MICROBIOTIC SOIL CRUSTS

IN

SAGEBRUSH HABITATS OF SOUTHERN IDAHO

by

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INTRODUCTION

During the last two decades increasing interest has been shown regarding the role of microbiotic soil crusts in arid and semi-arid habitats (Harper & Marble 1988; Johansen 1993; St. Clair & Johansen 1993). These crusts consist of lichens, bryophytes, algae, microfungi, cyanobacteria, and bacteria growing on or just below the soil surface within the inter-plant matrix (Eldridge & Greene 1994). Soil crusts of this type have been known by a number of names, including cryptogamic (Kleiner & Harper 1972), microphytic (West 1990; Williams 1993), microfloral (Loope & Gifford 1972) and cryptobiotic (Belnap 1993). Although all terms somewhat describe the nature of the soil crusts, St. Clair and Johansen (1993) determined that microbiotic was the most accurate term and recommended its use. Eldridge and Greene (1994) also chose this term, as does the current author. The word "cryptogamic" refers to plants that do not produce seeds, including bryophytes, ferns and fern allies. The later two are not components of biotic soil crusts. The term also excludes the cyanobacterial, bacterial, and fungal components. The suffixes "-phyte" and "-floral" tend to exclude the non-plant components of the crusts. The term "microbiotic" refers to the diminutive, often microscopic nature of the crust components, along with their biological origin. The term serves to differentiate the biotic crusts from those that are formed by a variety of physical processes (Williams 1993).

Microbiotic soil crusts are found world-wide in arid and semi-arid environments. Their occurrence in the semiarid steppe regions of the Great Basin, Colorado Plateau, and the Columbia Basin in western North America is well documented. In some areas, microbiotic crusts can comprise 70 to 80 percent of the living cover (Belnap 1990). A number of studies investigating the flora of the crusts (Shields 1957; Shields & Drouet 1962; Anderson & Rushforth 1976; Johansen et al. 1981; Ashley et al. 1985; Pearson &

Rope 1987; Grondin & Johansen 1993; St. Clair et al. 1993; Wheeler et al. 1993), as well as their ecological roles (Fletcher & Martin 1948; Loope & Gifford 1972; Kleiner & Harper 1977; Anderson et al. 1982a; Brotherson & Rushforth 1983; St. Clair et al. 1984; Johansen & Rushforth 1985; Belnap & Gardner 1993) have occurred within this geographic area The ability of both free-living and lichenized cyanobacteria to fix atmospheric nitrogen has been of particular interest (Cameron & Fuller 1960; Mayland et al. 1966; MacGregor & Johnson 1971; Snyder & Wullstein 1973; Rychert & Skujins 1974; Skujins & Klubek 1978; Klubek & Skujins 1980; Jeffries et al. 1992; Evans & Ehleringer 1993; Belnap et al. 1994).

The object of this project was to identify the species associated with microbiotic soil crusts in sagebrush habitat types of southern Idaho and determine the ecological roles filled by the individual taxa and the crusts as a whole. An attempt was made to determine relative importance of microbiotic soil crusts in each habitat type.

METHODS

The studv area

The study area was defined as that portion of Idaho south of approximately 44°30'00" north latitude supporting vegetation dominated by shrubby *Artemisia* genera. A detailed description of the geography, geology, and vegetation of the study area is located under the heading: **MICROBIOTIC CRUSTS IN SAGEBRUSH HABITATS OF SOUTHERN IDAHO.**

Literature and herbaria searches

The scientific literature was systematically searched for references to microbiotic soil crusts, sagebrush habitat types within southern Idaho and adjacent areas, and individual genera. The herbaria at Boise State University (SRP and the private herbaria of Roger Rosentreter and Ann DeBolt) were searched for specimens occurring within the study area that were determined to be components of microbiotic soil crusts. It was determined that these herbaria contained a reasonably comprehensive collection of soil crust components for the study area, due to the extensive collecting and curating efforts of Rosentreter and DeBolt. Hereafter, the notation "collections at SRP" will include those specimens residing in the private herbaria.

Field work

Since the purpose of this report is to review existing data regarding microbiotic soil crusts and their role in sagebrush habitats of southern Idaho, no field work was integrated into the study plan. However, personal field observations of the author and limited data from current graduate studies occurring at Boise State University are included.

ECOLOGICAL ROLES OF MICROBIOTIC SOIL CRUSTS

Soil stabilization

One of the important roles of microbiotic soil crusts is that of soil stabilization, resulting in reduction of erosion by wind and water (Booth 1941; Fletcher & Martin 1948; Bond & Harris 1964; Bailey et al. 1972; Schulten 1985; Belnap & Gardner 1993; Williams 1993). Early studies investigated binding of surface soil particles by algal filaments and fungal mycelium. Booth (1941) described algae as being pioneer species in the revegetation of severely disturbed lands. He found that water runoff from scalped plots contained over 10 times more soil than runoff from plots where an algal crust had been left intact. Fletcher and Martin (1948) also observed increased soil erosion due to water in non-crusted soils. They examined crusted soils microscopically and noted soil particles adhered to the mold hyphae. A later study by Belnap and Gardner (1993) used scanning electron microscopy to determine how the cyanobacterium ***Microcoleus vaginatus* changes** the structure of soils of various types. Living filaments surrounded by polysaccharide sheaths wind through moist soil, with soil particles adhering to the sheaths. When the soil is dry, particles remain firmly attached to the sheaths.

Undisturbed crusts from sandy soils might have sheath material occurring as deep as 10 cm. However, living filaments of ***M. vaginatus* only** occur as deep as 1 cm (Belnap & Gardner 1993). Microbiotic crusts are fragile when dry and are easily crushed by trampling by humans or livestock (Cole 1990; Belnap & Gardner 1993). While the surface crust can be regenerated by living filaments when the soil is again wet, the structure of soil and the abandoned sheaths below the surface is permanently destroyed (Belnap & Gardner 1993).

Williams (1993) determined that microbiotic crusts contribute to soil stability and reduce erosion due to wind and water. Microbiotic crusts were treated in three ways -- left intact (control), chemically killed but left undisturbed, and scalped -- then subjected to wind tunnel and simulated rain treatments. In the wind erosion experiment, threshold friction velocity was significantly less and trapped wind-eroded material was significantly greater for plots from which the microbiotic crusts had been removed completely. When simulated rainfall was applied, interrill erosion was significantly different between treatments, with the control having the least erosion in a 45-90 minute period, and the scalped treatment having the most. In the control treatment, fine soil particles were likely held in place by fungal hyphae and cyanobacterial filaments. The chemically killed crusts apparently disintegrated, releasing the soil particles that were previously bound.

Soil fertility

Microbiotic soil crusts have also been reported to contribute to soil fertility (Harper & Marble 1988; St. Clair & Johansen 1993; Belnap & Harper 1995). Cyanobacteria that are both free-living and associated with lichens contribute significant amounts of fixed nitrogen to desert soils (Rychert & Skujins 1974; Rychert et al. 1978; Evans & Ehleringer 1993). Kleiner and Harper (1977) observed that soils lacking microbiotic crusts had a lower organic matter content and less available phosphorus. Evidence exists supporting the hypothesis that microbiotic crusts enhance uptake of a number of essential elements by vascular plants, especially nitrogen (Harper & Pendleton 1993; Belnap & Harper 1995).

Microbiotic crusts fix carbon through photosynthesis and contribute to the primary production of arid and semi-arid ecosystems. Crust organisms, particularly algae and cyanobacteria, are able to colonize areas that are severely disturbed, or climates too harsh to support vascular plants (Shields & Durrell 1964). Lange et al. (1994) determined that Lichen soil crusts in the coastal fog zone of the Namib Desert had a photosynthetic potential similar to that of higher plant leaves, given optimal light and hydration conditions. Annual net carbon gain was estimated at 16 g C m^{-2} year-'. Estimates for net carbon gain by microbiotic crusts in semi-arid areas of the southwestern United States range from 6 to 23 kg C ha^{-1} $year^{-1}$ (Johansen 1993). Klubek and Skujins (1980) suggested that nitrogen-fixing heterotrophic bacteria in soil may obtain organic carbon from living and decomposing cyanobacteria Beymer and Klopatek (1991) demonstrated that organic carbon fixed by microbiotic crusts accumulates in the soil beneath the crusts. Since crust organisms occupy interspaces in plant communities where vascular vegetation is sparse or absent, they contribute nutrients to areas that would otherwise be relatively barren.

