test for difference between proportions. In this table, all statistically significant differences were below 0.008 ($p < 0.008$). Significance values are found in Appendix A.*

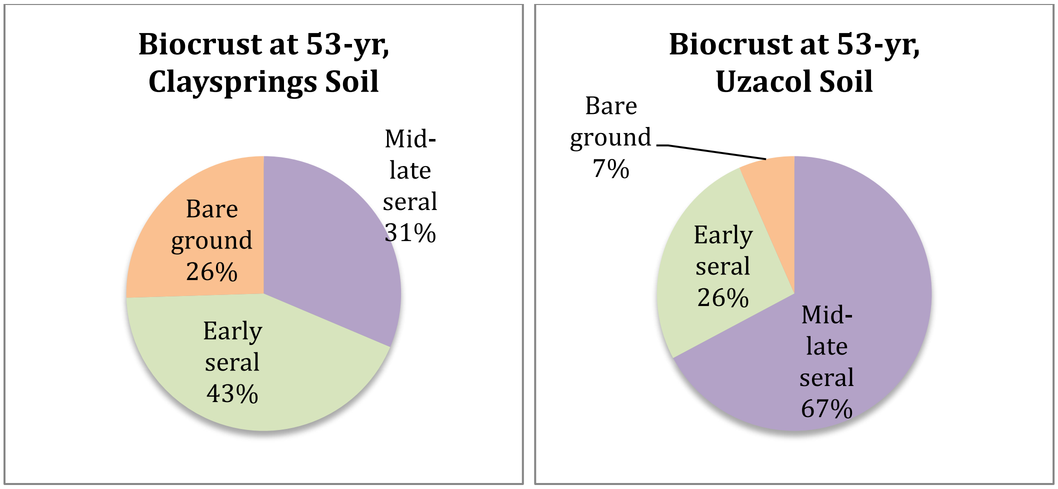

Fig. 15. Relative abundance of biocrust, for potential biocrust points (biocrust or bare soil), on Claysprings (left) and Uzacol (right) soil in the 53-yr exclosure site.

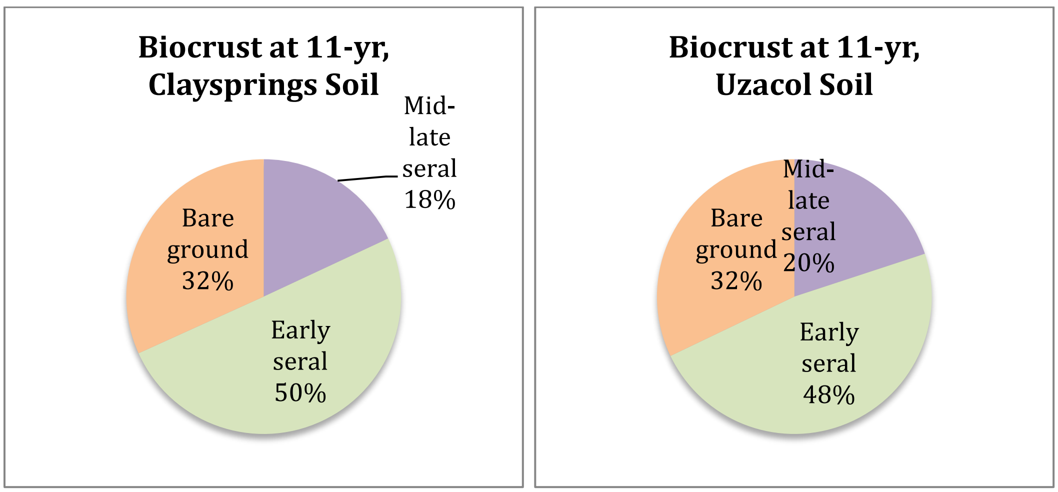

Fig. 16. Relative abundance of biocrust, for potential biocrust points (biocrust or bare soil), on Claysprings (left) and Uzacol (right) soil in the 11-yr site.

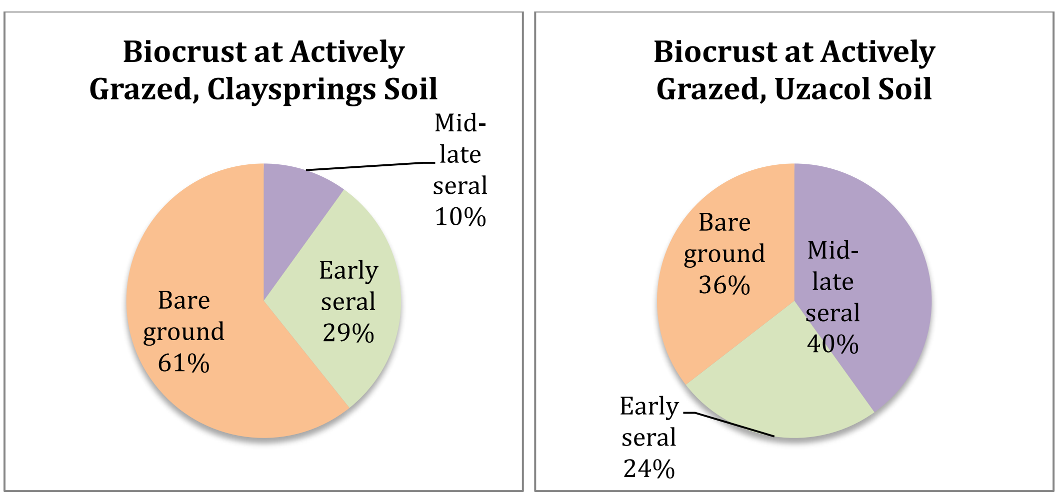

Fig. 17. Relative abundance of biocrust, for potential biocrust points (biocrust or bare soil), on Claysprings (left) and Uzacol (right) soil actively grazed site.

Mid-late seral biocrusts were significantly more abundant at the 53-yr sites than either the 11-year or actively grazed sites. While mid-late seral biocrusts were significantly greater at the 11-yr sites than the actively grazed sites on Claysprings soil, they were lower than either the 53-year or actively-grazed sites on Uzacol.

