



Lichens as air quality indicators in three areas of Southwestern Montana : lichen floristics and elemental analysis
by Lisa Ann Schubloom

A thesis submitted in partial fulfillment of the requirements for the degree of Master of Science in Biological Sciences
Montana State University
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Abstract:

Long distance transport of air pollutants can affect wilderness areas adversely, therefore, baseline data must be collected to predict what biological effects might be observed with changes in air quality. Determining sensitive lichen species along with elemental analysis of lichens is the most common approach for using lichens as bioindicators of air quality. Floristic survey and elemental analyses of 28 elements for *Bryoria fremontii*, *Letharia vulpina*, and *Umbilicaria hyperborea*, were conducted in two Class I Wilderness areas--the Anaconda-Pintler Wilderness (APW) and the Gates of the Mountains Wilderness (GMW)--and an area of national forest, the Elkhorn Mountains. The areas were chosen for their spatial relationship to past and present mining and smelting activities. All lichen species from all substrates were collected from 47 sites in the three areas. One-hundred ninety two lichen species were identified from 57 genera. Ninety-four of the lichen species (49%) identified are saxicolous, 50 species (27%) are lignicolous or corticolous, and 48 species (25%) are terricolous. The APW has 138 lichen species, the Elkhorn Mountains has 118, and the GMW has only 94. A west-to-east climatic gradient among the three study areas was indicated, with the APW showing a slightly more oceanic influence. Several lichen species with known sensitivities to air pollutants have been found in abundance all three areas, indicating little effect of pollution sources. Similar forest communities support the most similar lichen flora as indicated through matrices of lichen species occurring in the collection sites. According to elemental analysis, chemical composition of lichen thalli from the study areas fall within typical background levels as found in North America. *L. vulpina* and *B. fremontii* produced variable results for within, between and among study area comparisons, while *U. hyperborea* produced relatively consistent results. No evidence of air pollution was indicated through floristic survey or elemental analysis of lichens in the study areas. The turnover rate of elements is less than the time since the mining and smelting activities in southwestern Montana have ceased. The data collected give a temporal picture of atmospheric chemistry in these areas.

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A thesis submitted in partial fulfillment
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of

Master of Science

in

Biological Sciences

MONTANA STATE UNIVERSITY
Bozeman, Montana

May 1995

N378
Sch 783

ii

APPROVAL

of a thesis submitted by

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This thesis has been read by each member of the thesis committee and has been found to be satisfactory regarding content, English usage, format, citations, bibliographic style, and consistency, and is ready for submission to the College of Graduate Studies.

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ACKNOWLEDGMENTS

Funding for this project was provided by the Department of Range, Air, Watershed, and Ecosystem (RAWES), U.S. Forest Service; the Mountain Research Center and the Department of Biology, Montana State University.

I would like to thank Dr. Sharon Eversman, my advisor, for taking me out into the field and introducing me to the wonderful world of non-vascular plants. Her patience and assistance throughout the project were greatly appreciated. Valuable comments and suggestions for improving the thesis were offered by Drs. William Locke and Matt Lavin. Dr. Lavin also assisted in the NTSYS statistical analyses of the floristic data. Dr. Dan Gustafson created the color relief maps. My special thanks to Dr. Dwight Phillips for unlimited use of his computer equipment and for his understanding and encouragement throughout the past two years.

I am also indebted to Dr. Bruce McCune and Dr. Sharon Eversman for assistance with problems in lichen identification and to Dr. Tom Nash III for helping with the problematic lichen genus, *Xanthoparmelia*. Dr. R.V. Thurston provided laboratory space for lichen identification.

Thanks also to my friends and family, especially Brian, who have given me a solid base on which to stand. Most importantly, I extend my love and gratitude to my parents for supporting me in all that I set out to do.

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ABSTRACT

Long distance transport of air pollutants can affect wilderness areas adversely, therefore, baseline data must be collected to predict what biological effects might be observed with changes in air quality. Determining sensitive lichen species along with elemental analysis of lichens is the most common approach for using lichens as bioindicators of air quality. Floristic survey and elemental analyses of 28 elements for *Bryoria fremontii*, *Letharia vulpina*, and *Umbilicaria hyperborea*, were conducted in two Class I Wilderness areas--the Anaconda-Pintler Wilderness (APW) and the Gates of the Mountains Wilderness (GMW)--and an area of national forest, the Elkhorn Mountains. The areas were chosen for their spatial relationship to past and present mining and smelting activities. All lichen species from all substrates were collected from 47 sites in the three areas. One-hundred ninety two lichen species were identified from 57 genera. Ninety-four of the lichen species (49%) identified are saxicolous, 50 species (27%) are lignicolous or corticolous, and 48 species (25%) are terricolous. The APW has 138 lichen species, the Elkhorn Mountains has 118, and the GMW has only 94. A west-to-east climatic gradient among the three study areas was indicated, with the APW showing a slightly more oceanic influence. Several lichen species with known sensitivities to air pollutants have been found in abundance all three areas, indicating little effect of pollution sources. Similar forest communities support the most similar lichen flora as indicated through matrices of lichen species occurring in the collection sites. According to elemental analysis, chemical composition of lichen thalli from the study areas fall within typical background levels as found in North America. *L. vulpina* and *B. fremontii* produced variable results for within, between and among study area comparisons, while *U. hyperborea* produced relatively consistent results. No evidence of air pollution was indicated through floristic survey or elemental analysis of lichens in the study areas. The turnover rate of elements is less than the time since the mining and smelting activities in southwestern Montana have ceased. The data collected give a temporal picture of atmospheric chemistry in these areas.

INTRODUCTION

Long distance transport of pollutants can influence pristine wilderness areas (Udall, 1986; Insorova *et al.*, 1992; Pfeifer and Barclay-Estrup, 1992;). In order to predict what biological effects might be observed with changes in air quality, baseline data must be collected from areas of interest to reveal their current status. Two basic methods are used to monitor air quality. Direct, continuous and systematic measurements of atmospheric pollutants is the best technique, but is very costly and hard to implement in large areas. A more widely used method is the use of organisms that respond to environmental changes. Using biological indicators (bioindicators) is important because it gives an indication of where and how air pollutants enter living systems (Gilbert, 1973; Kral *et al.*, 1989). Lichens are universally established as bioindicators of air pollution (Nash and Wirth, 1988; Sloof and Wolterbeek, 1991; Insarova *et al.*, 1992). Element analysis of lichen tissues along with species lists of lichens is currently the most common approach for using lichens as bioindicators of air quality (Wetmore, 1989; St. Clair and Newberry, 1993).

The quantification of elements in lichens or the presence and absence of lichens have been used in many types of studies. Lichens have been successful at delimiting pollution dispersion patterns around emission sources through element analysis of lichen thalli (Nash and Wirth, 1988). Northrop Environmental Sciences (1987) mapped element concentrations for lichens in Great Smoky Mountains National Park to establish regional baseline composition of 23 elements. Sloof and Wolterbeek (1991) determined that the geographical concentration patterns for lichens in the Netherlands agreed with actual measurements of atmospheric concentrations and deposition. Walther *et al.* (1990a)

compared new element quantities in lichens around an industrial zone in southwest Louisiana to those measured five years earlier. Their results demonstrated that, according to temporal changes in metal levels of lichens, the effects of the industrial zone disappeared. In Baton Rouge, Louisiana, Walther *et al.* (1990b) also successfully mapped an industrial zone of pollution using two lichen species. Through a temporal study of lead composition in lichens, Schwartzman *et al.* (1991) discovered that lead concentrations in foliose lichens reflect the drop in gasoline lead emissions during the years 1973-1986. Pfeiffer and Barclay-Estrup (1992) showed an inverse relationship between levels of pollutants of a lichen species and distance from Thunder Bay, Ontario.

Some lichen species are extremely sensitive and disappear in polluted areas creating a "lichen desert" (Gilbert, 1973; Pearson, 1973). Mapping species distributions indicates regional levels of air pollution (Gilbert, 1973). Showman (1975) mapped corticolous lichens around a coal-fired power plant in Ohio, finding that the area of effect was smaller than expected. LeBlanc and DeSloover (1970) developed a quantitative scale for estimating air pollution epiphytes called an "index of atmospheric pollution" (IAP) which takes number of species present, their coverage and frequency into consideration. They then applied their IAP protocol to an industrial valley in Belgium and near Montreal, Canada and found direct correlation with suspected SO_2 levels in these areas. Lichen communities along ozone and sulfur dioxide gradients in Indianapolis were studied by McCune (1988), who found a negative correlation between lichen community richness and O_2 and SO_2 gradients in Indianapolis. Using IAP values, Hoffman (1974) demonstrated deleterious effects of a paper pulp mill on epiphytic lichens in Idaho.

Other studies have acquired baseline values of element concentrations in lichens for future detection of effects of pollution sources. For example, Ryan (1990) conducted

a floristic survey and element analysis in five Wilderness areas of California. Species lists and element composition of lichens were developed for Sequoia National Park (Wetmore, 1985), California, and the Saguaro National Monument (Wetmore, 1987), Arizona. St. Clair and Newberry (1993) examined the Anaconda-Pintler Wilderness and adjacent areas west of the retired Anaconda copper smelter for species present and element levels in several lichen samples.

Why Lichens for Air Quality Studies?

Lichen Floristics

A comprehensive list of lichen species is one of the most valuable indicators of ecosystem health. Since lichens are sensitive to air pollutants and human disturbances, the impoverishment and absence of sensitive lichen species provides a signal that other parts of the ecosystem may also be endangered (Wetmore, 1988). Until the presence of a sensitive species is determined, knowledge of its absence in the future is impossible. The occurrence of threatened and endangered species cannot be determined without first having a comprehensive list of species for a community.

Lichens are an integral part of an ecosystem, involved in many natural processes (McCune, 1982; McCune and Lesica, 1992). Many crustose lichens are among the first organisms to colonize bare rock and begin soil building and nitrogen fixation processes necessary for invasion and succession of developing plant communities (Miller, 1988). Linnaeus claimed crustose lichens to be "the first foundation of vegetation" (Syers and Iskandar, 1973). Lichens weather rock physically, through rhizine growth and expansion and contraction of the thallus, and chemically through the action of secondary compounds unique to lichens (Topham, 1977). Some of these secondary compounds are

chelating acids or metal complexing agents which dissolve or absorb rock forming minerals (Jones *et al.*, 1981; Adamo *et al.*, 1993).

Microbiotic crust communities of lichens which stabilize soil against water and wind erosion also aid in succession. Blue-green algae (cyanobacteria) in some lichen species of soil crusts enhance soil fertility through nitrogen fixation which may be used by developing vascular plant seedlings (St. Clair *et al.*, 1993; Eldridge and Greene, 1994). Lichens other than soil crusts with cyanobacteria as a phycobiont also contribute to nitrogen fixation in an ecosystem (Lawrey, 1984) at rates higher than free-living bacteria in the soil or rhizosphere (Crittenden and Kershaw, 1978). In environments where a scarcity of nodulated plants occurs, nitrogen fixing lichens may be particularly important suppliers of new nitrogen (Gunther, 1989).

