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# Effects of Grazing on Cryptogamic Crusts in Pinyon-juniper Woodlands in Grand Canyon National Park

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ABSTRACT.—Previously grazed pinyon-juniper woodlands in Grand Canyon National Park, northern Arizona, were studied to determine the effects of past and present grazing. The occurrence and biomass of cryptogamic crust were compared for five sites in and around the Park along a continuum from never grazed to recently grazed. All sites were similar in soil characteristics, elevation and overstory dominants. Cryptogamic crust was quantified using visible cover estimates and the chlorophyll *a* content of the crust as an indicator of biomass. Visible crust cover was reduced almost 80% on grazed (5.2%) as compared to ungrazed (23.3%) sites. Crust biomass, as estimated by chlorophyll *a* content, was reduced on grazed (3.1  $\mu$ g cm<sup>-2</sup>) compared to ungrazed (9.9  $\mu$ g cm<sup>-2</sup>) sites. There were no significant differences in species presence and absence data. Significant correlations existed between cryptogamic crust cover and the composition of the respective vascular plant communities, marked by a reduction of grasses and an increase of bare soil.

#### INTRODUCTION

Cryptogamic crusts consist of nonvascular photosynthetic plants, primarily algae, lichens and mosses that live on the soil surface, although nonphotosynthetic soil fungi are occasionally included as crust components (St. Clair and Rushforth, 1989). It has been suggested that the term cryptogamic be replaced by microphytic crusts in order to include the bacteria, fungi and actinomycetes, as well as the protozoans, nematodes and mites that are associated in this micro-ecosystem (West, 1990). However, visual estimates of these latter organisms are limited, whereas the cryptogamic components are for the most part readily apparent to the naked eye. Therefore, in the following pages we refer to cryptogamic crusts with the full realization that the cryptogams are the 'visible,' but not the complete cast of characters in this symbiotic organization.

Cryptogamic crusts are important elements of arid and semiarid ecosystems worldwide (Cameron and Fuller, 1960; Snyder and Wullstein, 1973; Johansen *et al.*, 1984; Harper and Marble, 1988). They often occur in the spaces between woody plants, and perform critical functions of protecting the soil from erosion (Bailey *et al.*, 1973), aiding in water infiltration, augmenting sites for seed germination (St. Clair *et al.*, 1984; Harper and Marble, 1988) and increasing soil nutrients (Shields and Durrell, 1964; Loope and Gifford, 1972; Brotherson and Rushforth, 1983; Beymer and Klopatek 1991). Harper and Marble (1988) provide an excellent overview of these functions.

Livestock grazing has persisted in the semiarid American West for more than 100 yr. Compaction and disturbance caused by the hooves of domestic livestock have negative impacts on physical properties of soil and soil crusts (Kleiner and Harper, 1977; Jeffries and Klopatek, 1987). Anderson *et al.* (1982) compared ungrazed areas in exclosures protected

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	Site 1	Site 2	Site 3	Site 4	Site 5
pH	7.8b	7.1a	7.3a,b	7.9b	8.0b
Organic carbon (g kg <sup>-1</sup> )	26.0b	33.9a	27.1b	32.0a	29.8a,b
Nitrogen (mg kg <sup>-1</sup> )	733b	907a,b	876a,b	1166a	1045a,b
Texture:					
% Sand	66b	60c	73a	63b,c	65b,c
% Silt	27b	32a	21c	33a	30a,b
% Clav	7a	8a	6a	4a	5a

TABLE 1.—Soil characteristics of five pinyon-juniper sites. The continuum of ungrazed to grazed is from left to right. Means with same letter are not significantly different (P < 0.05)

14-38 yr with adjacent grazed areas. They found 10 times more moss cover, three times more lichen cover and twice as much algal cover inside the exclosures than outside. Kleiner and Harper (1977) noted that seven of the 15 most prevalent species (cryptogamic and herbaceous) on ungrazed sites were absent on grazed sites, and total cryptogamic cover was nearly seven times as abundant on the virgin soil.

A number of studies describe re-establishment of crusts following disturbances (Anderson et al., 1982; Johansen et al., 1984; Johansen and St. Clair, 1986; St. Clair et al., 1984; Starks and Shubert, 1982). Anderson et al. (1982) concluded that the most pronounced recovery of the crust organisms occurs from 14–18 yr following protection from heavy grazing. St. Clair et al. (1984) noticed "a diverse and well-developed soil crust flora" after 20 yr of protection.