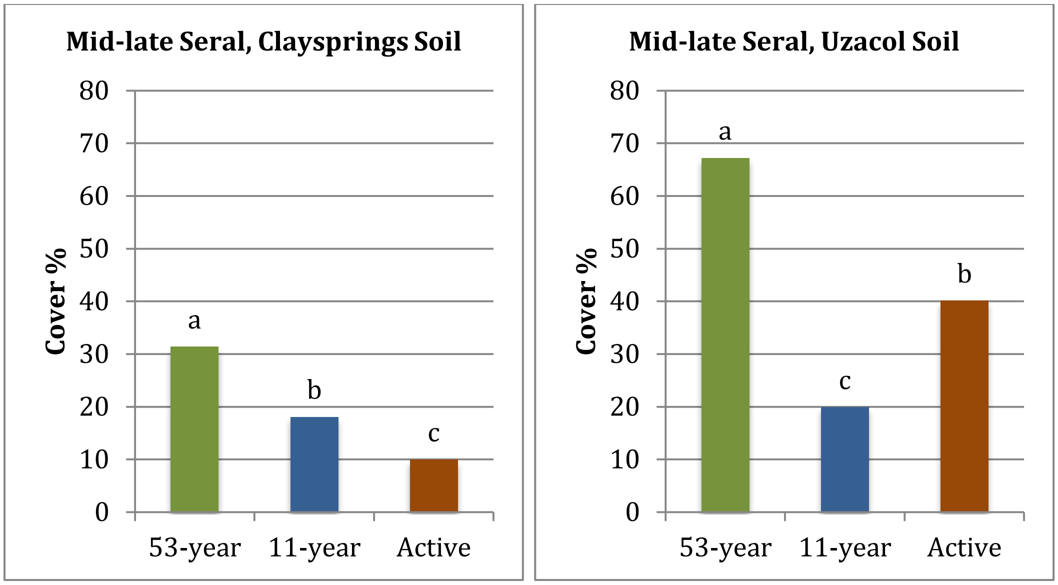

Fig. 18. Cover of mid-late seral biocrust by soil and grazing history. Different letters (a, b, or c) over the bars indicate statistically different groups ($p \leq 0.05$). Significance values are found in Appendix A Tables A2a and A2b.

Lichen abundance was one of the reasons that mid-late biocrust was significantly higher at 53-yr sites, compared to both 11-yr and actively grazed sites for both soil types (Tables 5 and 6; Fig. 19). For Claysprings soil there was no statistical difference ($p = 0.176$) in the much smaller lichen cover between the 11-yr and actively grazed site. Lichen is a late seral biocrust component.

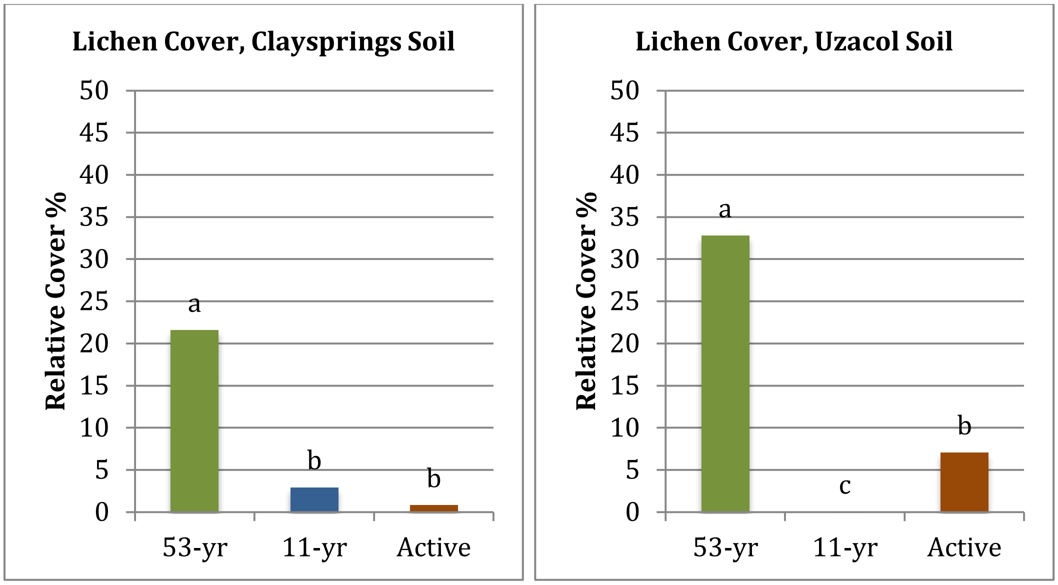

Fig. 19. Cover of lichen by soil and grazing history Different letters (a, b, or c) over the bars indicate statistically different groups ($p \leq 0.05$). Significance values are found in Appendix A Tables A3a and A3b.

Neither moss nor dark cyanobacteria (a mid-seral biocrust component) showed strong patterns at different grazing histories on the two soils. Moss was not statistically different at the Claysprings sites, largely because < 2% moss cover was present at all three grazing histories (Table 5). Uzacol soil sites had more moss cover with 11.5% cover at both the 53-yr and actively grazed sites (Table 6; Appendix A Tables A4a and A4b).

Light cyanobacteria (early seral biocrust) was generally highest in the 11-yr grazed sites (middle bar in Fig. 20). For both soils, light cyanobacteria had significantly higher cover than the actively grazed site. Light cyanobacteria was not statistically different on the 53- and 11-yr sites on Claysprings soil but was significantly higher than the 53-yr sites on Uzacol soil (Tables 5 and 6; Figures 20; Appendix A Tables A9a and A9b).