Lichens affect nutrient cycling in any ecosystem in which they occur (Pike, 1978). Although mineral activity in lichens is varied (Brown and Brown, 1991) their morphology and physiology allow active contribution of minerals into a plant community (Nieboer *et al.*, 1978; Pike, 1978). The turnover rate of certain elements in lichens is very quick, two to seven years, as compared to lichen longevity which is understood to be tens to thousands of years (Hale, 1983; Walther *et al.*, 1990a). For example, the cations K^+ and Ca^{++} have a short turnover rate enabling lichens to release much of these nutrients into the ecosystem through leaching during wetting and drying cycles and decomposition (Nieboer *et al.*, 1978).

Lichens are primary producers that accumulate biomass and carbohydrates (Pike, 1978) which can be an important source of food and cover for animals (Nieboer *et al.*, 1978). Many types of invertebrates utilize lichens for food. Yom-Tov and Galun (1971) discovered snails and slugs using lichens for a significant part of their diet, and Gerson

and Seaward (1977) observed beetles, moths, termites, stoneflies and earwigs feeding extensively on lichens.

Through studying quantities of lichen litter taken by different sized animals, McCune and Daly (1994) demonstrated that lichens are also obtained by vertebrate fauna. Lichens are undeniably important as a source of carbohydrates for reindeer and caribou, sometimes accounting for 60% of their total winter intake (Shanks, 1978; Klein and Vlasova, 1992). Several deer species in the United States consume lichens when snow cover prevents feeding on grasses (Richardson and Young, 1977; Sharnoff, 1994). The northern flying squirrel of northeastern California and Oregon use lichens as their principle food source in winter months (McKeever, 1960; Maser *et al.*, 1984). In addition to these species, Sharnoff (1994) produced a list of eleven ungulates, 24 small mammals, and 52 birds species that use lichens for forage, food, or nest material in North America.

Some insects and even amphibians (Sharnoff, 1994) carry lichen fragments and soredia on their backs for camouflage (Gerson and Seaward, 1977). Many lichen species provide actual homes for invertebrates (Gerson and Seaward, 1977; Hale, 1983). Bayazrov and Melekhina (1992) found several species of mites inhabiting three species of soil lichens in northern Scandinavia. Lichens have also been found contributing to the nests of birds and squirrels (Hayward and Rosentreter, 1994; Sharnoff, 1994).

Lichens are an important component of biodiversity in an ecosystem (Mangis *et al.*, 1991). A complete inventory of species is the first step in preserving ecological diversity. Sharnoff (1994) points out that lichens can play a part in preserving mammal diversity. For example, lichens are critical forage for the northern flying squirrel and at least two species of black vole, which are staple prey of the northern spotted owl and many carnivorous mammals. Interest in studies of lichens for sustaining diversity on

forest lands has been expressed by the Forest Service and Park Service (Lesica *et al.*, 1990; McCune and Lesica, 1992).

Element Analysis

Along with the floristic survey, collecting baseline quantities of certain elements in pristine wilderness areas is essential for an air quality monitoring regime. Elements in lichens can be quantified as a measure of atmospheric chemistry (Wetmore, 1988) and the entry of these contaminants into biological systems can be extrapolated. Lichens obtain nutrients directly from the atmosphere (Kappen, 1973; Ahmadjian, 1993) and to a lesser and undetermined amount from their substrate (Hale 1982). Since their thalli have no protective structures such as a waxy cuticle or stomates, they efficiently absorb air-borne elements (Hale, 1982) through particulate trapping, active uptake of anions, passive absorption of cations, and ion exchange (Nieboer and Richardson, 1981; Nash, 1990).

Elements and compounds of concern due to their toxicity to plants and animals are sulfur compounds, nitrogen compounds, arsenic, aluminum, copper, cadmium, iron, lead, manganese, nickel, zinc, vanadium, mercury, selenium, and the radioactive nucleotides of cesium (^{137}Cs) and strontium (^{90}Sr) from radioactive fallout (James, 1973; Markert, 1992). These compounds and elements are commonly detected in lichen tissues when they occur in the atmosphere as pollutants. Thus, analysis of lichen thalli for these compounds and elements serves as an indicator of current and historic levels of pollution.

Lichens absorb SO_2 at least 100 times faster than vascular plants and sensitive species of lichens will disappear in areas heavily contaminated with SO_2 (Gilbert, 1973; Pearson, 1973). Sulfur compounds are toxic to lichens in that they degrade the

chloroplasts and chlorophyll in the algal component, thus diminishing photosynthesis (Fields and St. Clair, 1984; Eversman and Sigal, 1986; Mangis *et al.*, 1991). Sulfur dioxide also causes loading of potassium which alters membrane permeability (Puckett *et al.*, 1973; Puckett *et al.*, 1977; Mangis *et al.*, 1991). Sulfur dioxide is primarily produced from smelters and the combustion of fossil fuels (Crock *et al.*, 1992).

Nitrogen oxides are less detrimental to lichens than sulfur gases but quantitative analysis of nitrogen in their tissues can serve as an indicator of atmospheric nitrogen levels (Nash, 1976). It has been found that nitrates may disturb lichen symbiosis by stimulating the algal component to grow, leading eventually to the breakdown of the symbiotic relationship (Balaguer and Manrique, 1991). The greatest source of human-made nitrates is the high temperature combustion of fossil fuels (Taylor *et al.*, 1975). Nitrogen gases contribute to acid rain, and nitrogen oxides may have an undesirable fertilizer effect on plant communities (Ekwebelam and Reid, 1984).

Arsenic is moderately toxic to plants and highly toxic to animals, depending on its form (Crock *et al.*, 1992). Coal combustion is a major source of atmospheric arsenic. Other sources include pesticides and wood preservatives (Nash, 1990; Crock *et al.*, 1992).

Phytotoxicity of cadmium is moderate but in mammals it can accumulate in the liver and kidneys resulting in high toxicity over time (Crock *et al.*, 1992). Fossil fuel combustion, cigarette smoke, mineral fertilizers, and waste incineration contribute to atmospheric cadmium (Markert, 1992).

Chromium is a component of anthropogenic atmospheric emissions from iron and steel mills, and fossil fuel combustion. The most common form of chromium (Cr III) is the least toxic although the Cr (IV) oxidation state can be very toxic to plants and animals in

high levels (Crock *et al.*, 1992).

Copper is an essential element for plants and animals but elevated levels are highly toxic to microorganisms and moderately toxic to mammals. One source of atmospheric Cu is nickel smelting (Crock *et al.*, 1992).

Lead is extremely phytotoxic and less damaging but cumulative in animals. Sources of lead are numerous, associated with industrialized areas and roads previously subject to the heavy use of leaded fuels. Lead can be transported great distances in the atmosphere, despite its high molecular weight (Crock *et al.*, 1992).

Nickel is a widespread component of terrestrial environments where naturally occurring concentrations are low. Elevated levels can be found associated with serpentine rocks (McIlveen and Negusanti, 1994) and areas around fossil fuel combustion and iron industry. Nickel is considered very toxic to plants but only minimally toxic to animals (Crock *et al.*, 1992).

Vanadium is moderately damaging to plants and is one of the least toxic metals to animals. Oil combustion and to a lesser extent coal combustion, are sources of vanadium in the environment. Zones of influence for emissions of metals from power-plants can be successfully traced through vanadium analysis (Crock *et al.*, 1992).

Zinc and manganese are essential micronutrients to all organisms so toxicity of these elements is uncommon and only occurs in rare instances such as gross over-fertilization. Base metal and battery industries contribute to most atmospheric zinc and manganese (Crock *et al.*, 1992).

Aluminum is toxic for plants and fish and a possible component in forest damage since it is made more soluble to plants by increases of acidity in soil (Markert, 1992).

Data obtained from studies using lichens as bioindicators of air pollution, through

the quantification of the elements listed above, are valuable for future determination of pollution sources. Present and proposed industries that are sources of air pollution are required by the 1974 Forest and Rangeland Renewable Resource Act, the 1976 Federal Land Management Policy Act, and most specifically the 1977 Clean Air Act, to be knowledgeable of their potential effects of to Class 1 wilderness areas. If lichens are indicating adverse effects to a wilderness area, it will be recommended that a state permit not be issued or that emission quantities be lessened. An example of this process took place in the Green Mountain National Forest's Lye Brook Wilderness of New York. A co-generation power plant was proposed for Halfmoon, New York located 50 kilometers from the wilderness. Predicted adverse effects of the plant were substantiated through water chemistry data, paralleling data from lichen baseline studies. The EPA concurred with the recommendation to require mitigation of increased sulfur deposition and pursued emission reductions from other sources (Parrott, 1991).

Objectives of this Study

One objective of this study is to expand our present knowledge of lichen distribution in Southwestern Montana through lichen floristics. Several questions can be addressed through species lists from the three study areas: Do the three study areas differ in diversity of lichens; what are the most common lichen species occurring in these areas; what is the most common substrate for lichens in these areas; which forest type hosts the most lichen species; and is there a relationship between forest community type and lichen flora?

Another objective of this study is to collect baseline data on the occurrence of sensitive lichen species and element composition of specific lichen tissues to determine

current air quality status of two areas designated as Class 1 Wilderness areas and an area of National Forest land. The long term database that can extend from this project will be helpful in evaluating the effects of air pollution in the event that a new source is constructed or current pollution levels increase. These data will be valuable in future permit application reviews and should feed back into the overall protection and management of Class 1 wilderness areas under review.

STUDY AREAS

The three study areas include two Class 1 Wilderness areas--the Anaconda-Pintler Wilderness (APW) and the Gates of the Mountains Wilderness (GMW)--and an area of non-wilderness, the Elkhorn Mountains, which is part of the Helena and Deerlodge National Forests.

The three study areas were chosen because of their southwest to northeast spatial relationship (Figure 1) to address three hypotheses. 1) Climatic differences related to lichen distribution along a west to east gradient could be shown through inventories of lichen species. 2) Through lichen elemental analysis and occurrence of sensitive species, air chemistry differences might be indicated as related to past and present mining and smelting activities in Anaconda, Butte and Helena. With winds prevailing from the west, the APW serves as a control due to its upwind orientation to the mining and smelting that occurred in Anaconda from 1883 to 1982 and in Butte from the late 1890's to 1973 (Shrovers *et al.*, 1991). The Elkhorn Mountains are 80 kilometers downwind from Anaconda and 60 km downwind from Butte. The GMW lies 40 km northeast of the mining and smelting activities ongoing in East Helena from 1964 (Herrin, 1987), 120 km northeast of Anaconda, and 100 km northeast of Butte. 3) The current management practices of these areas may have an impact on the flora or the air chemistry of these areas. The APW and the GMW have been protected by their designation as Class 1 Wilderness areas from recent direct human activities such as logging, mineral extraction and motorized vehicles. The Elkhorn Mountains are used heavily by four-wheelers and have much private land throughout.

