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REVIEW DRAFT

Microbiotic Crusts: Ecological Roles and Implications for Rangeland Management in the Interior Columbia Basin and Portions of the Klamath and Great Basin

STEPHEN G. LEONARD
Rangeland Scientist
USDI-Bureau of Land Management
Nevada State Office
Reno, NV 89520

ROGER ROSENTRETER
Botanist
USDI-Bureau of Land Management
Idaho State Office
Boise, ID 83706

MICHAEL G. "SHERM" KARL
Rangeland Management Specialist-Ecologist
USDA-Forest Service
Walla Walla, WA 99362

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Microbiotic Crusts: Ecological Roles

and Implications for Rangeland Management

Report by S. G. Leonard, R. Rosentreter, and M.G. Karl

This synopsis is based primarily on literature reviews, Microbiotic Crusts: A Review by John Dana Williams[1] and Microbiotic Soil Crusts in Sagebrush Habitats of Southern Idaho by Julie Kaltenecker and Marcia Wicklow-Howard[2] and other related literature. Additional relationships to grazing management are interpreted from these reviews, discussions with other experts in the field of microbiotic crusts, and relationships developed over years of observation. Widespread recognition of the potential roles, functions, and management of microbiotic crusts is a fairly recent phenomenon and research is limited, particularly within the Columbia Basin.

Microbiotic crusts consist of lichens, bryophytes, algae, microfungi, cyanobacteria, and bacteria growing on or just below the soil surface (Eldridge and Greene 1994). These types of crusts have also been known as cryptogamic, microphytic, microfloral, or cryptobiotic, but microbiotic (St.Clair and Johansen 1993) seems to be the most accurate description for the Interior Columbia River Basin (ICRB). Microbiotic crusts are found globally in arid and semiarid environments; many of the organisms are ubiquitous. Microbiotic crusts are distinguished from but often occur in association with physical and chemical soil crusts such as vesicular, rain, salt, gypsum, or silica crusts common to arid environments.

Ecological Roles

Microbiotic crusts play a role in nutrient cycling, soil stability and moisture, and interactions with vascular plants. Microphytic plants also provide forage for invertebrates while some lichens growing on or at the soil surface such as vagrant (non-attached) lichens might provide forage for big game species during critical

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[1]Williams, John Dana. 1995. Microbiotic Crusts: A Review. 55 p. Contract report. On file with: Interior Columbia Basin Ecosystem Management Project, 112 E. Poplar, Walla Walla, WA 99362.

[2]Kaltenecker, Julie; Wicklow-Howard, Marcia. 1995. Microbiotic Soil Crusts in Sagebrush Habitats of Southern Idaho. 48 p. Contract report. On file with: Interior Columbia Basin Ecosystem Management Project, 112 E. Poplar, Walla Walla, WA 99362.

winter periods. Some microphytes are also potential environmental indicators. The ecological role of microbiotic crusts is probably most significant in systems that support relatively sparse potential vascular vegetative cover.

Nutrient Cycling - Soils stabilized by microbiotic crusts tend to have greater concentrations of organic material, nitrogen, exchangeable manganese, calcium, potassium, magnesium, and available phosphorous (Harper and Pendleton 1993). Higher fractions of clay and silt collected from wind deposition in soils stabilized by cyanobacteria (Fletcher and Martin 1948, Kleiner and Harper 1972, 1977a, 1977b, Harper and Pendleton 1993) generally correspond to a higher cation exchange capacity and organic matter. The sheath material of the cyanobacterium Microcoleus vaginatus and clay particles bound to it (Belnap and Gardener 1993) are both negatively charged and thus potentially capable of binding positively charged macronutrients and are rich in organic acids, amino acids, and chelating agents (Lange 1974, 1976; Belnap and Gardener 1993; Harper and Pendleton 1993). Brown and Brown (1991) reported a number of nutrients and soluble intercellular chemicals are released from dry lichens when rewetted.