Establishment of vascular plants

Microbiotic soil crusts are thought to fill other important roles in shrub-steppe and grassland communities. Shields and Durrell (1964) observed that soil algae colonize disturbed sites, forming a moisture-retaining substrate for establishment of vascular plant seedlings. Lesica and Shelly (1992) found that mature individuals of the rare plant, *Arabis fecunda*, were more common on soil crust than expected. While it did not appear that seedling establishment was enhanced by the presence of a microbiotic crust in this study, survivorship might have increased due to an improved moisture and nutrient status. St. Clair et al. (1984) observed a trend toward higher seedling establishment of perennial grasses where microbiotic crusts were undisturbed by trampling. Graetz and Tongway (1986) suggested that loss of fine soil particles from areas where crusts had been destroyed by livestock trampling resulted in lowered cation exchange capacity of the soil, and increased leaching of nutrients into the soil. These nutrients would then be unavailable for use by germinating seeds. Harper, as cited by Belnap (1993) found that crusts significantly enhanced plant establishment and survival for 4 plant species on 3 different substrate types.

Soil moisture

The effects of microbiotic crusts on soil moisture have been investigated, with mixed results. Conflicting data result from variation in geographic location and climate, composition of the microbiotic crusts and the resulting soil microtopography, and soil type

(Brotherson & Rushforth 1983; Graetz & Tongway 1986; Eldridge & Greene 1994). During a rainfall event, the polysaccbaride sheaths of cyanobacteria can quickly absorb several times their weight in water (Campbell et al. 1989; Belnap & Gardner 1993). In fine-textured soils, the resulting net of swollen filaments might act as a seal on the soil surface (Brotherson & Rushforth 1983) while in sandy soils, spaces remain that allow penetration of water (Belnap & -Gardner 1993). Areas such as the Negev Desert and Israel with a high incidence of dew fall have well-developed cyanobacterial crusts that effectively seal the soil surface (J. Belnap, pers. comm.). Loope and Gifford (1972) found that a soil crust composed of crustose lichens decreased the percolation rate of water through the soil surface. However, pooling of water occurred due to the irregular surface structure of the crust, resulting in less runoff from the soil surface and increased infiltration of water into the soil following penetration of the crust. Brotherson and Rushforth (1983) obtained similar results for lichen and algal crusts. However, penetration of water through the soil surface was enhanced when mosses were present. This appeared to be due to moss thalli acting as a sponge. Although initial infiltration of water into the soil was reduced by some microbiotic crusts, depth of penetration, once water entered the soil, was enhanced in sites with high crust cover. Graetz and Tongway (1986) determined that water infiltration rates for biologically-crusted soils in southern Australia were one-third to one-half of rates observed for scalped plots. However, increased infiltration resulted in loss of nutrients from the soil surface due to leaching. Williams (1993) found that intact crusts of either ***living*** or ***chemically*** killed *Microcoleus vaginatus* neither enhanced nor impaired the movement of water through the surface of a sandy loam soil, when compared to an area where the crust had been removed. This study was done in an area that had been previously trampled by livestock, and had only 3 years recovery time. This may have not been sufficient for soil dilation or crust recovery.

The polysaccharide sheaths of algae and cyanobacteria increase the water-holding capacity of the soil (Campbell et al. 1989; Belnap & Gardner 1993). Booth (1941) found that soil moisture was greater in the top inch of soil which had an algal crust, as compared to bare soil. Brotherson & Rushforth (1983) noted that the elevated silt levels associated with microbiotic crusts might also contribute to reduction of soil water evaporation.

DISTURBANCE EFFECTS

Physical disruption of the soil surface

A number of workers have investigated the effects of disturbance on microbiotic soil crusts. There is strong evidence to support the hypothesis that physical disruption of the crust by trampling or vehicle impacts reduces coverage values, species richness, and rates of nitrogen fixation (Rogers & Lange 1971; Kleiner & Harper 1972; Anderson et al. 1982b; Brotherson et al. 1983; Andrew & Lange 1986; Johansen & St. Clair 1986; Marble & Harper 1989; Cole 1990; Beymer & Klopatek 1992; Belnap et al. 1994).

Land use by domestic livestock results in compaction and disturbance of the surface soil, with resulting negative impacts on microbiotic soil crusts. Kleiner and Harper (1972) observed increased floristic diversity and about 7 times the microbiotic crust cover in ungrazed versus grazed sites. Brotherson et al. (1983) determined that the lichen and moss components of microbiotic crusts are more severely affected than the algal/cyanobacterial components. The lichen component of soil crusts, in particular, does not contain any “increaser” species, i.e., species that respond to disturbance by increasing in population size. Beymer and Klopatek (1992) observed reduced visible cover, along with a significantly reduced chlorophyll *a* content, when comparing grazed to ungrazed sites. They did not find a difference in species diversity when comparing treatments. Rogers and Lange (1971) and Andrew and Lange (1986) investigated the effects of sheep stocking pressure on surface soils supporting microbiotic crusts in South Australia. Coverage of the lichen soil crusts declined with increased proximity to watering places. Crusts were completely destroyed within 50 m of a watering place after 2 years of use.

Marble and Harper (1989) determined that season of use by Livestock had a significant effect on microbiotic crust coverage values and species richness. Decreases in these two parameters were observed in areas used by livestock during both early and late winter as opposed to areas used only during the early winter. Freedom from trampling during late winter and spring, when soil moisture is high and microbiotic species are metabolically active, might permit the organisms to recover from the disturbance enough to reduce soil erosion.

Human activities can also cause destruction of soil crusts. Activities such as use of OHV's (off-highway vehicles) and military vehicles in these sensitive areas result in compaction of the soil surface and crushing of the crusts. Belnap et al. (1994) observed a 77-97% reduction in nitrogenase activity in soil crusts subjected to disturbance by raking, scalping, and tracked vehicles. Nitrogenase activity remained greatly reduced after 9 months. Since microbiotic crusts are a primary contributor of nitrogen in arid and semi-arid regions (Evans & Ehleringer 1993), loss of soil crusts due to human activities could result in a serious degradation of soil fertility. An increase in soil erosion will also be an important consequence of soil crust destruction.

Recovery depends on the composition of the soil crust, severity and timing of the disturbance, climatic events during and following disruption, and proximity of inoculant sources (Anderson et al. 1982b; Johansen 1986; Johansen & St. Clair 1986; Marble & Harper 1989; Belnap 1993). Cole (1990) observed that crusts destroyed by human trampling redeveloped within 1 to 3 years. The coverage of soil crusts returned to pre-trampling levels within 5 years, however, the structure of the crusts was less complex prior to the trampling treatment. Anderson et al. (1982b) found that partial recovery from trampling by livestock occurred in 14 to 18 years. Belnap (1993) determined that recovery rates were extremely slow in areas where the crust had been entirely removed In these sites, estimated time for full recovery ranged from 30 to 40 years for cyanobacteria. Recovery time for non-heterocystic species is slower (>30 years), while heterocystic species appear to recover in approximately 10 years (J. Belnap, unpubl. data). Full recovery for lichens is estimated at 45 to 85 years, and mosses could potentially take as long as 250 years. Inoculation of soil surfaces with crust organisms could speed the process somewhat, though not to a great degree (Belnap 1993).

It must be emphasized that visual assessments of recovery for algal and cyanobacterial soil crusts are usually inadequate. Belnap (1993) recorded recovery of inoculated and uninoculated, scalped plots using both visual and chemical (chlorophyll a) estimates. While all plots appeared to have recovered in terms of coverage by cyanobacteria after 1 year, chlorophyll a content was significantly less in scalped plots, as compared to the untreated control. Much of the crust consisted of abandoned cyanobacterial sheath material. Belnap et al. (1994) determined that while any physical disruption of the soil crust resulted in a significant, long-term reduction in nitrogenase activity, chlorophyll content was not significantly decreased in treatments that left the disturbed crust in place. Thirty years following the cessation of winter-only grazing in Canyonlands National Park, nitrogen fixation by cyanobacterial crusts was still at depressed levels (J. Belnap, pers. comm.).

Fire effects

Fire can also destroy microbiotic crusts. Greene et al. (1990) observed reduction in coverage of soil crusts following fire. Soil erosion rates and the amount of bare soil surface per unit area increased A decline in aggregate stability in the O-l cm horizon was also observed Johansen et al. (1982) noted a reduction in biomass of an algal crust after burning, although species diversity of the crust did not vary significantly between burned and unburned areas.