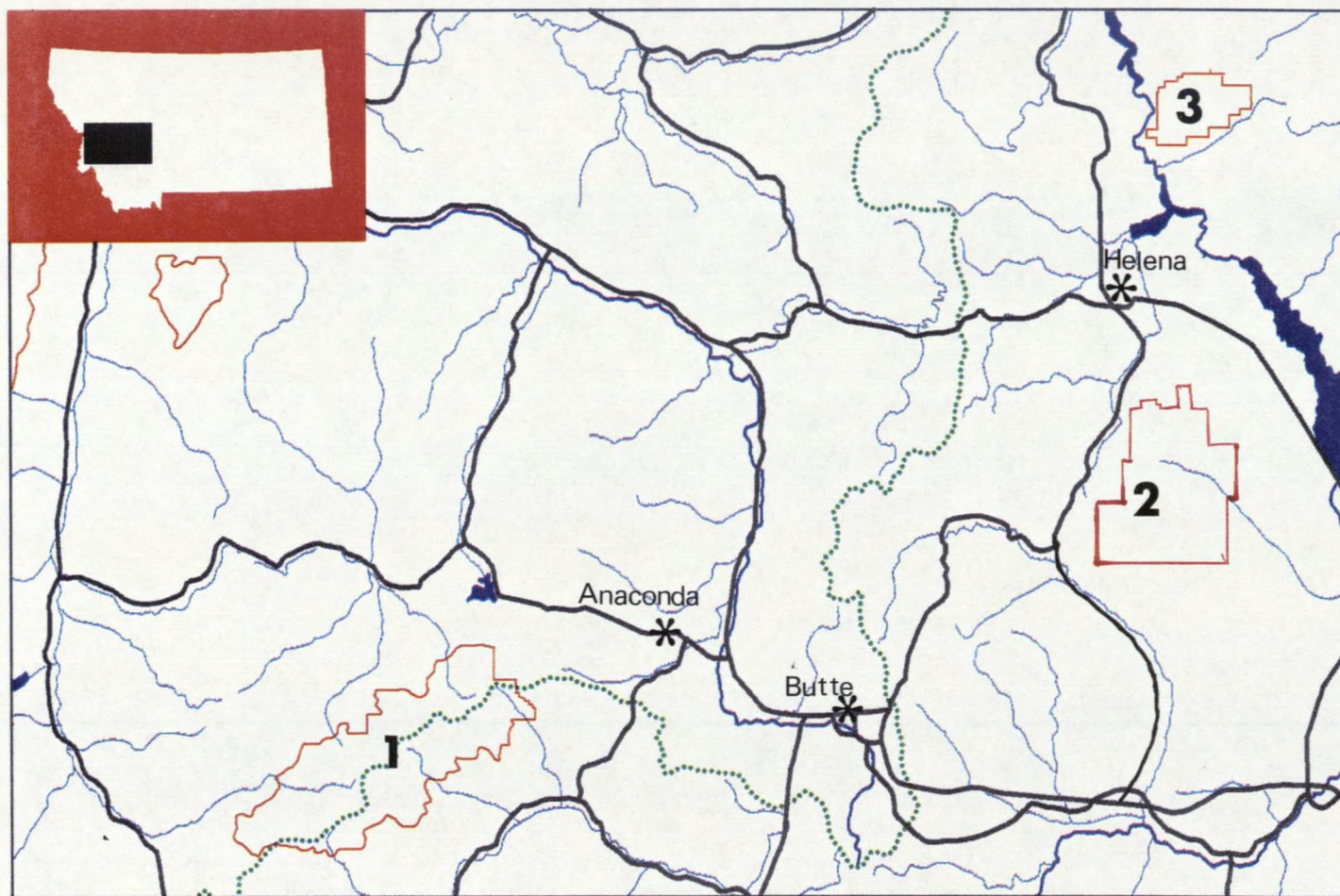


Figure 1. Study areas: 1) Anaconda-Pintler Wilderness, 2) Elkhorn Mountains, 3) Gates of the Mountains Wilderness. Major roads are black, waterways are blue, and the Continental Divide is green.

Anaconda-Pintler Wilderness

Features

The APW spans 65,000 hectares across the Continental Divide southwest of Anaconda (Figure 2). Its elevations range from 1555 meters to 3290 meters. It contains the headwaters for Rock Creek and branches of the Bitterroot and Big Hole Rivers. Mountain goats, bighorn sheep, black bears, elk, moose, and deer are some of the diverse fauna that inhabit the APW.

Geology

Zimbleman (1986) shows the APW to be mostly composed of sedimentary rocks of Middle Proterozoic (Precambrian) and Paleozoic age, and igneous rocks, mostly granodioritic to granitic of Cretaceous to Tertiary age.

Soils

The APW soils are various types of Inceptisols which are 30-80 cm deep. Inceptisols show distinct horizon development and are weakly to strongly acid. The finest materials occur at the surface and increase in size with depth. The "A" horizon is dark brown to black with a high organic content, but nutrient status is fairly low (Price, 1981). The Northwestern half of the APW has Inceptisols on moderate to very steep slopes. These are soils that support a complete cover of herbs and grasses that form a tight interlocking, and a highly organic root zone. At the highest elevations in the heart of the wilderness are rock outcroppings and talus. Inceptisols-Alfisols which are moderately deep, well-drained, acidic soils with distinct horizons (Price, 1981), are found further south and east for the length of the wilderness. The southeastern border is

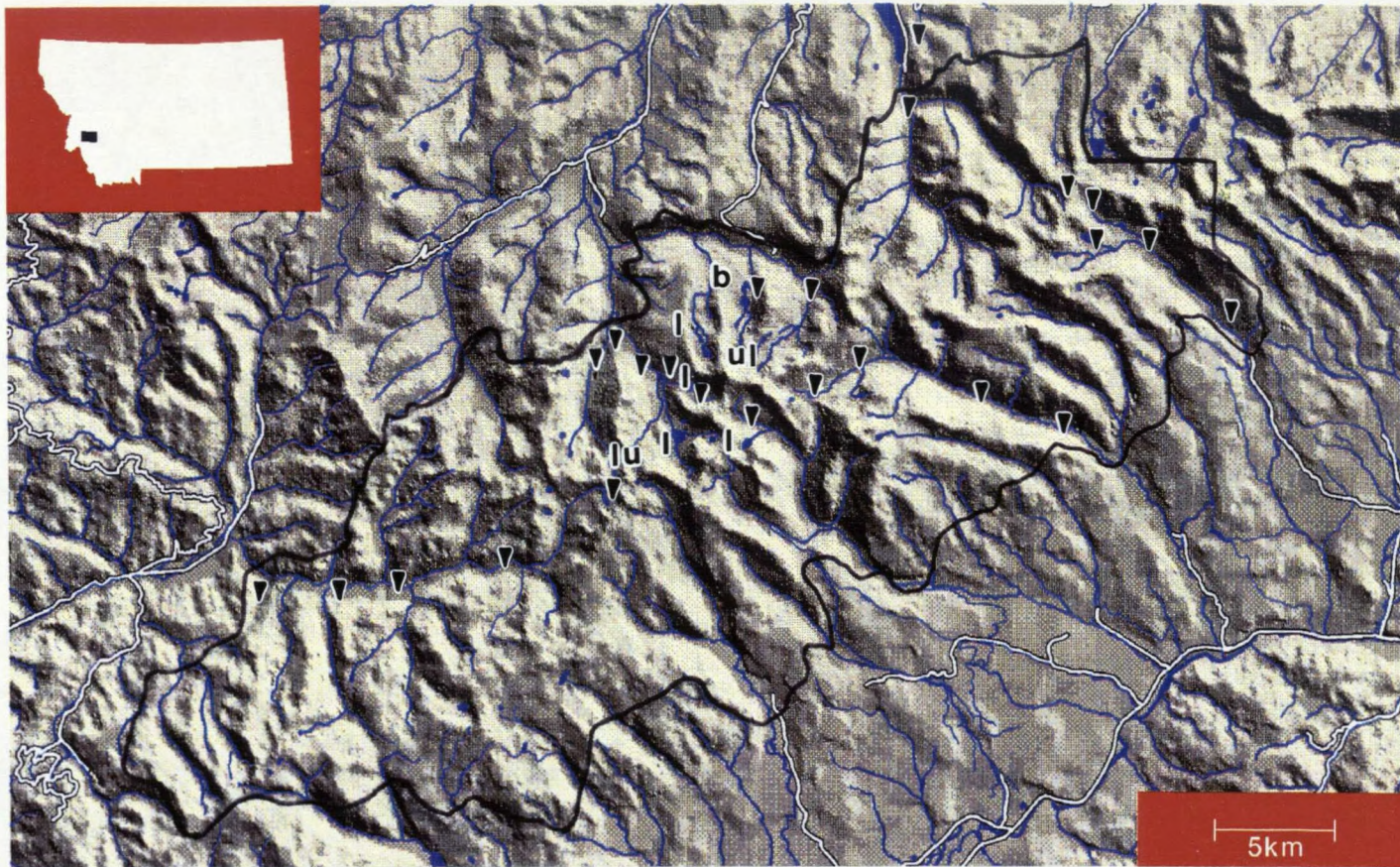


Figure 2. The Anaconda-Pintler Wilderness study area with major roads and waterways. ▼ = floristic collection sites. b = Bryoria fremontii sample collected for element analysis, l = Letharia vulpina sample collected for elemental analysis, u = Umbilicaria hyperborea sample collected for elemental analysis.

categorized as having Inceptisols-Alfisols characteristic of undulating to rolling soil in valleys and on foothill glacial moraines (Simonson *et al.*, 1978).

Vegetation

The APW is predominantly forested, with the exception of wetland and aquatic habitats, and the flora of the APW is very diverse. Lower elevations are dominated by nearly pure stands of *Pinus contorta* Dougl. with *Vaccinium scoparium* Leiberg ex Cov., *Calamagrostis rubescens* Buckl., *Carex geyeri* Boott or *Physocarpus malvaceus* (Green) Kuntze undergrowth. *Pseudotsuga menziesii* (Mirb.) Franco forests and occasionally *Pinus ponderosa* Dougl. also occur at lower elevations. As elevation increases, *Picea sp.* and *Abies lasiocarpa* (Hook.) Nutt. forests, with *Carex geyeri*, *Menziesia ferruginea* Smith, *Galium triflorum* Michx., *Vaccinium scoparium*, *Xerophyllum tenax* (Pursh) Nutt. and *Linnaea borealis* L. as varying underbrush, are encountered. At higher elevations, *Pinus albicaulis* Engelm. and *Larix lyallii* Parl. grow to timberline. Alpine tundra vegetation generally occurs over 2900 meters in elevation.

Climate

Based on the nearest weather data from Sula and Anaconda, the mean annual precipitation at the lowest elevations in the APW is roughly 30 cm (NOAA, 1992). Nearly all of the area above 2500 m receives at least 102 cm of precipitation annually and the highest elevations receive up to 150 cm annually (Farnes, 1971). The mean annual temperature is 6.9°C (NOAA, 1992). The average length of freeze-free season is 50 days or shorter with the average first day of freeze between August 13 and 23 and the average last day of freeze between June 4 and July 19 (Caprio, 1965).

Anthropogenic influences

Most of the forests bordering the wilderness have been logged intensively, resulting in much dirt or gravel road traffic adjacent to the area. Other anthropogenic influences are activities allowed in the wilderness such as horse packing, hiking and fishing.

Elkhorn Mountains

Features

The Elkhorns are a 34,000 hectare area of the Helena and Deerlodge National Forests that lies southwest of Helena approximately 20 kilometers and northeast of Boulder about 5 kilometers (Figure 3). Elevations range from 1145 m to 2440 m. The Elkhorn Mountains lie in the Missouri River water shed. Major drainages include Prickly Pear, Muskrat, Warm Springs, Crow and Beaver Creeks. Wildlife includes elk, deer, mountain goat, beaver, black bear, and moose.