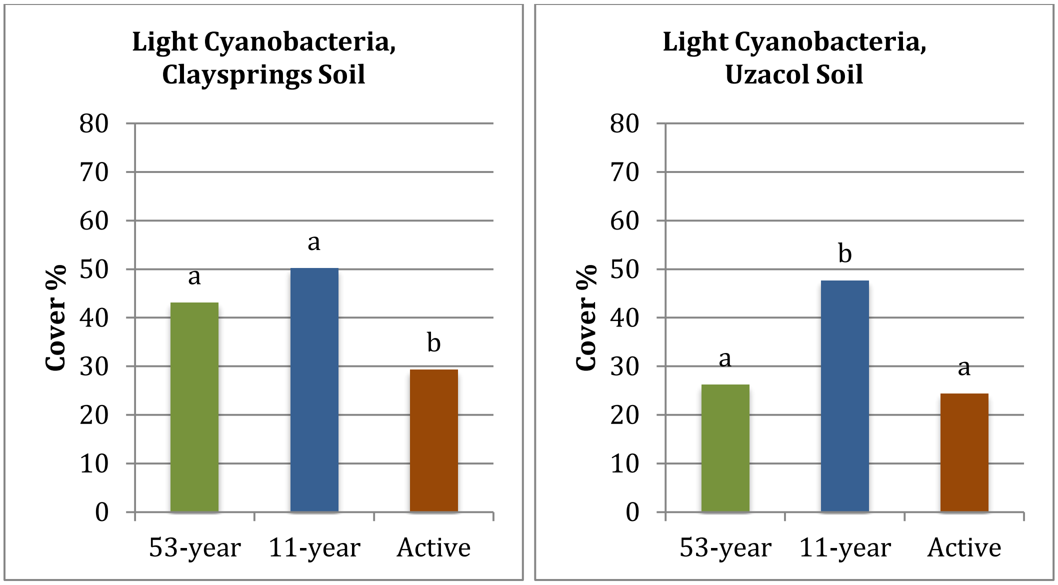

Fig. 20. Light cyanobacteria cover by soil and grazing history.. Different letters (a, b) over the bars indicate statistically different groups ($p \leq 0.05$). Significance values are found in Appendix A Tables A9a and A9b.

Bare ground was lowest in 53-year sites, next lowest in the 11-year sites, and highest in active grazing sites (Fig. 21). The differences were not significant between the 53-year and 11-year sites on Claysprings soil, or between the 11-year and actively grazed sites on Uzacol soil.

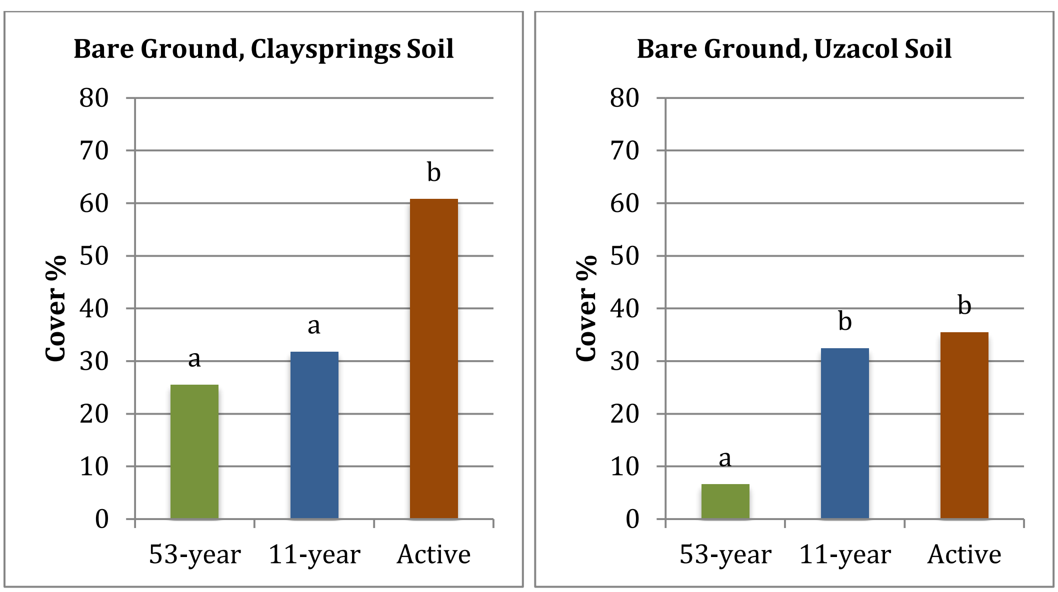

Fig. 21. Bare ground cover by soil and grazing history. Different letters (a, b) over the bars indicate statistically different groups ($p \leq 0.05$). Significance values are found in Appendix A Tables A10a and A10b.

Number of lichen and moss species. Thirteen lichen species and five unidentified lichen species were intercepted on the transects or observed in the Level of Development plots (Table 7). Five moss species and one unidentified moss species were intercepted on the transects or observed in the Level of Development plots (Table 7). Because there were different numbers of transects by grazing history, the most appropriate reporting value for grazing history and soil is by average number of species per transect (Fig. 22).

Table 7. All biocrust species observed along transects.

Lichen	Moss
Aspicilia sp.	*Bryum argenteum*
Asplecia reptans	*Crossidium* sp.
Buellia elegans	*Didymodon vinealis*
Collema coccophorum	*Pterygoneurum ovatum*
Collema tenax	*Syntrichia caninervis*
Fulgensia bracteata	*Syntrichia ruralis*
Placidium lacinulatum	
Placidium squamulosum	
Psora crenata	
Psora decipiens	
Psora montana	
Psora tuckermanii	
Rhizopaca peltata	
Squamarina sp.	
Toninia sp.	
Toninia sedifolia	
2 unknown species	

The number of moss and lichen species per transect by soil and grazing history are reported in Fig. 22. The 53-yr sites had significantly more species per transect than the actively grazed sites for both soil types. The Claysprings soil had slightly fewer (non-significant statistically) species on the 11-year than the 53-yr site; but significantly more species per transect than the actively grazed site. The Uzacol soil 11-yr sites had significantly fewer species than the 53-yr site, but statistically similar number of species compared to the actively grazed site.