Nitrogen fixation by many cyanobacterial, algal, and lichen species in microbiotic crusts has been well documented (Rozanov 1951, MacGregor and Johnson 1971, West and Skujins 1977, Skujins and Klubek 1978a 1978b). Growth chamber experimental results have demonstrated that vascular plants can use nitrogen fixed by microbiotic crusts (Mayland et al. 1966, Mayland and McIntosh 1966, Snyder and Wullstein 1973). Various authors have reported nitrogen fixation by microbiotic crusts in arid ecosystems ranging from extremely low values of .02 Kg/ha/yr (Jeffries et al. 1992) to as high as 100 Kg/ha/yr (Rychert and Skujins 1974) during optimal moisture and temperature conditions. Evans and Ehleringer (1993) concluded that microbiotic crusts were the source of nitrogen within a juniper/sagebrush woodland ecosystem that apparently contained no other nitrogen-fixing organisms. Annual nitrogen use by vascular plants in the Great Basin is estimated at approximately 12 Kg/ha/yr (West and Skujins 1977); this might be similar to the arid components of the Columbia Basin.

There are still questions about the availability of nitrogen fixed by microbiotic crusts to vascular plants (West 1990) in a natural setting. Nitrification and denitrification take place at the same time in the same place in microbiotic crusts (Skujins and Klubek 1978a). Nearly all of the nitrogen fixed during optimal conditions is lost through volitilization within 10 weeks, 20% within a week and 80% in five weeks.

There are also questions regarding quantitative measurements of biologically-fixed nitrogen (Weaver 1986, West 1990). However, the argument has been made that the important issue is not how much nitrogen is fixed, but whether or not nitrogen is fixed and if it is available and necessary for vascular plants and community structure (Snyder and Wullstein 1973, Rychert et al. 1978, Harper and Pendleton 1993, Evans and Ehleringer 1994).

Soil stability - Soil stability or the antithesis soil erosion is dependent on a variety of factors including soil texture and structure, position on the landscape, roughness, and of course protective cover of rock, litter and vegetation. Vascular vegetation cover and litter have traditionally been considered the primary variables with management. However, cover of vascular plants and litter are often extremely low in arid ecosystems, even at potential. In some areas, microbiotic crusts can comprise 70 to 80 percent of the living cover (Belnap 1990). Microbiotic crusts can provide cover in drought years when vascular plants are dormant or minimally expressed. Development of microbiotic crusts can provide an accretionary phenomenon in an often erosional environment (Campbell et al. 1989) and reduce erosion by wind and water (Booth 1941, Fletcher and Martin 1948, Bond and Harris 1964, Bailey et al. 1972, Schulten 1985, Belnap and Gardner 1993, Williams 1993).

Microbiotic crusts contribute to aggregate structure, and thus stability, by binding soil particles within the physical structures of the microphytes and trapping soil particles in gelatinous exudate (Bond and Harris 1964, Marathe 1972, Anantani and Marathe 1972, Gahel and Shtina 1974, Danin and Yaalon 1980, Schulten 1985, Graetz and Tongway 1986, Campbell et al. 1989, Danin et al. 1989, Belnap and Gardener 1993). Microfaunal detritus might also contribute to decomposition of organic matter and enhance soil aggregation (Gahel and Shtina 1974, Danin 1978). Microtopography becomes more complex with microbiotic development. The resulting surface roughness reduces water velocities and associated erosion and creates ponding to enhance sediment deposition (Brotherson and Rushforth 1983, Alexander and Calvo 1990). Well developed aggregate stability and surface roughness both resist soil particle dislodgment by wind as well (Chepil and Woodruff 1963). Microbiotic crusts dominated by moss and algae have remained intact for 6-8 months following wildfire (Johansen et al. 1993) and might continue to provide protection from erosion for some time after their death (Williams 1993).