Geology

The Elkhorns are a complex range consisting of a foundation of folded and faulted sedimentary rock formations that range in age from Precambrian to Cretaceous. The sedimentary formations support an extensive cover of volcanic rocks erupted from the Boulder Batholith. These volcanic andesites have the same chemical composition as the pale gray granites of the Boulder Batholith (Alt and Hyndman, 1986).

Soils

The lower elevations surrounding the Elkhorn Mountains are a band of Mollisols-Inceptisols. These soils are a combination of the Inceptisols described above, and



Figure 3. The Elkhorn Mountains study area with major roads and waterways. ▼ = floristic collection sites. b = *Bryoria fremontii* sample collected for element analysis, l = *Letharia vulpina* sample collected for elemental analysis, u = *Umbilicaria hyperborea* sample collected for elemental analysis.

Mollisols which are very similar to the Inceptisols in having well developed horizon and deep profile, but they have neutral to slightly alkaline pH with a higher presence of bases, and therefore, a better nutrient status than straight Inceptisols (Price, 1981). Inside the rim of Mollisols-Inceptisols are three types of soil. The western half of the area has Inceptisols-Alfisols on moderate sloping to very steep mountains. Alfisols have moderate to high alkalinity. The eastern middle portion has Inceptisols and the southeastern corner of the area has Mollisols-Inceptisols-Alfisols characteristic of gently sloping to very steep mountains (Simonson *et al.*, 1978).

Vegetation

The vegetation of the Elkhorn Mountains is fairly diverse. The drier sites in the lower elevations support *Artemisia tridentata* Nutt. with *Agropyron spicatum* (Pursh) Scribn. & Smith and *Juniperus communis* L. *Pinus ponderosa* is found in the drier valley bottoms with *Agropyron spicatum*, and *Festuca idahoensis* Elmer. The dominant forest types at lower elevations are *Pseudotsuga menziesii* with a very wide range of undergrowth. *Pinus contorta* forests also have diverse types of undergrowth. Forests dominated by *Picea sp.* and *Abies lasiocarpa* are higher in elevation. *Pinus albicaulis* can be found at highest elevations at timberline.

Climate

Mean annual precipitation at the lowest elevations is 28.2 cm (NOAA, 1992). Higher elevations receive 50 to 75 cm of precipitation annually (Farnes, 1971). Mean annual temperature is 5.6° C, based on weather data from Boulder (NOAA, 1992). The freeze-free season lasts from 70 to 110 days. First fall freeze occurs between August 23 and September 22 and the last freeze falls between June 4 and July 19 (Caprio, 1965).

Anthropogenic Influences

The Elkhorn Mountains have been heavily mined and excavated for mineral resources. Many roads, including four-wheel trails, and private lands occur throughout the area.

Gates of the Mountains Wilderness

Features

The GMW is a 12,000 hectare area of forested mountains and limestone cliffs bordering the Missouri River 30 km northeast of Helena (Figure 4). Its elevation ranges from 1140 m to 2100 m. Most streams in this dry wilderness are intermittent and run into Willow Creek to the north and Beaver Creek to the south. Mountain goats, elk, deer, black bear, and turkeys are found in the GMW.

Geology

The high peaks of the GMW are made up of primarily white Mississippian Madison limestone. Swales are underlain by shale-rich units (Alt and Hyndman, 1986).

Soils

Nearly all soils of the GMW are of the Mollisol-Inceptisol-Alfisol type, found on gently sloping to very steep mountains. An area of soils weathered from rock outcroppings and talus is found near the northwestern border of the area. The very eastern edge of the GMW is made up of Mollisols-Inceptisols which are dark-colored soils of sub-humid to humid grasslands (Simonson *et al.*, 1978).



Figure 4. The Gates of the Mountains Wilderness study area with major roads and waterways. ▼ = floristic collection sites. b = *Bryoria fremontii* sample collected for element analysis, l = *Letharia vulpina* sample collected for elemental analysis, u = *Umbilicaria hyperborea* sample collected for elemental analysis.

Vegetation

The GMW is quite homogeneous, mostly with *Pinus contorta* and *Pseudotsuga menziesii*, and undergrowth of *Symphocarpus albus* (L.) Blake, *Juniperus communis*, *Spiraea betulifolia* Pallas, *Calamagrostis rubescens* Buckl., *Agropyron spicatum*, and *Physocarpus malvaceus*. *Populus tremuloides* Michx. occurs in areas with easily accessible ground water. Nearly the whole area is forested, with the exception of small open meadows and rock fields.

Climate

Weather data from Helena and Holter Dam report an annual precipitation of 25.9 cm and a mean annual temperature of 7.4 °C (NOAA, 1992). Higher elevations of the GMW receive up to 50 cm of precipitation annually (Farnes, 1971). The average freeze-free season ranges from 70 to 110 days throughout the wilderness. The first fall freeze usually occurs between September 2 to September 22 and even later. The last freeze day occurs on the average between June 4 and May 25 (Caprio, 1965).

Anthropogenic Influences

Since it is a Class 1 Wilderness, which has only one adjacent road, direct anthropogenic influences are minimal. Horse packing and backpacking are the only activities taking place within its borders as fishing is not available.

PART I
FLORISTIC SURVEY

STATEMENT OF PROBLEM

Only a handful of studies have been conducted involving lichen floristics in Montana. The only parts of Montana systematically studied are areas in and around the Anaconda-Pintler and Selway Bitterroot Wilderness areas (St. Clair and Newberry, 1993), Glacier National Park (DeBolt and McCune, 1993; Sanchini, 1986), Yellowstone National Park (Eversman, 1990), parts of the Bitterroot Mountains (McCune, 1984), the Swan River Valley (McCune, 1982; McCune and Antos, 1982), parts of eastern Montana (Looman, 1964a; Eversman, 1982), various alpine areas (Imshaug, 1957), and areas around Bozeman and Missoula (Eversman, unpublished data). Very little information on lichen distribution in southwestern Montana is available.

The primary objective of the floristics portion of this study is to expand the present knowledge of lichen distribution in Montana and to determine the occurrence of sensitive species. This has been accomplished through making species inventories of three areas of Southwestern Montana: the Anaconda-Pintler Wilderness area, the Elkhorn Mountains and the Gates of the Mountains wilderness area. These data will also complement element analysis of specimens collected in the same areas.

METHODS

Field Procedures

The floristic survey was conducted from 8 June to 13 September 1992. A total of 47 collection sites in the three study areas include 24 in the APW, 11 in the Elkhorn Mountains, and 12 in the GMW. Sites were chosen based on vegetation type and elevation in certain accessible and representative drainages. Latitudinal and longitudinal coordinates, elevation, aspect, vegetation series, and present vegetation were recorded for each site (Table 1). Trails were generally followed up a drainage and collection sites were identified as different vegetation zones were encountered. Additional sites such as talus slopes, an open meadow, an aspen grove, and rock fields were included to ensure the completeness of the survey. Figures 2, 3, and 4 show the site locations within maps of each study area. The collection sites were not permanently marked. An attempt was made to collect all species present from all substrates (rock, soil, duff, dead trees, live trees, fallen trees, and other lichens). This was accomplished by spending an hour and a half to two hours at each site. Site location substrate, exposure, and relative abundance were recorded for each specimen. Photographs were taken at each collection site to aid in the identification of plant species.

Laboratory Procedures

The specimens were identified at MSU from 1992-1994 using standard morphological techniques, water mounts of ascospores, ultraviolet fluorescence, and chemical tests (K, P, C, KC, and IKI). Identification keys of Imshaug (1951), Wetmore

Table 1. Floristic collection site locations (trail, road, lake, ridge or creek), total number of species identified from all substrates, latitudinal and longitudinal coordinates, elevation, aspect, vegetation habitat type (Pfister *et al.*, 1977), and present vegetation.

Site	Total #	Location:	Coordinates	Elev.(m)	Aspect	Series/(phase)	Present Vegetation
		Species Trail,Lake,Rd.,Creek,Ridge	Latitude, Longitude			(Pfister <i>et al.</i> , 1977)	
Anaconda-Pintler Wilderness							
A1	30	Trail 29	45° 59' 12", 113° 29' 3	2240	W	ABLA/CAREX	PICEA/ABLA
A2	19	Trail 29	45° 59' 18", 113° 29' 2	2290	SW	ABLA	talus
A3	20	SE of Edith L.	45° 58' 46", 113° 28' 4	2400	NW	ABLA/GATR	PICEA/ABLA
A4	15	Trail 131	46° 00' 34", 113° 11' 5	2130	-	ABLA/VASC	PICO
A5	14	Trail 131	46° 02' 01", 113° 14' 1	2270	S	ABLA/ARCO	PICEA/ABLA
A6	16	Trail 131	46° 02' 06", 113° 16' 0	2500	-	ABLA/PIAL/VASC	PICEA/ABLA/PIAL
A7	11	Tr. 131 at Seymour Lake	46° 02' 40", 113° 16' 2	2760	SE	PIAL/VASC	PIAL
A8	23	Tr. 131 on Goat Flat	46° 02' 46", 113° 16' 3	2880	N	PIAL	alpine
A9	17	Trail 126	45° 57' 50", 113° 16' 2	1830	SW	ABLA/VASC/CARU	PICO
A10	18	Trail 126	45° 58' 40", 113° 19' 4	2010	-	ABLA/VASC	PICEA/ABLA
A11	16	Trail 9	45° 59' 20", 113° 23' 2	2260	N	ABLA/MEFE	PICEA/ABLA
A12	21	Trail 9 at Warren Lake	45° 58' 41", 113° 24' 4	2600	S	LALY/PIAL	LALY/PIAL
A13	13	Trail 433	45° 54' 28", 113° 42' 0	1650	-	ABLA/VASC	PIAL
A14	20	Trail 433	45° 54' 25", 113° 40' 0	1680	-	PSME	boulders
A15	29	Trail 433	45° 54' 34", 113° 37' 3	1710	S	PSME	PSME/PIPO
A16	24	Trail 433	45° 54' 47", 113° 35' 0	1950	W	ABLA/GATR	PICEA/ABLA
A17	25	Ridge N. of Hidden Lake	45° 56' 47", 113° 31' 2	2650	SW	PIAL/ABLA	PIAL/ABLA
A18	20	Trail 28	45° 59' 50", 113° 31' 5	1980	N	ABLA	PICO
A19	29	Trail 28	45° 59' 50", 113° 32' 0	2010	N	ABLA	PICEA/ABLA/PICO
A20	26	Trail Head 38	46° 05' 16", 113° 21' 5	1870	-	ABLA	PICO/PICEA/ABLA
A21	23	Rd 5141 to E. Fork Res.	46° 09' 49", 113° 25' 1	1680	S	PSME	rock outcropping
A22	35	Trail 111 at Carpp Lake	46° 00' 54", 113° 27' 0	2340	W	ABLA/VASC	PICO
A23	26	Trail 9	45° 57' 55", 113° 26' 3	2400	SE	ABLA/CAGE	PICEA/ABLA/PICO
A24	20	Trail 111	46° 00' 42", 113° 25' 0	2290	-	ABLA/VASC	PICEA/ABLA
Elkhorn Mountains							
E1	27	Elkhorn Creek	46° 13' 44", 111° 58' 1	1710	W	JUCO/AGSP	ARTR/JUCO
E2	25	Queen's Gulch	45° 15' 45", 111° 56' 5	1830	NW	PSME	PSME
E3	30	Queen's Gulch	46° 16' 06", 111° 54' 1	2220	N	ABLA/VASC	PICO
E4	35	Tr. 75 at Leslie Lake	46° 17' 03", 111° 53' 0	2500	W	ABLA/VASC	PICEA/ABLA
E5	16	Tr. 75 at Elkhorn Skyline	46° 17' 17", 111° 53' 1	2530	SW	PIAL	talus
E6	24	Prickly Pear Rd. 424	46° 22' 00", 111° 55' 0	1520	S	PSME	PIPO/PSME
E7	26	Prickly Pear Rd. 424	46° 21' 53", 111° 59' 0	1660	-	PSME/CARU	PSME
E8	27	Prickly Pear Rd. 424	46° 21' 28", 111° 56' 5	1770	S	ABLA/CARU	PICO
E9	34	Prickly Pear Rd. 424	46° 20' 33", 111° 53' 5	2110	NW	ABLA/CACA	PICEA/ABLA
E10	46	Middle Fork Warm Sprgs	46° 24' 00", 111° 58' 0	1660	S	PSME	PSME/PIPO
E11	39	Trail 72	46° 18' 55", 111° 59' 5	1890	S	PSME	PICO/PSME
Gates of the Mountains Wilderness							
G1	13	Trail 260	46° 52' 45", 111° 44' 3	1840	E	PSME/AGSP	PSME/JUCO
G2	21	Trail 259	46° 52' 55", 111° 46' 1	1890	W	PSME	PICO
G3	9	Trail 259	46° 52' 35", 111° 46' 1	1870	-	FEID	meadow
G4	10	Trail 259	46° 53' 15", 111° 47' 4	1840	S	PSME/POTR/CARU	POTR
G5	17	Trail 259	46° 52' 45", 111° 46' 0	1990	SE	PSME/JUCO	PSME
G6	20	Trail 260	46° 51' 00", 111° 44' 4	1650	NE	PSME/CARU	PSME/PICO
G7	25	Trail 258	46° 54' 56", 111° 52' 4	1570	SE	PSME	Rock field
G8	14	Trail 258	46° 54' 56", 111° 52' 0	1400	N	PSME/PHMA	PSME/PIPO
G9	22	Trail 260	46° 55' 19", 111° 46' 4	1660	-	PSME	PSME/PICO
G10	24	Trail 252	46° 52' 37", 111° 48' 1	1900	N	PSME	PSME
G11	16	Trail 252	46° 55' 08", 111° 48' 4	1460	-	PSME/SPBE	PSME/PIPO
G12	28	Trail 253	46° 53' 11", 111° 52' 2	1310	W	PSME	PSME/PIPO