Recovery rates of soil crusts following fire can vary depending on the organisms involved and the climate (Johansen et al. 1993). In the lower Columbia Basin burning treatments decreased the number of algae in soil crusts by an order of magnitude, although species composition remained similar (Johansen et al. 1993). Little change in algal density occurred for the first 16 months following the fire. Recovery of the algal community occurred during the second winter following treatment, between January and March. Three factors were identified to explain this phenomenon: 1) Hydrophobic organic compounds might have been released by the fire and sealed the soil surface, resulting in increased runoff and less available soil moisture. 2) Algae might need a vascular plant canopy for recovery. Vascular plant cover would potentially reduce light intensity from the sun, reduce wind erosion, and improve soil moisture. Coverage of vascular plants was completely destroyed by the burning treatment. 3) Almost twice as much precipitation fell during the second winter. In addition, air temperatures were above freezing between January and March during the second year, whereas during the previous winter air temperatures had'been consistently below freezing. It was also observed that immediately following the fire the algal/moss crust, although dead, was still intact. It was hypothesized that the dead crust might be important in stabilizing the soil following a fire when vascular vegetation has been destroyed The dead crust broke down over a period of 6 to 8 months following the fire, by which time the vascular vegetation had begun to recover.

Johansen et al. (1982) observed significant differences in density and biomass of algae sampled from burned and unburned soil crusts near Wallsburg, Utah. Three years following fire, burned algal crusts had significantly lower density and biomass than unburned crusts. However, the floras of burned and unburned crusts were very similar, especially with regards to diatoms. It was noted that the burned site was possibly preferentially grazed by livestock due to a higher amount of grass. The trampling caused by grazing activity could have impeded the recovery of the algal crust on the burned site.

Johansen et al. (1984) measured the recovery of algae, lichens, and mosses at Camp Floyd State Park, Utah, following fire. Three years following the fire, coverage of all 3 crust components was significantly lower than in an adjacent, unburned community. Within 5 years the algal crust had reestablished and there were no significant differences in either algal coverage or species composition between burned and unburned crusts. Although mosses and lichens had begun to invade the burned area by the fifth year following the fire, recovery in terms of both biomass and composition was far from complete. Only 2 lichens were found in the burned areas, *Collema tenax* and *Caloplaca tominii.* Both taxa have vegetative diaspores which are dispersed by wind and water. Species lacking this dispersal method were absent from the burned site. The only moss found in the burned area was *Pterygoneurum ovatum,* a weedy species that likely dispersed into the area from adjacent grazed areas. It was noted that an important factor in the recovery of all crust components might have been the above-normal annual precipitation that occurred during the last 3 years of the study (years 3-5).

Johansen and Rayburn (1989) estimated that most algal communities will recover within 5 to 10 years following fire, while Lichens and mosses might take 10 to 20 years to fully recover. Additional disturbance, such as trampling by Livestock, could lengthen the recovery period (Johansen and Rayburn 1989).

Post-fire rehabilitation

The author is currently conducting a study on the recovery of microbiotic soil crusts following fire and subsequent rehabilitation of vascular vegetation, or the lack thereof, on the western Snake River Plain. Increased tire frequencies within the Snake River Plain have resulted in conversion of much of the area to annual grassland dominated by exotic species such as *Bromus tectorum* (cheatgrass) and *Taeniatherum asperum* (medusahead) (Whisenant 1990). Extensive areas are seeded with perennial exotic and-native grasses and shrubs following fire. Typical seeding methods involve tilling the soil. Microbiotic soil crusts are therefore subjected to two destructive forces, fire and plowing of the soil surface.

Transects were established in 3 treatment types: unburned *Artemisia tridentata* ssp. *wyomingensis* habitat types, adjacent areas burned between 1980 and 1983 that were seeded with perennial grasses, and areas within the same burns that were not rehabilitated. Percent cover of microbiotic soil crust components and cheatgrass for each of the treatment types are summarized in Table 1. Bryophytes were divided into 2 types: tall moss (*Tortula ruralis*) and miscellaneous short mosses. *T. ruralis* is normally found beneath the canopies of shrubs and, to a lesser extent, bunchgrasses. Short mosses occur predominately in interspace positions and beneath bunchgrass canopies. They are also found within annual grass communities where the litter layer has not accumulated to such a depth that it excludes light, approximately less than ***1 cm. T. ruralis*** is abundant in the unburned sagebrush communities and is mostly absent **from** the burned/unseeded areas. In burned/seeded ***areas,*** this moss ***is*** found at the base of bunchgrasses. ***T. ruralis*** was found in the burned/unseeded treatment at Rattlesnake Creek along a transect that ran adjacent to dead sagebrush, indicating that this area did not burn as intensely as the ***surrounding*** area. When recently burned sites were examined, ***T. ruralis was*** found surviving in similar, less intensely burned areas. Mosses in southern Utah have been reported as being part of the climax crust community and very slow to recover **from** disturbance (Belnap 1993). The results suggest that ***T. ruralis*** is just beginning to establish approximately 11-14 years following **burning** and rehabilitation, and that the moss needs shading and protection from bunchgrasses or shrubs in order to persist.

The short mosses were abundant in all treatments. Some of these mosses, such as ***Ceratodon purpureus*, *Bryum argenteum,* and *Funaria hygrometrica*,** are cosmopolitan in distribution and often found in disturbed sites. In disturbed sagebrush habitats' in southwestern Idaho, they appear to be pioneer species and likely serve to stabilize the soil surface. Although they can be abundant in annual grass communities, these mosses are eventually excluded due to density of vegetation and persistent litter accumulation. Along some transects cheatgrass coverage exceeded **80%,** at which point the mosses became absent.

In this study, ***lichens were also*** slow to recover from disturbance. ***Like T. ruralis*,** they were virtually absent from the burned/unseeded areas. The only lichen found here ***was Caloplaca tominii,*** a common species that disperses vegetatively. Coverage values were higher for the burned/seeded treatments, though not approaching the densities found in unburned sagebrush communities. However, many of the species found in the unburned treatments were found in the seeded sites, though in less abundance. Some lichen species are parasitic on mosses or grow on dead organic matter, such as *Poa secunda* mounds. Most lichens grow very slowly, at rates of approximately 1 mm annually. Thus, a well-developed lichen component is considered part of the climax stage for microbiotic soil crust communities and requires some development of vascular plants and bryophytes in order to establish and persist.

Table 1 also lists the percent cover of cheatgrass for each treatment. Cheatgrass coverage was minimal in the unburned sagebrush and burned/seeded treatments, but exceeded 90% for some transects in the burned/unseeded treatments.

The results from this study suggest that restoration of vascular and nonvascular vegetation are closely tied. Microbiotic soil crusts are slow to reestablish following severe disturbance. Early to mid-seral stages in microbiotic crust communities are reached over a decade following disturbance for sites on the western Snake River Plain.

MICROBIOTIC CRUSTS IN SAGEBRUSH HABITATS OF SOUTHERN IDAHO

Vegetation dominated by species of sagebrush (*Artemisia*) occupies a substantial portion of the 11 western states, with the bulk of the distribution in Utah, Nevada, southern Idaho, eastern Oregon, western Montana, Wyoming, and Colorado (Blaisdell et al. 1982). Sagebrush vegetation covers an estimated 17 million acres (6.9 million ha) in Idaho (Tisdale et al. 1969). Some of this area, particularly in the northern region supporting sagebrush steppe, has been converted to farmland. Some of the area has also been degraded by livestock overgrazing and repeated fires, resulting in reduced shrub and bunchgrass cover and invasion by ***exotic annual grasses such as Bromus tectorum*** and

Taeniatherum asperum (West 1988). On the Snake River Plain, fire frequency has increased from intervals of 60 to 100 years to intervals of less than 5 years due to conversion of the sagebrush steppe to annual grassland (Whisenant 1990). Much of the area is public land managed by the Bureau of Land Management (BLM). Other public land managers include the U.S. Forest Service, Department of Energy, Department of Defense, National Park Service, and State of Idaho.

The Snake River Plain is the dominant physical feature of southern Idaho. It is 360 miles (579 km) long and 50 to 80 miles (80 to 129 km) wide. The plain is bordered on the southwest by the Owyhee Plateau, on the south by the northern extension of the Basin and Range Province, on the east by the Middle Rocky Mountain Province, and on the north by the Northern Rocky Mountain Province (Hironaka et al. 1983).