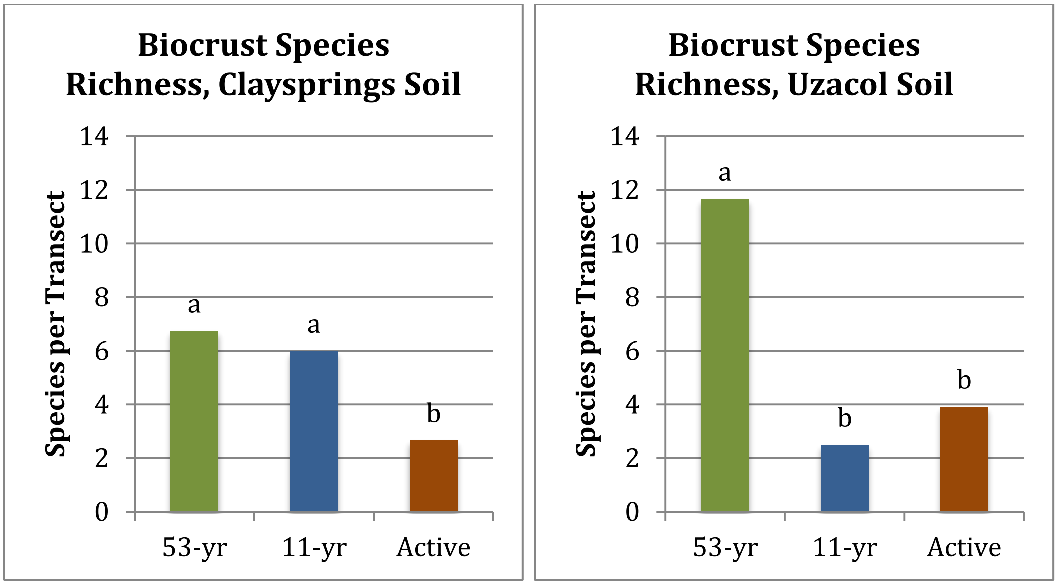

Fig. 22. Average number moss plus lichen species per transect by soil and grazing history. Different letters (a, b) over the bars indicate statistically different groups ($p \leq 0.05$). Significance values are found in Appendix A Tables A8a and A8b.

Level of Development, a measure of the density and development of dark cyanobacteria when found in 25cm x 25cm plots (see Methods), was generally highest (sum of levels 3 and 4) in the 53-yr site, and lowest (level 1) in the actively grazed sites (Figs. 23 and 24). Pair-wise statistical analyses of level 3 and level 1 show this, as described in the next paragraphs for each soil type. In both Claysprings and Uzacol soils, level 3 of dark cyanobacteria development was significantly highest in the 53-year sites. Level 1, the lowest level of biocrust development, was significantly highest on the actively grazed sites compared to the 53-yr sites for both soil types. On Claysprings soil the level 1 development on 11-year sites was not statistically different than 53-yr sites (Fig. 23); and on the Uzacol soil the level 1 development on 11-yr sites was statistically (although unexpectedly) higher than the actively grazed sites (Fig. 24).

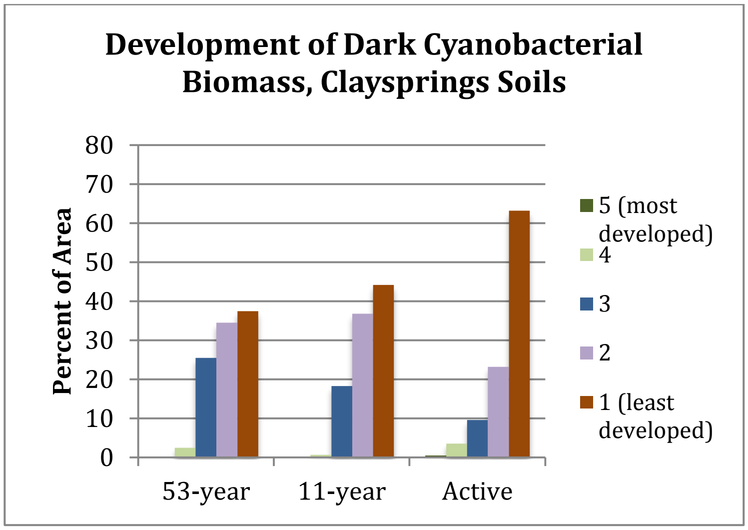

Fig. 23. Average percent of different levels of development of dark cyanobacteria on Clarysprings soil transects by grazing history. Significance values are found in Appendix A Tables A6a, A6b, A11a and A11b.

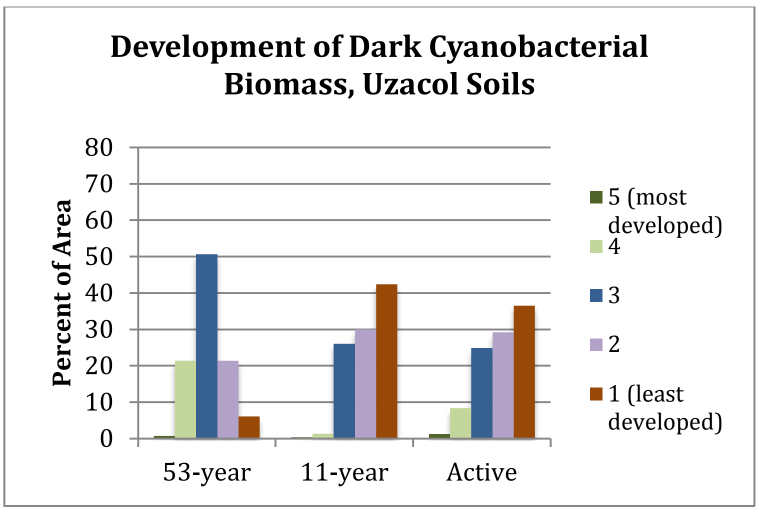

Fig. 24. Average percent of different levels of development of dark cyanobacteria on Uzacol soil transects by grazing history. Significance values are found in Appendix A Tables A6a, A6b, A11a and A11b.

