BIOSPHERICS ENVIRONMENTAL INC.

AN ASSESSMENT OF LICHEN AND BRYOPHYTE BIODIVERSITY AND BIOLOGICAL SOIL CRUST COMMUNITY RELATIONSHIPS IN THE HANFORD REACH NATIONAL MONUMENT

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Executive Summary

This report presents the results of a study of the lichens and bryophytes of The Hanford Reach National Monument. The main objectives to this study are to enhance biodiversity research of the lichens and bryophytes of the microbiotic crusts and other habitats, including rocks and stones, shrubs, and wetlands, to initiate a study of the community relationships of soil crust assemblages, and to investigate environmental relationships of the soil crusts.

The vegetation of the Monument, one of the largest protected arid land areas in North America, is a diverse complex of communities, ranging from sagebrush-steppe to communities on talus slopes. There has been a great deal of disturbance across the area through time, in particular by fires and grazing of domestic animals. Introduced plants, in particular cheatgrass, are common and widespread in some areas. A great amount of biological research has been completed or is underway in the area.

Biological crusts are complex groupings of various organisms, admixed with organic and inorganic materials, that grow over soil in many arid and semi-arid landscapes. The dominant organisms that comprise crusts are lichens, bryophytes, and cyanobacteria. These organisms are intermixed with fungal hyphae, plant roots, litter, and soil, and, as a unit, are often thin and compact.

Biological crusts are an important component of arid land biodiversity and ecosystem integrity and health. They perform a number of ecologically important roles including soil stability, protection from wind erosion, surficial hydrology, and nutrient capture and release. Unfortunately, most biological crusts are fragile and readily disturbed. Until recently, little research has been completed on the biological soil crusts in the Hanford area.

Lichens and bryophytes are difficult groups to study with confidence and they are overlooked in arid land studies. Constraints include taxonomic problems and lack of experts, the small size and intermixing of taxa in the field, and life history and natural variation of species.

Field work was completed between July, 2002, and April, 2003. Two types of sites were chosen: those that were suited for crust community investigations and sites that were selected to examine the biodiversity across the Monument. Collections of lichens and bryophytes were made at both biodiversity and community sites, and were identified by the author and a number of other experts.

Plots were laid out along 20 m transects placed in 15 sites across the Monument in order to measure the cover of a number crust variables, including mineral soil, litter, total crust, vascular plants bases, stones, and individual microbiotic species or species groups. Surficial soil samples were collected from each site for analysis. Data from the field plots were then analyzed with Nonmetric Multidimensional Scaling, an ordination method suited to data collected in patchy and discontinuous habitats, as is characteristic in the often heavily disturbed soil crusts of the Monument.

Over 90 species of lichens are reported here from the Monument, although taxonomic work is still required in order to identify all of the taxa. The number of species is expected to increase as collections are identified and more sites are investigated.

Fifty-four lichen taxa are found on soil crusts, twenty-six taxa are saxicolous, and eleven lichen taxa are epiphytic. At least 35 bryophyte taxa were found during this survey. It is possible that some of the unidentified lichens and mosses collected during this survey will have notable biogeographic distributions, or be new to science.

Based on field research and the data analysis, three late seral soil crust communities have been identified on the Monument: the *Trapeliopsis steppica - Bryoerythrophyllum columbianum* Community, characteristic of finer soils found mainly on the west side of the Monument, the *Syntrichia* spp. - *Caloplaca tominii* Community, characteristic of coarser, principally sandy soils found on the east and north parts of the Monument, and the *Phaeorrhiza sareptana - Lecanora* spp. - *Encalypta rhaptocarpa* Community, characteristic of stony soils at higher elevations.

Research regarding environmental factors that influence the distribution of microbiotic taxa and the development of potential communities on the Monument is in its early stages. Soil factors, including structure, pH, electro-conductivity, and CaCo3 availability, appear most critical in the development and composition of biological crusts, although only the importance of soil structure has been supported here. Other environmental factors that may be important include elevation and heat. Disturbance factors, such as fire and grazing animals, appear to be most important in the seral stage development of the crusts. Some soil crusts appear to be strongly impacted by invasive plant species, in particular cheatgrass.

Recommendations in this report include continuing and expanding the lichen and bryophyte biodiversity studies on the Monument, and ecological studies such as continuing the investigation of crust communities, monitoring of the soil crust, successional studies, studies on the impact of elk on the crust, and soil crust management studies.

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1. Introduction

1.1 Purpose

Lichens and bryophytes are common, yet sometimes overlooked, components of the shrub-steppe and grassland plant communities of the intermountain west. They represent an important constituent of the biodiversity of arid lands and are an essential part of biological soil crusts. Biological crusts, also known as cryptogamic or microbiotic crusts, occupy much of the soil surface in the interspaces between vascular plants and perform a number of essential ecological functions in arid lands.

This report presents the results of a study of the lichens and bryophytes of the biological soil crusts and other habitats in The Hanford Reach National Monument near Richland, in south-central Washington State (Fig. 1). It also presents recommendations that are designed to guide future research on lichens and bryophytes in this diverse and ecologically dynamic area.

There are three main objectives to this study:

1. to expand upon previous biodiversity research of the lichen and bryophyte components of the biological crusts of the shrub-steppe and grasslands at The Hanford Reach National Monument. Lichens and bryophytes in habitats other than soil crusts, including rocks and stones, shrubs and trees, and wetlands, were also investigated,
2. to initiate an investigation of the relationships between microbiotic species assemblages and the major vascular plant communities, and
3. to investigate relationships between the distribution of lichen and bryophyte assemblages and readily measurable environmental variables.

1.2 The Study Area

The Hanford Reach National Monument is part of what is generally termed the Hanford Site (Soll et al. 1999, Sackschewsky and Downs 2001). The Monument is comprised of five management areas encompassing some 700 km^2 (Fig 2):

1. The Fitzner/Eberhardt Arid Lands Ecology (ALE) Reserve,
2. The Saddle Mountain Unit (The Saddle Mountain National Wildlife Refuge),
3. The Wahluke Unit (formerly the Columbia Basin Wildlife Area),
4. The McGee Riverlands Unit, and
5. The River Corridor Unit, including the Hanford Reach of the Columbia River, islands in the Reach, and adjacent uplands.

These five management areas surround Central Hanford which is not included in this study.

The vegetation of the Hanford Reach National Monument is characterized by a complex of arid land plant communities, ranging from sagebrush-steppe and perennial and annual grasslands to communities on talus slopes. It is the one of the largest protected areas for these vegetation types in North America. Research on the definition and characterization of the plant communities in the Monument is ongoing. To date, some 17 potential terrestrial plant communities have been identified (Pacific Northwest National Laboratory 2002). Most of the communities are restricted in their distribution and overlap to some degree. However, three communities dominate over large areas. They are:

1. the Wyoming big sagebrush (*Artemisia tridentata* ssp. *wyomingensis*) / bluebunch wheatgrass (*Pseudoroegneria spicata*) community,
2. the Wyoming big sagebrush (*Artemisia tridentata* ssp. *wyomingensis*) / needle and thread (*Stipa comata*) community, and
3. the bitterbrush (*Purshia tridentata*) / Indian ricegrass (*Oryzopsis hymenoides*) community.

There has been widespread disturbance across much the Monument over time. Fires have frequently burned large areas of shrub steppe since the mid 1950's, especially in the ALE Reserve. Domestic animal grazing has also impacted much of the northern portions of the area. Further, there has been extensive invasion by exotic plants over wide areas, in particular cheatgrass (*Bromus tectorum*). Elk are present in relatively large numbers in some areas, and are responsible for considerable localized disturbance, especially in some remaining sagebrush sites in the ALE Reserve.

A great amount of additional biological research has been completed or is underway in the Monument area (Soll et al. 1999). This includes a number of permanent plots, such as BRMaP (Biological Resources Management Plan) plots, Biodiversity plots, and Steppe-in-Time Plots, that have been set up in order to investigate vegetation change and other environmental attributes.

More complete details about the ongoing biological work as well as the history of the Hanford site can be found in Soll et al. (1999), Sackschewsky and Downs (2001), United States Department of Energy (2001), and the U.S. Fish and Wildlife Service website (http://hanfordreach.fws.gov/index-expanded.html; for details on each of the management areas).

1.3 Biological Soil Crusts

Biological soil crusts are complex groupings of organisms that grow over the soil surface in many arid and semi-arid landscapes (Belnap et al. 2001, Ponzetti 2000). The dominant organisms that comprise crusts are lichens, bryophytes (principally mosses but also a few liverworts), single-celled algae, and cyanobacteria (Belnap et al. 2001, Belnap 2003, McIntosh 1986). These organisms are intermixed with fungal hyphae, plant roots, litter, and soil, and, as a unit, are often thin and compact. Because of the numerous organisms that typically comprise them, biological crusts are an important component of arid land biodiversity.

Biological crusts perform a number of ecologically important roles that contribute to ecosystem integrity and health (Belnap et al. 2001, Evans and Johansen 1999, Ponzetti 2000). For example, they contribute to soil stability. Open soils are often in constant movement, as particles are displaced by wind and water. As a biological crust develops, the soil stabilizes and soil displacement is reduced or eliminated, mainly due to the binding of soil particles by the various crust organisms (Belnap 2003, Belnap and Gardner 1993, Schulten 1985). The complex microtopography of surficial crusts creates a boundary of still air at its surface which also protects it and the underlying soil from wind erosion (Eldridge and Kinnell 1997, Neuman and Maxwell 1999, Lehrsch et al. 1988). The presence of intact biological crusts may also inhibit the establishment of cheatgrass (*Bromus tectorum*) and other invasive species (Belnap et al. 2001, Kaltenecker et al. 1999).

The presence of a crust influences hydrology at the soil surface. It appears that, at least in some areas, water infiltration rates are increased when a crust is present, although the degree of infiltration is influenced by a number of factors, including soil type, crust composition, and climate (Eldridge 1993, Ponzetti 2002).

Lichens, bryophytes, cyanobacteria, and green algae in the crust fix atmospheric carbon, contributing to the overall productivity of a plant community. Free-living cyanobacteria and those lichens with a cyanobacterial component are capable of fixing atmospheric nitrogen, which is released into the soil and subsequently used by the associated vascular plants and fungi, enhancing the ecosystem (Belnap et al. 2001, Evans and Belnap 1999). In some cases, vascular plants that grow in areas of well developed crusts have higher accumulations of phosphorus, potassium, iron, calcium, magnesium, and manganese than in sites that lack crusts (Belnap et al. 2001, Ridenour and Callaway 1997).

Most biological soil crusts are fragile and readily disturbed. Susceptibility to disruption is related to site factors such as soil type, local climate, and the composition of the vascular plant community (Belnap et al. 2001, Ponzetti 2000). Over the past century, most biological crusts in the Pacific North-west have been heavily altered and sometimes destroyed by livestock, agricultural practices, fire, and off-road vehicle use. There is evidence that the biological crusts in the Pacific North-west, including those in the Hanford area, evolved in low disturbance environments, where impacts by large herbivores and fire were much less severe than at present (Mack and Thompson 1982).

1.4 Previous Soil Crust Research in the Hanford Area

Biological soil crusts have frequently been overlooked in studies of shrub-steppe vegetation and, until recently, little research has been completed on the crusts of the Hanford area. McIntosh (1986) collected lichens and bryophytes with Bill Rickard at ALE in 1981, before several landscape-scale wildfires had swept the site. Johansen et al. (1993) studied the effects of fire on the algal and cyanobacterial crust components of crusts on the ALE Reserve.

The first published study of the biological crusts at Hanford was completed in 1998 by Link et al. (2000; discussed in Soll et al. 1999). They reported 29 lichen and six moss species following a survey of 13 locations across the Hanford site, including six locations in the Central Hanford area. Six of the lichen species they collected were unidentified at the time of their survey, and, since then, two have been described as new species of *Trapeliopsis* (McCune et al. 2002). Five of their lichen collections were reported as new to Washington State.

Ponzetti et al. (2000) completed an extensive grazing management-related ecological study of the biotic crust communities in the Horse Heaven Hills, in Benton County south of the Yakima River, some 20 km to the south and south-west of the Hanford site. Their research revealed that approximately 58 lichen species and 11 bryophytes, including ten mosses and one liverwort, comprise the soil crust in this area. They also reported another 50 or more species of lichens that grow on rock, wood, or bark.

