Biological Soil Crusts in Three Sagebrush Communities Recovering from a Century of Livestock Trampling

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Abstract—Biological soil crusts and their recovery from long-term livestock impacts were studied in three sagebrush communities in east-central Idaho. In 1996, biological crust and vascular plant cover were measured outside and inside of livestock exclosures in Wyoming big sagebrush (*Artemisia tridentata* ssp. *wyomingensis*), mountain big sagebrush (*Artemisia tridentata* ssp. *vaseyana*), and low sagebrush (*Artemisia arbuscula*) communities. The Wyoming big sagebrush exclosure had the greatest cover of biological crust relative to the vascular plant canopy. Biological crust cover was double inside the Wyoming and mountain big sagebrush exclosures compared to the areas outside, indicating substantial recovery since release from livestock use 8 and 11 years previous, respectively. The low sagebrush site had the least biological crust cover, which did not differ due to livestock exclusion. A gravelly soil surface and dominance of rhizomatous grasses appear to limit biological crust development on the low sagebrush site.

Biological soil crusts are a conspicuous entity in many arid and semiarid ecosystems, providing living cover in environments where soil conditions and high evapotranspiration rates do not support dense vascular plant cover. Biological crusts (also known as microbiotic, microphytic, cryptogamic, or cryptobiotic crusts) are composed of lichens, bryophytes, algae, microfungi, cyanobacteria, and other bacteria. They reduce soil erodibility (Williams and others 1995a,b; Belnap and Gillette 1998) and enhance nutrient cycling (Beymer and Klopatek 1991; Evans and Ehleringer 1993; Belnap 1995) in semiarid and arid plant communities worldwide. Polysaccharide sheaths associated with cyanobacteria bind soil particles (Belnap and Gardner 1993), creating a stable matrix that resists wind erosion (Williams and others 1995b; Belnap and Gillette 1998). Roughened soil surfaces formed by biological crusts create catchments for water, reducing sheet erosion (Williams and others 1995a). Mosses and lichens provide cover, protecting the soil surface from raindrop impacts. Tissues from vascular plants grown in biologically crusted soils have greater nutrient content compared to plants grown in uncrusted soils (Belnap and Harper 1995), indicating that they may support the vascular plant community via mechanisms that enhance nutrient uptake (e.g., chelating compounds). Organisms associated with biological crusts fix carbon through photosynthesis (Beymer and Klopatek 1991). Additionally, cyanobacteria and lichens with cyanobacterial photobionts fix atmospheric nitrogen. This contribution of carbon and nitrogen can be significant in systems where above and below-ground biomass of live vascular plants and litter is low (Skujins 1981; Beymer and Klopatek 1991; Evans and Ehleringer 1993).

Studies of livestock impacts to biological crusts in the Great Basin, Colorado Plateau, and Australia have documented reductions in biological crust cover and species richness due to livestock trampling (Kleiner and Harper 1972; Anderson and others 1982a,b; Brotherson and others 1983; Andrew and Lange 1986; Johansen and St. Clair 1986; Marble and Harper 1989; Beymer and Klopatek 1992). Biological crusts in interspaces are most vulnerable since they are not protected from trampling by a shrub overstory. The destabilized interspace soil is susceptible to the formation of flow patterns and accelerated erosion (Belnap 1995). Because crustal components might be responsible for much of the available nitrogen in some ecosystems, trampling impacts are likely to modify both the amount of nitrogen cycling through the system and its spatial distribution within the community (Evans and Ehleringer 1993). Studies by Belnap and others (1994) and Belnap (1996) documented long-term depression of nitrogen fixation in cyanobacterial-dominated crusts on the Colorado Plateau due to anthropogenic-related soil disturbances. Disturbance severity ranged from mild (raking, trampling with smooth-soled shoes) to severe (off-road vehicles, military tanks). Suppression of nitrogen fixation persists long after crusts appear to be recovered in terms of visible cover and biomass (Belnap and others 1994).

Although biological crusts have received considerable attention by the scientific community over the last decade, land management agencies have only recently begun to consider impacts to biological crusts and the resulting effects on soil health in making land management decisions. Traditional studies on livestock impacts and vegetation recovery have focused on vascular plant communities. This study, initiated by the Bureau of Land Management's (BLM) Lemhi Resource Area in east-central Idaho, examined changes in biological crust and vascular plant cover following exclusion of livestock roughly one decade previous. The study focused on sites supporting three different sagebrush taxa to determine how biological crusts recover over a range of edaphic and biotic conditions. Little published work exists

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on biological crust ecology in the Pacific Northwest, with the exception of a study by Johansen and others (1993) on post-fire recovery in the lower Columbia Basin.