Soil stability tests were done to measure soil structural development and erosion resistance. At the 53-yr sites over 70% of soil samples were in the highest stability class (class 6) for both soil types, and that was statistically greater than both the 11-year and actively-grazed sites (Figs. 25 and 26). The high stability class (class 6) was greater in the 11-yr compared to the actively grazed site for both soil types; this was statistically significant for the Clarysprings soil, but not for the Uzacol soil.

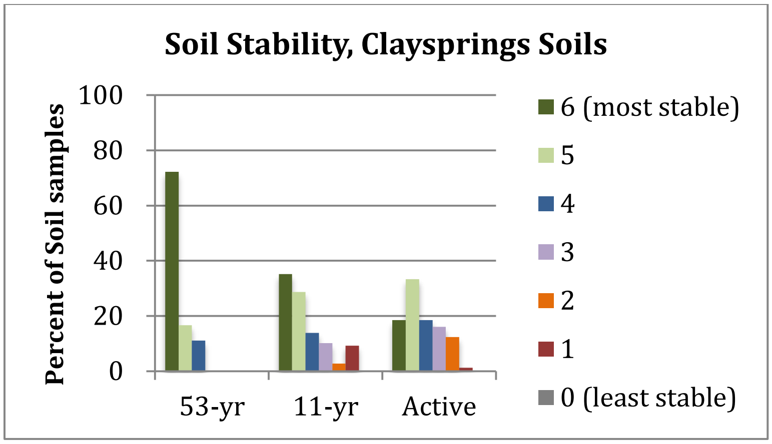

Fig. 25. Percent of soil samples with different average stability ratings (0 to 6) for Clayprings soil. Significance values are found in Appendix A Tables A7a, A7b, A11a and A11b.

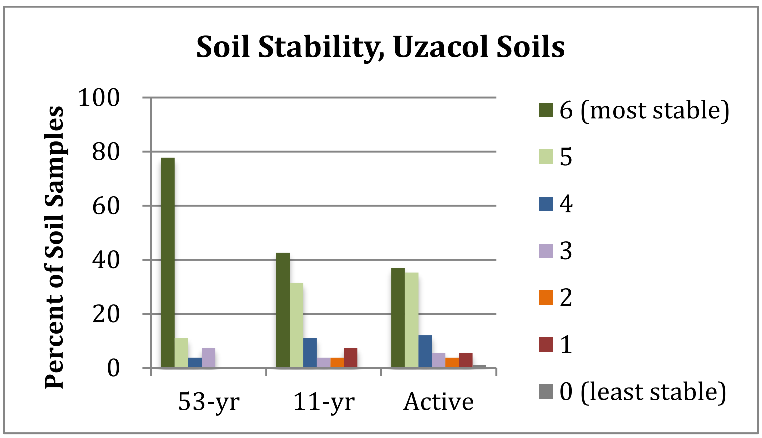

Fig. 26. Percent of soil samples with different average stability ratings (0 to 6) for Uzacol soil. Significance values are found in Appendix A Tables A7a, A7b, A11a and A11b.

DISCUSSION

Grazing and Recovery

The 53-yr site, where livestock had been excluded for the previous five decades, when compared to the actively grazed site for both soil types had the following statistically significant characteristics:

- more total biocrust;
- more mid-late seral biocrust;
- more lichen;
- greater level of darkness (dark cyanobacteria development);
- greater soil stability;

- greater number of lichen and moss species; and
- less bare ground.

A study by Gomez et al. (2012) also found dramatically higher (300%) total biocrust cover in areas where livestock had been excluded for 40 years compared to surrounding areas used for cattle grazing. These patterns noted above are consistent with a process of recovery associated with protection from cattle grazing for 53 years. Many of these patterns also existed when comparing the 53-yr and 11-yr sites, but to a lesser degree.

The 11-yr site, where livestock had been excluded for the previous decade (although horses did get into this area as observable by their scat) had the following statistically significant differences compared to the 53-yr sites for both soil types:

- less mid-late seral biocrust
- less lichen cover
- less dark cyanobacteria development
- lower soil stability.

The 11-yr site had intermediate values between the 53-yr and the actively grazed sites, which were not always statistically significant, for the following attributes for both soil types:

- total biocrust cover;
- dark cyanobacteria development;
- soil stability; and
- bare ground.

The 11-yr site had more light cyanobacteria than the actively grazed sites (statistically) and the 53-yr sites for both soil types. The greater amount of light cyanobacteria at the 11-yr sites is consistent with the results reported by Jimenez Aguilar et al. (2009) who found increases in light cyanobacteria after only two years of grazing removal during a rainy season, while cover in grazed plots did not increase.

These findings reported here are consistent with a process of recovery for 11 years since cessation of cattle grazing.

The actively grazed site had the following (statistically significant) characteristics compared to the 53-yr sites, and a less strong pattern compared to the 11-yr sites, for both soil types:

- less total biocrust cover;
- less cover of mid-late seral biocrust;
- less cover of lichen;
- less developed dark cyanobacterial crust;
- fewer species of biocrust per transect;
- lower soil stability;
- less light cyanobacteria;

- greater amount of bare ground.

These results indicate a successional process of recovery of soil biocrusts associated with removal of livestock. The process begins with the establishment of light cyanobacteria, which in this study occurred in the 11-year period after cattle exclusion (despite an unknown amount of horse trespass), a relatively rapid process. Over a longer period of time (53 years in this study) the mid-late seral biocrust (especially lichens in this study) establish, presumably using light cyanobacteria and/or dark cyanobacteria as a substrate which results in lower abundance of light cyanobacteria as a cover type over time. In this later successional stage there are also more species of biocrust and less bare ground.

Some results were unexpected:

For Uzacol soil, lichen was higher at the actively grazed sites compared to the 11-yr site. This may be due to horse trespass, or simply a result of patchiness on the landscape.

Dark cyanobacteria, on Claysprings soil, was highest at the 11-yr site, and lower at both the 53-yr and actively grazed site. It may be that lichen eventually replaced a former proportion of dark cyanobacteria in the 53-year site.