Von Reis and her students at the Columbia Basin College in Pasco are undertaking a long-term study of *Texosporium sancto-jacobi* (a nationally rare lichen species; McCune and Rosentreter 1992) in the region (J. von Reis, pers. comm.). Although this species has not yet been found on the Monument, there is a high potential for it to be present.

1.5 Constraints on the Identification of Lichens and Bryophytes

Lichens and bryophytes are difficult groups to study with confidence in field studies. There are a number of reasons for these difficulties, including:

1. <u>Taxonomic problems and lack of experts</u>: These two groups of organisms have relatively few specialists who fully understand specific genera, let alone the full suite of taxa that are present in a particular arid land ecosystem. This is partly due to the inherent difficulties in their identification, such as the necessity for microscopic examination or chemical testing of specimens before conclusive identifications can be made. Few taxonomic keys and little illustrative material is available for most groups. Some species must be sent away to experts, sometimes overseas, before confirmation can be made. Because of this, a number of species from this survey remain tentatively identified or identified only to genus. Also, there are sometimes conflicts in species concepts and identical specimens may be identified differently between experts.

2. <u>Small size and intermixing of taxa in the field</u>: Most species of arid land lichens and bryophytes are small in stature. Lichen thalli, apothecia, and many mosses often range from >1mm to 2mm in size at maturity, are often difficult to see in the field, and often must be collected for confirmation. The small stature of many species leads to difficulties in identification, even with the use of microscopes; most species of arid land mosses must have cross-sections of their leaves made and lichen spores must be examined before positive identifications can be made. Further, bryophyte and lichen taxa are often intermixed over the soil surface, with, often, over 10 species being present on ~2 cm^2 patches of soil, and this may lead to some species being missed during fieldwork.

3. <u>Species variation</u>: Identification of many species of dryland lichens and bryophytes often depends on the maturity of the organism. Mature specimens with reproductive structures, at least with respect to many of the lichens, are most readily identified. However, many specimens lack reproductive organs, or are

juvenile and difficult or impossible to identify, such as the case with many taxa found in the more heavily or repeatedly disturbed areas of the Monument. Also, many species have a variety of growth forms that may be related not only to age but to environmental conditions. This can lead some researchers to identify multiple collections as one or more species, depending on their experience and taxonomic background.

2. Methods

2.1 Survey Dates and General Protocols

Following an initial visit in order to gain familiarity with the site on July 10 and 11, 2002, five field work periods were completed: August 21 – 24, October 23 – 27, December 3 – 7, December 16 – 20, and April 23 – 25, 2003. The latter visit was used to visit various community sites following the winter growth period of the microbiotic taxa.

Some of the earlier periods of field work were used to visit existing permanent vegetation plots, such as BRMaP and Biodiversity plots, and to search for areas where crust community sampling could be conducted. Sites that may be useful in future research activities, such as monitoring crust recovery, were investigated. All sites locations were recorded with a portable GPS unit using UTM NAD27 DATUM.

Although much of the Monument area was surveyed, some areas that may have been useful for this survey were unavailable, either because of time constraints or inaccessibility.

2.2 Biodiversity Research Protocols

One hundred and eighteen sites across the Monument were investigated for the presence of lichens and bryophytes. Most of the sites were chosen based on their relative lack of disturbance, as these sites usually have a richer diversity than disturbed sites. All identifiable lichen and bryophyte species were listed in the field at each site, and general collections were made for identification or confirmation later. Some baseline ecological data, including vegetation type, were recorded in addition to the microbiotic species information at most sites.

Although the primary focus of the project was on soil crust taxa, additional collections were made on rock outcrops, talus, rocks and stones, and on branches and bark of shrubs and trees. Two collections were made in wetland habitats: one site along the Columbia River along Hanford Reach, and another in a seepage area in the southern portion of the Wahluke Unit.

2.3 Biological Crust Community Sampling Protocols

i. Site Selection

Fifteen sites were selected for biological crust community sampling and analysis. Searches for well-developed biological crusts were made across the Monument before site selection was finalized. Local experts familiar with regional crusts were consulted for locations of mature crusts. A number of problems were encountered during this selection process. Wide stretches of the Monument have been heavily disturbed, and biological crusts are either absent, in an early successional state, or too patchy to sample. Also, most of the sites that were recommended by experts were either found to have been burned since the observer had last been there, or were not located. Some areas, however, had reasonably mature, although patchy crust development, and sampling was focused in those sites.

The initial intent of the study was to select sites representative of the major vascular plant communities and to sample associated crust assemblages. Owing to the disturbed condition of much of the Monument, however, it was difficult to find clearly defined vascular plant communities with sufficiently developed crusts. Therefore, the site selection protocol was modified to emphasize the better-quality crust assemblages, and the associated vascular plant communities were described following site selection.

ii. Sampling Protocols

All of the crust sampling sites exhibit a more or less irregular mosaic of patterning from patches of open soil to patches of crust, mainly as a result of past or ongoing disturbance of some kind. Thus, it is difficult to be confident that the transects were placed in an area fully representative of that site. Because of this, the sampling protocol that was proposed at the beginning of the project was modified, and a single 20 m transect was used instead of two, and 20 plots were sampled on the single transect.

The following sampling protocol was used in each of 15 sites:

- The most homogeneous part of the site was selected and one 20 m long transect was placed across the most representative part of the crust community, avoiding shrubs when possible. It was placed parallel to a slope, if present, and UTMs were logged at the start of each transect. Only at Site 4 was this protocol significantly altered; in this site we sampled in undisturbed areas under 20 shrubs along a 80 m transect in order to compare the microbiotic species there with the open crust areas.
- Photographs were taken using a Nikon Cool Pix 950 digital camera. Photographs were taken down the center of each transect from the origin, as well as across the community. Other representative photographs were also taken in order to fully document the character of the plot and the surrounding vascular plant community.
- Twenty 20 X 20 cm plots were sampled at 1m intervals along each transect (this relatively small plot is considered to be an effective method for measuring cover of microbiotic species; Belnap et al. 2001); if a plot was located on a spot that was heavily disturbed, it was moved either to the opposite side of the transect, or 40 cm along the transect if the opposite side was also disturbed.
- Cover of mineral soil, litter, total crust, vascular plants bases, stones, and individual species or species groups were estimated using the sampling scale of Ponzetti (2000; Table 1). This sampling scale is most useful in this work with small species in small plots, as it reduces errors that would arise if actual percent were estimated. Also, it speeds up sampling and data entry. One observer was used for all plots in order to reduce potential estimation errors. In most sites, there were unidentifiable taxa that were lumped into two

categories: unidentified bryophytes (UB) or unidentified lichens (UL). At all sites, greater than 95% of all species present along or near the transect were captured in the sampling plots. Microbiotic species that were not encountered in the plots during the sampling are listed in the site descriptions. Prior to analysis, lichen and bryophyte cover data were averaged from the 20 plots at each site.

- Collections of representative species were stored in small coin packets from many of the plots in order to confirm identifications later, and to see if smaller taxa were missed and could be added to the field sheets.
- descriptive notes were made at all sites; these included data on general habitat conditions including surficial soil characteristics, such as soil texture, along with slope and aspect.

Table 1. Sampling Cover Scale

Scale Value	Representative % Cover
1	< or = 1
2	> 1 - 4
3	> 4 – 10
4	> 10 – 25
5	> 25 – 50
6	> 50 – 75
7	> 75 – 95
8	> 95 - 100

iii. Soil Analyses

Surficial soil samples were collected from each site near the center of the transect. So that the crust was not disturbed, these samples were usually taken from three to four areas of open soil, and sealed in plastic bags. Four sub-samples from each soil sample were assessed in a plant physiology laboratory at the University of British Columbia for conductivity and pH, mostly following the protocols outlined by Ponzetti (2000). Soil texture was estimated by hand for purposes of site characterization.

Soil pH and electro-conductivity values fluctuated significantly within samples and were not used in the site-based community analysis.

iv. Data Analysis

In order to assess species and site relationships, data were analyzed using Nonmetric Multidimensional Scaling (NMS). This is an ordination method designed to produce a graphical representation of a set of data points, in this case species and sites, based on their similarity or dissimilarity (Kenkel and Orloci 1986, McCune and Grace 2002, Ponzetti 2000). Distance in the ordination diagram is roughly proportional to the dissimilarity between sampling units (sites) calculated from the correlation values (r) of their species composition data. The goodness of fit of the ordination dimensions to the actual calculated distance matrix is represented by a stress value, with smaller stress values representing a better fit than larger values.

Unlike other commonly used ordination methods in ecology (e.g., principal components analysis and correspondence analysis), NMS does not require assumptions of linearity or unimodality of species along environmental gradients (Kenkel and Orloci 1986). Thus, NMS is often considered the method of choice where species distributions are patchy and discontinuous, as is represented by this data set (De Grandpré et al, 2000, Kenkel and Orloci 1986, Pyke et al. 2001, Qian et al. 2003). The ordination axes generated by NMS represent the optimum number of dimensions for summarizing the data and do not necessarily account for sequentially declining proportions of variation in the data as is the case with other ordination methods. For this reason, once the final k-dimensional solution has been determined for a given dataset, the selection of axis combinations to use for graphing is that which leads to the clearest overall interpretation.

All of the confirmed species or genera that were recorded in the plots were used in the analysis (45 taxa in total). Unidentified taxa were not used in the analysis.

The NMS was run in autopilot mode using PC-ORD 4.17 (McCune and Mefford 1999).

2.4 Collection, Identification, and Specimen Processing Protocols

Collections of lichens and bryophytes were made at both biodiversity and community sites for identification later. Over 2000 individual specimens were examined during this project. Larger representative collections of individual species were packaged in paper envelopes and stored for processing.

The lichens were identified with the assistance of a number of experts, including J. Ponzetti, B. McCune, and T. Goward. Bryophytes were identified by the author, and some specimens have been sent away for confirmation or identification by other experts.

A number of references were used in the identification process. Because of the relatively early stage in the investigation of arid land lichens, there are no complete references available for this group, although Goward et al. (1994), McCune and Rosentreter (1995), and Brodo et al. (2001) are useful guides. There are more references available for the bryophytes, including Flowers (1973), Lawton (1971), McIntosh (1986, 1989), Rossman (1977), and some of the recently published works for the Bryophytes of North America Project (2003; available online at http://www.buffalomuseumofscience.org /BFNA/). Herbaria at Oregon State University, at the University of British Columbia, and at the homes of T. Goward and Jeanne Ponzetti were visited in order to help in the identification of lichens.

An increasing number of arid land lichen and bryophyte taxa are under revision and many generic names are in flux. In most cases, the taxonomic names that are used here are the more familiar traditional names, with a few exceptions. For example, following the work of Zander (1993), the moss genus *Syntrichia* is used here instead of the more familiar *Tortula* for the larger and more coarser species of this group. Some researchers consider *Syntrichia ruralis* var. *papillosissima* to be a separate species, but we kept it as a variety here, pending results of the on-going research of Chan (2003).

Representative specimens of all known species, once identified, will be packaged, labeled, and sent to the US Fish and Wildlife offices in Hanford. Additional specimens will be housed at Oregon State University, the University of British Columbia, and, for the bryophytes, at the University of Washington, a request of Judith Harpel, a bryologist for the USDA Forest Service.

3. Results

3.1 Biodiversity Survey

i. Lichens

This study found 54 lichen taxa growing as part of the terrestrial soil crust community. Thirty-six of these taxa have been identified to species, while the identification of the remainder remains conditional. Of these, four taxa have tentative species identities and 14 have been identified to genus.

In addition to the terrestrial lichens, at least 26 saxicolous lichen species were collected on rock outcrops, rocks, or stones. Most saxicolous collections have been identified to genus only, and five taxa are of unknown identity.

Eleven lichen taxa are epiphytic on bark of shrubs and trees. Most have been identified to genus, with species identification pending.

Four lichen species have been found on two substrata. *Lecanora muralis* and the unknown *Xanthoria*-like lichen are both primarily saxicolous, but are also found on soil. *Physconia enteroxantha* is found commonly on both bark and soil, and *Candelaria concolor*, primarily epiphytic, was occasionally found on compact, fine-textured soil.