(1968), Poelt (1969), Bird (1970), Egan (1971), Esslinger (1975), Brodo and Hawksworth (1977), Hale (1979), Thomson (1967, 1979, 1984), and Vitt *et al.* (1988) were employed.

Thin-layer chromatography was utilized for identification of secondary compounds to determine species within the *Cladonia chlorophaea* group, *Rhizoplaca*, and *Xanthoparmelia* (Culberson and Krisstinson, 1970; Culberson, 1972; Culberson and Johnson, 1982). The nomenclature of each species was cross-checked for synonymy with Egan (1987). Voucher specimens are located in the MSU Herbarium (MONT), Bozeman.

Elevations and latitudinal and longitudinal coordinates at each site were determined using topographical maps of the three study areas.

Data Analyses

Each collection site was classified by the current dominant vegetation based on Pfister *et al.*, (1977). Species lists were combined from sites with the same dominant vegetation within each study area and placed in a table of species present versus a vegetation gradient based on moisture and elevation (Pfister *et al.*, 1977). Another table of species present at each site relative to vegetation was created to see if a relationship exists between occurrence of lichen species and dominant vegetation.

Similarity indices were calculated using the statistical program NTSYS-pc version 1.8 (Rohlf, 1993). Jaccard's Index of Floristic Similarity (Jaccard, 1908) is strictly based on the number of common presences of species and omits absences or negative matches. Dice's Similarity Index (Sokal and Sneath, 1963) not only uses common presences, but shared absences as well. Jaccard's Index of Similarity was used to calculate the degree of similarity among floras of entire study areas. It would be

problematic to also use Dice's Index to compare floras of the entire study areas because only part of each study area was sampled. Therefore, to also compare common absences would be misleading. Jaccard and Dice's Indices were both applied, however, in comparing lichen floras at each of the 47 study sites within the study areas because each site was relatively small and sampled thoroughly.

Both Jaccard's index and Dice's index give distance values that were subjected to an unweighted pair group method (UPGMA) cluster analysis which creates a dendrogram. It is from the resulting dendrogram that similarities between the areas and sites are visualized. A cophenetic correlation coefficient tells how similar the original distance values are from those on the dendrogram, and thus suggest the accuracy of the clusters on the dendrogram.

RESULTS AND DISCUSSION

Lichen Species

One-hundred ninety two species were identified from 57 genera (Appendix A).

These numbers are probably somewhat less than the actual number of species present in these study areas. Each site was only visited once and the expanse within the study areas *not* sampled far exceeds the area sampled. These data are, however, a valuable addition to the present knowledge of lichen distribution in Montana.

Most Common Species and Substrates

Ninety-four of the lichen species identified were found on rock, 50 species were found on bark or lignum (tree trunks, decorticate trees, logs, branches) and 48 species were found on or around the forest floor (soil, detritus, and "forest floor") (Table 2).

Table 2. Number and percent of species found on varying substrates compiled from species lists from all three study areas.

	Number	Percent of Total
Rock	94	49
Soil, Detritus	13	7
Forest Floor	35	18
Tree trunks, Bark, Logs, Decorticate trees	26	14
Branches	24	13

The most consistently collected lichen species in the three study areas are separated into substrate groups and are listed below. The most common saxicolous species (those on rock) in the three areas were: *Aspicilia cinerea* (Nyl. ex Malbr.), *Bellemeria alpina* (Sommerf.) Clauz. & Roux, *Lecanora rupicola* (L.) Zahlbr., *Lecidea atrobrunnea* (Ramond in Lam. & DC.) Schaerer, *Pseudephebe pubescens* (L.) M. Choisy, *Rhizocarpon disporum* (Naeg. ex Hepp) Müll. Arg., *R. riparium* Räsänen, and *Umbilicaria hyperborea* (Ach.) Hoffm var. *hyperborea*. The most consistently collected terricolous species (those found on the forest floor, soil, detritus, and duff) were: *Cladonia carneola* (Fr.) Fr., *C. cenotea* (Ach.) Schaerer, *C. chlorophaea* (Flörke ex Sommerf.), *C. fimbriata* (L.) Fr., *Peltigera aphthosa* (L.) Willd., *P. canina* (L.) Willd., *Peltigera rufescens* (Weis) Humb., and *Trapeliopsis granulosa* (Hoffmn.) Lumbsch. The most common and abundant epiphytic lichens (those found on trees) were: *Bryoria abbreviata* (Müll.Arg.) Brodo & D.Hawksw., *B. fremontii* (Tuck.) Brodo & D.Hawksw., *B. fuscescens* (Gyelnik) Brodo & Hawksw., *Hypogymnia imshaugii* Krog, *H. physodes* (L.) Zahlbr., *Lecanora hageni* (Ach.) Ach., *Letharia vulpina* (L.) Hue, *Parmeliopsis ambigua* (Wulfen in Jacq.) Nyl., *P. hyperopta* (Ach.) Arnold, *Platismatia glauca* (L.) Culb. & C.Culb., *Tuckermannopsis chlorophylla* (Willd. in Humb.), *T. pinastri* (Scop.) Hale, and *Usnea hirta* (L.) Weber ex Wigg. Most of these species are easy to see in the field and are relatively easy to identify which could be factors leading to their common occurrence in these data.

Sixty-nine species were collected from only one site. Twenty-six were found singularly in the APW, 21 in the Elkhorn Mountains and 22 in the GMW (Appendix A).

Phytogeography

Geographical distribution of the species identified from the three study areas (Appendix A) are based on information given in the keys used for identification (listed

above) and other lichen floras (Howard, 1950; Looman, 1964b; Pike *et al.*, 1975; Schroeder *et al.*, 1975; McCune, 1982; Eversman, 1990; DeBolt and McCune, 1993).

Three species with western dry-rock grassland distributions were collected from one of the three areas; *Psora decipiens* from the APW, *Xanthoparmelia chlorochroa* from the Elkhorn Mountains, and *Xanthoparmelia wyomingica* from the APW. Two species have an arid southwestern distribution; *Lecanora novomexicana* identified from all three study areas and *Acarospora strigata* collected from the GMW. One species, *Coelocaulon aculeatum*, is restricted to alpine areas and was collected only from the APW.

Ten lichens with Pacific Coastal affinities (McCune, 1984) were found in one or more of the study areas. *Bryoria abbreviata*, *Bryoria glabra*, *Hypogymnia imshaugii*, and *Tuckermannopsis platyphylla* were found in all three areas. *Alectoria sarmentosa* was collected from the APW and the Elkhorn Mountains. *Melanelia subelegantula* was found in the APW and the GMW. *Alectoria imshaugii* and *Hypogymnia metaphysodes* were only collected from the APW. *Bryoria pseudofuscescens* was found only in the Elkhorn Mountains and *Bryoria capillaris* was found only in the GMW.

The rest of the species collected from the three study areas are best associated with boreal and western temperate forests, most with circumpolar distributions.

New Lichen Species for Montana

The following species have not been previously identified from Montana based on previous lichen studies (see Appendix A for substrate and collection site(s)). These species bring the total number of lichen species reported for Montana up near 500:

Buellia lepidastr (Tuck.) Tuck.--APW
Catillaria chalybeia (Borrer) Massal.--GMW
Cladonia macrophylla (Schraerer) Stenh.--APW
Cladonia symphylicarpa (Ach.) Fr.--APW, GMW
Diploschistes canadensis Räsänen--APW

Lecanora allophana Nyl.--APW
Lecidea lithophila (Ach.) Ach.--Elkhorn Mountains
Pannaria leucosticta (Tick. in Darl.) Tuck ex Nul.--APW
Rhizocarpon concentricum (Davies) Beltram.--GMW
Usnea cavernosa Tuck.--GMW
Usnea filipendula Stirton--GMW

*Buellia lepidastr*a has previously been found in eastern United States from New England to Alabama (Imshaug, 1951) and also appears in the key of Bird (1970) for lichens of west-central Canada. *Catillaria chalybeia*'s North American distribution is uncertain but it has been reported from Greenland, Maine, Ohio, California, Saskatchewan and the Black Hills of South Dakota (Wetmore, 1968). *Cladonia macrophylla* is collected in alpine-Arctic boreal areas and is widespread on soil and humus (Hale, 1979). Thomson (1984) describes this species as distinctly northern and circumpolar but has been found in the Adirondak Mountains in New York and the Rocky Mountains in Alberta and British Columbia. *Cladonia symphycarpa* appears to be circumpolar, Arctic to temperate (Thomson, 1984) and occurs in Kansas, Colorado and Michigan (Hale, 1979). *Diploschistes canadensis* has been identified from alpine areas of Colorado and New Mexico (Egan, 1971) and is reported in Bird (1970) from west-central Canada. *Lecidea lithophila* has an uncertain distribution but occurs in Quebec, New York, Lake Superior region, California, and the Black Hills of South Dakota and Wyoming (Wetmore, 1968). *Pannaria leucosticta* occurs in Quebec to the Black Hills of South Dakota and also occurs from Quebec down to the Ozarks (Wetmore, 1968). *Rhizocarpon concentricum* has been identified from Idaho (Schroeder *et al.*, 1975), Washington (Howard, 1950), Quebec, Alabama, Minnesota, and the Black Hills of South Dakota and Wyoming (Wetmore, 1968). *Usnea cavernosa* is a very common *Usnea* species, widespread on conifers in northern United States and Canada (Hale, 1979; Wetmore, 1968). It has been identified from Quebec to the Smoky Mountains and the Black Hills of

South Dakota and Wyoming (Wetmore, 1968) and west to Washington (Howard, 1950). *Usnea filipendula* is widespread on trees in open forests (Hale, 1979). It has an extensive distribution from Washington (Howard, 1950), Idaho (Schroeder et al., 1975), the Rocky Mountains, and from New England down throughout the Appalachian Mountains (Hale, 1979).