In this paper we describe the effects of grazing disturbance in pinyon-juniper woodlands in and around Grand Canyon National Park with particular emphasis on the components of cryptogamic crust. We emphasize the consequences of varying grazing regimes on both the cover and biomass of the crusts and relate this to changes in the structure of the vascular plant community.

### SITE DESCRIPTIONS

Cryptogamic crusts occur in virtually every ecosystem in Grand Canyon National Park (GNCP), Arizona, from the mixed conifer forests and pinyon-juniper woodlands to the shrub deserts. Five mature pinyon-juniper woodland sites were selected on the Colorado Plateau in GCNP and the adjacent Kaibab National Forest in northern Arizona. The sites [Shiva (site 1), Overlook (site 2), Duck (site 3), Sewage (site 4), Grazed (site 5)] represent a continuum of grazing histories from never grazed by domestic livestock to currently grazed. Selection of sites was made subjectively to ensure that the dominant vegetative community (pinyon-juniper woodland) structure was fairly similar among the five sites. Sites with shrubs that indicated edaphic or microclimatic differences (*e.g., Artemisia tridentata, Yucca baccata*) were not chosen. All sites are at similar elevations and are underlain by Kaibab limestone covered with thin rocky soil (lithic Entisols) that does not vary significantly (*i.e.*, when comparing site 1 and 5) (Table 1).

Site 1 is located on top of Shiva Temple, a 130-ha mesa within Grand Canyon and 11.3 km N of Grand Canyon Village at an elevation of 2300 m. It is connected to the North Rim by a saddle approximately 300 m below the rim which is sometimes crossed by small mammals, deer and elk. Shiva Temple has never been grazed by domestic livestock.

Site 2 is located on the South Rim along the West Rim Drive at an elevation of 2100 m,

ca. 1.6 km W of Grand Canyon Village and 460 m S of the First Trail Overlook on the rim. It has not been grazed since the mid 1930s.

Site 3 is located on the South Rim approximately 10 km E of Grand Canyon Village, at an elevation of 2200 m. It was grazed until the 1930s South Rim fencing project and still occasionally suffers from some trespass grazing.

Site 4 is located beside the fence which marks the boundary between GCNP and the Kaibab National Forest, ca. 6.4 km SW of Grand Canyon Village (elevation, 2050 m). It straddles a flowing stream which drains from sewage treatment ponds to the N, representing the only surface water in the area. The water acts as an attractant for wildlife and cattle and directly increases grazing pressure. This site was also fenced in the 1930s, but the fence has gone unrepaired for long periods and has resulted in recent intense trespass grazing.

Site 5 (grazed) is located outside GCNP in the Kaibab National Forest, directly across the park boundary fence from site 4. It is subject to grazing on a current allotment rotation (C. Jankiewicz 1985, pers. comm.), and was actively grazed during the study. A stock pond located ca. 90 m S of the boundary fence encourages cattle to congregate in the area.

## METHODS

Cryptogamic crust sampling.—A  $0.5 \times 0.5$  m quadrat, nested within each rectangular plot used in the vascular vegetation sample (50 quadrats per site), was sampled for ocular estimates of visible crust cover (Brotherson *et al.*, 1983). The quadrat frame was marked off at 5-cm intervals to assist in the estimate of surface cover.

At each site, 24 surface samples (without regard to visible crust cover) were collected at random 10-m intervals along stratified transects (20 m apart) for crust biomass estimations. The intent was to compare chlorophyll a content of crusts. Thus, samples were taken only in spaces not under tree canopies (interspaces), because personal observations showed that crusts generally do not establish on litter under pinyon and juniper canopies.

Each sample was collected to a depth of 1 cm with an aluminum cylinder 5 cm in diam. A flat trowel was slipped beneath the sample in order to remove samples of the specified depth. Any vascular seedlings or bits of litter that could inflate the chlorophyll *a* volume were removed by hand. Each intact sample was transferred in the field to a 125-ml sample bottle containing 60 ml of dimethyl sulfoxide (DMSO) (Ronen and Galun, 1984; Bell and Sommerfeld, 1987) and stored in the dark on ice until returned to the laboratory. In the laboratory, defrosted samples were stirred to maximize exposure of the organisms to DMSO, heated 1 h in an oven at 65 C and cooled. Two aliquots (6–10 ml) per sample were spun at low speed (1560 × g) for 20 min using a table-top centrifuge. Two 3-ml aliquots of supernatant were removed from each sample. The optical density of the pigment extract was determined using a recording spectrophotometer at 750 (measurement of turbidity) and 665 nm (absorption spectra of chlorophyll *a*), before and after acidification with 10  $\mu$ l of 1 N HCl. All work was done under dim light to prevent pigment degradation.