Tables 2 - 4 list the lichens reported from terrestrial, saxicolous, and epiphytic habitats on the Hanford Reach National Monument. An indication of the relative occurrence of terrestrial lichens, that is their relative commonness or rareness across the Monument, is included in Table 2. Some twenty-six lichens are common and widespread to locally common across the Monument, and the remaining taxa are uncommon to rare. Not enough information is available to assess relative occurrence for saxicolous lichens. All of the epiphytic lichen taxa in Table 4 were collected on sagebrush, and collections of *Candelaria concolor* and *Physcia* sp. were made on bitterbrush and on introduced trees. Many of the epiphytic lichens listed in Table 4 appear to be relatively widespread, but this needs further investigation.

Table 2. Terrestrial Lichens on the Hanford Reach National Monument, and from Link et al. (2000).

(Relative occurrence: C = common and widespread, L = locally common, but not widespread, U = uncommon, and R = rare)

	2002/2003	Link et al.	Relative Occurrence
Acarospora schleicheri	X	X	L
Amandinea punctata	X	X	L
Arthonia glebosa	X	X	C
Aspicilia filiformis	X	X	U
Aspicilia reptans	X	X	L

Aspicilia spp. (2)	X	X	R
Aspicilia cf. *terrestrialis*	X		R
Caloplaca jungermanniae	X	X	L
Caloplaca stillicidiorum	X		L
Caloplaca tominii	X	X	C
Caloplaca sp.	X		R
Candelaria concolor	X		R
Candelariella terrigena	X	X	L
Catapyrenium sp.	X		R
Cladonia cariosa	X		C - U
Cladonia fimbriata		X	
Cladonia cf. *pyxidata*	X	X	C - U
Cladonia sp. (unknown number)	X		L
Collema cf. *coccophorum*	X		U
Collema tenax	X	X	C
Collema spp. (2)	X		U - R
Diploschistes muscorum	X	X	C
Endocarpon pusillum	X	X	L
Lecanora sp.	X		R
Lecanora hagenii	X	X	L
Lecanora muralis	X	X	L
Lecanora zosteri	X		U
Lecidiella stigmatea	X		U
Lepraria sp.	X		R
Leptochidium albociliatum	X	X	L
Leptogium lichenoides	X	X	C
Leptogium spp. (2)	X		R
Massalongia carnosa	X	X	U
Megaspora verrucosa	X		L
Mycobilimbia lobulata	X		R
Peltigera rufescens	X	X	R
Phaeorrhiza sareptana	X		L
Physconia enteroxantha	X	X	C
Physconia isidiigera	X	X	U
Physconia muscigena	X		R
Placidium sp.	X		R

Placynthiella cf. *uliginosa*	X	X	C
Psora cerebriformis	X		U
Psora decipiens	X		R
Psora globifera	X	X	L
Psora luridella	X	X	U - R
Psora montana	X	X	L
Toninia sedifolia	X		R
Trapeliopsis bisorediata	X	X	L
Trapeliopsis sp. (possibly *T. californica*)	X		R
Trapeliopsis steppica	X	X	L
possibly *Xanthoria* sp.	X		R

Table 3. Saxicolous Lichens on the Hanford Reach National Monument.

Acarospora cf. *fuscata*
Acarospora sp.
Aspicilia cf. calcarea
Aspicilia cf. contorta
Aspicilia sp.
Caloplaca sp.
Candelariella cf. *vitellina*
Endocarpon cf. *pulvinatum*
Lecanora cf. *garovaglii*
Lecanora muralis
Lecanora cf. *rupicola*
Lecanora sp.
Lecidia atrobrunnea
Lecidia cf. *tessellata*
?*Lobothallia* sp.
Melania cf. *disjuncta*
Melania sp.
Neofuscelia sp.
Rhizocarpon sp.
Rhizoplaca peltata

Rhizoplaca sp.
?Sarcogyne sp.
Umbilicaria cf. *arctica*
Umbilicaria spp. (2)
?Verrucaria sp.
Xanthoria sp.*
Unknown spp. (2-5)

Table 4. Epiphytic Lichens on the Hanford Reach National Monument.

Candelaria concolor
?*Cyphelium tigillare*
Lecanora cf. piniperda
Leptogium sp.
Melanelia sp.
Physcia sp.
Physconia enteroxantha
Xanthoria spp. (2)
Unknown spp. (2)

ii. Bryophytes

At least 35 bryophyte taxa were found during this survey (Table 5). Twenty-eight species identifications are confirmed, and seven have been identified to genus only. Twenty-four bryophyte species are associated principally with soil crusts. Five species are principally saxicolous, although two of these species, *Grimmia alpestris* and *G. trichophylla,* are also found on some crusts with finer soils, and one species, *Grimmia anodon*, is found on the edges of silt-rich cliffs. Five species are associated with wetland habitats.

Table 5 lists the bryophyte species found on the Monument. An indication of the relative occurrence of bryophyte species across the Monument is included in this table.

Table 5. Bryophytes on the Hanford Reach National Monument.

Habitat: C = soil crust, R = rock or stones, W = wetland

Relative occurrence: C = common and widespread, L = locally common, but not widespread, U = uncommon, and R = rare

	Habitat	**Relative Occurrence**
Aloina bifrons	C	L
Aloina cf. *rigida*	C	R
Amblystegium sp.	W	R
Anacolia mensiesii	R	R
Barbula sp.	C	R
Bryoerythrophyllum columbianum	C	C
Bryum argenteum	C	L
Bryum cf. *caespiticium*	C	C
Bryum sp.	C	C
?Calliergon sp.	W	R
Ceratodon purpureus	C	C
Crossidium seriatum	C	R
Didymodon brachyphyllus	C	U
Didymodon cf. nevadensis	C	R
Didymodon tophaceus	W	R
Didymodon vinealis	C	L
Didymodon spp. (2)	C	U
Drepanocladus aduncus	W	R
Encalypta rhaptocarpa	C	U
Funaria hygrometrica	W	R
Grimmia alpestris	R/C	U - R
Grimmia anodon	R/C	R
Grimmia ovalis	R	U
Grimmia trichophylla	R/C	U
Phascum cuspidatum	C	R
Pseudocrossidium obtusulum	C	L
Pterygoneurum ovatum	C	U
Pterygoneurum subsessile	C	R
Syntrichia caninervis	C	C
Syntrichia princeps	C	L

Syntrichia ruralis	C	C
Syntrichia ruralis var. *papillosissima*	C	C
Tortula brevipes	C	C
Trichostomopsis australasiae	C	C

3.2 Biological Crust Community Survey

i. Site and Microbiotic Assemblage Descriptions

The 15 microbiotic crust plot-based sampling sites are described below. Table 6 provides a summary of locations and sampling times for these sites.

Site 1 (Fig. 3)

This site is located on the west facing slope near the top of Rattlesnake Mountain in ALE. The vascular plant community is characterized by scattered low shrubs (eg., *Eriogonum* spp. and *Artemisia tripartita*), forbs (eg., *Balsamorhiza* spp., low pussytoes, *Antennaria dimorpha*, and *Lomatium* spp.), and the grasses blue-bunch wheatgrass and Sandberg's bluegrass (*Poa sandbergii*). It has very stony, loamy soils (~regosolic). The major disturbances are probably frost perturbation and wind. There is some sign that fire has burned through the site, but the effects of fire have probably been minimized because of limited fuel loads. There is no evidence of animal-related disturbance. It is the highest elevation community in the survey.

The crust here appears to be mid to, possibly, late seral. Characteristic crust lichen species include *Caloplaca* cf. *stillicidiorum*, *Caloplaca tominii*, *Cladonia* spp., *Endocarpon pusillum*, *Megaspora verrucosa*, *Phaeorrhiza sareptana*, *Physconia* spp., and species of *Psora*, in particular *Psora globifera*. Characteristic bryophyte species include *Ceratodon purpureus*, *Encalypta rhaptocarpa*, *Pterygoneurum ovatum*, and a small form of *Syntrichia ruralis*. *Lecanora muralis* is common on stones in the site, and also grows on soil, especially adjacent to the stones it inhabits . Species not recorded in the sample plots include *Arthonia glebosa* and *Grimmia alpestris*.

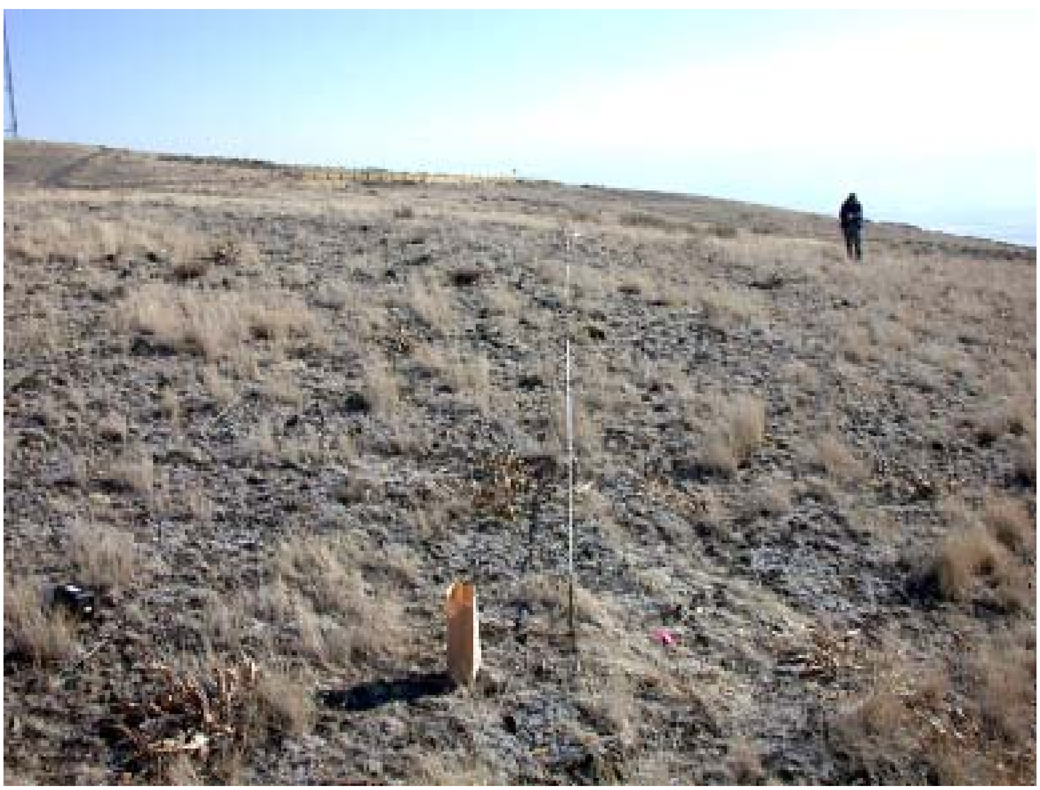

Figure 3. Biological Soil Crust Sampling Site 1.

Site 2 (Fig. 4)

Site 2 is a grassland located on Iowa Flats south of the ALE Station within an area that has been heavily burned relatively recently. The vascular plant community is characterized by blue-bunch wheatgrass, and Sandberg's bluegrass, with low cover of balsamroot (*Balsamorhiza careyana*), desert parsley (*Lomatium* spp.), and sulfur lupine (*Lupinus sulfureus*). The site has loamy soils. This area had been missed by the most severe impacts of recent fires, but still exhibits bases of burned grasses, as well as some burned lichens and mosses. All shrubs were burned off the site during the 1980’s. There is no evidence of large animal disturbance, although some there is some evidence of recent burrowing animal activity, possibly pocket gophers.

The biological crust here is recovering from the effects of the fire and much of it should be considered early seral, yet some isolated and small patches of fairly mature crust are present, indicated by the presence of *Acarospora schleicheri* and *Trapeliopsis steppica*. Many of the lichens, including *Diploschistes muscorum* and *Leptochidium albociliatum*, are frequently found burned and appear dead and decomposed, although there is some growth on a few individual burned lichens. Some burned mosses also show signs of recovery with small plants growing out of the center of the dead leaves.

Characteristic crust lichen species include *Aspicilia* spp. (including *A. reptans*), *Cladonia* sp., *Diploschsites muscorum*, *Lepraria* sp., and *Leptochidium albociliatum*. Characteristic bryophyte species include *Bryoerythrophyllum columbianum* and *Ceratodon purpureus*. Species not recorded in the sample plots include, *Arthonia glebosa*, *Candelariella terrigena*, *Didymodon brachyphyllus*, *Grimmia trichophylla*, *Lecanora* cf. *hagenii*, *Lecidella* sp., *Megaspora verrucosa*, *Psora globifera*, *P.* cf. *montana*, *Syntrichia princeps* and *S. ruralis*. Many of the recovering crust taxa are too juvenile to identify.