Accretionary sheets develop when hydrated sheaths of algal filaments trap silt and clay particles as they are blown across a microbial mat (Campbell et al. 1989). The algal and cyanobacterial components of microbiotic crusts are phototrophic and their upward growth continues to entrap soil particles.

Soil moisture - The influence of microbiotic crusts on infiltration and soil moisture is apparently mixed depending on soil type, degree of development and types of organisms in the crust, climate, disturbance history, and state of wetness when rewetted. Depending on the situation, their influence has been reported as positive, negative, and neutral.

Greater infiltration rates have been attributed to microbiotic crusts in pinyon-juniper woodlands by Loope and Gifford (1972) and beneath sagebrush overstories by Seyfried (1991), Johnson and Gordon (1988) and Johnson and Blackburn (1989). Reduced infiltration capacities related to microbiotic crusts have been reported by Bond (1964), Rogers (1977), Stanley (1983), Brotherson and Rushforth (1983), and Graetz and Tongway (1986). Reduced infiltration capacities have been attributed to swelling of sheath material during imbibition that effectively creates an impermeable seal. Complete surface sealing in areas of high dew fall and hydrophobicity have been reported in other areas of the world but to our knowledge have not been observed in the Columbia River Basin or similar environments. Williams (1993) found that crusts of living or chemically killed Microcoleus vaginatus had no significant effect on infiltration of a sandy loam soil and Belnap and Gardener (1993) reported that spaces remain after imbibition in sandy soils that allow penetration of water. Fletcher (1960), working in the Sonoran Desert of Arizona, reported an increase in infiltration capacities during a brief period after drying and cracking, but a decrease after extended drying periods, apparently the result of microphytes losing the ability to bind soil and maintain soil surface structure.

Interactions with vascular plants - Microbiotic crusts and vascular plants exist in a complex interrelationship that can be either competitive, mutualistic, or neutral, depending on the phenological stage of the organisms, climate, edaphic resources, plant-animal interactions, and resource management. Both primary and secondary successional stages might also influence relationships between microbiotic crusts and vascular plants. Although not covered directly in the reviews provided, Rice (1984) explores many allelopathic relationships, stimulatory as well as inhibitory, between soil biota and vascular plants that appear to change with or affect succession. These relationships might also affect vegetation patterning in both the vascular and microbiotic components of a community. Our knowledge of these complex interrelationships is extremely limited and over generalizations can easily be made.

Documented mutualistic interactions include enhanced floristic diversity (Graetz and Tongway 1986, Mucher et al. 1988, Meyer 1986, Kleiner and Harper 1972, 1977b, Beymer and Klopatek 1992) and increased seedling establishment of vascular plants (St. Clair et al. 1984, Sylla 1987:cited by West 1990, Harper and Marble 1988, Eckert et al. 1986). The increased seedling establishment and diversity is attributed to microbiotic crust structure providing safe sites and enhanced nutrient and water conditions for vascular plant growth. There is also evidence that the black body effect of dark colored microbiotic crusts increase surface temperatures during periods of increased moisture associated with snow melt. Elevated metabolic rates and nutrient uptake could occur in vascular plants during this period relative to colder sites lacking a crust component (Salisbury and Ross 1978, Harper and Pendleton 1993). Some of the microfloral components apparently also benefit from microsite characteristics provided by vascular vegetation. Twisted moss _Tortula ruralis_ is apparently favored by a sagebrush canopy (Rosentreter 1992) and some algae in the Columbia River Basin may require vascular vegetation establishment to recover from fire (Johansen et al. 1993). Vesicular arbuscular mycorrhizae (VAM) infection of vascular plants is known to enhance uptake of both water and phosphorus. Harper and Pendleton (1993) found greater VAM infection of annual and perennial plants growing in cyanobacterial-_Collema_ species crusted soils. The VAM may be enhanced somewhat by the microenvironment provided by the crust. VAM levels, like microbiotic crusts, respond negatively to soil disturbance (Doerr et al. 1984, Call and McKell 1984) and grazing (Bethlenfalvay and Dakessian 1984). Whether they are interdependent or merely responding directly in the same manner has yet to be determined.