Chlorophyll a content was determined using an equation (APHA, 1980) modified to express pigment content on the basis of surface area:

$$\mu$$
g Chl *a* cm<sup>-2</sup> =  $\frac{26.73(\uparrow)(v)}{(A)(L)}$ 

where (^) is the difference in absorbance (between 665 nm-750 nm) before acidification and (665 nm-750 nm) after acidification; (v) is the extract volume in ml; (A) is the surface area of subsample tested in  $cm^2$  [or volume in ml for the carbon dynamics experiment (Beymer and Klopatek, 1991)]; and (L) is the path length of the spectrophotometer cuvette in cm.

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This equation accounts for the presence of any degradation product of chlorophyll a (especially phaeophytin a) which would interfere with the absorbance. It uses wavelengths suited to DMSO extraction, rather than acctone. It also corrects for turbidity in the sample, which was generally not a problem with centrifuge use.

Ten crust samples were taken at random intervals along one transect at each site for identification of the cryptogamic organisms. Samples were removed with an aluminum cylinder with a diam of 5 cm and carefully transferred to  $60 \times 15$  mm petri dishes and returned to the laboratory. The cylinder was cleaned between samples with 95% ethanol.

Mosses and lichens from each sample were dried and identified using the nomenclature of Johnsen (1978) for mosses and Egan (1987) for lichens. Algae were cultured on agar plates with Bold's Basal Medium (BBM), enhanced with 40 ml soil water and 30 mg sodium metasilicate for diatoms. Soil from the top 1 cm was sprinkled on the agar plates containing this medium. The plates were kept in an environmental chamber with photoperiod 12 h light/12 h dark, temperature 18–22 C and fluence rate 4320  $\mu$ W cm<sup>-2</sup>. Colonies that grew were transferred periodically to fresh plates and then identified. Blue-green algae (Cyanobacteria) were identified directly from the agar plates. Permanent slide mounts were made with Hyrax mounting medium for diatoms (Chrysophyta). Unicellular green algae (Chlorophyta) were observed in wet mount slides over periods of hours to determine zoospore activity and morphology for identification. Algal nomenclature is according to Smith (1950) and Metting (1981).

Vegetation sampling.—The density, frequency and cover of the perennial shrubs, grasses and forbs were sampled with 0.5 m<sup>2</sup> rectangular quadrats. At each study site, five 200-m parallel transects were located at least 20 m apart and 10 plots were randomly located on each resulting in a total of 50 quadrats per site. Only vegetative cover is reported on in this article. Nomenclature of all vascular plants is according to Phillips *et al.* (1987).

Data and statistical analyses.—Data and statistical analyses were performed on the Arizona State University IBM 3091 mainframe computer using SAS statistical software (SAS, 1985). Analysis of variance (AOV) and least significant difference (LSD) were used to examine the data for between-site differences in crust cover, crust chlorophyll a content, soil nitrogen content, soil carbon content and soil texture (sand, silt and clay content). Simple linear regression was used to determine the relationships between crust cover and chlorophyll a content.

#### RESULTS

### CRYPTOGAMIC CRUST ANALYSES

Cover and biomass.—Both of the indicators of crust vigor (expressed as percent cover and chlorophyll *a* content) showed steady declines along the grazing continuum from ungrazed to currently grazed (Table 2). Visible crust cover declined from the ungrazed site ( $\bar{x} = 23.3\%$ ) to the grazed site ( $\bar{x} = 5.2\%$ ). Analysis of variance revealed that the crust cover on site 1, the ungrazed site, was significantly higher than all other sites. Site 5 (currently grazed) crust cover was significantly lower than all sites other than the trespass grazed site (4).

Chlorophyll *a* content, the indicator of crust biomass, also declined from the ungrazed site in all other sites (Table 2). The AOV of the means of biomass from each site showed a significant difference between ungrazed site 1 (9.9  $\mu$ g cm<sup>-2</sup>) and all other sites (Table 2). The intermediate sites 2 (6.8) and 3 (6.4) were significantly different from the others but not from each other. Grazed sites 4 (4.2) and 5 (3.1) were significantly different from other sites.