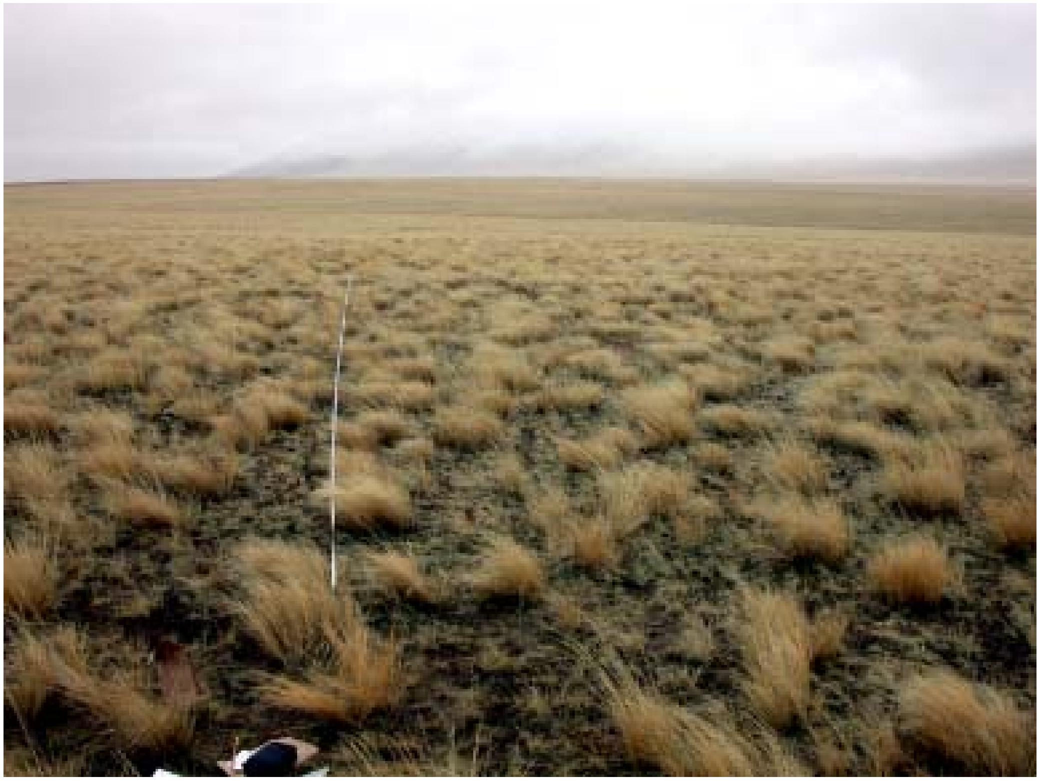

Figure 4. Biological Soil Crust Sampling Site 2.

Site 3 (Fig. 5)

This site is located north of State Route 24 on a flat in the western part of the Saddle Mountain Unit. The vascular plant community is characterized by Wyoming sagebrush, Sandberg's bluegrass, and minor amounts of balsamroot. It has somewhat stony, sandy soils. Cheatgrass is common across the site but not dominant. Disturbances appear to be minor trampling by large grazing animals and associated wind erosion. A number of old wildlife trails cross the area near the site. There is some evidence of cattle usage in the past.

The crust here appears to be early to mid seral. Characteristic crust lichen species include *Caloplaca tominii* and *Placynthiella* cf. *uliginosa*. Characteristic bryophyte species include *Ceratodon purpureus*, *Didymodon* sp., *Syntrichia caninervis*, *S. princeps*, *S. ruralis*, and *Trichostomopsis australasiae*. Species not recorded in the sampling include *Arthonia glebosa*, *Cladonia* sp., *D. vinealis*, and *Tortula brevipes*.

Site 4 (Fig. 5)

This site is adjacent to Site 3 and was designed to measure the biological crust under the canopies of large and healthy sagebrush. There is little evidence of disturbance under the shrubs. The only cryptogam recorded was *Syntrichia ruralis*, but many of the crust taxa characteristic of Site 3 from the adjacent areas are present at the edges of the shrubs and in some open canopy areas under the shrubs.

Figure 5. Biological Soil Crust Sampling Sites 3 and 4.

Site 5 (Fig. 6)

This site is located south of State Route 24 on a flat over a broad sand dune in the Saddle Mountain Unit. The vascular plant community is characterized by Indian ricegrass (*Oryzopsis hymenoides*), needle-and-thread (*Stipa comata*), Sandberg's bluegrass, and small amounts of rabbit-brush (*Chrysothamnus* spp.). The site has coarse sandy soils. Cheatgrass is patchy but not dominant across the site. Wind erosion appears to be the only significant disturbance on site, although there is some evidence of a previous fire.

The crust here appears to be early seral. Characteristic crust lichen species include *Caloplaca tominii* and *Placynthiella* cf. *uliginosa*. Characteristic bryophyte species include *Bryum argenteum*, *Ceratodon purpureus*, *Syntrichia caninervis*, *S. ruralis*, and *Trichostomopsis australasiae*. Species not recorded in the sampling include *Arthonia glebosa*, *Cladonia* sp., *Collema* sp., *Didymodon* spp., *Lecanora* cf. *zosteri*, *Leptogium* cf. *lichenoides*, and *Tortula brevipes*.

Figure 6. Biological Soil Crust Sampling Site 5.

Site 6: (Fig. 7)

Site 6 is located in central ALE within a patch of grassland which, at some point, had a sagebrush component. The vascular plant community is characterized by bluebunch wheatgrass, Sandberg's bluegrass, and low pussytoes. It has loamy soils. This site has been missed by the most severe impacts of recent fires, but still exhibits minor fire damage on grasses, shrubs, and in the crust. There is some evidence of recent burrowing animal activity. Very little cheatgrass is present.

The crust here appears to be early to mid seral. Characteristic crust lichen species include *Arthonia glebosa*, *Cladonia* sp., *Leptochidium albociliatum*, and *Trapeliopsis bisorediata*. Characteristic bryophyte species include *Aloina bifrons*, *Bryoerythrophyllum columbianum*, *Ceratodon purpureus*, *Didymodon* sp., and *Syntrichia caninervis*. Species not recorded in the sampling include, *Acarospora schleicheri*, *Collema* sp., *Endocarpon pusillum*, *Leptogium* cf. *lichenoides*, *Syntrichia ruralis*, *Trapeliopsis* spp., and *Trichostomopsis australasiae*.

Figure 7. Biological Soil Crust Sampling Site 6.

Site 7 (Fig. 8)

This site is located in central ALE, north-west of Site 6. It is within a remnant patch of shrub-steppe surrounded by an area that has been heavily burned. The vascular plant community is characterized by sagebrush, bluebunch wheatgrass, and Sandberg's bluegrass. It has loamy soils. Minor fire damage is present on grasses, sagebrush, and in the crust. It appears that when the fire swept past this area small portions within this site may have burned or been damaged by heat from the fire. There is some evidence of large animal disturbance, with a few trails and patches of disturbed crust. There is some evidence of recent burrowing animal activity. Cheatgrass is scattered across the site, but is not common.

The crust here appears to be generally mid seral, with patches of relatively mature crust. Characteristic crust lichen species include *Arthonia glebosa*, *Aspicilia* spp., *Cladonia* sp., *Collema* sp., *Diploschistes muscorum*, *Leptochidium albociliatum*, *Leptogium* cf. *lichenoides*, *Psora* spp. and *Trapeliopsis steppica*. Characteristic bryophyte species include *Bryoerythrophyllum columbianum*, *Ceratodon purpureus*, *Didymodon* spp., *Syntrichia caninervis*, and *S. ruralis*. Species not recorded in the sampling include *Endocarpon pusillum*, *Grimmia alpestris*, and *G. trichophylla*.

Figure 8. Biological Soil Crust Sampling Site 7.

Site 8 (Fig. 9)

This site is located in the McGee Ranch Unit south of Umtanum Ridge. It is adjacent to BRMaP 29. The vascular plant community is characterized by sagebrush and some spiny hopsage (*Grayia spinosa*), bluebunch wheatgrass, balsamroot, Sandberg's bluegrass, and some needle-and-thread grass. It has somewhat stony, sandy-loam soils. There is evidence of a 1996 fire on site as some of the sage have burn scars. There is also evidence of large animal disturbance. Very little cheatgrass is present.

The crust here is diverse and appears to be mid seral. Characteristic crust lichen species include *Caloplaca tominii*, *Cladonia* sp., and *Psora* spp., in particular *P. cerebriformis* and *P. globifera*. Characteristic bryophyte species include *Aloina bifrons*, minor amounts of *Bryoerythrophyllum columbianum*, *Bryum argenteum*, *Ceratodon purpureus*, *Didymodon vinealis*., *Pseudocrossidium obtusulum*, *Syntrichia caninervis*, *S. ruralis* and *Trichostomopsis australasiae*. Species not recorded in the sampling include *Didymodon tectorum* and *Psora* cf. *montana*.

Figure 9. Biological Soil Crust Sampling Site 8.

Site 9 (Fig. 10)

Site 9 is located in the west side of ALE within a remnant patch of shrub-steppe surrounded by an area that has been lightly to heavily burned. The vascular plant community is characterized by sagebrush , bluebunch wheatgrass, Sandberg's bluegrass, Cusick's bluegrass (*Poa cusickii*), and minor amounts of balsamroot. Its soils are fine sandy loams. The area has been missed by the most severe impacts of fire, but still exhibits minor fire damage on grasses, shrubs, and in the crust, especially on the larger thallose lichen species. There is minor evidence of some large animal disturbance,. Cheatgrass is relatively common across the site.

The crust here is diverse, and appears to have patches of late seral crust where disturbance is low, although many portions appear mid seral. Characteristic crust lichen species include *Aspicilia* sp., *Cladonia* sp., *Diploschistes muscorum*, *Leptochidium albociliatum*, and *Trapeliopsis steppica*. Characteristic bryophyte species include *Bryoerythrophyllum columbianum*, *Ceratodon purpureus*, *Didymodon* spp., *Grimmia trichophylla, Syntrichia princeps*, and *S. ruralis*. Species not recorded in the sampling include *Massalongia carnosa*, *Psora globifera*, and *Syntrichia caninervis*.

Figure 10. Biological Soil Crust Sampling Site 9.

Site 10 (Fig. 11)

Site 10 is towards the north end of ALE just south of the transmission lines within a relatively large remnant patch of shrub-steppe. The vascular plant community is characterized by sagebrush, hopsage, and Sandberg's bluegrass. The soil is a loam, with occasional stones. There is occasional minor fire damage to grasses, shrubs, and to the crust. This site has been partly heavily disturbed by elk, with much of the more open crust trampled along trails. Very little cheatgrass is present.

The crust here is diverse, and appears to have patches of late seral crust where disturbance is low, although many portions appear mid seral. Characteristic crust lichen species include *Arthonia glebosa*, *Aspicilia* spp., *Candelariella terrigena*, *Cladonia* sp., *Leptogium* sp., *Leptochidium albociliatum*, *Massalongia carnosa*, and *Psora* spp., in particular *P. globifera* and *P. montana*. Characteristic bryophyte species include *Aloina bifrons*, *Bryoerythrophyllum columbianum*, *Didymodon* spp., *Syntrichia caninervis*, *S. ruralis*, and *Trichostomopsis australasiae*. Species not recorded in the sampling include *Acarospora schleicheri*, *Candelaria concolor* and *C. terrigena*, *Collema* sp., *Didymodon vinealis*, *Lecanora muralis*, *Physconia enteroxantha*, and *Psora cerebriformis*.