Moss cover was low at all the Claysprings sites; at the Uzacol site there was moss cover of about 11% at both the 53-yr sites and the actively grazed sites, but only 0.7% at the 11-yr site. Gomez et al. (2012) found that moss did not increase in areas where livestock had been excluded for 40 years compared to surrounding areas used for cattle grazing. They conclude that moss recovery is slower than lichen recovery which is consistent with our findings.

Some uncertainties related to this study, that may have affected the observation of trends, include:

- the unknown impacts from unauthorized horse grazing in the 11-yr site;
- unknown reason for locating the exclosure[6];
- inconsistency in transect location process;
- landscape variability that may not have been accounted for; and
- climate change.

The results presented here are consistent with other studies that have documented greater abundance of biocrusts in areas where livestock have been excluded, compared to actively grazed sites (Concostrina-Zubiri et al. 2014; Gomez et al. 2012). Our data provide additional detail, indicating that light cyanobacteria are able to establish relatively quickly after a disturbance, and later are replaced by mid-late seral biocrust development, as found in the 53-year exclosure. Similar development of light cyanobacteria crusts were detected by Grand Canyon Trust (2015) in point-intercept surveys on 170 BLM transect sites in Grand Staircase-Escalante National Monument.

[6] Garth Nelson (personal communication) of CANM notes that the exclosure was "part of the Garden Pitting and Seeding" treatment" of 1962 and 1963.

The low amount of lichen in both the 11-yr sites and the actively grazed sites suggest that lichen are very vulnerable to disturbance by livestock. The dramatically higher cover of lichen in the 53-yr sites suggests that lichen can make significant recovery within a period of decades. This is not to suggest that these sites have reached complete recovery of lichen and other late-successional biocrusts. Full recovery of biocrusts at these dryland sites would certainly require a longer time period, perhaps over 100 years. In a review paper by Bowker (2007) he indicates that unassisted recovery times for biocrusts in different locations vary from 6 years to a century, and even millenia. Bowker indicates that efforts that involve assisted recovery may greatly reduce recovery times.

The findings of this study can help land managers better understand the recovery process of biocrusts and the role that livestock grazing has in biocrust degradation.

Soil Differences

The two soils where data were collected for this study differed in biocrust cover as well as different responses to rest from grazing.

Uzacol soil had significantly more moss and dark cyanobacteria than Claysprings soil. This was the case even at the actively grazed site, suggesting that Uzacol soil may be more resistant to negative impacts from disturbance than Claysprings soil, or may have greater biocrust potential.

Claysprings soil had statistically more light cyanobacteria, an early seral biocrust, and more bare ground than Uzacol soil. Perhaps the Claysprings soil is less resilient during and/or after disturbance, resulting in more bare ground and early seral biocrust.

NRCS Ecological Site Expectations

The CANM currently does not regularly document the presence of light cyanobacterial crusts when assessing whether biocrusts are present, recovering, declining, or absent on CANM soils that could be expected to support significant cover of biocrusts.

When rating the ecological condition of sites within CANM, the BLM uses Ecological Site Descriptions and Ecological Reference Site Sheets developed by Natural Resources Conservation Service (NRCS). The ecological reference site sheet CANM is using for the Claysprings soils (i.e., “Mudstone/Sandstone Hills”; Schlichting and Gishi 2008)) was written in 2008 for Major Land Resource Area (MLRA) #35 which may capture the southernmost portion of CANM. CANM appears to lie primarily within MLRA #36.[7] The reference sheet does not mention light or dark cyanobacterial crusts in its list of what is considered soil cover (i.e., “rock, litter, standing dead, lichen, moss, plant canopy.”)

[7] A map of NRCS MLRAs can be found at https://www.nrcs.usda.gov/wps/portal/nrcs/detail/ut/technical/landuse/pasture/?cid=nrcs141p2_034196 . Accessed April 9, 2017.

The expected soil stability rating for Claysprings soil is "4" in the ecological reference site sheet, although the 53-year exclosure appears to be 6 or 5 in soil stability (Fig. 25). Even the actively grazed site appears to average a 4. Thus the ecological reference site sheet for Claysprings soil appears to offer an unrealistically low estimate of the stability this soil can demonstrate when not trampled.

Even more dramatically, the expected soil stability rating in plant interspaces for Uzacol soils in the "Clayey Salt Desert" ecological reference sheet) is 2-3 (Murray, et al. 2005). This reference sheet is written for MLRA #34A, which lies north of CANM, primarily in Wyoming, with a minor portion in northwestern Colorado. Soil stability was documented to be primarily at 6 in the CANM 53-year site, and between 4 and 5 in both the 11-year and actively grazed sites in our study (Fig. 26).

A "reference community" is defined by the NRCS (2017) as:

> …the plant community that existed at the time of European immigration and settlement. It is the plant community that was best adapted to the unique combination of environmental factors associated with the site.

Thus it is not clear upon what site(s) the NRCS has built its low expectation for Claysprings and Uzacol soil stability in CANM. Were the reference sites being grazed by livestock? If not currently grazed, how recently had livestock grazed the reference sites? Were the reference sites in the same precipitation and temperature regime as CANM?

Local, permanent exclosures, as opposed to potentially distant reference sites, are an invaluable tool for understanding the actual (rather than "expected") potential of undisturbed local soils and plant communities, as well as the impacts of ungulate grazing outside such exclosures.

Management Implications

The different results for different soil types and grazing regimes documented in this study provide insights that are useful for managers of public lands and natural areas.

If cattle are reintroduced to Flodine Park (and Yellow Jacket allotments) where cattle grazing has not occurred for 11 years, then light cyanobacteria that have recovered will likely be damaged or eliminated and bare soil will increase. If Flodine Park and Yellow Jacket allotments are allowed to recover without cattle, then mid-late seral biocrusts will likely be able to further develop.