The sagebrush region of southern Idaho extends from elevations of approximately 2000 ft (610 m) to about 9500 ft (2896 m). The area receives 7 to 20 inches (178 to 508 mm) annually. In the western portion of the state precipitation occurs during the winter with less than 35 percent occurring during April through September. The eastern portion of the state receives greater than 50 percent of its annual precipitation during April through September due to storms caused by moist upper air masses. Average annual temperatures range from 37 to 52 degrees F (2.8 to 11.1 degrees C) (Hironaka et al. 1983).

The variability found in the soils of southern Idaho reflects the diversity in topography and parent materials found in the area. Basalt lava flows underlie the Snake River Plain and are mantled with loessial deposits in the east and sedimentary deposits in the west. Soils reflect the warm, dry climate of the area and are primarily classified as Camborthids, Calciorthids, Durorthids, Haplargids, Calcixerolls, and Durixerolls. The soils of the Owyhee Uplands are predominately Argixerolls and Haplargids derived from igneous parent materials. The climate of this area is cooler and moister than that of the *Snake* River Plain. The wide valley floors of the Basin and Range Province are covered with deep sediments from Lake Bonneville. Soils here are classified as Calcixerolls, Argixerolls, and Calciorthids. The north-south oriented mountain ranges in this province have a relatively cool, dry climate and support soils classified as Calcixerolls, Argixerolls, and Cryoborolls. The central mountains of Idaho lie within the'area covered by the Idaho batholith. The valleys lying in the rain shadow of these mountains have soils classified as Torriorthents, Argixerolls, Calciorthids, and Haplaquolls (Hironaka et al. 1983).

Hironaka et al. (1983) described sagebrush habitat types for southern Idaho. These habitat types are dominated by the following species and subspecies of sagebrush: ***A. rigida, A nova, A. arbuscula, A longiloba, A. arbuscula*** ssp. ***thermopola, A tridentata*** ssp. ***wyomingensis, A tridentata*** ssp. ***tridentata, A tridentata*** ssp. ***vaseyana, A. tridentata*** ssp. ***xericensis, A tridentata*** ssp. ***spiciformis, A. tripartita,*** and ***A. cana*** ssp. ***viscidula.*** Most of the sagebrush vegetation in Idaho is represented by the taxa within A ***tridentata*** (Winward 1970).

While the habitat types represent a range of soil and climatic conditions, it might be possible to predict the presence of microbiotic crusts and, potentially, their major components, given information regarding these conditions. Rogers (1972) determined the microbiotic crusts were predominant on loamy soils in southeastern Australia, although they also occurred on hard-setting clay and sandy soils. Patterns of mean annual rainfall and maximum summer temperature appeared to explain the distribution of soil crust lichens in the region. Many lichens are very heat sensitive when wet (Rogers 1989) and might not be able to tolerate conditions in hot areas where much of the ***rainfall occurs*** during the summer months. This could explain the predominance of cyanobacteria, which are well-adapted to dry, alkaline conditions, in the soil crusts of such areas (Durrell & Shields 1961; Bond & Harris 1964; Shields & Durrell 1964; Rogers 1989). Rogers (1972) found, however, that a number of lichen species were widespread despite climatic and soil chemistry conditions. Several of *these* taxa -- *Endocarpon pusillum, Cladonia* sp. (squamules), *Psora decipiens* -- are common in the western portion of the Snake River Plain. Anderson et al. (1982a) identified soil parameters favoring development of microbiotic crusts in southern Utah Areas with a higher percentage of surface rock and sand had less well developed crusts. Species diversity increased with increasing proportions of silt and clay. The best crust development was observed for finer-textured soils with higher salinity.

Searches of SRP and the literature (Lawton 1971; Rossman 1977; Pearson & Rope 1987; McCune 1992; McCune & Rosentreter 1992) yielded lists of lichens and bryophytes (Tables 2 and 3 in Appendix A) either known or suspected to occur in sagebrush habitats of southern Idaho. These lists are by no means exhaustive, but should reflect many of the common and some of the uncommon species for the region. Unfortunately, for many of the specimens the habitat was listed only as "Artemisia grassland", without mention of the species present. Attempts were made to determine the habitat types for these specimens. A diversity of algal and cyanobacterial species are undoubtedly present in all habitat types, although no floristic studies have been done for these components of microbiotic crusts in the area However, such work is planned for the spring of 1995 by the author for *Artemisia tridentata* ssp. *wyomingensis* habitats in southwestern Idaho. Specimens of *Microcoleus* spp. and *Nostoc* spp. from crusts in southwestern Idaho have been deposited in the Boise State University herbarium (SRP). *Scytonema* spp. are also known to be present (R. Rosentreter, Idaho State Office, BLM, pers. comm.). Extensive cyanobacterial crusts such as those of southern Utah have not yet been documented for the area It is likely that many species listed by Johansen et *al. (1993)* might be found *in A. tridentata* habitats of southern Idaho with fewer green algae species where soils tend to be more alkaline.

The following is a discussion of the sagebrush habitat types of southern Idaho according to Hironaka et al. (1983) (with the addition of 2 taxa, *Artemisia papposa* and *A. spinescens),* with regards to the existence and the relative importance of microbiotic soil crusts within the plant communities. Microbiotic crusts will stabilize surface soils in all habitat types where they are present, but will be less important in types where vascular plant cover or litter cover is high. Nitrogen-fixing lichens or cyanobacteria will contribute to the nutritional status of the plant community. Types with similar soils and climatic conditions are grouped together where possible to simplify the discussion.

Artemisia spinescens

Artemisia spinescens often occurs in the transition zone between sagebrush and salt desert shrub habitat types and is considered part of the salt desert shrub cover type (Society for Range Management 1994).

Specimens for several soil crust lichens from an *Atriplex/A. spinescens* community near Murphy, Idaho, are deposited at SRP. These taxa include *Aspicilia reptans, Lecanora garovaglii,* and *Aspicilia alphoplaca,* along with the vagrant species *Aspicilia hispida.* The cyanobacterium *Microcoleus* has also been collected from this site. Soil crusts are undoubtedly an important component of the plant communities supporting *A. spinescens.* Their occurrence in the desert shrub communities of the Great Basin has been well documented in the published literature (see Johansen 1993 for a recent review; also

Anderson & Rushforth 1976 and St. Clair et al. 1993 for species lists). Algal and cyanobacterial soil crusts are also important in these desert shrub communities.

Artemisia spinescens is an important spring browse plant for domestic livestock and native ungulates (Society for Range Management 1994). Trampling by livestock, along with other physical disturbances such as use by OHV's and military vehicles, will destroy microbiotic crusts in these areas, resulting in increased erosion of surface soils. Destruction of crusts dominated by nitrogen-fixing cyanobacteria and lichens will result in a reduction in nutrient status for the plant community, not only in terms of nitrogen, but also organic carbon. Soil moisture conditions might also be negatively impacted

Artemisia rigida/Poa secunda

Artemisia rigida* is** restricted in Idaho to basalt scablands in the extreme west-central part of the state, as far south as Gem County, and the Palouse grasslands in northern Idaho. Most of the species' distribution lies in similar habitats in eastern Oregon and Washington. The ***A rigida / Poa secunda habitat type occurs on shallow to moderately deep, extremely stony or extremely rocky soils over basalt bedrock in the 12 to 20 inch (305 to 508 mm) precipitation zone.

Rossman (1977) documented the presence of soil crust lichens and mosses in ***A. rigida / P. secunda / Lomatium cous*** communities on the Lawrence Memorial Grassland Preserve in north central Oregon. A number of the species listed for the preserve have also been documented for southern Idaho in other habitat types including the lichens ***Caloplaca jugermanniae, C. stillicidiorum, Diploschistes muscorum* (listed as *D. scruposus*, which *occurs* on *rock, see* McCune 1992), *Collema tenax, Leptogium lichenoides, L. albociliatum, Cladonia pyxidata, Psora luridella, Peltigera rufescens,*** and the mosses

Ceratodon purpureus and ***Tortula ruralis***. The annual precipitation for the site is approximately 11 inches (280 mm). Precipitation for the southern extension of the A. *rigida* type in Idaho is slightly greater at 12 inches (305 mm) or more.