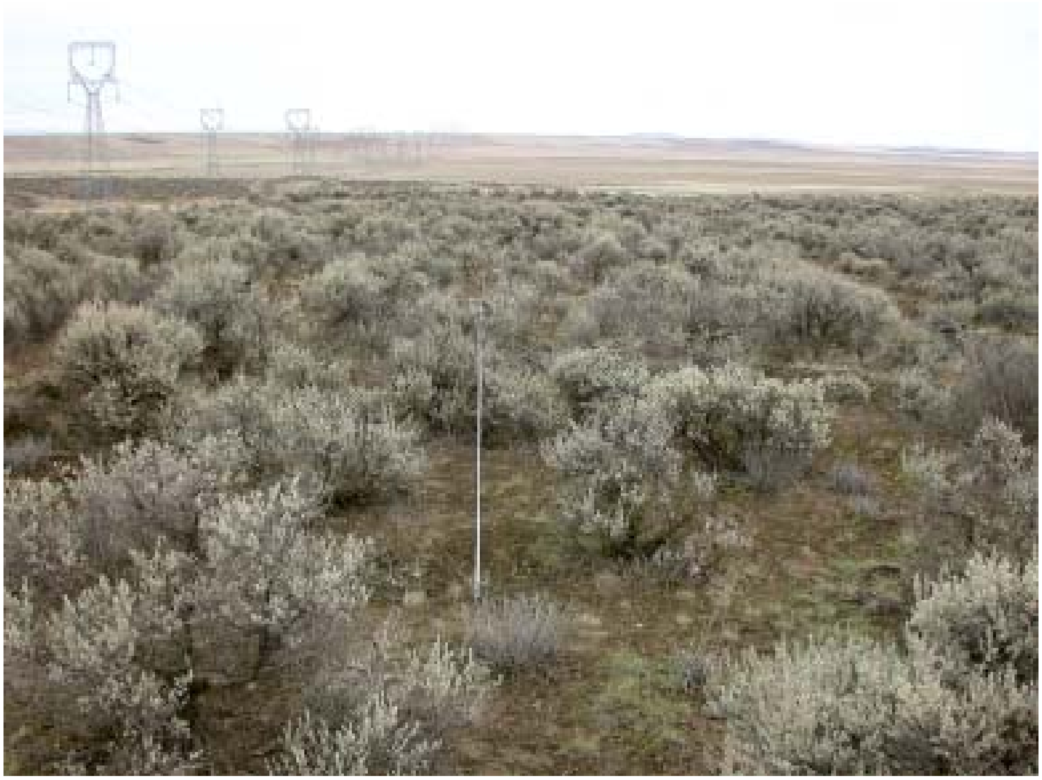

Figure 11. Biological Soil Crust Sampling Site 10.

Site 11 (Fig. 12)

This site lies within an extensive area of shrub-steppe in the central portion of the McGee Ranch Unit. The vascular plant community is characterized by sagebrush, bluebunch wheatgrass, and Sandberg's bluegrass, and its soil is a somewhat stony, sandy loam. Cheatgrass is relatively common. There is no evidence of fire on site. There is minor evidence of large animal disturbance, although evidence of small mammal activity, likely rabbits, is common.

The crust here appears to be early to mid seral. Characteristic crust lichen species include *Arthonia glebosa*, *Aspicilia* sp., *Caloplaca tominii*, and *Collema* sp. Characteristic bryophyte species include *Aloina bifrons*, *Bryoerythrophyllum columbianum*, *Bryum argenteum*, *Ceratodon purpureus*, *Didymodon vinealis*., *Pseudocrossidium obtusulum*, *Syntrichia caninervis*, *S. ruralis*, *Tortula brevipes*, and *Trichostomopsis australasiae*. Species not recorded in the sampling include both species of *Trapeliopsis*.

Figure 12. Biological Soil Crust Sampling Site 11.

Site 12 (Fig. 13)

This site is located in the central portion of the McGee Ranch Unit. The vascular plant community is characterized by rabbit-brush, needle-and-thread grass, Sandberg's bluegrass, and balsamroot. The soil is a sandy, somewhat stony loam. Cheatgrass is relatively common. There is some evidence of fire, and sagebrush appears to have been burned off this site. There is minor evidence of large animal disturbance, and wind erosion is probably common.

The crust here appears to be early to mid seral. Characteristic crust lichen species include *Caloplaca tominii* and *Collema* sp., and characteristic bryophyte species include *Aloina bifrons*, *Bryum argenteum*, *Bryum* sp., *Didymodon* sp., *Syntrichia caninervis*, *S. ruralis*, *Tortula brevipes*, and *Trichostomopsis australasiae*. Species not recorded in the sampling include *Caloplaca jungermanniae*, *Didymodon vinealis*, and *D. tectorum*.

Figure 13. Biological Soil Crust Sampling Site 12.

Site 13 (Fig. 14)

This site is located on a flat in the western end of the Saddle Mountain Unit adjacent to Highway 24. The vascular plant community is characterized by bitterbrush (*Purshia tridentata*), minor amounts of rabbit-brush and sagebrush, Indian ricegrass, needle and thread grass, Sandberg's bluegrass, *Lomatium* spp., and balsamroot. It has sandy, somewhat stony soils. Cheatgrass is common but patchy across the site. Disturbances include wind erosion and burrowing animal activity. There is some evidence of fire on site.

The crust here appears to be early to, in patches, mid seral. *Caloplaca tominii* and *Collema* sp. are the only common crust lichen species. Characteristic bryophyte species include *Bryum argenteum*, *Ceratodon purpureus*, *Syntrichia princeps*, and *S. ruralis*, especially in protected areas near shrubs. Species not recorded in the sampling include *Arthonia glebosa*, *Cladonia* sp., *Didymodon* spp., *Lecanora* cf. *zosteri*, *Leptogium* cf. *lichenoides*, and *Tortula brevipes*.

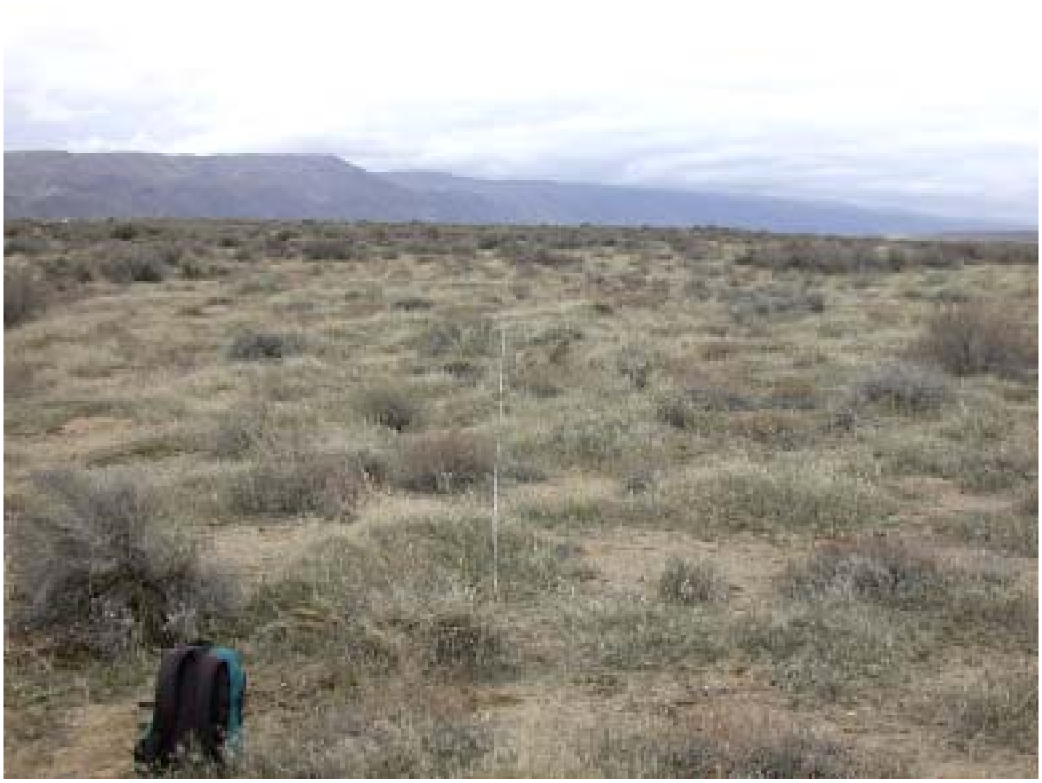

Figure 14. Biological Soil Crust Sampling Site 13.

Site 14 (Fig. 15)

This site is located south of Highway 24 on a flat, hummocky area near the central part of the Saddle Mountain Unit. The vascular plant community is characterized by sagebrush, spiny hopsage, balsamroot, Indian ricegrass, and Sandberg's bluegrass. It has sandy soils. Cheatgrass is common across the site. The major disturbances appear to be trampling by large grazing animals, in particular deer, along trails near the site, and wind erosion.

The crust here appears to be early to, in a few patches, mid to late seral. *Caloplaca tominii* is the only common crust lichen species, although a number of other species are present in small amounts. Characteristic bryophyte species include *Ceratodon purpureus*, *Didymodon* sp., *Syntrichia caninervis, S. princeps, S. ruralis*, *Tortula brevipes*, and *Trichostomopsis australasiae*.

Figure 15. Biological Soil Crust Sampling Site 14.

Site 15 (Fig. 16)

This site is located on a flat in the south-eastern end of the Wahluke Unit. The vascular plant community is characterized by rabbit-brush and Sandberg's bluegrass. It has sandy soils. There are some undefined minor disturbances present. Cheatgrass is sporadic across the site. In this portion of the Wahluke Unit, cheatgrass can form extensive swards across the landscape, and crust is absent from wide areas, except for a few patches such as this site. In the densest cheatgrass swards with heavy litter, the only microbiotic species that was found was the moss *Syntrichia ruralis*, and only as individual stems.

The crust here appears to be early seral. Characteristic crust lichen species include small amounts of *Caloplaca tominii* and *Cladonia* sp., although there were many juvenile unidentified lichens sampled from this community. Characteristic mosses include *Ceratodon purpureus*, *Didymodon* sp., *Syntrichia princeps*, S. *ruralis*, and *Trichostomopsis australasii*.

Figure 16. Biological Soil Crust Sampling Site 15.

Table 6. Biological soil crust community sampling sites, 2002-2003.

Site	Management Unit	UTM Coordinates (11U)	Elevation (Ft.)	Soil Type	Slope	Aspect
1	ALE	0300789/5140760	3520	stony loam	20^o-30^o	W - SW
2	ALE	0306215/ 5139957	1140	sandy loam	0^o	0
3	Saddle Mountain	0293688/5172363	787	loamy sand	+/- 5^o	SE
4	Saddle Mountain	0293688/5172363	787	loamy sand	+/- 5^o	SE
5	Saddle Mountain	0302951/ 5176023	432	sandy loam	0^o	0
6	ALE	0296714/5146925	1618	sandy loam	5^o-10^o	SW
7	ALE	0291354/5150809	946	sandy loam	0^o-5^o	0 - NW
8	McGee-Riverlands	0286889/5165518	1362	sandy loam	+/- 5^o	N

9	ALE	0288469/5152773	810	sandy loam	0^o	0
10	ALE	290797/5158731	782	sandy loam	0^o	0
11	McGee-Riverlands	288564/5164812	1053	loamy sand	$+/-0^o$	0
12	McGee-Riverlands	0288614/5165458	1040	sandy loam	0^o-5^o	0 - N
13	Saddle Mountain	0289687/5169108	454	loamy sand	0^o	0
14	Saddle Mountain	0297146/5177298	640	sandy loam	0^o – 5^o	0 - N
15	Wahluke	0321208/5160233	400	loamy sand	0^o	0

ii. Site and Microbiotic Species Relationships

Figure 17 represents the results from the NMS ordination analysis of the fifteen community sampling sites. Table 7 lists the species and genus codes represented in the ordination. Since distances between the sample units approximate similarity or dissimilarity in species composition (McCune and Grace 2002), S5, S12, S13, and S14 have similar species assemblages, but are dissimilar to S11, and still more dissimilar to S2. Tables 8 to 11 show some of the statistics from the NMS analysis. The analysis determined that the 'best' solution for the data was 3-dimensional. Since Axis 3 has higher r-squared value (0.296) than axis 2 (0.042), the ordination based on Axes 1 and 3 provides a better graphic representation of the relationships in the data than the ordination on Axes 1 and 2.

The vectors in Figure 17 represent relationships and relative significance of four of the environmental and community variables that were measured at each plot during the survey. The mineral soil variable was the least correlated of the five variables and it is not displayed in Figure 17.