		Chlorophyll a			
Site	Cryptogams	Litter	Rock	Bare soil	(μg cm <sup>-2</sup> )
1	23.3a	32a	18a	11c	9.9a
2	12.8b	31a	19a	17b	6.8b
3	11.7b	34a	11b	17b	6.4b
4	10.2b,c	28b	13b	30a	4.2c
5	5.1c	27b	14b	30a	3.1c

TABLE 2.—Means of ground cover other than vascular vegetation and chlorophyll a of cryptogamic crusts in pinyon-juniper woodlands. Sites represent a continuum from ungrazed to grazed from top to bottom. Mean values followed by the same letter are not significantly different (P < 0.05)

Species composition.—The five sites were similar in their arrays of cryptogamic species (or genera) present (Table 3). Most species were ubiquitous. All but one of the genera of Cyanobacteria (blue-green algae), all but two genera of Chlorophyta (green algae) and all Chrysophyta (diatoms) identified were present on all five sites.

Three species of lichens were absent from sites 1 and 2. Two of them, Agrestia hispida and Toninia cf. aromatica, appeared on site 4 and the other, Collema coccophorum, was found on sites 3 and 5. Agrestia hispida also was present on site 3. Moss composition was uniform among the sites.

Differences between the major groups of crust organisms present were not quantified. However, some general trends were observed. On all sites, blue-green algae and unicellular green algae appeared to be the most common among crust organisms. They grew on every agar plate on which soils were cultured. Lichens also were quite common, appearing in nearly every sample crust. The least common crust organisms were mosses.

The percent of bare soil was highest on the currently grazed (5) site (33% cover), in fact, three times higher than that on the ungrazed (1) site (11%) (Table 2). The rise in the amount of bare soil with increased grazing pressure was approximately inversely proportional to the decline of crust cover, demonstrating that the decline in crust cover results in more bare ground and not more vascular plant cover. The amount of ground covered by litter and rock was fairly constant among the five sites.

#### VEGETATION ANALYSES

Perennial shrubs, grasses and forbs.—Grazing effects were also evident among the vascular plants. Total grass cover was highest on the ungrazed site 1 with 19.2% with site 4 the lowest at 10.6% (Fig. 1). Sites 1 and 4 were significantly different from each other and from the remaining three sites. Mutton grass (*Poa fendleriana*), a C-3 grass, highly palatable to cattle, was the dominant herbaceous species on every site. Its cover was lowest on the currently grazed site (6.6%), with the neighboring site 4 (7.6%) next lowest, and highest on the ungrazed site 1 (19.1%). Squirreltail grass (*Sitanion hystrix*), a species that is known to increase with grazing pressures (U.S. Forest Service, 1979), was nearly codominant with mutton grass (especially under the tree canopies) on site 5 with 5.4% cover. It did not occur on the ungrazed site but was present on the intermediately grazed sites. Alternatively, cliffrose (*Cowania mexicana* var. *stansburiana*), a browse species for deer and cattle that decreases with grazing pressure (U.S. Forest Service, 1979) was not present on the grazed sites.

Other recognized grazing-increased plants appeared more prominently on the grazed sites than the ungrazed or intermediate sites and included bladderpod (*Lesquerella intermedia*),

Table	3.—Cryptogamic	crust organisms	present on	five pinyor	i-juniper	sites.	Continuum	of	un-
grazed to	grazed is from lef	it to right. (+ pr	esent, – abs	ent)					

	Sites								
Organisms	Site 1	Site 2	Site 3	Site 4	Site 5				
Cyanobacteria									
Calothrix sp.	+	+	+	+	+				
Lyngbya sp.	+	+	+	+	+				
Microcoleus sp.	+	+	+	+	+				
Nostoc sp.	+	+	+	+	+				
Oscillatoria sp.	+	+	+	+	+				
Plectonema sp.	+	+	+	+	+				
Scytonema sp.	+	+	+	+	+				
Tolypothrix sp.	+	+	+	+	+				
Schizothrix sp.	-	_	_	_	+				
Chlorophyta									
Chlorella sp.	+	+	+	+	+				
Chlorococcum sp.	+	+	+	+	+				
Chlorosarcinopsis sp.	+	+	+	+	+				
Pseudotetracystis sp.	+	+	+	+	+				
Tetracytis sp.	+	+	+	+	+				
Spongiococcum sp.	+	?	?	+	+				
Oocystis sp.	_	—	—	—	+				
Neochloris sp.	+	_	_	_	_				
Chrysophyta									
Hantzschia amphioxys	+	+	+	+	+				
Navicula mutica	+	+	+	+	+				
		Lichenes							
Catapyrenium lachneum	+	+	+	+	+				
Collema sp.	+	+	+	+	+				
Dermatocarpon sp.	+	+	+	+	+				
Peltigera didactyla	+	+	+	+	+				
Psora cerebriformis	+	+	+	+	+				
Toninia sp.	+	+	+	+	+				
Agrestia hispida	_	_	+	+	—				
Toninia cf. aromatica	_	_	—	+	—				
Collema coccophorum	-	_	+	_	+				
Bryophyta									
Tortula ruralis	+	+	+	+	+				
Unknown moss	+	+	+	+	+				