In other instances, microbiotic crusts have been described as inhibiting the amount of vascular plant seedlings established and reducing community structure (Dulieu et al. 1977, Savory and Parson 1980, McIlvanie 1942). Harper and Pendleton (1993) indicated competition between cyanobacteria and _Sorghum halepense_ for Ca, P, Mn, and Na in a greenhouse study. West (1990) reviewed material that would indicate a 1:1 tradeoff relationship between vascular plants and components of microbiotic crusts for space and nutrients. Kushnir (1973) and Kushnir and Shrol (1974) isolated bacteria and fungal components from the rhizosphere of steppe communities that had inhibiting allelopathic compounds to vascular plants. Alternately, water soluble extracts from leaves of Atriplex, Eurotia, and Artemisia apparently inhibit nitrogen fixation of algae-lichen crusts beneath their canopies (Rychert and Skujins 1974). Beymer and Klopatec (1992) state that reduced microbiotic crust in an ecosystem will not necessarily lead to a direct change in vascular vegetation structure but recommended using microbiotic crust as an indicator of ecosystem health because of significant correlations between microbiotic cover and associated vascular plants.

The apparent discrepancies of relationships to vascular plants and other roles discussed so far should not be surprising. The limited studies to date are often far removed in both time and space and there are many factors that can complicate interpretation of results. The present plant communities often differ widely. Some plants such as Stipa are better adapted morphologically to establish in well developed microbiotic crusts (West 1990). Inhibitive germination to less adapted weedy exotics might be a positive ecological factor for rare plants that are displaced by exotics (Rosentreter 1994). Soil properties and degree of microbiotic crust development need to be considered when comparing results. Sandy soils may allow better root penetration (Belnap and Gardener 1993). Microbiotic cover might not always provide a good measure of development (Belnap 1993). Johansen et al. (1993) suggests also that there might be much greater regional differences in crust biology than previously assumed based on macroscopic appearance and the presence of some ubiquitous taxa. There are probably many other differences. Until microbiotic crust components are consistently related to specific soils and their respective potential vascular vegetation communities and related dynamics, the confusion will continue.

Forage - Sharnoff (1993) described lichens as the base of a food web which includes invertebrates and their predators. The sheer number and diversity of soil invertebrates (Niwa and Sandquist, this assessment) suggests that the entire microfloral and autotrophic components of microbiotic crusts also perform this function. The relative contribution of microbiotic crusts compared to vascular plant components is unknown because our limited knowledge concerning relationships with the possible millions of invertebrates that may depend on components of these crusts for forage or habitat.

Although not technically microbiotic crusts, some soil lichens are known to provide forage for large ungulates. Lichens are thought to be a primary source of carbohydrate energy for caribou, and thus are particularly important in winter (Sharnoff 1993). Thomas and Rosentreter (1989) have suggested that vagrant forms of several lichens common to the sagebrush steppe may be an extremely important winter forage for pronghorn antelope.

Environmental indicators - Lichens, including many associated with microbiotic crusts, have been used as bioindicators of air quality. Lichens have an ability to concentrate elements that may be present in low concentrations in the ambient air (Tyler 1989, Nieboer et al. 1972). Lichens are also relatively easy to collect, preserve, and analyze for pollutant related studies (Stolte et al. 1993). Rosentreter[3] indicated 120 soil lichens, including 17 associated with steppe soil crusts and 9 associated with calcareous steppe environments, as potential bioindicators of air quality in the Columbia River Basin.