The litter variable (L) exhibited a moderately negative correlation with both Axis 1 (r = - 0.465) and Axis 3 (r = - 0.463; Table 8). All other correlations of environmental and community variables with Axis 1 tended to be weak. Correlations of variables with Axis 3 tended to be moderate, with total herb cover (H; r = 0.655) and total crust cover (C; r = 0.630) exhibiting the strongest correlations. Correlations of all variables with Axis 2 tended to be weak.

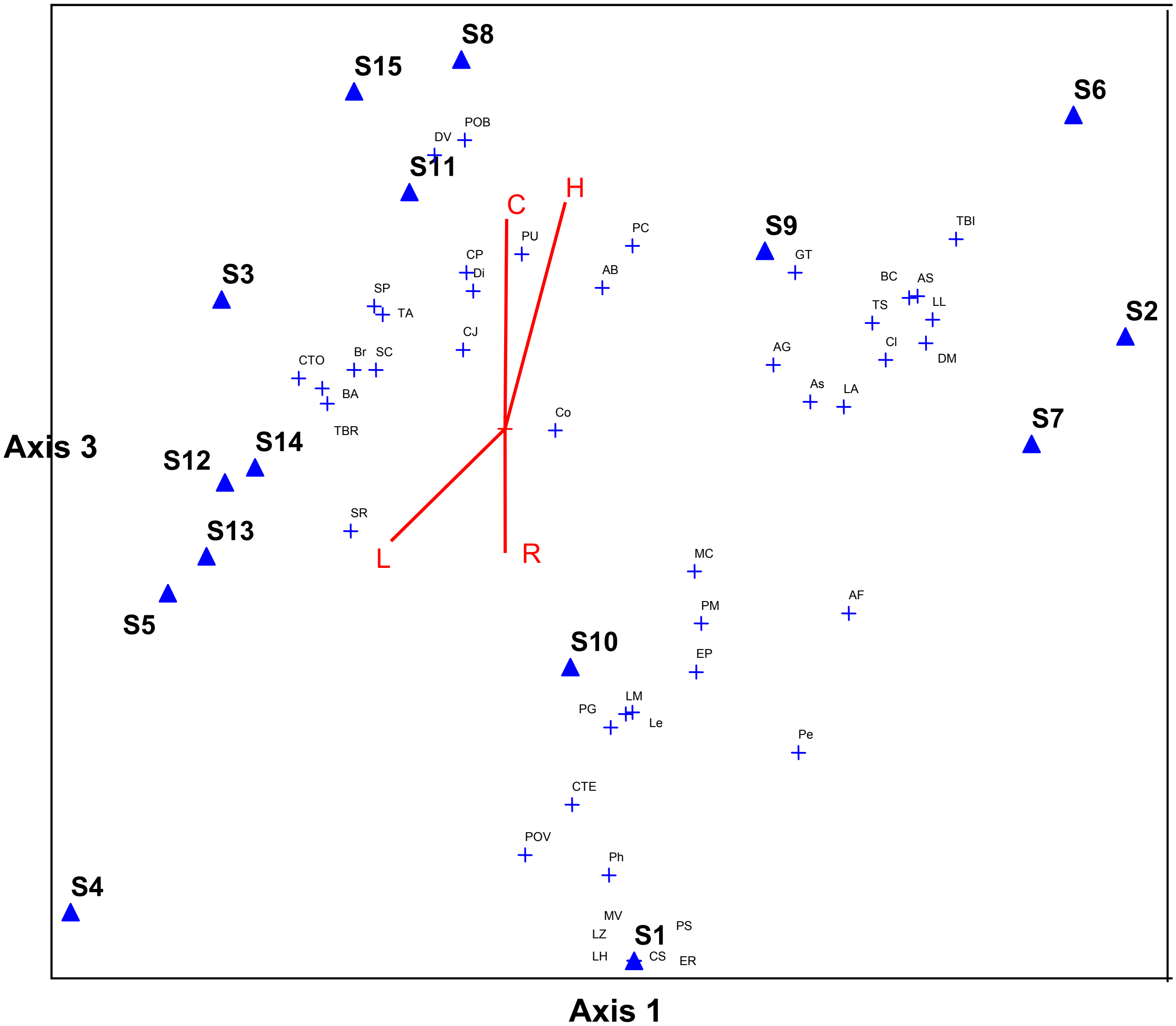

Fig. 17. NMS Ordination of Biological Crust Sites (S1 – S15), showing the relative locations of 45 bryophyte and lichen taxa, and the positions of four environmental vectors. Letter codes for environmental and community vectors are as follows: R = percent cover of stones; L = percent cover of litter; H = percent cover of the herbaceous layer; C = percent total cover of microbiotic crust.

Table 7. Species Codes for Lichens and Bryophytes Used in NMS Analysis (Fig. 17).

LICHENS	Code	BRYOPHYTES	Code
Acarospora schleicheri	AS	*Aloina bifrons*	AB
Arthonia glebosa	AG	*Bryoerythrophyllum columbianum*	BC
Aspicilia filiformis	AF	*Bryum argenteum*	BA
Aspicilia spp.	As	*Bryum* sp.	Br
Caloplaca jungermaniae	CJ	*Ceratodon purpureus*	CP
Caloplaca stillicidiorum	CS	*Didymodon* sp.	Di
Caloplaca tominii	CTO	*Didymodon vinealis*	DV
Candelariella terrigena	CTE	*Encalypta rhaptocarpa*	ER
Cladonia sp.	Cl	*Grimmia trichophylla*	GT
Collema sp.	Co	*Pseudocrossidium obtusulum*	POB
Diploschistes muscorum	DM	*Pterygoneurum ovatum*	POV
Endocarpon pusillum	EP	*Syntrichia caninervis*	SC
Lecanora hagenii	LH	*Syntrichia princeps*	SP
Lecanora muralis	LM	*Syntrichia ruralis*	SR
Lecanora zosteri	LZ	*Tortula brevipes*	TBR
Leptochidium albociliatum	LA	*Trichostomopsis australasiae*	TA
Leptogium lichenoides	LL		
Leptogium spp.	Le		
Massalongia carnosa	MC		
Megaspora verrucosa	MV		
Peltigera sp.	Pe		
Phaeorrhiza sareptana	PS		
Physconia sp.	Ph		
Placynthiella cf. uliginosa	PU		
Psora cerebriformis	PC		
Psora globifera	PG		
Psora montana	PM		
Trapeliopsis bisorediata	TBI		
Trapeliopsis steppica	TS		

Table 8. Stress In Relation To Dimensionality (Number of Axes).

Ordination of sites in species space; 15 sites 45 species
PC-ORD, Version 4.17; May 9, 2003.

	Stress in real data 15 run(s)			Stress in randomized data Monte Carlo test, 30 runs			
Axes	Minimum	Mean	Maximum	Minimum	Mean	Maximum	p
1	26.969	39.169	53.513	28.292	42.272	53.498	0.0323
2	11.446	14.647	18.028	15.904	20.331	34.774	0.0323
3	6.178	6.300	6.772	8.184	11.068	14.644	0.0323
4	3.860	5.215	18.360	5.253	6.865	8.629	0.0323

p = proportion of randomized runs with stress < or = observed stress
i.e., p = (1 + no. permutations <= observed)/(1 + no. permutations)

Conclusion: a 3-dimensional solution is recommended.

TABLE 9. Pearson and Kendall Correlations of Species with Ordination Axes.

	Axis 1			Axis 2			Axis 3		
	r	r-sq	tau	r	r-sq	tau	r	r-sq	tau
AS	.570	.325	.422	-.159	.025	-.141	.230	.053	.234
AG	.605	.366	.432	.407	.165	.309	.181	.033	.185
AF	.450	.203	.391	-.063	.004	-.172	-.305	.093	-.141
As	.641	.411	.537	.127	.016	.157	.070	.005	.112
CJ	-.045	.002	.056	.471	.222	.432	.108	.012	-.019
CS	.102	.010	.156	-.161	.026	-.104	-.530	.281	-.365
CTO	-.574	.330	-.403	.501	.251	.362	.177	.031	.060
CTE	.085	.007	.047	.096	.009	.047	-.599	.359	-.516
Cl	.958	.918	.823	-.173	.030	-.144	.216	.047	.206
Co	.101	.010	.139	.502	.252	.375	-.004	.000	-.161
DM	.646	.417	.592	-.445	.198	-.355	.166	.028	.071
EP	.255	.065	.401	-.257	.066	-.271	-.410	.168	.090
LH	.102	.010	.156	-.161	.026	-.104	-.530	.281	-.365
LM	.177	.031	.282	.245	.060	.310	-.525	.276	-.282
LZ	.102	.010	.156	-.161	.026	-.104	-.530	.281	-.365
LA	.670	.448	.576	.057	.003	.059	.053	.003	.106
LL	.590	.348	.469	.059	.004	-.028	.190	.036	.331
Le	.146	.021	.328	.268	.072	.047	-.408	.166	-.359
MC	.219	.048	.328	.351	.123	.109	-.206	.042	-.109
MV	.102	.010	.156	-.161	.026	-.104	-.530	.281	-.365
Pe	.319	.102	.357	-.288	.083	-.244	-.446	.199	-.244
PS	.102	.010	.156	-.161	.026	-.104	-.530	.281	-.365
Ph	.092	.009	.131	-.120	.014	.094	-.501	.251	-.131
PU	.020	.000	.234	-.065	.004	-.109	.253	.064	.266
PC	.150	.023	.266	.323	.104	.141	.270	.073	.047
PG	.146	.021	.304	.201	.041	.276	-.517	.267	-.193
PM	.300	.090	.378	.378	.143	.302	-.374	.140	-.151
TBI	.637	.406	.580	.156	.024	.176	.337	.113	.252
TS	.427	.182	.453	-.269	.072	-.328	.154	.024	.141
AB	.220	.049	.345	.648	.420	.450	.404	.163	.199
BC	.804	.646	.753	.123	.015	.122	.329	.108	.326
BA	-.494	.244	-.326	.344	.119	.203	.135	.018	.081
Br	-.360	.130	-.192	.518	.269	.405	.175	.030	.128
CP	-.133	.018	.038	-.458	.209	-.268	.664	.441	.574
Di	-.086	.007	.030	-.268	.072	-.030	.479	.229	.406
DV	-.082	.007	.098	.461	.212	.404	.404	.164	.014
ER	.102	.010	.156	-.161	.026	-.104	-.530	.281	-.365
GT	.257	.066	.319	-.350	.122	-.207	.175	.031	.131
POB	-.041	.002	.109	.355	.126	.234	.368	.135	.172
POV	.021	.000	-.158	-.077	.006	.190	-.565	.319	-.443
SC	-.340	.116	-.081	.665	.442	.664	.196	.038	.101
SP	-.305	.093	-.201	-.350	.123	-.201	.356	.127	.224
SR	-.700	.490	-.421	.271	.073	.268	-.588	.346	-.478
TBR	-.333	.111	-.146	.426	.181	.250	.060	.004	.146
TA	-.378	.143	-.139	.133	.018	.219	.447	.199	.339

TABLE 10. Pearson and Kendall Correlations of Environmental Vectors with Ordination Axes.

Axes:	**1**			**2**			**3**		
	r	r-sq	tau	r	r-sq	tau	r	r-sq	tau
M	.167	.028	-.106	.297	.088	.260	.422	.178	-.106
L	-.465	.216	-.429	-.255	.065	-.234	-.463	.214	-.156
C	.049	.002	.029	.178	.032	.144	.630	.397	.298
H	.339	.115	.279	-.131	.017	-.125	.655	.429	.471
R	-.033	.001	-.176	-.019	.000	.238	-.485	.235	-.217

TABLE 11. Coefficients of Determination for the Correlations Between Ordination Distances and Distances in the Original N-Dimensional Space.

	R Squared	
Axis	Increment	Cumulative
1	.594	.594
2	.042	.635
3	.296	.932

All of the sites to the right of the ordination diagram (Fig. 17) occur on silt loam, sandy loam, or stony loam soils, and are all on the ALE Reserve. Sites to the left are located on the McGee-Riverlands, Saddle Mountain, and Wahluke units, and exhibit sandy loam to sandy soils, suggesting a soil gradient along Axis 1.

Four groupings have been chosen for discussion and are described here. These groups are as follows:

Group 1 (Sites 2, 6, 7, and 9)

Group 1 includes four sites on silt loam soils of the ALE Reserve. The sites have similar vascular plant assemblages. Herb layers are characterized by bluebunch wheatgrass and Sandberg's bluegrass along with associated forbs. Wyoming big sagebrush is still present Sites 7 and 9. Sites 2 and 6 have burned recently but the species composition of their biological crusts still exhibit strong similarities to the other sites in the group.