snakeweed (*Gutierrezia sarothrae*) and bitterweed (*Hymenoxys acaulis* var. *arizonica*). Herbaceous forb cover (as well as number of forb species) was significantly greater on site 5, with the forbs being dominated by weedy, annual species.

# DISCUSSION

Grazing by domestic livestock reduced both cryptogamic crust cover and biomass. A regression analysis showed a linear correlation between crust cover and chlorophyll *a* content



FIG. 1.—Percent cover of shrub, herb and forb vegetation in five pinyon-juniper study sites

with a high positive correlation ( $\mu$ g Chl a = 0.975 + 0.388 cover,  $r^2 = 0.92$ ). The intercept is above that of a 1:1 relationship and demonstrates that there is more chlorophyll a(photosynthetic biomass) present in these crusts than appears in the visual estimates of crust cover. This is logical, considering the large quantities of algae and Cyanobacteria found upon culturing them on agar plates for identification. The ocular estimates of crust cover often exclude some algae, since only lichens, mosses and sometimes a prominent algal crust will be visible to the unaided eye. The many unicellular algae that live in the crusts of these pinyon-juniper woodlands, especially those directly beneath the lichens and mosses, are generally overlooked. Brownish diatoms and dark-colored blue-green algae are very difficult to see. But they all add to the chlorophyll a content (and biomass) of the crust layer.

Chlorophyll a is accepted as an important algal biomass indicator (Creitz and Richards, 1955; APHA, 1980; Starks and Shubert, 1982). Generally used with aquatic algae, the method was chosen here as an indicator of overall cryptogamic biomass because of the extreme heterogeneity of the various crust samples in the pinyon-juniper woodlands. All lichens, mosses and algae, including blue-green algae, contain chlorophyll a. Chlorophyll a content was only employed as a relative indicator of cryptogamic biomass with no attempt being made to designate absolute quantity.

In contrast to the findings of others (e.g., Andersen *et al.*, 1982; Johansen *et al.*, 1984), the species presence of cryptogamic crusts showed no definite pattern relative to the amount of grazing. The impact of grazing resulted in the reduction of the total amount of crust cover rather than a loss of species.

Vegetational structure also changed as a result of grazing. Specifically, cliffrose and mutton grass were reduced due to grazing with an increase in annual forbs. The overall vascular



FIG. 2.—Change in the tree cover and C-3 grass as related to the change (decreasing from right to left) in cryptogamic crust cover in pinyon-juniper woodlands

plant species richness showed no significant change due to grazing as a large variety of weedy annuals were present on the disturbed sites. However, plotting vegetation data against crust cover from the woodlands reveals additional relationships (Fig. 2). Again, (from right to left on the graph) the reduction in cryptogamic cover is accompanied by a reduction of the dominant C-3 grass species (mutton grass) with tree cover increasing to a maximum of 68%. The separation of the grass and trees exhibited in Figure 2 may be characteristic of semiarid ecosystems and can be portrayed in a catastrophe model (Jameson, 1988; Gosz and Sharpe, 1989). As the controlling factor (grazing of cool-season grasses accompanied by the elimination of crust organisms) moves toward an extreme, a point is reached at which the vegetation cover can no longer respond smoothly, yielding a jump to a different level or a discontinuity (catastrophe). Conversely, efforts to return the system back across this discontinuity may require disproportional expenditures of time and energy.

The detrimental effects of grazing on cryptogamic crust demonstrated in this study confirm the results of other research and further support the appeal for incorporation of grazing management techniques that promote the maintenance or reintroduction of cryptogamic crust (Brotherson *et al.*, 1983; Johansen, 1986). We are not suggesting that the reduction of cryptogamic crust in these ecosystems results in a change in vegetation structure. However, the cause-effect relationship of grazing with a reduction of cryptogamic crust and palatable forage species suggests that cryptogamic crust quantity may be used as an indicator of ecosystem condition.

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