The Study Area

The Lemhi Resource Area contains the north-south oriented valleys of the Lemhi River, Salmon River, and upper Birch Creek in east-central Idaho. These valleys support sagebrush-bunchgrass vegetation typical of the Columbia River drainage (Hironaka 1979). The valleys lie in an area where the climate is influenced by moist air masses from the Pacific Ocean and the Gulf of Mexico and dry, continental air from Canada (Moseley 1992). Average annual precipitation ranges from 230 to 560 mm, most of which occurs during the winter and spring in the Lemhi and Salmon valleys (USDI, BLM, unpublished data). Opposite conditions prevail in the Birch Creek Valley, with greater than 40% of the annual precipitation occurring between June and September (Hauxwell 1977).

Wyoming big sagebrush (*Artemisia tridentata* Nutt. ssp. *wyomingensis* Beetle and Young) dominates the lower, drier slopes of the valleys. It is replaced by mountain big sagebrush [*Artemisia tridentata* Nutt. ssp. *vaseyana* (Rydb.) Beetle] at mid-elevations where precipitation exceeds 300 mm annually. Windswept ridges and shallow, gravelly soils of glacial outwash fans are dominated by low sagebrush (*Artemisia arbuscula* Nutt.). The predominant bunchgrass throughout the Lemhi Resource Area is bluebunch wheatgrass [*Pseudoroegneria spicata* (Pursh) A. Love]. Idaho fescue (*Festuca idahoensis* Elmer) is co-dominant on north aspects. Presence of these palatable species resulted in extensive use of the valleys for livestock grazing beginning in the 1860's. Records of a late 19th century rancher, G. E. Shoup, document severe depletion of native vegetation by the late 1880's, with "large areas virtually going to dust" (Shoup 1935).

Methods

In spring 1996, three study sites were established, each occurring in a different sagebrush community and containing a livestock exclosure ranging in age from 8 to 11 years (Table 1). All sites occur on level or gently sloping topography of alluvial terraces. The Wyoming and mountain big sagebrush sites are located on deep, well-drained silt loams formed in calcareous alluvium (Cheney 1970). The low sagebrush site occurs on calcareous, gravelly loams derived from limestone glacial outwash (Hauxwell 1977). These soils are shallow, with a petrocalcic layer at approximately 30-40 cm.

Cover data were collected for biological crust components (lichen, moss), vascular plant canopy by species, rock and gravel, litter, and bare mineral soil along four randomly selected 10-m transects located inside and outside of each exclosure. All data were collected using a line-intercept method with the measuring tape placed near the soil surface to facilitate reading of ground cover. The smallest measurable unit was 5 mm. Sampling occurred between 3 and 6 June 1996. Cover data were analyzed using a two-way factorial analysis of variance. Interactions between treatment (livestock exclusion) and site effects were evaluated to assess the reliability of main effects across the study area. Tukey's HSD test was used to compare means between sites if main effects were significant. An alpha level of 0.05 was used to determine significance for all analyses.

As with many natural experiments (Diamond 1986), this study lacks replication (in this case, of each sagebrush type), limiting statistical interpretation. In addition, a "space-for-time" substitution was employed (Michener 1997) due to the lack of pre-exclosure baseline data. Therefore, the study should be treated as a case study, with statistical inferences applicable only to the sites described in this paper.

Voucher specimens representing all lichen and moss taxa comprising the biological crust at each site were collected, identified, and deposited at the Snake River Plains Herbarium (SRP), Boise State University, Boise, Idaho.

Results

Wyoming Big Sagebrush

Biological soil crusts were the dominant living cover in the Wyoming big sagebrush exclosure (Fig. 1). Crust cover was significantly higher in this exclosure compared to cover inside the other exclosures ($p \leq 0.05$). This site has the least annual precipitation (Table 1), which limits vascular plant cover (Fig. 1, 2). Biological crusts covered the interspaces, leaving little bare ground inside the exclosure (Fig. 3). The crust was comprised of lichens and mosses in nearly equal proportions. Biological crust cover was significantly greater ($p = 0.0017$) and amount of bare mineral soil was significantly less ($p = 0.0001$) inside the exclosure compared to the area outside (Fig. 3). Differences in shrub and herbaceous canopy as well as litter cover were all nonsignificant. Litter was concentrated under shrubs.