Occurrence of Sensitive Species

Several sensitive species have been identified in one or more of the three study areas (Table 3). In addition to those listed in Table 3, *Usnea* species are known to be sensitive to sulfur dioxide (Wetmore, 1987; Kiester, 1991) and several *Usnea* species were found in all three study areas (Appendix A).

The occurrence and abundance of sensitive species in the three areas indicate no air pollution damage to lichens. Epiphytic species of the foliose and fruticose types occurring on trees (bark and lignum) are known to have sensitivities to certain pollutants (LeBlanc and DeSloover, 1970) and several species of these types were identified from all three study areas (Table 4). Sensitivities have not been determined for the majority of lichen species found in the three areas. Very few studies have been conducted for determining heavy metal toxicity specifically for lichens. This study provides species lists of the three study areas for future determination of sensitive lichen species.

Study Area Comparisons

The APW has the most diverse lichen flora with 138 species, next is the Elkhorn Mountains with 118, and last is the GMW with only 94. The lichen types with the highest number of species for each area were crustose species on rock, fruticose species on the

forest floor and foliose species on bark (Table 4). A large number of fruticose species (21) on the forest floor are in the genus *Cladonia*. Abundance of *Cladonia* species is probably directly related to available moisture, suggesting that the forest floors of the APW are generally wetter than the Elkhorn Mountains or GMW. Four more *Cladonia* species (*C. cornuta*, *C. macrophylla*, *C. merochlorophaea*, and *C. umbricola*) were collected from the APW than the other two areas.

Table 3. Lichens with known sensitivities to SO₂, NO_x, O₃ and other pollutants found in one or more of the Anaconda-Pintler Wilderness (APW), the Elkhorn Mountains (Elk) and the Gates of the Mountains Wilderness (GMW) study areas. S=sensitive, I=Intermediately sensitive, I-S=intermediate to sensitive. Sensitivities based on data summaries of Wetmore (1987) and St. Clair and Newberry (1993).

Species	Location			SO ₂	NO _x	O ₃	Other
	APW	Elk	GMW				
<i>Acarospora chlorophana</i>	X	X		S			
<i>Alectoria sarmentosa</i>	X	X				S	
<i>Bryoria abbreviata</i>	X	X	X			S	
<i>Bryoria fremontii</i>	X	X	X			S	
<i>Bryoria fuscescens</i>	X	X	X	I			
<i>Cladonia coniocraea</i>	X	X	X	I			
<i>Cladonia fimbriata</i>	X	X	X	I-S			
<i>Hypogymnia imshaugii</i>	X	X	X			I	
<i>Hypogymnia physodes</i>	X	X	X	I			
<i>Letharia columbiana</i>	X	X	X			I	
<i>Letharia vulpina</i>	X	X	X			I	
<i>Parmelia saxatilis</i>	X	X		I			S to FI
<i>Parmelia sulcata</i>	X	X	X	I			S to FI
<i>Parmeliopsis ambigua</i>	X	X	X	I			
<i>Parmeliopsis hyperopta</i>	X	X	X	I			
<i>Peltigera canina</i>	X	X	X			S	
<i>Peltigera collina</i>	X					S	
<i>Peltigera rufescens</i>	X	X	X			I-S	
<i>Physcia caesia</i>	X	X	X	I			
<i>Physcia dubia</i>	X						I-S to FI
<i>Platismatia glauca</i>	X	X	X	I		S	
<i>Pseudephebe pubescens</i>	X	X	X			I	
<i>Rhizocarpon geographicum</i>	X						S to FI
<i>Rhizoplaca chrysoleuca</i>	X	X	X	S	S		S to PAN
<i>Rhizoplaca melanophthalma</i>	X	X	X	S			
<i>Tuckermannopsis chlorophylla</i>	X	X	X	S			

Table 4. Number of foliose (Fo), fruticose (Fr), and crustose (Cr) species collected on various substrates in the Anaconda-Pintler Wilderness (APW), the Elkhorn Mountains (Elk.Mts.) and the Gates of the Mountains Wilderness (GMW).

	ROCK			BARK & LIGNUM			FOREST FLOOR			TOTAL # OF SPECIES	NUMBER OF GENERA
	Fo	Fr	Cr	Fo	Fr	Cr	Fo	Fr	Cr		
APW	17	2	50	17	8	7	12	21	4	138	46
Elk. Mts.	20	1	33	16	13	7	10	14	4	118	40
GMW	13	1	32	11	13	5	6	13	0	94	36
Total of areas	34	2	58	21	18	11	15	24	9	192	57

Judging from the paucity of soil crustose species collected, I am certain that many went overlooked. This type of lichen is more difficult to find and to identify than other types of lichens.

The varying degrees of diversity among the three study areas are probably due to differences in climate, vegetation, and available rock substrate of the three areas. The APW has a wetter climate and is more diverse in its vascular vegetation than the other two areas. The Elkhorn Mountains do not support vegetation as diverse as that of the APW. The GMW has the least diverse vegetation and is the driest and warmest of the three areas.

Climate data show the lower elevations of the APW to be slightly wetter (2-5 cm) than lower elevations of the Elkhorn mountains, and the GMW. The areas' higher elevations vary greatly in that the APW receives up to 150 cm annually, the Elkhorn Mountains receive up to 102 cm annually and the GMW only receives up to 50 cm annually (Farnes, 1971).

The APW has 50 of the 58 saxicolous lichens identified from all sites within the three areas (Table 4). A wide variety of rock surfaces are exposed in the APW while the GMW has mainly limestone which is alkaline--less conducive for growth of some species.

The Elkhorn Mountains also lack a wide variety and abundance of rock substrates compared to the APW.

Jaccard's Index of Similarity shows that the APW lichen flora is most similar to the Elkhorn Mountains lichen flora with 53 percent similarity of species. It also indicates that the GMW lichen flora is very different from both the APW and Elkhorn Mountains with 39 percent similarity of species relative to the APW and Elkhorn Mountains (Table 5).

Table 5. Percent similarity between the three study areas based on Jaccard's coefficient of similarity. Total number of taxa are below the areas in parentheses.

	APW	Elkhorn Mts.	GMW
APW (138)	100		
Elkhorn Mts. (118)	53	100	
GMW (94)	39	39	100

When the similarity values from Jaccard's Index are subjected to cluster analysis, the resulting dendrogram (Figure 5) yields tree distances that are nearly identical to the original distance values (cophenetic correlation coefficient $r=0.99$).

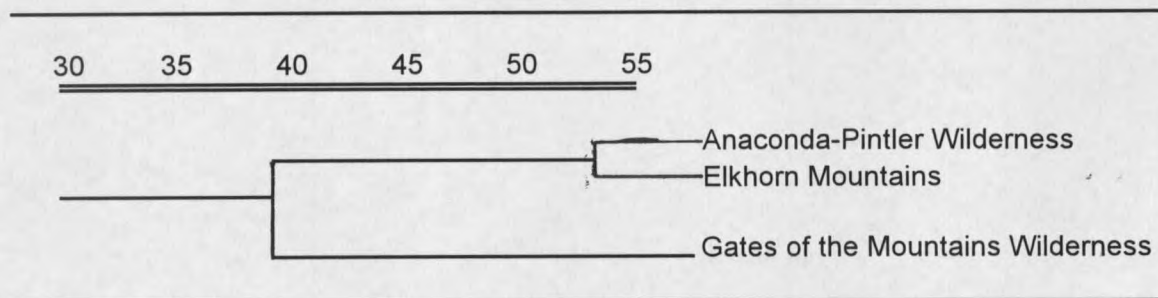


Figure 5. Dendrogram of study area relationships based on Jaccard's Index of Similarity calculated from a matrix of all species present for each area. Values are percent similarity.

Several factors could be attributing to the low similarity values given for the GMW as related to the other study areas. The distance values are strongly biased by large differences in size of the lichen flora (number of species); therefore, since the GMW has a much smaller lichen flora than the other areas, by default it will be less similar. Also, all of the species from all sites within each study area were placed in the database used to calculate the similarity values regardless if each type of site was sampled in each area. For example, aspen groves and meadows exist in all three areas but were only sampled from the GMW. The species identified from these sites were included in the database, therefore, the lack of data from these types of sites from the other two areas is misrepresentative of the areas.

Lichen Flora Related to Vascular Vegetation in the Study Areas

Species occurring in different types of dominant vegetation from all three study areas (Appendix B, Table 17) were analyzed in an effort to determine if there is a specificity of lichen distribution to vascular plant communities and to see if the lichen floras within different forest types differ among the three study areas. Species were arranged according to common substrate, and the lichen species for study sites with the same vascular plant communities were combined for each of the three study areas. A limited specificity between lichen distribution and vascular plant communities was discovered but differences between the lichen floras of the study areas for a given vascular plant community was apparent.

Rock sites (talus, rock outcroppings) of the APW had the largest number of species (46) compared to the rock sites of the Elkhorn Mountains (16 species) and the GMW (25 species). Rock lichen communities in all three of the areas are composed of

saxicolous species typical of Arctic boreal areas (Wetmore, 1968). In addition, seven species were found in the APW which are not usually found on rock; *Xanthoparmelia wyomingica* usually found on soil, *Cladonia ecmocyna*, *C. symphycarpa* and *Peltigera rufescens* typically found on soil and on the forest floor, and *Chrysothrix chlorina*, *Parmelia sulcata*, and *Parmeliopsis hyperopta* normally found on bark or lignum.

One *Juniperus communis* site in the Elkhorns (E1) with 27 species and one *Juniperus communis* site in GMW (G1) with 13 species had only four species in common; *Lecidea auriculata* Th. Fr., *Peltigera rufescens*, *Letharia vulpina*, and *Usnea hirta*. Site E1 was much more rocky, supporting 19 saxicolous species while site G1 had little rock and was mostly sandy soil, hence only supporting seven saxicolous species.

One mountain meadow was sampled from the GMW (site G3). Not surprisingly, all nine species collected were saxicolous and terricolous. No meadows were sampled in the other two study areas.