Lichen diversity is high in this group of sites. Defining lichens include *Acarospora schleicheri*, *Arthonia glebosa*, *Aspicilia* sp., *Cladonia* sp., *Diploschistes muscorum*, *Leptochidium albociliatum*, *Leptogium* cf. *lichenoides,* and *Trapeliopsis bisorediata* and *T. steppica*. These sites exhibit relatively high cover of mosses, with *Bryoerythrophyllum columbianum*, *Aloina bifrons*, *Syntrichia caninervis*, and *S. ruralis* usually present.

Group 2 (Sites 3, 4, 5, 8, 11, 12, 13, 14, and 15)

This is a somewhat diverse group of sites characterized by sandy to somewhat stony, sandy soils. The vascular plant communities are characterized by poorly developed to well-developed shrub layers, with sagebrush, bitterbrush, and rabbitbrush dominant on particular sites. Characteristic grasses include Sandberg's bluegrass, needle-and-thread, Indian ricegrass, and, occasionally, bluebunch wheatgrass. Sites 3, 4, 5, 13, and 14 are in the Saddle Mountain Unit, Sites 8, 11, and 12 are in the McGee Ranch Unit, and Site 15 is in the south-east portion of the Wahluke Unit. The biological crusts in Sites 5, 13, 14, and 15 are comparatively early seral and in Sites 3, 8, 11, and 12 are generally later in their successional trend. Site 4 is an outlier site and represents a late seral condition under sagebrush.

Mosses are the major defining species for this group. They include *Bryum argenteum*, *Bryum* sp., *Ceratodon purpureus*, *Didymodon vinealis*, *Didymodon* spp., *Pseudocrossidium obtusulum*, *Syntrichia caninervis, S. princeps, S. ruralis*, *Tortula brevipes*, and *Trichostomopsis australasiae*. *Caloplaca tominii* and *Placynthiella* cf. *uliginosa* are representative lichens.

Group 3 (Site 1)

This site on the west-facing slope near the summit of Rattlesnake Mountain, is unique among the sample sites. It is the highest elevation site in the survey and its stony loam, regosolic soils are distinct from the soils of the other community sampling sites.

The vascular plant community is characterized by scattered low shrubs, along with bluebunch wheatgrass, Sandberg's bluegrass, and forbs. There is some sign that fire has burned through the site, but the effects of fire have probably been minimized by the discontinuous distribution of vascular plants on the stony soil . The crust here appears to be mid to, possibly, late seral.

It has a large suite of characteristic species, in particular the lichens *Caloplaca* cf. *stillicidiorum*, *Lecanora* spp., *Megaspora verrucosa*, *Phaeorrhiza sareptana*, and *Physconia* sp. *Lecanora muralis* is common on stones in the site, and also grows on soil, especially adjacent to stones. Defining bryophyte species include *Encalypta rhaptocarpa* and *Pterygoneurum ovatum*.

Group 4 (Site 10)

The species composition of the crust at site 10 is roughly intermediate between the associations on silt loam, sand, and stony loam soils described above, as its placement near the center of the diagram indicates. The vascular plant community of this unburned remnant of shrubland on the ALE Reserve is characterized by big sagebrush, spiny hopsage, and Sandberg's bluegrass. The soil is a sandy loam, with occasional stones. Characteristic lichen species include *Candelaria terrigena*, *Endocarpon pusillum*, *Lecanora muralis*, *Leptogium* sp., *Massalongia carnosa*, and *Psora* spp. There are no bryophytes that define this site.

4. Discussion

4.1 Biodiversity Survey

This survey has shown that the Hanford Reach National Monument has a rich assemblage of lichens and mosses with over 120 species found in a variety of habitats. Due to the inherent difficulties associated with the identification of these groups, a number of taxa still await identification, and the number of species is expected to increase as identification work continues. The saxicolous, epiphytic, and wetland species reported in this study represent the first formal collections from these habitats on the Monument.

Investigation of the biogeographical significance of the lichens and bryophytes present on the Monument is ongoing. It is possible that some of the as yet unidentified mosses will prove to be species of biogeographic significance. At least one moss, *Crossidium seriatum*, a rare endemic western North American species, is new to Washington State. One lichen taxon, possibly *Xanthoria*, has an uncertain generic affinity, and may represent a new lichen record for North America (T. Goward pers. comm.).

Lichens

At least 24 species of soil crust lichens have been added to the list reported by Link et al. (2000; Table 2). The two new species of *Trapeliopsis* reported by Link et al., recently identified as *T. bisorediata* and *T. steppica* (McCune et al. 2002), were confirmed during the present survey. Twenty-two of the 23 taxa identified by Link et al. (2000) have been confirmed, with only *Cladonia fimbriata* unconfirmed. Species of *Cladonia* are almost always present only as squamules and are difficult to identify to species without mature podetia (reproductive structures). There are probably more species of *Cladonia* present than reported. *Acarospora geogena*, listed by Link et al. (2000), is probably best considered within the *A. schleicheri* complex (B. McCune pers. comm. 2002).

Ponzetti et al. (2000) found a comparable number of terrestrial lichen taxa (52) from the nearby Horse Heaven Hills area. This area was characterized by generally more extensive and less disturbed crusts than on the Hanford Reach National Monument, and has a wider diversity of crust habitats. Ponzetti et al. (2000) also reported approximately 40 saxicolous lichens and 16 epiphytic lichens from the Horse Heaven Hills area.

Bryophytes

This study has recorded more than five times the number of bryophyte taxa as had previously been reported for the Hanford Site. Four of six mosses collected earlier (Link et al. 2000) have been confirmed, and two of their collections were found to be misidentifications. In their collections, *Grimmia* cf. *montana* is *G. alpestris*, and *Ceratodon purpureus* is *Grimmia trichophylla*. *Ceratodon purpureus* has been confirmed for the Monument by the present study, but *G. montana* has not. Ponzetti et al. (2000), focusing primarily on lichens, reported 11 bryophyte species on the Horse Heaven Hills.

Four species of bryophytes found in 1981 by McIntosh (1986) on the ALE Reserve were not found during the present survey, although they are suspected to still be present on the Monument. They include the mosses *Bryoerythrophyllum recurvirostrum*, *Didymodon vinealis* var. *luridus*, and *Grimmia pulvinata*, and the thallose liverwort, *Athalamia hyalina*.

During the present survey, a number of collections were made of unusual forms of *Syntrichia caninervis* and *S. ruralis* that do not clearly fit into familiar North American taxonomic concepts, and strongly resemble European species. These taxa are presently under investigation at the University of British Columbia (Chan 2003), and will be sent to European authorities for confirmation.

4.2 Biological Crust Community Analyses

i. Potential Microbiotic Soil Crust Communities

Species that have similar ecological requirements overlap in space to form assemblages that traditionally have been called communities. Although there has been a great deal of ecological discussion regarding vascular plant communities, very little information is available concerning arid land bryophyte and lichen communities.

There are some constraints to defining crust communities in the Monument, first and foremost being the various types and degrees of disturbance and the resultant irregularity and patchiness of the soil crusts. Most of the sites that were sampled have had fire disturbance at some level of intensity, and some have ongoing disturbance by animals and wind. Although the crusts at most sites appear to be at an early to middle successional stage of development, some sites have patches of crust that probably represent late seral stages.

A minor constraint in the process of defining communities is the incomplete stage of the taxonomy and understanding of morphological variation of many of the taxa in the Monument. While the major contributing taxa are known, a better understanding of the taxonomy of the associated microbiotic species will enable researchers to define soil crust communities more accurately.

Because of these constraints, combined with the generally early stage of exploration of the soil crusts on the Monument, the following community identifications and descriptions remain speculative, and further research is required before they can be more fully understood and clarified. The following late seral soil crust communities are postulated, based on extensive reconnaissance of the site and supported by the results of community sampling and multivariate analysis.

Trapeliopsis steppica - Bryoerythrophyllum columbianum Soil Crust Community (Fig. 18)

General Description: Lichen and moss dominated communities on sandy-loam soils.

Associated vascular plants: sagebrush, blue-bunch wheatgrass, Sandberg's bluegrass, Carey's balsamroot, *Lomatium* spp.

Additional Microbiotic Indicator Species: Lichens: *Acarospora schleicheri*, *Arthonia glebosa*, *Aspicilia* sp., *Cladonia* sp., *Diploschistes muscorum*, *Leptochidium albociliatum*, *Leptogium* cf. *lichenoides,* and *Trapeliopsis bisorediata*.

Early to mid successional species: Lichens: *Arthonia glebosa*, *Cladonia* sp., *Diploschistes muscorum*, *Trapeliopsis bisorediata*.

Comments: This Community is typical of Group 1 Sites. It was also observed during a visit to ALE in 1981 (McIntosh 1986), and was relatively widespread around the ALE Research Laboratories before the period of extensive fires; the mosses *Aloina bifrons*, *Bryoerythrophyllum columbianum*, *Syntrichia ruralis*, and *Trichostomopsis australasiae*, and the lichen *Diploschistes muscorum* were collected there from all eight grazing control plots sampled during this visit.

This crust community is associated mainly with the Wyoming big sagebrush/bluebunch wheatgrass vascular plant communities on the generally finer sandy-loam and silt loam soils that predominate on the west side of the Monument. Although sample sites for this community type were all on flat to relatively gentle slopes, this community may be present on steeper slopes at higher elevations in the Rattlesnake Hills and along the slopes of Rattlesnake Mountain.

Using Ponzetti's revised calcareous indicator scale (Ponzetti 2000; modified from McCune and Rosentreter 1995), five of the indicator lichens for this community, *Acarospora schleicheri*, *Arthonia glebosa*, *Diploschistes muscorum*, *Leptochidium albociliatum*, and *Leptogium* cf. *lichenoides*, are classified as non-calciphiles. This suggests that the soils on which these crusts grow are low in calcium and, following Ponzetti (2000), may also have comparatively low pH. Ponzetti (2000) found that crust cover in the Horse Heaven Hills was generally highest on these types of soils.

Figure 18. The *Trapeliopsis steppica* - *Bryoerythrophyllum columbianum* Soil Crust Community (from Site 7).

***Syntrichia* spp. (in particular *Syntrichia ruralis*, but also *S. caninervis* and *S. princeps*) - *Caloplaca tominii* Soil Crust Community (Fig. 19)**

General Description: Moss-dominated communities on sandy soils.

Associated vascular plants: sagebrush, rabbit-brush, bitterbrush, Sandberg's bluegrass, Indian ricegrass, needle and thread grass.

Additional Indicator Species: Mosses: *Bryum argenteum*, *Bryum* sp., *Caloplaca jungermanniae*, *Ceratodon purpureus*, *Didymodon vinealis*, *Didymodon* spp., *Pseudocrossidium obtusulum*, , *Tortula brevipes*, and *Trichostomopsis australasiae*. Lichen: *Placynthiella* cf. *uliginosa*.

Early to mid successional species: Mosses: *Bryum* spp., *Ceratodon purpureus*, *Didymodon* spp.

Comments: This crust community is characterized by Group 2 sites. It develops on sandy soils, with a relatively low proportion of clays and/or silts. The sands themselves range from fine- to coarse-textured. The community is associated with a variety of vascular plant community types, including Wyoming big sagebrush, bitterbrush, and rabbitbrush shrublands. Although sample sites were primarily on gentle slopes, this community may also develop on steeper slopes, although many of these slopes are lacking significant crust cover.

Since this community is characterized by sandier soils, it is probably less stable and more readily affected by disturbance than other crust community types (Ponzetti 2000), with early seral stage species probably more common across the site, even in late seral community stages. Site 4, characterizing a moss dominated shrub understory, is closely aligned with this community.

Using Ponzetti's calcareous indicator scale (Ponzetti 2000; revised from McCune and Rosentreter 1995), two of the indicator lichens for this community, *Caloplaca tominii* and *C. jungermanniae*, are classified as calciphiles. This suggests, although probably weakly, that the soils on which these crusts grow are high in calcium and, following Ponzetti (2000), also have comparatively high pH.

Figure 19. The *Syntrichia* spp. - *Caloplaca tominii* Soil Crust Community (from Site 14).