The ***A rigida/P.secunda/L. cous*** habitat type within the Lawrence Memorial Grassland Reserve occurs within the inter-mound region of a mound-intermound system, also known as biscuit scabland (Rossman 1977). This peculiar topography consists of circular to ovoid mound 10 to 20 m in diameter and 100 to 120 cm high. The mounds are surrounded by stone rings. The inter-mound areas have shallow soils, with bedrock at approximately 18 cm. This type of topography is lacking in ***A rigida*** habitats in southern Idaho. Daubenmire (1970) noted the presence of a well-developed microbiotic crust in ***A rigida/P. secundu*** associations of the Washington steppe. Species present included the mosses ***Bryum argenteum lanatum, Ceratodon purpureus, Grimmia alpestris, G. montana,*** and ***Tortula ruralis,*** and ***the*** terricolous ***lichens Acarospora schleicheri, Cladonia pyxidata, Catapyrenium lachneum*** (listed ***as Dermatocarpon hepaticum*** and ***D. rufescens), Psora globifera (as Lecidea globifera), Leptogium lichenoides, and Peltigera canina. These*** crusts occur in areas of loess interupted by b&salt fragments.

In Idaho ***A rigidu*** is associated with poorly-drained basalt flats with thin, rocky soils and sparse vegetative cover. (Rosentreter & McCune 1992). Rosentreter and McCune (1992) noted the presence of mosses in ***A rigida*** habitats, along with vagrant (unattached) forms of ***Dermatocarpon miniatum, Dermatocarpon reticulatum, Cladonia pocillum, Diploschistes muscorum, Lecanora garovagiii, L. phaedrophthalma, Umbilicaria hyperborea, U. phaea,*** and ***Xanthoparmelia plittii. These lichens occur in areas lacking an*** accumulation of plant litter, a phenomenon which I have noted with regards to terricolous lichens. Vagrant lichens are locally common and restricted to unusual habitats such as this. They are noteworthy for this reason, although they do not comprise a part of the soil crust community. Due to the stony nature of the soils in the ***A. rigida*/*P. secunda*** associations in west-central and southern Idaho, the crust is less developed with lower species diversity. Here, the crust is unimportant with regard to reduction of soil erosion and hydrologic relations. The unattached lichens and mosses likely serve as a mulch in areas where plant litter is scarce. Nitrogen-fixing species such as *Collema tenax* and *Peltigera rufescens* can contribute nitrogen to this nutrient-poor environment. All species, both terricolous and vagrant, contribute to organic matter and species diversity.

Daubenmire (1970) stated that A. *rigida* is readily consumed by livestock where ***grass*** forage is unavailable, and that ***Bromus tectorum increases as*** a result of disturbance. Protection of good examples of these unique plant communities from grazing would therefore be important from a diversity standpoint, as increased litter from ***B. tectorum*** could exclude crust organisms as well as vagrant species. In addition, fire frequency would likely increase, due to the heightened fuel load where vegetation is normally sparse.

Artemisia papposa communities

Artemisia papposa is restricted to ephemerally flooded, shallow, stony basalt and frigid, heavy clay *soils* in Elmore and Owyhee counties, adjacent Oregon and Nevada. Sites supporting this species are located at 4000 to 6500 ft (1220 to 1950 m) elevation. The presence of the ***rock lichen Dermatocarpon reticulatum, which usually occurs in*** streams and ephemeral drainages, is indicative of saturated spring soil conditions (Rosentreter 1992). Vagrant lichen species as described above for *A. rigida* habitats also ***occur in A papposa*** communities. Due to the stony nature of the soils, coupled with seasonal ponding, microbiotic crusts are not well-developed in these communities, as many lichens common to soil crusts are relatively intolerant of saturated conditions. Cyanobacteria are more tolerant of the seasonally saturated conditions. The cyanobacterium ***Nostoc*** has been collected from ***A. papposa*** sites (specimens at SRP).

Management concerns are identical to those for A. *rigida* associations -- degradation of the plant community by grazing impacts could result in increase cover by ***Bromus tectorum*** and the associated litter.

Artemisia nova/Agropyron spicatum, A nova/Festuca idahoensis

Artemisiu nova is restricted to shallow to moderately deep, calcareous soils derived from limestone or loess in eastern Idaho. The species is more common in Utah and Nevada., and is at its northern limit in Idaho. ***A. nova occurs*** at moderate elevations (5000 to 7000 ft; 1524 to 2134 m) in the 8 to 11 inch (203 to 279 mm) precipitation zone. More than 40 percent of the annual precipitation falls between April and August. Soil surface horizons for ***A nova*** habitat types are gravelly silt loam at the lower precipitation zone and gravelly loam on moderately deep soils. Due to the gravelly nature of the surface horizon, occurrence of microbiotic crusts is less predominant in these habitat types. Lichen species listed in Table 2 with an affinity for strongly calcareous soils are present. Specimens at SRP document the occurrence of ***Collema tenax*** and several vagrant species in the ***A nova / Agropyron spicatum*** habitat type. The cyanobacterium ***Nostoc commune var. flagelliforme occurs in*** mats on the soil surface (specimen at SRP).

Artemisia arbuscula/Poa secunda

This habitat type usually occurs in a mosaic with other habitats of the *Artemisia* *arbuscula* series on shallow soils with little or no development. See the following discussions for ***A arbuscuia /Agropyron spicatum*** and ***A arbuscuia / Festuca idahoensis*** for information regarding potential soil crust development that might extend to this type.

Artemisia arbuscula/Agropyron spicatum

In the Birch Creek and Little Lost River drainages of eastern Idaho, ***the Artemisia arbuscula /Agropyron spicatum*** habitat type is adjacent to the more mesic side of ***A nova/A. spicatum,*** with ***A arbuscula*** occurring on similar, noncalcareous soils. The habitat type also occurs in western and extreme southeastern Idaho where annual precipitation exceeds 8 to 12 inches (203 to 305 mm). Elevations are moderate at 5000 to 7000 ft (1524 to 2134 m). Where soils are derived from basalt or rhyolite, the surface horizon is silt loam to silty clay loam. Soils derived from limestone have a strongly calcareous, gravelly silt loam surface horizon. Considerable clay below the surface horizon restricts internal drainage. In eastern Idaho more than 40 percent of the annual precipitation occurs between May and August.

As with the ***A nova/A spicatum*** habitat type, microbiotic crusts are not predominant in this type, due to the gravelly nature of the soils. However, in western Idaho, the habitat type occurs on finer textured soils that are often stony. In these areas, terricolous lichens and mosses are more common, but extensive crusts, such as those observed ***in A tridentata*** habitat types, are not present. Specimens of ***Aspicilia hispida***, a vagrant species, collected from this habitat type in Nevada are housed at SRP. In the Reynolds Creek drainage of the Owyhee Mountains, I observed crusts of minimal to moderate development in this habitat type. The moss ***Tortula ruralis is the*** main component present, occurring beneath shrubs and on the edges of small ***terraces*** that are associated with the shrubs and bunchgrasses. Where the moss is associated with these terraces, it appears to have a stabilizing *effect: Lichens* including ***Caloplaca, Psora,*** and ***Aspicilia*** species, along with several other mosses were observed on a brief reconnaissance of the area. In an exclosure that had been protected from grazing for approximately 30 years, lichen and moss coverage was, roughly estimated, 10 to 40 percent (including the mat of ***T. ruralis*** beneath the shrubs). Coverage of vascular vegetation was high. Due to deeper ***soils, the A. arbuscula*** in the exclosure was taller than that on adjacent, more exposed ridges. ***In*** the shallow-soil ***A arbuscula communities, only Caloplaca*** and a small amount of ***T. ruralis*** was observed. This is likely due, in part, to the rocky nature of the soil. The areas observed were also grazed by cattle.

Soil surface runoff during spring snow melt is common in this region. At Reynolds Creek, ***T. ruralis*** undoubtedly plays a part in soil stabilization where it occurs on the small terraces. Lichens, when present, also contribute to the stabilization of the moderate to steep slopes of the area. The coverage of lichens and mosses was noticeably less outside of the grazing exclosure.

Artemisia arbuscula/Festuca idahoensis

This type occurs at moderate elevations of 5000 to 7000 ft (1524 to 2134 m) in areas where temperatures are lower and annual precipitation is higher. It occurs primarily in western Idaho and is not found on calcareous soils. Soils are moderately deep and derived from basalt mixed with loess or rhyolitic welded tuff. Surface horizons are silt loam. ***Agropyron spicatum*** and ***Poa secunda*** might also be present in the under-story. Terricolous lichens collected from the Owyhee uplands are deposited at SRP, including ***Caloplaca stillicidiorum, Catapyrenium*** sp., ***Collema tenax, Endocarpon pusillum, Heppia***

lutosa, Lecanora zosterae, Phaeorrhiza sareptana, and ***Psora globifera.*** Bryophytes are undoubtedly present as a major component of the soil crusts.