In comparing just the *Pseudotsuga menziesii* sites, those in the Elkhorns proved to be the most diverse, hosting 54 lichen species on all substrates, compared to 45 species in the GMW, and 27 in the APW. This hierarchy may be attributed to the fact that the APW has very few Douglas fir forests within its boundaries and only one Douglas fir site was sampled, while the Elkhorns and the GMW support large areas of Douglas fir forests where several sites were sampled. Species in common for Douglas fir forests in the three areas were *Cladonia cenotea*, *C. chlorophaea*, *C. coniocraea*, *C. multiformis*, *C. pyxidata*, *Peltigera apthosa*, and *Peltigera canina* which are all terricolous, and the epiphytes *Parmelia sulcata*, *Parmeliopsis ambigua*, *P. hyperopta*, *Platismatia glauca*, *Tuckermannopsis chlorophylla*, *T. platyphylla*, *Bryoria fremontii*, *B. fuscescens*, *Hypogymnia imshaugii*, and *H. physodes*.

The single *Populus tremuloides* site (G4) only has 10 species represented. Four of these species--*Candelariella xanthostigma* (Ach.) Lettau, *Phycia adscendens* (Fr.) H. Olivier, *P. stellaris* (L.) Nyl., and *Xanthoria polycarpa* (Hoffm.) Rieber--were collected solely from this site and tend to grow on deciduous trees rather than conifers (Hale, 1979).

Of the *Pinus contorta* forests, those in the Elkhorn Mountains had 47 lichen species and the APW had 46 species. *Pinus contorta* forests in the GMW had 26 species. Given that five sites in the APW were combined and compared to only two sites each for the Elkhorns, we would expect more species to be found in the APW *Pinus contorta* forests. These data suggest that lodgepole pine forests have fairly homogeneous lichen flora. Three saxicolous, five terricolous and nine corticolous species were in common for *Pinus contorta* forests in all three areas (Appendix B, Table 17).

Eleven APW *Picea/Abies lasiocarpa* (spruce/fir) sites were combined and compared to two Elkhorn spruce/fir sites. The APW sites were more diverse with 76 species and spruce/fir sites in the Elkhorns had 60 species. These areas had five saxicolous, 20 lignicolous, and 12 terricolous species in common (Appendix B, Table 17). No spruce/fir forests were found in the GMW.

All four of the *Pinus albicaulis* (white bark pine) sites (A7, A8, A12, and A17) were from the APW, where 58 species were collected and identified. Only two saxicolous species, *Lecanora polytropia* and *Lecidea atrobrunnea*, were common to all four sites (Appendix B, Table 17). Elevation could be a factor in this surprising dissimilarity since the sites range from 2600 m at Warren Lake (site A12) to 2880 m at Goat Flat (site A8).

My collections indicate that the Douglas fir forests had the most diverse lichen flora, totaling 106 species from 12 sites in the three areas combined. All of the spruce/fir

forests combined (13 sites) had 95 lichen species, and the lodgepole pine forests combined (9 sites) had 83 lichen species. It is interesting to note that the greatest number of species were found on rock as compared to other substrates (Tables 3 and 4) but all of the rock sites combined (five sites) had a total of only 63 species. These data indicate that saxicolous species are widely distributed throughout an area. Rocks are an important substrate which occur in every type of forest.

Lichen Flora Related to Vascular Vegetation in Each Collection Site

A table of species collected from each of the 47 sites (Appendix B, Table 18) was compiled to see if any patterns could be detected. Species were divided into groups according to their most common substrate. The 47 study sites were arranged primarily by habitat type based on a combination of increasing moisture and elevation (Pfister *et al.*, 1977). This matrix indicated little about the lichen specificity with regard to altitude or moisture, but demonstrated that in all sites, except the rock, the meadow, and *Juniperus communis* sites, the majority of species were found on some form of bark or lignum, or on the forest floor. It also showed that only a few species were restricted to low or high elevation. This makes sense, knowing that lichens thrive in all kinds of extreme habitats.

Jaccard's similarity index was applied to the species lists from the 47 individual collection sites to see if similar types of vegetation support similar lichen flora. The 47 by 47 triangular distance matrix (Appendix B, Table 19) was subjected to UPGMA cluster analysis resulting in a dendrogram (Figure 6) with a cophenetic correlation coefficient of 0.82.

Evidence that similar lichen floras exist in similar vegetated areas is not seen with the data tables (Appendices B and C, Tables 16 and 17) but the dendrogram (Figure 6)

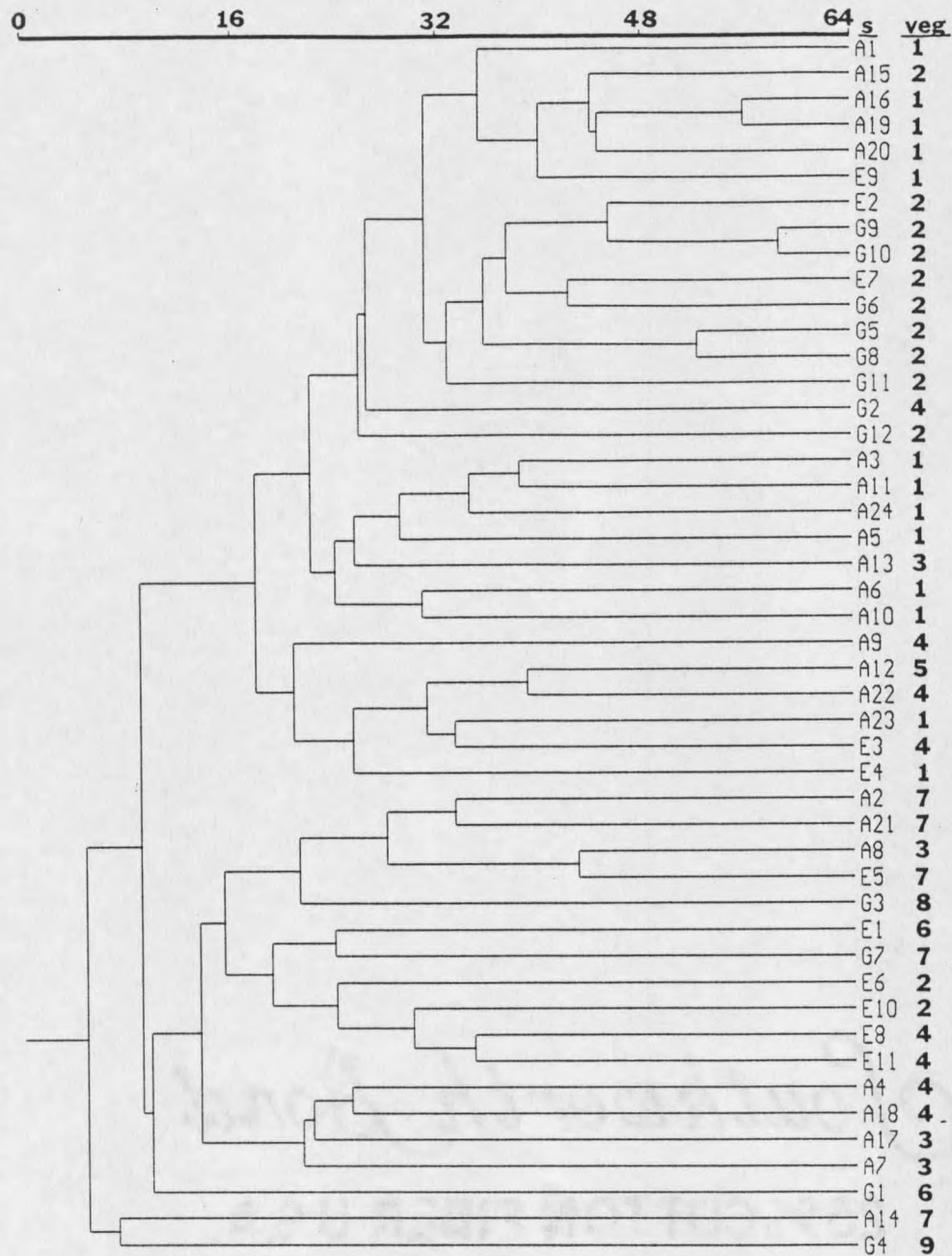


Figure 6. Dendrogram of collection site relationships based on Jaccard's Index of Similarity calculated from a matrix of all lichen species present on all substrates for each of the 47 collection sites. s=sites; veg=current dominant vegetation: 1=*Picea/Abies lasiocarpa*; 2=*Pseudotsuga menziesii*; 3=*Pinus albicaulis*; 4=*Pinus contorta*; 5=*Larix lyallii*; 6=*Juniperus communis*; 7=Talus or Rock outcropping; 8=meadow; 9=*Populus tremuloides*. Values across the top are percent similarity.

clearly depicts certain relationships. Lichen flora from six sites on the dendrogram (A1, A15, A16, A19, A20, E9) are at least 35 percent similar and they all occur in *Picea/Abies lasiocarpa* forests except site A15 which is from forest dominated by *Pseudotsuga menziesii*. Eight other sites (E2, G9, G10, E7, G6, G5, G8, G11) occur in *Pseudotsuga menziesii* forests with at least 33 percent similarity of lichen flora. Another similar group (at least 24% similar) are lichen floras from A3, A11, A24, A5, A13, A6, and A10. These are lower elevation *Picea/Abies lasiocarpa* sites except site A13 which has *Pinus albicaulis*. The bottom half of the dendrogram, starting with site A9, includes many types of current vegetation. Clustered within these sites are the rock sites A2, A21, E5, and G7, a meadow (site G3), an alpine site (A8) and a *Juniperus communis* site (E1). The sites least similar to any other in lichen flora are the *Populus tremuloides* site (G4) and a rock outcropping in the APW's East Fork of the Bitterroot drainage (A14) which appear at the very bottom of the dendrogram.

Dice's index was also applied to the site data. In comparing the lichen species collected from each of the 47 sites, the sampling error is considered minimal such that shared absence of lichen species is potentially meaningful. The 47 by 47 triangular distance (Dice's) matrix (Appendix B, Table 20) was subjected to UPGMA cluster analysis, which resulted in a dendrogram (Figure 7) with a cophenetic correlation coefficient of 0.79. This dendrogram shows almost identical relationships as those depicted in the dendrogram derived from Jaccard's values. In fact, the first 21 sites (top of figure downward) are in the same order and have similar clustering. Dice's dendrogram produced higher similarity values for the same groups of sites. For example, the six sites of *Picea/Abies lasiocarpa* (A1, A15, A16, A19, A20, E9) are at least 52 percent similar on Dice's dendrogram versus 35 percent on Jaccard's dendrogram.