Table 1—Characteristics of study sites located within the Lemhi River and Birch Creek valleys, east-central Idaho.

Site name	Year exclosure established	Elevation	Average annual precipitation	Soil textural class
		m	*mm*	
Wyoming big sagebrush	1988	1,433	180-250	silt loam
Mountain big sagebrush	1985	1,747	300-410	silt loam
Low sagebrush	1986	2,149	280-330	gravelly loam

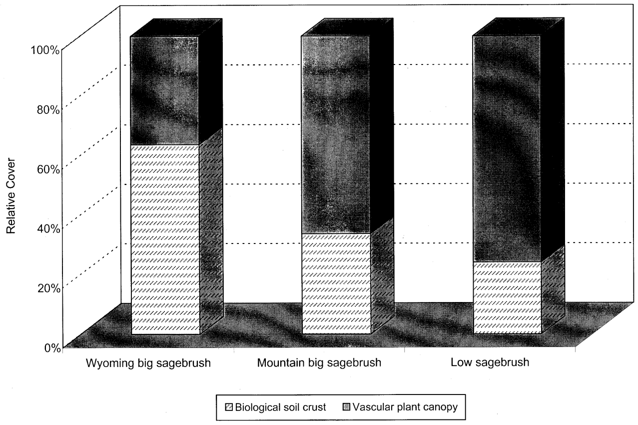

Figure 1—Relative cover of the vascular plant canopy and biological soil crust inside livestock exclosures in three sagebrush communities (*N* = 24).

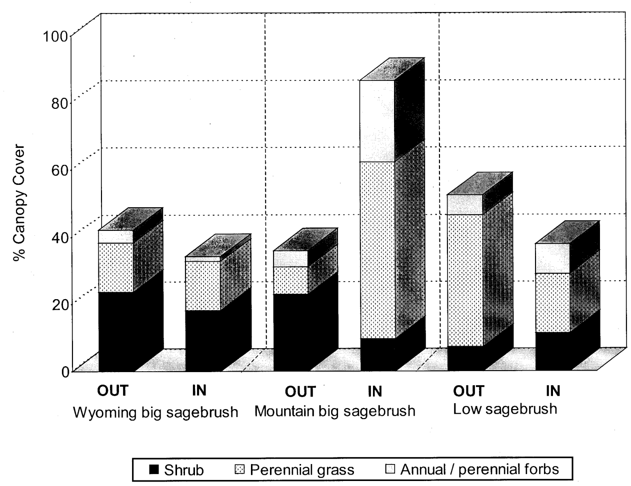

Figure 2—Mean canopy cover of vascular vegetation life forms outside and inside of livestock exclosures in three sagebrush communities (*N* = 24).

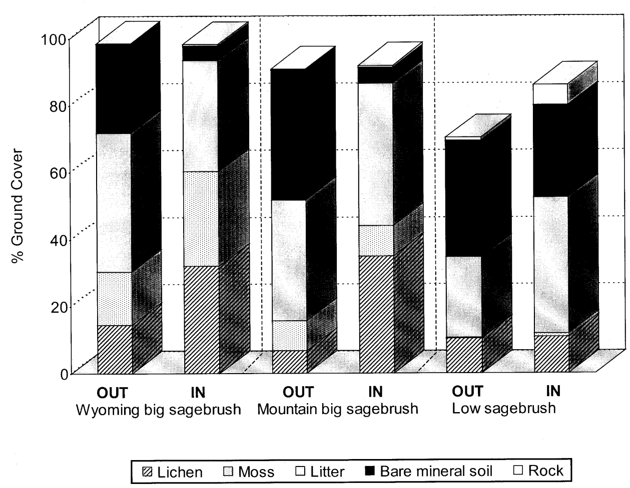

Figure 3—Mean ground cover outside and inside of livestock exclosures in three sagebrush communities (*N* = 24).

Mountain Big Sagebrush

This site had greater potential for vascular plant and litter cover compared to the Wyoming big sagebrush site due to higher annual precipitation (Table 1). Biological crusts accounted for 40% of the soil surface cover inside the mountain big sagebrush exclosure (Fig. 3). However, they were a less dominant element inside the exclosure relative to the vascular plant community when compared to the Wyoming big sagebrush site (Fig. 1). Cover of biological crusts and herbaceous plants were significantly greater inside the exclosure ($p = 0.0044$ and $p = 0.0002$, respectively) and occurred primarily in interspace locations (Fig. 2, 3). Shrub cover was significantly less inside the exclosure ($p = 0.0150$). Biological crust and litter outside the exclosure were found only in protected areas under the shrub canopy. Cover of bare mineral soil was significantly less inside the exclosure ($p = 0.0028$) (Fig. 3).