Rosentreter also reports soil lichens as indicators of calcium carbonates (CACO3) and old growth, which for steppe lichens would mean an advanced ecological status associated with minimal soil disturbance. Nine lichens are identified as calcareous steppe indicators and forty-five tundra lichens are indicators of calcium carbonates. All nine calcareous steppe indicators and seventeen lichens associated with steppe soil crusts are believed to be indicators of advanced ecological status.

Microbiotic crust association with potential vegetation types

In general, microbiotic crusts are more prevalent in the drier vegetation types and others with naturally sparse vascular vegetation potential because of soil depth, stoniness, soil chemistry, or position on the landscape (windswept ridges, etc.). Potential vegetation types in the Columbia River Basin associated with substantial microbiotic components include 1) most salt desert shrub (except riparian types), 2) many of the sagebrush types, and 3) the more xeric juniper and pinyon-juniper woodland

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[3]Rosentreter, R. 1994. Lichens. 9 p. plus tables. Report on file with: Interior Columbia Basin Ecosystem Management Project. 112 E. Poplar, Walla Walla, WA 99362.

types.

Within these types, crust development may vary with surface rock fragment cover and vascular plant cover and spacing. In pinyon-juniper types in New Mexico surface pebbles were positively correlated with high lichen cover (Ladyman et al. 1993); however in sagebrush types in southern Idaho, crusts become less prominent with very gravelly surface soils (Kaltenecker and Wicklow-Howard 1995) possibly because of the lack of fines in the surface layer. Microbiotic crusts decrease in the more mesic mountain big sagebrush types with high grass-forb densities (Kaltenecker and Wicklow-Howard 1995) and as tree densities increase to less than four meter spacing in pinyon-juniper woodlands (Ladyman et al. 1993). An estimated potential for microbiotic crust development for potential vegetation (PNV) types identified in the Columbia River Basin is presented in table 1. PNV types not listed in the table are presumed to have low to no potential for microbiotic <u>crust</u> development per se; however, lichen, moss, algae, and cyanobacteria might still provide significant microfloral components in the total plant community.

Table 1. ESTIMATED POTENTIAL FOR MICROBIOTIC CRUST DEVELOPMENT

PNV TYPE	HIGH	MODERATE	LOW
salt desert shrub	*----------> flooded	(all except greasewood types)	seasonally
low sage steppe (xeric-stiff sage)	*------------	---------------->	
Wyoming sage (warm)	*---------->	(incl. ARTRT/AGSP	types)
Wyoming sage (cool)	*------------	-----> gravelly	
juniper woodland	*------------	----->decreases density or	w/ incr. tree gravelly surface
low sage steppe (mesic)	*------	----------------- decreases w/incr.	-----------> elev & herb. cover
low sage (mesic)-juniper woodland	*------	----------------- decreases w/incr. density and/or	-----------> elev. & tree herb. cover

mtn. big sage steppe (E. mesic)		*-------------- (lower dens. AGSP non-gravelly)	-----------> (high dens. herb. cover (FEID,SYMPH) or gravelly)
mtn. big sage steppe (W. mesic)		same as above	
mtn. big sage -juniper woodland		*-------------- decreases w/incr. density and/or	-----------> elev. & tree herb. cover
threetip sage			?<--*-->? suspected but no documentation

Rangeland management implications

Nearly all researchers studying microbiotic crusts in the western United States agree that surface disturbing activities reduce the maximum potential development of the crusts. These surface disturbing activities include activities ranging from grazing (most often cited) to off-road vehicle activities including both recreational and military to recreational hiking. Fire also depletes microbiotic crusts, at least temporarily. Introduced annuals such as Bromus tectorum (cheatgrass) and Taeniatherum asperum (medusahead) appear to impose longterm threats to microbiotic crust communities, particularly on those sites subject to high plant densities and litter accumulation. Airborne pollutants and urbanization can also affect abundance and composition of microbiotic crusts. Except where habitat is completely displaced such as in urbanization or altered by dominance of exotic annuals, most research indicates recovery of microbiotic crusts is fairly rapid (ranging from a few years to 100 years) following removal of the disturbance. This section will concentrate on the surface disturbing effects of livestock, fire, and the encroachment of exotic annuals.