***Phaeorrhiza sareptana* - *Lecanora* spp. - *Encalypta rhaptocarpa* Soil Crust Community (Fig. 20)**

<u>General Description</u>: Lichen and moss dominated communities on stony loam (regosolic) soils at higher elevations.

<u>Associated vascular plants</u>: scattered low shrubs (eg., *Eriogonum* spp. and *Artemisia tripartita*), Carey's balsamroot, bluebunch wheatgrass, Sandberg's bluegrass.

Additional Indicator Species: Lichens: *Candelariella terrigena*, *Caloplaca stillicidiorum*, *Megaspora verrucosa*, *Peltigera* sp., *Physconia* sp.; Moss: *Pterygoneurum ovatum.*

Early to mid successional species: *Pterygoneurum ovatum*.

Comments: This community is characteristic on stony loam soils in low shrub/bluebunch wheatgrass communities at higher elevations in the Monument. It has a diverse assemblage of relatively small lichens, including *Caloplaca* and *Lecanora* spp., many of which inhabit the bases of dead grasses and other litter that are common across the site. Although represented by a single sample site, microbiotic species associations similar to this community were observed at a number of other sites in the Rattlesnake Hills area and near the top of Saddle Mountain. The generally cooler and moister conditions at this and similar sites may contribute to the distinctive microbiotic flora of these sites.

Using Ponzetti's calcareous indicator scale (Ponzetti 2000; revised from McCune and Rosentreter 1995), one of the indicator lichens for this community, *Phaeorrhiza sareptana*, is classified as a calciphile. This suggests, although weakly, that the soils on which these crusts grow may be high in calcium and, according to Ponzetti (2000), also have comparatively high pH.

Figure 20. The *Phaeorrhiza sareptana* - *Lecanora* spp. - *Encalypta rhaptocarpa* Soil Crust Community (From Site 1).

ii. Environmental Relationships

Research regarding environmental relationships of both microbiotic taxa and their community assemblages on the Monument is in its early stages. The Monument is an extensive and ecologically diverse area and further investigation is required in order to more fully understand the potentially wide and complex environmental factors that affect the distribution of different species and the respective soil crust composition.

Soil

Soil factors, including structure, pH, electro-conductivity, and CaCo3 availability, appear most critical in the development and composition of biological crusts (Belnap et al. 2000, Ponzetti 2000). However, Ponzetti (2000) states: 'Our understanding of the relationship between soil chemistry and crust composition is in its infancy'. This is underlined by the research presented here.

Values for pH and electro-conductivity determined in the laboratory were too variable within individual samples to include in the analyses. In part, this problem possibly arose because of the method by which soil samples were taken in the field. Samples were not taken from directly under the crust, as done by Ponzetti (2000), but from areas of open soil, in order to reduce disturbance to the biological crust. The soil sampling locations were always lower than the level of the crust, and represent, with respect to the crust, sub-surficial soil samples. Observations of biological crusts both in the field and through a dissecting microscope indicate that the composition of the soil on which the crust develops is usually somewhat different, at least compositionally, than the sub-crust soils. In many cases, the soils directly under the crust and within the crust matrix are comprised of finer material. Also, most of the soil sampling sites were disturbed to some degree, and soils were always collected from more than one location at the sites. This probably contributed to the variability in the results.

However, soil textures were relatively consistent in the samples. There appears to be a strong relationship between soil texture and crust composition and stability. Soils with finer materials, including silts, clays, and finer sands, occur most commonly on the west side of the Monument and east of the Columbia River in the central part of the White Bluffs area. These soils appear to favour the development of crusts with a relatively high richness and cover of lichen species (e.g., the *Trapeliopsis steppica* - *Bryoerythrophyllum columbianum* Soil Crust Community). Soils comprised of coarser materials, such as the sandier soils that predominate in the Wahluke, McGee Riverlands, and Saddle Mountain Units, appear to have a higher richness and cover of bryophytes, and comparatively few lichens are present (e.g., the *Syntrichia* spp. - *Caloplaca tominii* Soil Crust Community).

The relative stoniness of soils appears to be an important factor in crust composition. Site 1 (the *Phaeorrhiza sareptana* - *Lecanora* spp. - *Encalypta rhaptocarpa* Soil Crust Community) is the stoniest of all the sites and Site 10 has somewhat stony soils. However, the difference in species composition between Site 1 and the other sites may have more to do with the higher amount of stable litter that is colonized by a number of lichen species, and not the high percentage of stones. Although litter is common in other sites, it is often not colonized by microbiotic species to the degree it is at Site 1.

Other Environmental Factors

Regional climate, in particular heat and elevation influence crust composition (Belnap et al. 2000). The generally cooler, and possibly moister, conditions at the highest elevation site (Site 1; (the *Phaeorrhiza sareptana* - *Lecanora* spp. - *Encalypta rhaptocarpa* Soil Crust Community) appear to support this view, although other factors, such as stoniness and stable litter, are also associated with these differences.

Based on the present research, it is difficult to draw firm conclusions with respect to total crust cover, basal herb cover, and litter cover variables shown as vectors in Figure 17. For example, with respect to crust cover, disturbance was common and erratic across individual sites and varied between sites, and respective crust development patchy. Conclusions cannot be made with respect to the relationship of sites and species to basal herb cover either. The cover of herbs appears to vary somewhat across each site and it is uncertain whether the sampling design captured this variation. Litter is also a difficult variable to measure with confidence. It also varied widely within sites and site to site, especially depending on the degree of cheatgrass cover, which was included in this measurement.

Disturbance, though variable in severity and extent, was common across the entire Monument, rendering crust development patchy. The influences of wildfire and disturbance by grazing or burrowing animals are reflected in the seral stages of the various crusts; i.e., increasing disturbance leads to an increase in early seral taxa at any particular site, and a generally lower seral stage of succession across the local landscape. Many soil crusts across the Monument have been affected to a greater or less degree by fire. Large areas are devoid of readily discernible crusts, although following rainfall, juvenile crust development can be seen in many of these sites. The types of devastating fires that caused this severe damage were probably non-existent or rare in the pre-European past.

Although grazing impacts from domestic animals has stopped in the Monument, lasting effects of this activity can be seen in some sites. Elk also impact the soil crust to some degree in some areas of the Monument, especially in the remaining small patches of Wyoming big sagebrush on the ALE Reserve where, apparently, elk use has concentrated since the 2000 wildfire. A herd of over 80 elk was sighted near Community Site 9 during the study. The impacts of elk are not beneficial to the recovery of soil crusts.

Some areas appear to be strongly impacted by invasive plant species, in particular cheatgrass. In a few areas on sandy soils, the presence of small amounts of cheatgrass may provide some mosses with a foothold in an otherwise unstable site. In general, however, cheatgrass comes to dominate the interspaces between perennial vascular plants and smothers microbiotic crusts with its copious annual production and resultant dense litter (Belnap and Philips 2001, Belnap et al. 2001). Cheatgrass infestations promote changes in other ecosystem factors such as soil chemistry, soil nutrient regimes, and soil fauna (Evans et al. 2001, Belnap and Phillips 2001) which may impact microbiotic crusts. Impacts of these changes on crust communities are unknown but are worth investigating.

5. Recommendations

5.1 General Comments

This study has significantly increased our knowledge of the lichen and bryophyte biodiversity in the Hanford Reach National Monument. However, the investigation of the community and environmental relationships of soil crust organisms remains at an early stage. Communities of microbiotic organisms are often difficult to define, especially in disturbed environments (McCune and Grace 2002), and very little is known about the community dynamics and rates of succession in soil crusts (Ponzetti 2000, Ponzetti et al. 2000). The Monument provides an excellent opportunity to observe this process on a broad scale. Knowledge of the environmental relationships of taxa and communities is often lacking. Detailed studies of soil factors, in particular, are likely to yield important information in terms of species distributions on the landscape. Such knowledge will help in the conservation and restoration of microbiotic crust communities in the future.

5.2 Biodiversity and Taxonomic Studies

No biological inventory is ever truly complete in an area of the size and landscape complexity of the Hanford Reach National Monument. While most of the representative microbiotic taxa have likely been reported from large areas of the Monument, some areas of potential significant biodiversity have probably not been investigated. As a minimum, the following areas merit further investigation:

1. Central Hanford, in particular Gable Mountain, Gable Butte, and the Hanford Dunes.
2. Western portions of the Rattlesnake Mountain area on ALE.
3. The Yakima Ridge area on ALE.
4. Springs, streams, and shaded gullies of the Rattlesnake Hills north of Rattlesnake Mountain.
5. Outcrops, ridges, and bluffs in the White Bluffs area. From a distance, much of this area appears to be barren, but areas of microbiotic species richness are likely to be found, especially alongside shaded gullies.
6. Lithosols, talus, and rock outcrop communities throughout the area, at all elevations.

Many microbiotic taxa need further study before they can be clearly defined taxonomically, not only with respect to local populations, but also with respect to these groups elsewhere. The Monument area and other portions of the Hanford Site are among the richest available sites for this type of research. For example, even though a study on the *Syntrichia ruralis* complex has been initiated (Chan 2003), more collecting and assessing of various forms with respect to environmental variables will greatly aid in sorting out this group. A few other groups that would benefit from taxonomic evaluation include:

1. *Ceratodon purpureus*; there are at least three mature ‘forms’ of this moss species in the Hanford area, as well as some developmental forms; taxonomists have been attempting to define this species for many years, either as one species with many forms, or as two to three distinct species.
2. the *Psora montana – P. luridella* - *P. globifera* complex; lichenologists differ in their opinions regarding whether this is two or three species; the three ‘species’ are present in the area and merit study here.
3. the lichen genus *Aspicilia*; Rosentreter (1998) recently described two new species in this genus, yet more work needs to be completed before this genus is understood in arid land ecosystems. There appears to be a diverse assortment of species of *Aspicilia* in the Monument, and a study could be initiated here.

5.3 Ecological and Long Term Monitoring Studies

Studies of soil crust communities and their relationships to environmental factors are in their initial stages on the Monument and a great deal could be learned by their continuation. Communities are often difficult to define, especially in disturbed environments (McCune and Grace 2002).

We recommend that these studies continue, although we suggest using a different methodology. Using transects and systematic plots to sample the crust in this highly disturbed area, even though it has produced some useful data, does not adequately capture the different sectors of a crust community. A more subjective sampling program may be preferred. This could be a stratified random scheme, based on a subjective partitioning of each community site, followed by random sampling within each stratum. Strata could represent various seral or disturbance states at a site, but must be chosen only after careful inspection by qualified experts.

Studies should be undertaken in order to better document the relationship of communities and species to various environmental factors, in particular soil factors. When possible, soil chemistry and composition should be measured in the field, and confirmed by laboratory analyses.

Monitoring changes in the soil crust through time will contribute to a more thorough understanding of the ecological dynamics of all the ecosystems in the Monument. Monitoring is often used to provide an objective platform for changing or maintaining a current management practice (Rosentreter et al. 2001). Data collected by monitoring programs can also be applied to basic questions of conservation biology, and can assist in the development and refinement of best management practices. Rosentreter et al. (2001) and Belnap et al. (2000) provide guidance in the development of soil crust monitoring plans.

Little is known about the rates or species dynamics of succession in soil crusts. Although Ponzetti (2000) and Ponzetti et al. (2000) provide some information regarding species succession, there remains a great deal to learn.

The impacts of elk on the ecosystem, including biological crusts, should be investigated further. Permanent elk-proof exclosures should be constructed at a few sites which would allow researchers to monitor crust recovery over time, exclusive of elk impacts.

Lichens and bryophytes are inherently difficult to identify with confidence in field studies as experts are often required, and all taxa may not be recognized or identified even then. However, although lichen and bryophyte experts will provide more complete results, trained non-experts can confidently identify many of the common, indicator or target species, and results will be of considerable value. Further, measurements of the change of total crust cover or identifiable functional groups over time, without the measurement of individual species, will prove valuable (Belnap et al. 2001).

At present, no proven techniques are available for the restoration of microbiotic crusts at a landscape scale (J. Belnap pers. comm. 2002). Therefore, all management activities related to restoration, invasive species, and fire management, along with general road and facilities maintenance, should be conducted in such a way as to minimize or eliminate any adverse effect on existing quality microbiotic crust (Belnap 1994). Research into management actions that can enhance or restore biological soil crust communities should be strongly considered. Some promising techniques are outlined in Belnap et al. (2001).

6 References

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