Since A arbuscula is a preferred forage species for domestic sheep, damage to microbiotic crusts due to trampling is likely. Soil crusts in this habitat type are therefore important for erosion control during the wet spring.

Artemisia arbuscula ssp. thermopola/Festuca idahoensis

Artemisia arbuscula ssp. ***thermopola*** occupies shallow, poorly drained, soils of ridgetops and glacial outwashes in central Idaho. This type usually occurs within forest openings on relatively high elevation sites. Harper and Marble (1988) found that in Utah, cover of microbiotic crusts decreased with increasing elevation and as vascular plant cover increased No specimens were found for this habitat type. Due to the texture and hydrologic properties of the soils, it is highly unlikely that microbiotic crusts are. a component of plant communities within this habitat type.

Artemisia longiloba/Festuca idahoensis

The ***Artemisia longiloba / Festuca idahoensis*** habitat type is found in Blaine and Camas ***counties*** and ***in the*** Owyhee uplands. ***A longiloba is*** restricted to claypan soils. The ***soils*** of ***this*** type ***are usually*** rocky and ***similar to those*** on which ***the A arbuscula / F. iduhoensis*** type is found, with a moderately deep, fine-texture surface horizon. Although no specimens were found for this habitat type, microbiotic crusts potentially exist here and are dominated by lichens and mosses.

***Artemisia tridentata* ssp. *wyomingensis* habitat types**

Artemisia tridentata ssp. *wyomingensis* is widespread in southern Idaho, extending across the Snake River Plain and into the adjacent foothills. Understories of the associations are dominated by ***Poa secundu, Sitanion hystrix, Agropyron spicatum, Stipa thurberiana,*** and ***Stipa comata.*** Annual precipitation ranges from 7 to 12 inches (178 to 305 mm). All types occur on soils with a silt loam surface horizon, except the ***A t.*** ssp. *wyomingensis / S. comata* type, which is restricted to sandy loam or highly calcareous silt loams. The occurrence of *the* moss *Tortula ruralis* and other mosses and lichens in the understory was documented for the ***A t.*** ssp. ***wyomingensis / P. secundu*** and ***A t.*** ssp. ***wyomingensis / S. thurberiana*** habitat types by Hironaka et al. (1983).

The presence of microbiotic soil crusts in ***A. t.*** ssp. ***wyomingensis*** habitat types is well documented by collections at SRP. Studies presently being conducted by researchers at Boise State University are located in these types in southwestern Idaho. Many of the lichens and bryophytes listed in Tables *2* and *3,* particularly *the* mosses *Tortula ruralis* (under shrub canopies), ***Ceratodon purpureus, Bryum argenteum,*** and ***Funaria hygrometrica*** are found in these habitat types. Filamentous cyanobacteria, including ***Microcoleus*** and ***Nostoc*** sp., are also present, but are inconspicuous compared to the descriptions of cyanobacterial crusts found in Utah. *The* rare *lichen Texosporium sancti-jacobi* is a component of *soil crusts in* ***A*** *t.* ssp. *wyomingensis* and ***A*** *t.* ssp. *tridentata* stands on the western Snake River Plain near Boise (McCune & Rosentreter 1992). In eastern Idaho, the algal and cyanobacterial components might be more conspicuous, due to the moisture regime of that region.

Soil crust lichens have also been well documented for *Artemisia tridentata* habitats at the Idaho National Engineering Laboratory near Arco (Pearson & Rope 1987). Some of the species are common to soil crusts found in the southwestern Idaho (see also the discussion below for *the A. t.* ssp. *tridentata/Agropyron spicatum* habitat type).

Many of *the Artemisia tridentata* habitats of the Snake River Plain have undergone conversion to annual grassland dominated by *Bromus tectorum* due to overgrazing and increased fire frequencies (Yensen 1982; Whisenant 1990). In severely degraded areas dominated by annual grasses and forbs, the vegetation and litter layer can become so thick as to exclude all lichens and mosses. Lichens are generally absent or nearly so from these areas (J. Kaltenecker, unpubl. data). Rossman (1977) noted a similar exclusion of microbiotic species due to high cover of *Bromus tectorum* or bunchgrasses in north central Oregon. Weedy mosses such *as Ceratodon purpureus* are often present in disturbed areas with high annual grass cover, but where a thick litter layer has not yet accumulated (J. Kaltenecker, unpubl. data).

Artemisia trident&a ssp. *tridentata/Agropyron spicatum*

Habitat types of *Artemisia tridentata* ssp. *tridentata* have historically occupied the deep, fertile soils of floodplains. Much of this area has been converted to agriculture. The primary difference between this habitat type and *A. t.* ssp. *wyomingensis /A. spicatum is* one of soil depth In eastern Idaho at the Idaho National Engineering Laboratory (INEL) near Arco, stands of one subspecies grade into stands of the other. A change in soil texture appears *to* be important, *with A. t.* ssp. *tridentata* being dominant on sandy soils and *A. t.* ssp. *wyomingensis* on finer textured soils (Shumar & Anderson 1986). Stands of this habitat type in southwestern Idaho support microbiotic crusts similar in composition to *those in the A t.* ssp. *wyomingensis /A. spicatum* habitat type, with a diverse lichen/moss assemblage where the understory has not been converted to annual grasses

(J. Kaltenecker, unpubl. data). A specimen of the liverwort *Cephaloziella byssacea* from this habitat type is deposited at SRP. Habitats in eastern Idaho might have a more developed algal/cyanobacterial crust due higher summer precipitation.

Artemisia tridentata ssp. *tridentata/Festuca idahoensis*

This habitat type covers limited areas in Idaho, occurring at elevations of 5500 to 7000 ft (1676 to 2134 m) with average annual precipitation of 16 to 18 inches (406 to 457 mm). Two areas supporting this type are the Shoshone Basin near the Idaho/Nevada border and the Craters of the Moon National Monument near Carey. Surface horizons tend to be loam and silt loam. Specimens of a common soil crust lichen, ***Diploschistes muscorum,*** from this habitat type are deposited at SW, indicating that lichen components, along with mosses, are present. Tisdale et al. (1965) noted that coverage of cryptogamic species was low in ungrazed stands of this habitat type near Carey.

Artemisia tridentata ssp. *tridentata/Stipa comata*

This habitat type occurs on deep, sandy soils or deep, well-drained, highly calcareous soils in the 10 to 14 inch (254 to 356 mm) precipitation zone. Microbiotic crusts in this habitat type have a high lichen and moss component. Lichens present include *Caloplaca tominii, Candelariella terrigena, Catapyrenium lachneum, Cladonia pyxidata, Lecidea* sp., *Leprocaulon subalbicans, Arthonia glebosa, Psora himalayana, Endocarpon pusillum, Collema tenax, Polychidium albociliatum, Cladonia pocillum, Acarospora schleicheri, Aspicilia reptans, Diploschistes muscorum* and *Psora montana*. Bryophytes present include *Tortula ruralis, Ceratodon purpureus, Bryum argenteum,* and *Funaria hygrometrica.* The cyanobacterium *Microcoleus* occurs in this habitat type at a study site near Hammett, Idaho. Specimens for all of the above are deposited at SRP and in the private herbarium of Kelly Larsen, Boise State University graduate student.

Kelly Larsen is currently studying the effects of microbiotic crusts on the establishment of ***Stipa comuta, Stipa thurberiana,*** and ***Bromus tectorum,*** with study plots in this habitat type. Degradation of vegetation caused by overgrazing and fire could lead to wind erosion of the sandy soils. Maintenance and restoration of the soil crusts in this habitat type are therefore important for soil stabilization.

Artemisia** trident&a* **ssp. *vaseyana/Agropyron spicatum, A. *t.* **ssp. *vaseyana/Festuca idahoensis, A. t.* ssp. *vaseyana/Stipa*** *comata*

The ***Artemisia tridentata*** ssp. *vaseyana* habitat types occur in cooler, more mesic conditions than ***their A. t.*** ssp. *wyomingensis* and ***A t.*** ssp. ***tridentata*** counterparts. These types are found where annual average precipitation is 12 to over 16 inches (305 mm to 406 ***mm). Agropyron spicatum*** and ***Festuca idahoensis*** occur in higher precipitation zones when they occur on calcareous soils. Surface soil horizons range from silt loams for ***F. idahoensis*** sites ***to*** sandy for ***Stipa comata*** sites. Specimens of a number of common soil crust lichens collected in ***A. t.*** ssp. *vaseyana* habitat types are deposited at SRP, including ***Caloplaca tominii, Candelariella terrigena, Collema tenax, Diploschistes muscorum, Endocarpon pusillum, Fulgensia fulgens, Lecanora muralis, Phaeorrhiza sareptana,*** and ***Thrombium epigaeum.*** Bryophytes are also predominant in the crusts. However, where forb and grass density increases due to higher annual precipitation, occurrence of microbiotic crusts decreases, and they eventually disappear from the plant community.