Grazing management - Although extensive microbiotic crusts and ungulate herbivores coexist in similar steppe ecosystems from the Ukraine through Tadzhik (Mack and Thompson 1982, Gillette and Dobrowolski 1993), consensus in the U.S. is that land use by large ungulates (livestock or wildlife) results in negative impacts on the crusts.

All studies reviewed indicated a reduction in potential cover and mixed results regarding species composition. Only a few studies indicate or even discuss differences in season of use or quantify animal densities over time. Most comparisons between grazed and protected areas such as exclosures or parklands have presented grazing only in generalities such as "heavy", "moderate" or "light" without further definition or readily acknowledge that specifics relative to present and past grazing practices are unknown. Studies by Anderson, Harper, and Holmgren (1982) and Marble and Harper (1989) relative to sites on the Desert Experiment Range in the eastern Great Basin have the longest documented grazing controls available. Grazing treatments considered had been applied continuously for fifty years on similar range sites with exclosures in each paddock for comparison. Results from these studies are considered applicable to the Columbia River Basin, particularly the salt desert shrub and adjacent dry sagebrush potential vegetation types because of climatic and floristic similarities of the area. Additional inferences can be drawn from other studies and professional observations but the subject of grazing impacts on microbiotic crusts and the thresholds at which those impacts become limiting on site sustainability and productivity in various soil-site-climatic settings deserves considerably more research.

Marble and Harper (1989) found heavy grazing treatments (17 sheep days/acre) in early winter only did not significantly affect either microbiotic cover and composition or vascular plant cover and composition. Extending the grazing season to late winter in this area characterized by moist winters and dry summers except for occasional torrential thunderstorms significantly reduced both microbiotic crust cover and species richness. Differences are attributed sufficient soil moisture in late winter /early summer to permit some regrowth of cryptograms (microbiotic species) and coincide with Lusby's (1979) findings that extending the grazing season from February 15 to May 15 results in increased runoff/erosion from depletion of microbiotic crusts. No quantified comparison has been published for light and moderate grazing strategies to our knowledge; however, personal observations of light winter grazing does not appear to show any visible differences of any treatments with the control exclosures.

Continuous seasonlong grazing is shown to be deleterious to microbiotic crusts. Jefferies and Klopatec (1987) showed a near complete destruction of microbiotic crust on a site heavily grazed yearlong compared to similar pristine and light to moderate winter gazing on sandy blackbrush sites in southern Utah and northern Arizona.

Brotherson et al. (1983) also showed significant reduction of both microbiotic crust and vascular vegetation cover on yearlong moderate to heavily grazed sites near the Navajo National Monument, Arizona.

Likewise, intensifying physical impact through short duration grazing strategies is also deleterious to microbiotic crusts. While this might be beneficial in some ecosystems dominated by summer moisture such as Zimbabwe (Savory and Parsons 1980) and the Great Plains region of the U.S., it is probably not beneficial in the winter moisture, dry summer climates of much of the Great Basin (Johansen 1986) and the Columbia River Basin. Platou and Tueller (1985) suggest that the natural grazing system that evolved in the Great Plains closely resembles high-intensity short duration grazing, while the natural grazing system in the shrub-steppe is more similar to the rest-rotation system designed by Hormay (1970).

Dr. Bruce Ryan[4], in the contracted <u>East Side Lichen Report for Washington and Oregon</u> also provides a model that suggests that moderate grazing by livestock as well as native herbivores might lead to later stage healthy lichen communities. Severe (heavy) grazing or trampling alternately lead to the replacement of bunchgrass by weedy annuals and with the accompanying dust, mud, and fire result in an impoverished lichen community.