These data suggest that biocrusts on Claysprings soil may be more vulnerable to impacts from livestock grazing. Therefore recovery of biocrusts may be a more protracted process on these soils. Management of cattle, however, is generally unable to target management to particular soils, as, for instance, Claysprings and Uzacol soils exist in close proximity to each other within pastures.

This study indicates that early seral biocrusts can at least partially recover during 11 years of

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Appendix A.

The tables below present the average values for the different grazing histories and soil types for ten biocrust indicators. In addition, they present the statistical differences of pairwise comparisons (proportions or counts) between sites with different grazing histories. The "expected trend" represents the direction of change that would be expected with active grazing or 11 years of rest from grazing, compared with the 53-year exclosure. Pair-wise comparisons that are statistically significant at $p \leq 0.05$ are indicated in **bold font**.

Table A1a. Total biocrust cover (trend and significance are in relation to 53-year sites).

Hypothesis: Total biocrust cover will be greatest in the 53-year sites.				
		53-year	11-year	Actively grazed
Claysprings soil	% Cover of available area	74.5	68.2	39.3
	Expected trend		Yes	Yes
	Significance (p-value)		0.3713	**0.0001**
Uzacol soil	% Cover of available area	93.4	67.5	64.5
	Expected trend		Yes	Yes
	Significance (p-value)		**0.0001**	**0.0001**

Table A1b. Total biocrust cover (trend and significance are in relation to 11-year sites).

Hypothesis: Total biocrust cover will be greater in the 11-year sites than in the actively grazed sites.			
		11-year	Actively grazed
Claysprings soil	% Cover of available area	68.2	39.3
	Expected trend		Yes
	Significance (p-value)		**0.0001**
Uzacol soil	% Cover of available area	67.5	64.5
	Expected trend		Yes
	Significance (p-value)		0.5514

Table A2a. Mid-late seral biocrust cover (trend and significance are in relation to 53-year sites).

Hypothesis: Mid-late seral biocrust cover will be greatest in the 53-year sites.				
		53-year	11-year	Actively grazed
Claysprings soil	% Cover of available area	31.4	18.1	9.9
	Expected trend		Yes	Yes
	Significance (p-value)		**0.0299**	**0.0001**
Uzacol soil	% Cover of available area	67.2	19.9	40.1
	Expected trend		Yes	Yes
	Significance (p-value)		**0.0001**	**0.0002**

Table A2b. Mid-late seral biocrust cover (trend and significance are in relation to 11-year sites).

Hypothesis: Mid-late seral biocrust cover will be greater in the 11-year sites.			
		11-year	Actively grazed
Clayspring soil	% Cover of available area	18.1	9.9
	Expected trend		Yes
	Significance (p-value)		**0.0141**
Uzacol soil	% Cover of available area	19.9	40.1
	Expected trend		No
	Significance (p-value)		**0.0001**

Table A3a. Lichen cover (trend and significance are in relation to 53-year sites).

Hypothesis: Lichen cover will be greatest in the 53-year sites.				
		53-year	11-year	Actively grazed
Clayspring soil	% Cover of available area	21.6	2.9	1.0
	Expected trend		Yes	Yes
	Significance (p-value)		**0.0001**	**0.0001**
Uzacol soil	% Cover of available area	32.8	0.0	4.6
	Expected trend		Yes	Yes
	Significance (p-value)		**0.0001**	**0.0001**

Table A3b. Lichen cover (trend and significance are in relation to 11-year sites).

Hypothesis: Lichen cover will be greater in the 11-year sites.			
		11-year	Actively grazed
Clayspring soil	% Cover of available area	2.9	1.0
	Expected trend		Yes
	Significance (p-value)		0.1763
Uzacol soil	% Cover of available area	0.0	4.6
	Expected trend		No
	Significance (p-value)		**0.0001**

Table A4a. Moss cover (trend and significance are in relation to 53-year sites).

Hypothesis: Moss cover will be greatest in the 53-year sites.				
		53-year	11-year	Actively grazed
Clayspring soil	% Cover of available area	2.0	1.1	1.0
	Expected trend		Yes	Yes
	Significance (p-value)		0.6001	0.6011
Uzacol soil	% Cover of available area	11.5	0.7	11.5
	Expected trend		Yes	No
	Significance (p-value)		**0.0002**	0.9922

Table A4b. Moss cover (trend and significance are in relation to 11-year sites).

Hypothesis: Moss cover will be greater in the 11-year sites.			
		11-year	Actively grazed
Clayspring soil	% Cover of available area	1.1	1.0
	Expected trend		Yes
	Significance (p-value)		0.9703
Uzacol soil	% Cover of available area	0.7	11.5
	Expected trend		No
	Significance (p-value)		**0.0001**

Table A5a. Dark cyanobacteria cover (trend and significance are in relation to 53-year sites).

Hypothesis: Dark cyanobacteria cover will be greatest in the 53-year sites.				
		53-year	11-year	Actively grazed
Clayspring soil	% Cover of available area	7.8	14.1	7.9
	Expected trend		No	No
	Significance (p-value)		0.226	0.9981
Uzacol soil	% Cover of available area	23.0	19.2	24.0
	Expected trend		Yes	No
	Significance (p-value)		0.5402	0.8698

Table A5b. Dark cyanobacteria cover (trend and significance are in relation to 11-year sites).

Hypothesis: Dark cyanobacteria cover will be greater in the 11-year sites.			
		11-year	Actively grazed
Clayspring soil	% Cover of available area	14.1	7.9
	Expected trend		Yes
	Significance (p-value)		**0.0385**
Uzacol soil	% Cover of available area	19.2	24.0
	Expected trend		No
	Significance (p-value)		0.2792

Table A6a. Dark cyanobacterial development, for Level 3 (the most abundant of the more developed classes) (trend and significance are in relation to 53-year sites).