Low Sagebrush

The low sagebrush site had the least biological crust cover relative to the cover of vascular vegetation when compared to the two big sagebrush communities ($p \leq 0.05$) (Fig. 1). Cover of bare mineral soil and surface rock (gravels) inside the exclosure was higher compared to the areas inside both big sagebrush exclosures (Fig. 3). The biological crust was dominated by lichens; very little moss occurred on this site (Fig. 3). There was no difference in biological crust cover, bare mineral soil, or litter inside and outside the exclosure. Shrub canopy cover was greater inside the exclosure ($p = 0.0084$) (Fig. 2, 3), while cover of the dominant perennial grass, western wheatgrass [*Pascopyrum smithii* (Rydb.) A. Love], was greater outside the exclosure ($p = 0.0037$).

Discussion

Potential for Biological Crust Development

Soil texture and cover of vascular vegetation appeared to influence the relative cover of biological crusts in each plant community. Biological crusts had higher cover on fine-textured silt loams supporting the two big sagebrush communities, both of which had negligible cover of surface gravels when compared to the low sagebrush site. Surface gravels function as cover and protect the soil surface from erosion, thereby acting as an ecological replacement for biological crusts in that role.

The Wyoming big sagebrush site receives the least annual precipitation of the two big sagebrush sites and thus has less potential for vascular plant cover. Interspaces inside the Wyoming big sagebrush exclosure had a continuous cover of biological crust and very little bare mineral soil, indicating greater ecological importance of biological crusts as soil protection on sites where effective precipitation is inadequate to support continuous cover of vascular vegetation and litter. Crustal organisms require minuscule moisture to carry out metabolic activity and are highly drought tolerant.

If undisturbed they can maintain site stability through prolonged drought periods that vascular plants may not tolerate (Belnap and Gillette 1998).

The mountain big sagebrush site has adequate moisture to support relatively high canopy cover (>80%) with a diversity of herbaceous vegetation. Biological crust accounts for approximately 40% of the soil surface cover. While the crust is probably not as critical for soil stabilization on this site due to high cover of vascular plants and litter, mosses and lichens form a rather bumpy carpet under the canopy and contribute to both the structural and biological diversity of the site. Contributions to nitrogen inputs on this site are as yet unknown, but the presence of nitrogen-fixing lichen species [*Collema coccophorum* Tuck., *Collema tenax* (Sw.) Ach., *Heppia lutosa* (Ach.) Nyl.] indicate a potential role.

The low sagebrush site has decreased potential for vascular plant cover due to the droughty nature of the well-drained, gravelly, calcareous soils. Cover of surface gravels were an obvious limiting factor to biological crust development. Another factor may be the presence of western wheatgrass, a rhizomatous species. Rhizomatous grasses tend to occur in homogeneous, dense stands, leaving little area available for occupation by biological crusts (Mack and Thompson 1982). Although canopy cover values for western wheatgrass were not high (Fig. 2), the data do not reflect the effect of tillering on the soil surface, which resulted in more continuous cover compared to bunchgrasses. Values for bare mineral soil inside the low sagebrush exclosure were high compared to the other two sites (Fig. 3); however, bare soil occurred in small, discontinuous patches broken by gravel and rhizomatous vegetation.