Recommended grazing practices include:

1) Seasonal grazing in early to mid winter at moderate stocking rates for the ecological sites involved is the preferred strategy. Most of the potential vegetation types with high potential for microbiotic crust development occur at lower elevations with minimal snow cover in most years.

- Microbiotic crusts are most resilient when soils are moist. Removal of livestock before early spring allows reformation of crust structure during this time of optimal growth conditions without further disturbance. Muddy conditions during this period should also be avoided (Kaltenecker and Wicklow-Howard 1995).

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[4]Ryan, Bruce. 1994. <u>East Side Lichen Report for Washington and Oregon</u>. Contract report. 4 volumes. On file with: Interior Columbia Basin Ecosystem Management Project, 112 E. Poplar, Walla Walla, WA 99362.

- Winter grazing is also most advantageous to vascular plant components, including associated riparian communities.

- In many areas, winter grazing substantially reduces supplemental feed costs associated with livestock production.

- Furthermore, winter grazing most closely replicates the grazing strategy of native herbivores as proposed in a contracted report by Burkhardt[5] (1994).

2) Rest rotation strategies that minimize frequency of surface disturbance during dry seasons and maximize periods between disturbances might also be considered.

- Dispersal of livestock throughout useable portions of pastures rather than concentration for "herd effect" should be emphasized.

3) Kaltenecker and Wicklow-Howard suggest determining stocking levels and season of use on an annual basis to require managers and permittees to work together to maintain optimal coverage of both vascular plants and microbiotic crusts.

4) Grazing management objectives should include desired levels of microbiotic crust based on site capability and rangeland health indicators of site stability and nutrient cycling.

- Kaltenecker and Wicklow-Howard (1995) suggest 50% coverage of lichens and mosses as the target for A. tridentata types in southern Idaho.

- Additional research is needed to determine realistic microbiotic crust objectives by soil type in most potential vegetation types but initial estimates can be determined by using comparisons areas determined to be in "healthy condition" as described by the National Research Council (1994).

5) Protect relic sites as rangeland reference areas. Avoidance might be most

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[5]Burkhardt, J. Wayne. 1994. Herbivory in the Intermountain west-an overview of the evolutionary history, historic cultural impacts and lessons from the past. 49 p. Contract report. On file with: Interior Columbia River Basin Ecosystem Management Project, 112 E. Poplar, Walla Walla, WA 99362.

appropriate for some sites such as highly erodible soils with low vascular plant potential or relic areas in high ecological condition that provide intrinsic value as comparison areas for ecological potential and for future scientific research.

- Attracting livestock to these areas with water development, salt and mineral blocks, etc. should be avoided.

- In some cases, exclusion by fencing might be necessary.

Fire - Microbiotic crusts are temporarily damaged by fire (Harper and Marble 1988, West 1990). The degree of damage and rate of recovery can depend on pre-fire conditions, intensity and frequency of fire, soil, and climate. Crust aggregation might persist for 6-12 months following fire, even though organisms in the crust may be dead. Johansen and Rayburn (1989) state that soil algae are first to recover and can form a protective crust in 5-10 years. Soil lichens and mosses might take 10-20 years to achieve substantial cover. Depending on a variety of factors, recovery can range from 1-2 years (Johansen et al. 1993) to 30 years (Callison et al. 1985).

Fire is a natural component of the more productive sagebrush steppe potential vegetation types. Bunting (1995) cites early references to the grassland appearance of the vegetation at higher elevation, productive sites which would be consistent with high fire frequencies of less than 30 years (Fisher et al. 1987, Arno and Gruell 1988, Burkhardt and Tisdale 1976) and lower potential for microbiotic crusts. However, an average return frequency of 50 years within most of the shrub-steppe (Wright et al. 1979) to as high as 100 years in the more arid Snake River Plain (Peters and Bunting 1994) is adequate to restore microbiotic crust components. A variety of successional stages in development would be evident at the landscape scale that might produce a shifting community mosaic at historic frequencies. An increase in fire frequency associated with flammable exotics such as cheatgrass and medusahead poses a considerable risk to maintaining advanced stages of microbiotic crust succession. Fire intervals of less than five years can occur on the annual grasslands of the Snake River Plain in southern Idaho (Whisenant 1990).