Hypothesis: Dark cyanobacterial development will be greatest in the 53-year sites.				
		53-year	11-year	Actively grazed
Clayspring soil	% Cover	25.5	18.3	9.6
	Expected trend		Yes	Yes
	Significance (p-value)		**0.0287**	**0.0001**
Uzacol soil	% Cover	50.7	26.0	24.8
	Expected trend		Yes	Yes
	Significance (p-value)		**0.0001**	**0.0001**

Table A6b. Dark cyanobacterial development, for Level 3 (the most abundant of the more developed classes) (trend and significance are in relation to 11-year sites).

Hypothesis: Dark cyanobacterial development will be greater in the 11-year sites.			
		11-year	Actively grazed
Claysprings soil	% Cover	18.3	9.6
	Expected trend		Yes
	Significance (p-value)		**0.0001**
Uzacol soil	% Cover	26.0	24.8
	Expected trend		Yes
	Significance (p-value)		0.7042

Table A7a. Soil stability (trend and significance are in relation to 53-year sites).

Hypothesis: Soil stability (class 6, which is highest stability class) will be greatest in the 53-year sites.				
		53-year	11-year	Actively grazed
Claysprings soil	% of samples	72.2	35.2	18.5
	Expected trend		Yes	Yes
	Significance (p-value)		**0.0001**	**0.0001**
Uzacol soil	% of samples	77.8	42.6	37.0
	Expected trend		Yes	Yes
	Significance (p-value)		**0.0029**	**0.0002**

Table A7b. Soil stability (trend and significance are in relation to 11-year sites).

Hypothesis: Soil stability (class 6, which is highest stability class) will be greater in the 11-year sites.			
		11-year	Actively grazed
Claysprings soil	% of samples	35.2	18.5
	Expected trend		Yes
	Significance (p-value)		**0.0158**
Uzacol soil	% of samples	42.6	37.0
	Expected trend		Yes
	Significance (p-value)		0.5

Table A8a. Number of lichen/moss species per transect (trend and significance are in relation to 53-year sites).

Hypothesis: Number of lichen/moss species per transect will be greatest in the 53-year sites.				
		53-year	11-year	Actively grazed
Claysprings soil	Mean number of species	6.8	6.0	2.7
	Expected trend		Yes	Yes
	Significance (p-value)		0.7328	**0.0147**
Uzacol soil	Mean number of species	11.7	2.5	3.9
	Expected trend		Yes	Yes
	Significance (p-value)		**0.0001**	**0.0001**

Table A8b. Number of lichen/moss species per transect (trend and significance are in relation to 11-year sites).

Hypothesis: Number of lichen/moss species per transect will be greater in the 11-year sites.			
		11-year	Actively grazed
Clayspings soil	Mean number of species	6.0	2.7
	Expected trend		Yes
	Significance (p-value)		**0.0145**
Uzacol soil	Mean number of species	2.5	3.9
	Expected trend		No
	Significance (p-value)		0.1576

Hypotheses that don't have 53-year sites as the highest expected value are presented below.

Table A9a. Light cyanobacteria cover (trend and significance are in relation to 53-year sites).

Hypothesis: Light cyanobacteria cover will be greatest in the 11-year sites and 2nd highest at 53-year sites.				
		53-year	11-year	Actively grazed
Claysprings soil	% Cover of available area	43.1	50.2	29.3
	Expected trend		Yes	Yes
	Significance (p-value)		0.3558	0.0612
Uzacol soil	% Cover of available area	26.2	47.7	24.4
	Expected trend		Yes	Yes
	Significance (p-value)		**0.0042**	0.7734

Table A9b. Light cyanobacteria cover (trend and significance are in relation to 11-year sites).

Hypothesis: Light cyanobacteria cover will be greater in the 11-year sites.			
		11-year	Actively grazed
Claysprings soil	% Cover of available area	50.2	29.3
	Expected trend		Yes
	Significance (p-value)		**0.0001**
Uzacol soil	% Cover of available area	47.7	24.4
	Expected trend		Yes
	Significance (p-value)		**0.0001**

Table A10a. Bare soil cover (trend and significance are in relation to 53-year sites). These data have the same pattern as the "total biocrust cover" data (above) because those two values sum to 100%.

Hypothesis: Bare soil cover will be lowest in the 53-year sites.				
		53-year	11-year	Actively grazed
Clayspings soil	% Cover of available area	25.5	31.8	60.7
	Expected trend		Yes	Yes
	Significance (p-value)		0.373	**0.0001**
Uzacol soil	% Cover of available area	6.6	32.5	35.5
	Expected trend		Yes	Yes
	Significance (p-value)		**0.0001**	**0.0001**

Table A10b. Bare soil cover (trend and significance are in relation to 11-year sites). These data have the same pattern as the "total biocrust cover" data (above) because those two values sum to 100%.

Hypothesis: Bare soil cover will be lower in the 11-year sites than in the actively grazed sites.			
		11-year	Actively grazed
Claysprings soil	% Cover of available area	31.8	60.7
	Expected trend		Yes
	Significance (p-value)		**0.0001**
Uzacol soil	% Cover of available area	32.5	35.5
	Expected trend		Yes
	Significance (p-value)		0.5469

Table A11a. Level 1 (least developed class) dark cyanobacterial development (trend and significance are in relation to 53-year sites).

Hypothesis: Level 1 (least developed class) dark cyanobacterial development will be lowest in the 53-year sites.				
		53-year	11-year	Actively grazed
Claysprings soil	% Cover	37.5	44.2	63.2
	Expected trend		Yes	Yes
	Significance (p-value)		0.0988	**0.0001**
Uzacol soil	% Cover	6.0	42.3	36.5
	Expected trend		Yes	Yes
	Significance (p-value)		**0.0001**	**0.0001**

Table A11b. Level 1 (least developed class) dark cyanobacterial development (trend and significance are in relation to 11-year sites).

Hypothesis: Level 1 (least developed class) dark cyanobacterial development will be lower in the 11-year sites.			
		11-year	Actively grazed
Claysprings soil	% Cover	44.2	63.2
	Expected trend		Yes
	Significance (p-value)		**0.0001**
Uzacol soil	% Cover	42.3	36.5
	Expected trend		No
	Significance (p-value)		0.0901