Microbiotic crusts, where present in these habitat types, are likely most important for soil stabilization. Destruction of the crusts (and other vegetation) due to livestock grazing and use of off-road motorized and non-motorized vehicles will result in increased soil erosion.

Artemisia tridentata ssp. *vaseyana/Symphoricarpos oreophilus/Agropyron spicatum*, *A. t.* ssp. *vaseyana/Symphoricarpos oreophilus/Festuca idahoensis*, *A. t.* ssp. *vaseyana/Symphoricarpos oreophilus/Carex geyeri*

These types occur on coarser textured soils derived from basalt or granitic parent materials, ranging in elevation from 6000 to 8500 feet (1829 to 2591 m). Due to the tendency of these types to occur on gravelly soils in higher precipitation zones and to have a high forb and graminoid cover, it is unlikely that microbiotic soil crusts exist in these habitat types.

Artemisia tridentata ssp. *xericensis/Agropyron spicatum*, *A.. t.* ssp. *xericensis/Festuca idahoensis*

Artemisia tridentata ssp. *xericensis* is limited in distribution to Adams, Washington, Payette, and Gem counties, and a small part of the northwestern comer of Boise county in west-central Idaho. It occurs below 4500 ft (1372 m) where average annual precipitation exceeds 12 inches (305 mm) and summer temperatures are relatively warm (Rosentreter & Kelsey 1991). Soil surface horizons are loam to silt loam. The *A. t.* ssp. *xericensis / F. idahoensis* type is restricted to steep north slopes. This type supports a more diverse forb component than the more xeric type dominated by *A spicatum.* Microbiotic crusts are present in both types and dominated by lichens and mosses, except for where forb and graminoid density is high enough to exclude crusts. Algae and cyanobacteria are also present (R. Rosentreter, pers. corn.). Mosses are probably more predominant *in* the ***A. t.*** ssp. ***xericensis / F. idahoensis type*** due to the north aspect. Much of the A. ***t.*** ssp. ***xericensis / A. spicatum*** habitat type has been subject to overgrazing and repeated fires in the past, resulting in conversion to exotic annual grasses, particularly ***Taeniatherum asperum*** (Mattise & Fritz 1994).

Artemisia tridentata ssp. spiciformis/Bromus carinatus, A. t. ssp. spiciformis/Carex geyeri

Artemisia tridentata ssp. ***spiciformis occurs*** from 7000 to 9000 ft (2134 to 2896 m) in areas that receive greater than 18 inches (457 mm) average annual precipitation. Soils where ***Bromus carinatus*** dominate the under-story are very gravelly sandy loam to very gravelly silt loam. Due to the coarse texture of the soil, plus the presence of a rich forb community, it is unlikely that microbiotic crusts are predominant in this habitat. Likewise, although soils information is not available for the ***A t.*** ssp. ***spiciformis / Carex geyeri*** habitat type, crusts are likely excluded from this type due to the rhizomatous nature of ***C. geyeri,*** plus the presence of other graminoids and forbs.

Artemisia tripartita/Agropyron spicatum, Artemisia tripartita/Festuca idahoensis

These habitat types are restricted to eastern Idaho, occupying a climatic position between ***Artemisia tridentata*** ssp. ***wyomingensis*** and ***A t.*** ssp. vaseyanu. The ***A. tripartita / Festuca idahoensis*** type is the more mesic of the two. Soil surface horizons range from silt loam to loam and are derived from a variety of parent materials. Although no specimens were observed for these habitat types, it is likely that microbiotic crusts are part of the ***community*** structure. Tisdale et al. (1965) noted the presence of "cryptogams" ***in A tripartita / F. idahoensis*** habitat types near Carey, Idaho. However, cover of this community component was low, usually less than 5 percent. Warm summer temperatures coupled with summer precipitation, might result in a higher incidence of algae and cyanobacteria in these habitat types.

Artemisia cana ssp. *vescidula/Festuca idahoensis*

This habitat type occurs in moist meadows and along streams. Due to the high forb and graminoid density usually associated with moister conditions, it is unlikely that microbiotic crusts are found in this habitat type.

FUNCTXONAL GROUPS FOR MICROBIOTIC SOIL CRUST COMPONENTS

Eldridge and Greene (1994) suggested a system of separating microbiotic crust components into functional groups depending on diagnostic field traits, habitat preference, and abiotic relationships. Three categories were defined:

1) Hypermorphs (above ground) - these species occur primarily under shrubs and bunchgrasses and in moist microsites. They act as mulch for vascular plants and cushion the soil surface against the effects of wind and ram. The species in this category are primarily bryophytes, particularly *the* moss *Tortula ruralis.* However, a number of lichen species found growing on top of mosses are also included in this group.

2) Perimorphs (at ground) - this category includes mosses, lichens, algae, and cyanobacteria that occur in interspace locations and serve primarily to improve soil stability and contribute to the nutritional status of the soil through nitrogen and carbon fixation.

3) Cryptomorphs (hidden below ground) - these species also act to improve soil stability and nutritional status, but are, at least in some areas, the least obvious of the

crust components. Visual estimates for coverage of this group are usually inadequate. This category includes filamentous forms of fungi, cyanobacteria, and green algae.

Unfortunately, categorization of crust components into specific functional groups is not an easy task. Species often fit into more than one group. Examples are lichens that occur both on the soil surface (perimorphs) and on top of mosses (hypermorphs), and hyphae extending into the soil (cryptomorphs) that are associated with lichens or fungi on the surface (perimorphs). Table 4 in Appendix A lists lichens and bryophytes for , sagebrush habitats in southern Idaho, along with their potential functional groupings. Species are placed into the functional group in which they play the most significant role. All cyanobacteria and green algae are considered cryptomorphic and are not listed here. Some taxa *in these* groups *(such es Microcoleus vaginatus)* might also be perimorphic, however, extensive cyanobacterial crusts have not to date been documented for this region and their role is assumed to be cryptomorphic.

Another potential method of grouping microbiotic crust components is by their successional roles following a disturbance. Cyanobacteria and algae initiate soil stabilization and enrichment before their recovery is visually apparent (Shields & Durrell 1964; Belnap 1993). The lichens *Caloplaca tominii* and *Collema tenax* have been noted as species found in recently disturbed sites. Both species produce vegetative propagules, which may facilitate quick recovery (Johansen et al. 1984; Johansen & St. Clair 1986; Belnap 1993; St. Clair et al. 1993). Cosmopolitan, sometimes weedy mosses, including ***Pterygoneurum ovatum, Ceratodon purpureus, Bryum argenteum, B. caespiticium,*** and ***Funaria hygrometrica*** have also been documented as some of the initial colonizers following disturbance (Lawton 1971; Johansen et al. 1984; Downing & Selkirk 1993). Indicators of later successional ***stages*** include the moss ***Tortula ruralis, which usually*** occurs beneath shrubs and bunchgrasses, and the rare lichen *Texosporium sancti-jacobi* (McCune & Rosentreter 1992).

Seral stages for microbiotic crust communities are better identified by the diversity and abundance of lichen species present. An early seral community would be visually identified by the presence of small patches of lichen species that disperse only by asexual fragmentation, and weedy mosses. Sites supporting large patches of lichens that reproduce sexually, and the moss *Tortula ruralis*, could be considered mid- to late-seral. It might be difficult to distinguish between the latter 2 stages. Data from my study indicate that in mid-seral *Artemisia tridentata* ssp. *wyomingensis* habitat types, total lichen cover is about 5 to 10 percent, with total microbiotic crust cover exceeding 50 percent. More work needs to be done to assess seral stages in other sagebrush habitat types.