Fire has not been considered a factor in most salt-desert shrub rangelands (West 1994) except for the more productive Great Basin wildrye types. West now attributes the introduction of fire into these types to the profusion of introduced exotics following

El Nino effects of the mid-1980's. The same profusion of exotics into the less productive sagebrush types has also introduced or increased fire frequency into types where microbiotic crusts are assumed by many to be the dominant cover for soil stability.

Exotic annuals - In addition to the increased fire risk to microbiotic crusts, Kaltenecker and Wicklow-Howard (1995) indicate that cover of exotic annuals and associated litter can displace microbiotic crust components. In particular, mosses only occur where the litter layer has not accumulated to a depth that it excludes light (less than 1 cm.). Mosses also become absent when cheatgrass cover exceeds 80%.

Recommended management practices relative to fire and invasion of flammable exotics include:

1) Reduce the frequency and size of wildfires where microbiotic crust development is at risk. Kaltenecker and Wicklow-Howard support green stripping and suggest road widening and paving to improve firebreak capabilities.

2) Assess burned lands to determine if rehabilitation is needed.

- Kaltenecker and Wicklow-Howard indicate that burned areas reseeded to perennial exotic and native grasses and shrubs on the Snake River Plain considerably more lichens and the moss <u>T. ruralis</u> than similar areas that were not rehabilitated even though microbiotic crusts were subjected to two destructive forces, fire and plowing.

- Evaluation of methods of reclamation that minimize impacts to the soil surface and surviving microbiotic crusts is recommended.

3) The salt-desert shrub communities (and lower precipitation sagebrush communities) present some unique problems.

- West (1994) presents evidence that cheatgrass will remain and even increase on these types now. Reclamation has been difficult because of the aridity of these types and the unpredictability of wet years. West suggests that without livestock consumption of some of these fuels, susceptibility to fire could increase further. Unfortunately, grazing would need to occur well into the growing season and thus to the potential detriment of microbiotic crust components.

- West also concludes that unless we can use knowledge of when to expect wetter conditions from El Nino events to more successfully reseed these rangelands to less fire-susceptible perennials, we are in for more difficult times for management. Prediction of El Nino might also be useful for the grazing management of flammable exotics in these communities. Grazing could be planned in advance for years with a higher probability of wet winter-spring conditions and subsequent growth of flammable exotics and deferred during years with high probability of drier, less productive conditions.

Technology exists now that significantly enhances predictive capability of El Nino effects somewhat in advance. Redmond and Cayan (1994) examined relationships using Southern Oscillation Index (SOI) values indicative of El Nino (and La Nina or "anti-El Nino) conditions relative to winter precipitation. SOI values greater than +0.50 or less than -0.50 for June-November coincide with the number of months with positive/negative precipitation anomalies of at least one standard deviation during the succeeding November-March 73% of the time in Oregon and Washington and 86% of the time in Idaho, Montana, and Wyoming. The discrimination between wet and dry months is greater for positive SOI values (wet months in the North West) than for negative SOI. In areas where annual precipitation is considered marginal for seeding establishment, risks of failure would be much less if the seeding was done prior to a wet winter (i.e. most often those preceded by a SOI greater than +0.50 during June-November). SOI values seldom change significantly the last month or two (Redmond, personal communication) of the period, so some lead time for preparation is available. Use of this predictive capability would substantially reduce risk of failure if used as a go or no-go indicator on a yearly basis for rangeland seeding. The SOI should also be evaluated relative to the production of flammable exotics and potential thresholds where planned grazing might be desirable to reduce fire susceptibility.

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