Recovery from Long-Term Livestock Use

The Wyoming big sagebrush site is stocked at a rate of 17.9 acre/animal unit month (AUM) and is used from 1 May to 1 June or 1 June to 1 July in alternating years. The current stocking rate has been in effect since 1950. Previous to 1992 the pasture was used only during May. Livestock were removed from the pasture approximately 2 days prior to the June 1996 sampling. Small differences in vascular plant canopy cover (Fig. 2), particularly perennial grasses, indicate that this grazing system may be protecting the vascular plant community. However, considerable increase in biological crust cover inside compared to outside the exclosure (Fig. 3) suggests that management on this site has not allowed biological crust recovery from historical (pre-1950) heavy livestock use. Biological crusts are most resilient to livestock use during cool seasons when the soil surface is frozen or snow-covered (Marble and Harper 1989; Memmott and others 1998). Crustal organisms need moisture for metabolic activities (including growth and reproduction), and livestock use immediately prior to a hot, dry period provides little opportunity for regrowth. This may be particularly detrimental in areas that receive brief, high intensity summer storms, which can result in soil loss on sites where the surface has been destabilized by trampling impacts (Marble and Harper 1989). The dramatic increase in biological crust cover in the 8 years following exclusion from grazing is remarkable in that visible recovery occurred much more quickly than the several decades estimated by Belnap (1993) for soil lichens and mosses in southern Utah. This indicates that environmental conditions in the Lemhi Valley are conducive to growth and reproduction of both lichens and mosses, possibly due to predominance of cool season moisture and short duration of the hot, dry season. Fall (October-November), winter (December-February), or early spring (March-April) livestock use would result in less damage to the biological soil crust. These regimes would allow at least 1 month of moist conditions for growth and reattachment of disturbed crustal organisms prior to the hot, dry season.

The mountain big sagebrush site was stocked lighter than the Wyoming big sagebrush site (23.3 acre/AUM). Between 1950 and 1994 this site was used from 15 May to 1 September. Season of use was modified drastically in 1995 and now extends from 15 May to 6 June. Livestock were removed immediately prior to the June 1996 sampling. Deep hoof prints (>5 cm deep) indicated that the soil was very wet while livestock were using the allotment. These conditions were probably due to snow melt followed by spring rains. As with the Wyoming big sagebrush site, visible recovery from livestock impacts was considerable inside the exclosure, both with regards to the biological crust (Fig. 3) and the herbaceous component of the plant community (Fig. 2). This site receives higher annual precipitation than the Wyoming big sagebrush site and thus has the potential for more rapid regrowth of both biological crust and vascular plants. However, the entire site is undoubtedly recovering from past season-long summer use, and 2 years of management change (i.e., shortening of the grazing season) were probably not adequate to see recovery in either the vascular plant community or the biological crust outside the exclosure. Continued spring use when the soil surface is extremely wet might inhibit biological crust recovery by churning the soil surface and burying the crust. Fall use, when soils are more likely to be moist but not saturated, would be a better option for this site and would protect the perennial grasses as well as the biological crust.

The low sagebrush site was used by sheep from 1950 to 1991 at a rate of 20.1 acre/AUM from 1 May to 15 July and 1 September to 9 September. The site was not grazed between 1992 and the sampling date in 1996. The data indicate that there was little change in biological crust cover regardless of the rest period (10 years since the exclosure was built vs. four years of rest outside the exclosure). Western wheatgrass might have increased and replaced bluebunch wheatgrass on the site due to decades of historical heavy use by sheep (S. Beverlin, BLM, Lemhi Resource Area, personal communication). Western wheatgrass is less impacted by grazing due to its rhizomatous nature and responds quickly to periods of rest. If bluebunch wheatgrass and other perennial bunchgrasses formerly dominated the herbaceous component of the community, it is possible that the site historically had slightly greater cover of biological crust than is now present. Gravels armor the soil surface and reduce trampling impacts. Lichens may recover more quickly on this site where greater elevation results in cooler temperatures and short periods of hot, dry weather.

Conclusions

An important observation of this study was the relatively rapid visible recovery of the biological crust, even on the driest of the three sites. Interspaces in the Wyoming big sagebrush community had almost complete cover of biological crust after only 8 years of rest. Due to the long history of livestock use in the study area, and indeed, much of western North America, it is difficult to determine the precise ecological potential of any given site. The measure of recovery used here is the increase in biological crust cover and the lack of bare mineral soil.

The results of this study indicate that a "one size fits all" approach is not appropriate with regard to biological crust management. Some biological crust communities may be more resistant to disturbance due to protection of the soil surface by rock or gravel. Others may recover more quickly due to cooler temperatures, higher annual precipitation, or short duration of the hot, dry season. The most fragile communities are those with little surface rock and vascular plant cover. Resistance and resilience of the entire community, i.e., both vascular plants and biological crust, need to be considered when applying livestock management to large areas containing multiple vegetation types.

Biological crusts are often a major component of arid and semiarid landscapes. Soil and nutrient losses resulting from damage to the crust can impact the vascular plant community and ultimately result in desertification (Belnap 1995). This study indicated that, in this geographic area, biological crusts can regrow relatively quickly following release from disturbance. More work is needed to determine how other functional aspects of the biological crust (e.g., nutrient cycling) are affected by management changes.

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