RESEARCH RECOMMENDATIONS

Much of the investigative work done thus far with microbiotic soil crusts has occurred in arid and semiarid areas where summer moisture contributes to a large part of the annual precipitation. According to Rogers (1989), lichens are less able to tolerate hot conditions when they are moist, and cyanobacteria tend to be the dominant component of the microbiotic crusts. In *Artemisia tridentata* habitats in southwestern Idaho, soil crusts in undisturbed areas show considerable development of lichen and moss components. The pinnacled cyanobacterial crusts described in the literature have not been observed in this region. Due to the variation in climatic, edaphic, and vegetative factors in southern Idaho, a first need is to document the presence or absence of crusts in different habitat types, and, if present, their components and relative coverage of each component. Chemical as well as visual means should be used to determine coverage and condition of algal and cyanobacterial soil crusts. The effects of microbiotic crusts on the hydrologic properties of soils are still debatable and depend on crust composition and soil type for each site. It would be careless to make assumptions regarding the ecological role of microbiotic crusts across a broad range of conditions. Therefore additional studies are needed regarding the effects of microbiotic soil crusts on water infiltration and overall soil moisture status.

Much of the work regarding nitrogen fixation in the western United States has been done on microbiotic crusts dominated by cyanobacteria. The areas where these studies were performed have different climatic patterns than much of southwestern Idaho, where summer moisture is rare. Information is needed on the nitrogen-fixing capabilities of the lichen- and moss-dominated soil crusts that occur in southwestern Idaho, along with the effects of various types of disturbance on this process. In particular, the effects of tire, grazing, and vehicular disturbance on coverage and physiological processes of the soil crusts need to be investigated The recovery of the crusts, particularly immediately following disturbance, should include the algal/cyanobacterial component using methods that assess nitrogen-fixation (nitrogenase activity, acetylene reduction) and abundance (chlorophyll ***a).***

Studies are currently in progress at Boise State University for ***Artemisia tridentata*** ssp. ***wyomingensis*** and ***A t.*** ssp. ***tridentata*** habitat types. A study on the effect of microbiotic soil crusts on the germination and success of 3 grasses -- ***Stipa comata, S. thurberianu,*** and ***Bromus tectorum*** -- determined that significantly more seedlings established in plots where the microbiotic crusts had been removed, crumbled, then reapplied, than in plots where the crusts were either left intact or the first 2 cm of the soil was removed (K. Larsen, unpubl. data). This suggests that the seeds bad difficulty penetrating an intact crust unless cracks were present, but the crumbled crust might have created microsites or a mulch that aided germination and establishment. Further research is planned to determine the effects of the treatments on seedling persistence.

Another study focuses on the effects of post-fire rehabilitation on microbiotic crusts. Sites were chosen that have areas with unburned sagebrush/bunchgrass communities, and areas that burned approximately 11 to 14 years ago, part of which were seeded to perennial grasses using a rangeland drill. All sites are currently ungrazed. Initial cover data indicates that lichens and mosses are recovering in areas that were rehabilitated following fire. Those areas that were not seeded to perennial grasses are dominated by annual grasses and forbs (J. Kaltenecker, unpubl. data). Research is planned to investigate the algal and cyanobacterial flora for each treatment. Another study proposes to look at the recovery of microbiotic crusts over the first 5 years following a fire, part of which will be seeded Work is needed regarding the use of alternate seeding techniques, such as a no-till drill, which could result in minimal disturbance *of* the crust following fire while allowing seeds to penetrate. This could allow establishment of perennial species while the crust remains intact and breaks down slowly (see Johansen et al. 1993 for a discussion of this process). An important component of studies assessing the effects of fire and rehabilitation is the exclusion of other disturbances, such as grazing. All studies should include the building of grazing exclosures encompassing replicates of all treatments following the disturbance and prior to allowing livestock access to the area. More work is also needed to determine levels and seasons of grazing that will minimize damage to microbiotic crusts by habitat type, soil type, and precipitation zone.

The advent of urban sprawl causes yet another disturbance to rangeland plant communities -- degradation of air quality. Lichens are sensitive to environmental pollutants and have been studied as indicators of such in cities and forested areas (Stolte et al. 1993). Lichens of microbiotic crusts might be useful as indicators of air quality problems near large cities or industrial areas. Belnap and Harper (1990) determined that chlorophyll degradation and electrolyte leakage in the foliose desert rock lichen, *Rhizoplaca melanophthalma*, increased significantly as distance from a coal-fired power plant decreased. A study was initiated in 1984 at the Idaho National Engineering Laboratory to evaluate the use of lichens there as biomonitors (Pearson & Rope 1987). Such research is suggested for urban areas in arid and semiarid regions, especially for cities that are currently undergoing extensive growth.

Large acreages of sagebrush habitats on the Snake River Plain have undergone conversion to agriculture, leaving adjacent sites supporting native vegetation subject to agricultural runoff. Some lichens have also been shown to be sensitive to nitrogen salts, such as those contained in plant fertilizers (Brown & Tomlinson 1993). More research is needed to determine physiological responses of soil lichens to contaminants of this type.

MANAGEMENT RECOMMENDATIONS

Numerous studies have documented the contributions of microbiotic crusts to rangeland ecosystems. However, their value is still sometimes questioned, usually due to erroneous interpretation and application of foreign studies to domestic rangelands. The value of microbiotic soil crusts usually boils down to how they fit into existing management goals for shrub and grassland ecosystems. If the goal is that of maintaining the intrinsic value of high quality habitats, then the focus of management should be to minimize impacts to intact plant communities, preserve the best, and look for ways of rehabilitating the vast acreages of severely disturbed rangeland.

The severity of degradation and loss of *Artemisia tridentata* habitat types due to overgrazing, fire, and agricultural use merits action. Surveys should be performed to located *A tridentata* habitats that are in late seral condition with undisturbed microbiotic crusts. The best of these should be established as research natural areas (RNA) or areas of critical environmental concern (ACEC). These sites could then serve as baselines for monitoring studies and potentially as sources of propogules for microbiotic crust components for surrounding areas in degraded conditions. A diversity of plant and microbiotic crust communities and seral conditions should be included.

Areas in *Artemisia tridentata* ssp. *wyomingensis* habitat types that have been ungrazed or only incidentally grazed for approximately 10 years, and which are in mid-seral condition, have microbiotic crust coverage values of 50 to 75 percent (J. Kaltenecker, unpubl. data). These are consistent with coverage values obtained by Eckert et al. (1986) for soil surface types that correspond with areas dominated by lichen and moss community components in shrub/bunchgrass communities. Fifty percent coverage of lichens and mosses should serve as a *minimum* target for A *tridentata* types and for seeded bunchgrass communities. Additional research is needed to determine minimum coverage targets for other habitat types.

Much of the public land in southern Idaho is used for grazing by domestic livestock. Movement of watering tanks and pipelines into remote areas should be prohibited to protect relict stands of native vegetation. Studies should be done to determine the level and season of grazing that allow target coverage values for vascular plants and microbiotic crusts to be met. Soil crusts are most fragile when dry, particularly the lichen and well-developed algal/cyanobacterial components. Crusts are most resilient when the soil *surface* is moist. Grazing in muddy conditions can be as damaging as grazing when the soil surface is dry. Policy should be considered for determining stocking levels and season of grazing on an annual basis depending on climate and range condition. This would require land managers to work more closely with permittees to maintain optimal coverage of both vascular plants and microbiotic crusts.

Use of OHV's in sagebrush-steppe habitats on public lands should be carefully monitored by land management agencies. Vehicular traffic should be restricted to designated use areas to avoid degradation and destruction of native plant communities. This type of land use often results in severe erosion problems. Areas with hilly topography should be a high priority for protection. Main roads should be maintained while of the many "two-track" roads that provide access to more remote areas should be closed. In particular, access should be restricted during muddy conditions, as people tend to drive vehicles into vegetated areas to avoid becoming embedded in deeply rutted roads. The Department of Defense uses desert areas in southwestern Idaho for military training maneuvers, including those using tanks, which results in severe degradation of habitats by vegetation destruction, soil compaction, and fire. Again, these maneuvers should be restricted to designated areas that have already been degraded

Burned lands should be assessed to determine if rehabilitation is needed to prevent invasion of exotic grasses and forbs. Methods should be used that minimize the impacts to the soil surface and surviving microbiotic crust components. Studies to determine methods of rehabilitation that increase the rate of recovery for microbiotic crusts should benefit those concerned with both vascular and nonvascular plants. Steps to reduce the frequency and size of wild fires should include the use of greenstripping and widening and paving of existing roads to act as firebreaks.

The importance of microbiotic crusts has only recently become a management concern in some arid and semiarid regions. A program is encouraged to educate land management personnel and users of public lands regarding the benefits of maintaining plant communities as a whole, rather just those obviously usable parts. Identification guides for microbiotic soil crust components in each habitat type should be compiled for use by agency personnel. Field training sessions incorporating identification of soil crusts along with their ecological roles should be held for each BLM District.

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