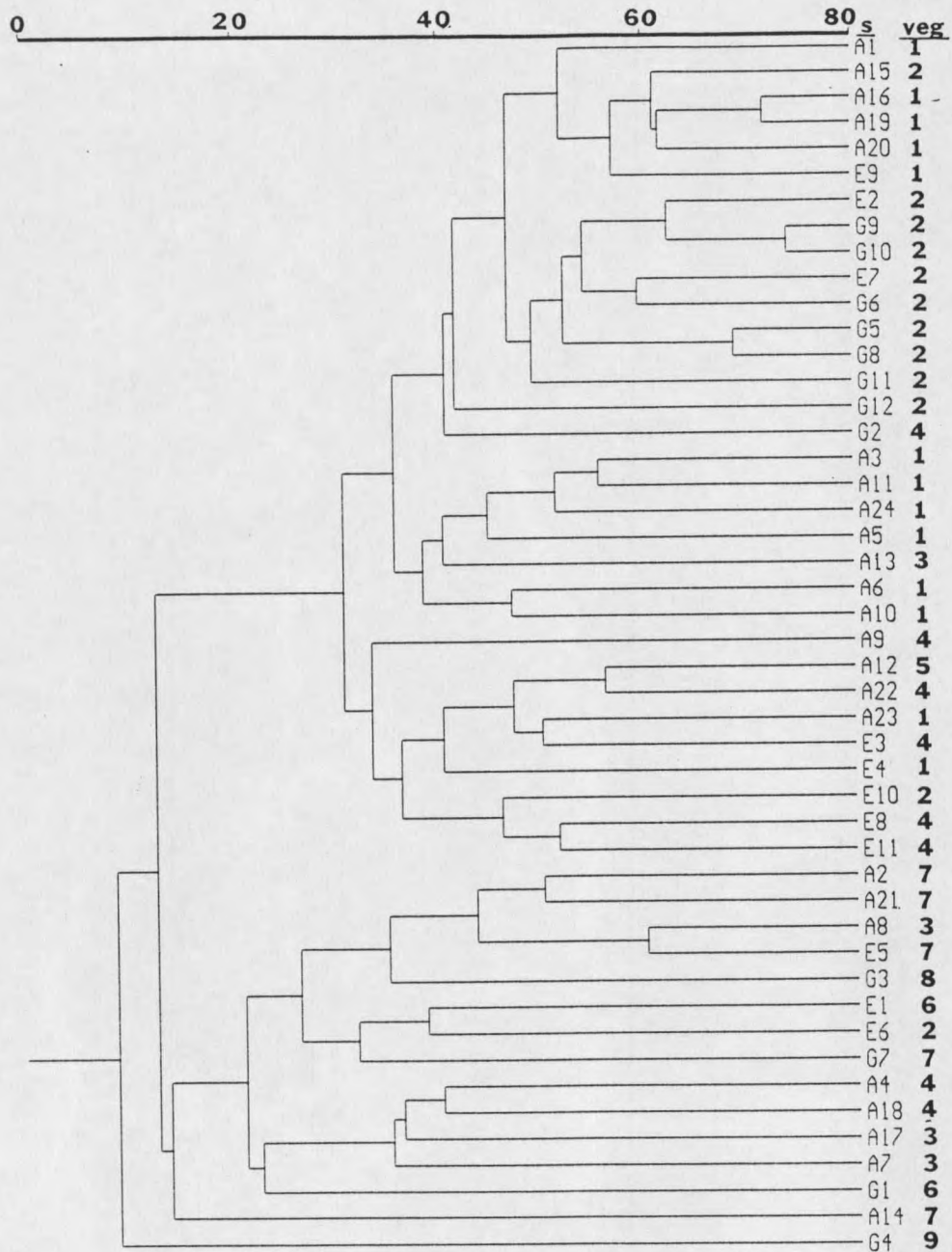


Figure 7. Dendrogram of collection site relationships based on Dice's Index of Similarity calculated from a matrix of all lichen species present and absent on all substrates for each of the 47 collection sites. s=sites; veg=current dominant vegetation: 1=*Picea/Abies lasiocarpa*; 2=*Pseudotsuga menziesii*; 3=*Pinus albicaulis*; 4=*Pinus contorta*; 5=*Larix lyallii*; 6=*Juniperus communis*; 7=Talus or Rock outcropping; 8=meadow; 9=*Populus tremuloides*. Values across the top are percent similarity.

Dice's index gave at least 49 percent similarity throughout the grouping of *Pseudotsuga menziesii* (E2, G9, G10, E7, G6, G5, G8, G11, G11) while Jaccard's index produced values of least 33 percent. The second cluster of *Picea/Abies lasiocarpa* sites (A3, A11, A24, A5, A13, A6, A10) are at least 39 percent similar for Dice. Again with Dice's dendrogram, the bottom portion is less easily interpreted as the sites become less and less similar.

Comparing both shared presences and shared absences of lichen species resulted in similar findings. Both dendrograms show that a relationship exists between vegetation and lichen flora. Sites with the most similar vascular vegetation have similar lichen flora.

As mentioned above, distance values for Jaccard and Dice's indices are strongly biased by large differences in size of flora (# of lichens identified per site). Small floras tend to cluster together and apart from larger floras. The numbers of lichen species collected at each site do not vary greatly (Table 1). The largest spread is between site G3 with only 9 species and site E10 with 46 species and these two sites are located on adjacent clusters in both Jaccard and Dice's dendrograms. Therefore, it appears that size of flora has little influence on the clustering of the collection sites.

Applying a principle components analysis (PCA) to the data for species occurrence at each site may have been a more valuable indicator of site relationships. A more precise and accurate correlation between site similarities based on lichen occurrence could be obtained.

SUMMARY

The APW has a more diverse lichen flora (138 species) than the Elkhorn Mountains (118 species) while the GMW is least diverse (94 species). Jaccard's similarity index showed the APW and the Elkhorn Mountains to be 53% similar in lichen species present and the APW and the Elkhorn Mountains were each 39% similar to the GMW.

The largest number of species were collected from rock (94 species). Fifty species were found on bark or lignum and 48 species were found on the forest floor. In spite of the diversity found on rock, the Douglas fir forests housed the richest assemblages of lichens found on all substrates. Eleven new species for Montana have been recorded.

The differences in lichen floras of the three areas appears to be related to climatic, vegetational and substratal differences and not due to differences in air chemistry. Many species classified as sensitive to air pollutants have been collected throughout all three study areas.

Jaccard and Dice's similarity indices revealed a strong relationship between vegetation type and lichen flora at the collection sites. Sites with similar vascular vegetation have the most similar lichen floras.

PART II
ELEMENTAL ANALYSIS

STATEMENT OF PROBLEM

The Clean Air Act of 1977 mandates Federal land managers to protect Class 1 Wilderness areas from adverse air pollution impacts. In 1990, the Forest Service hosted a Region 1 Air Quality Screening Workshop in which land managers and scientists came together to develop management strategies to protect "air quality related values" (AQRV's) in Wilderness areas. AQRV's are defined as those qualities (scenery, visibility, water quality, air quality, flora and fauna) that made a wilderness area worthy of its designation. Criteria and procedures for determining potential air pollution damage to Class 1 Wilderness areas were primary objectives of the workshop.

Lichen analysis is one method used throughout the world to monitor air quality status. National Forests and Parks in the United States have utilized lichens in air quality monitoring regimes through species lists and tissue analysis.

This project was initiated to attempt to relate air quality with lichen flora and tissue chemistry in two Class 1 Wilderness areas pursuant to the 1990 Air Quality Screening Workshop recommendations--the Anaconda-Pintler Wilderness and the Gates of the Mountains Wilderness-- and an area of National Forest land, the Elkhorn Mountains.

All areas were assumed to have low levels of elements as indicated by lichen thalli composition, but the APW was believed to have the lowest levels because it is located upwind from mining and smelting operations in Anaconda, Butte and East Helena, thus serving as a control area. Direct comparisons of certain elements in the lichen tissues from this study were made with those from other studies in the United States. A rare opportunity to compare lichen element data from the same area, the Anaconda-Pintler Wilderness, was used to test repeatability of lichen composition data.

METHODS

Field Procedures

Lichens most appropriate for element analysis are umbilicate or epiphytic species which can be collected without obtaining substrate in the sample and are plentiful enough to withstand repeated sampling. I chose to use the umbilicate species *Umbilicaria hyperborea* and the epiphytic species *Bryoria fremontii* and *Letharia vulpina* because they were found in abundance at least once in each study area. Twenty-one sites were established between 8 June and 13 September, 1992 (Table 6). Sites were not permanently marked in any way, but can be relocated using the latitudinal and longitudinal coordinates for each site and the figures 2, 3, and 4 of each study area. Desirable sites were those that intercept air particles without obstruction, such as high exposed ridges and peaks which are subject to prevailing winds.

At each site, at least 20 separate thalli of each lichen species were collected wearing rubber gloves and placed in sulfur-free cotton fiber bags. Samples were then brought back to Montana State University to be prepared for elemental analysis.

Laboratory Procedures

Dirt and rock contaminants were meticulously removed by hand with forceps from each whole thallus of the sample using a dissection microscope. All thalli from a sample were snap frozen in liquid nitrogen and finely ground to a powder with mortar and pestle which was thoroughly cleaned with 100% ethanol and air dried between samples. The

Table 6. Element sample codes, species, longitudinal and latitudinal coordinates, elevations, and substrates. PICEA=*Picea sp.*; PIAL=*Pinus albicaulis*; PSME=*Pseudotsuga mensiezii*; PICO=*Pinus contorta*.

Sample	Species Collected	Coordinates (W, N) Longitude, Latitude	Elevation (m)	Substrate
ANACONDA-PINTLER WILDERNESS				
AB1	<i>Bryoria fremontii</i>	113° 27' 38", 46° 01' 54"	2330	PICEA bark
AL1	<i>Letharia vulpina</i>	113° 29' 38", 45° 57' 40"	2460	bark
AL2	<i>Letharia vulpina</i>	113° 30' 52", 45° 57' 24"	2600	bark
AL3	<i>Letharia vulpina</i>	113° 27' 08", 45° 59' 35"	2620	PIAL bark
AL4	<i>Letharia vulpina</i>	113° 29' 30", 45° 59' 40"	2390	bark
AL5	<i>Letharia vulpina</i>	113° 29' 18", 45° 59' 18"	2370	tree trunks
AL6	<i>Letharia vulpina</i>	113° 27' 30", 45° 57' 20"	2760	tree trunks
AU1	<i>Umbilicaria hyperborea</i>	113° 29' 38", 45° 57' 40"	2460	rocks
AU2	<i>Umbilicaria hyperborea</i>	113° 27' 08", 45° 59' 35"	2620	rocks
ELKHORN MOUNTAINS				
EB1	<i>Bryoria fremontii</i>	111° 54' 08", 46° 20' 04"	2090	PICEA bark
EL1	<i>Letharia vulpina</i>	111° 54' 00", 46° 19' 15"	2090	PICEA bark
EL2	<i>Letharia vulpina</i>	111° 53' 03", 46° 17' 00"	2490	tree trunks
EL3	<i>Letharia vulpina</i>	112° 04' 12", 46° 18' 50"	1760	PSME bark
EU1	<i>Umbilicaria hyperborea</i>	111° 58' 12", 46° 20' 00"	1650	rocks
EU2	<i>Umbilicaria hyperborea</i>	111° 53' 03", 46° 17' 00"	2490	rocks
EU3	<i>Umbilicaria hyperborea</i>	112° 04' 12", 46° 18' 50"	1760	rocks
GATES OF THE MOUNTAINS WILDERNESS				
GB1	<i>Bryoria fremontii</i>	111° 46' 07", 46° 53' 15"	1890	PSME bark
GL1	<i>Letharia vulpina</i>	111° 44' 45", 46° 52' 15"	2010	PSME bark
GL2	<i>Letharia vulpina</i>	111° 49' 47", 46° 54' 19"	1960	PICO bark
GL3	<i>Letharia vulpina</i>	111° 48' 41", 46° 52' 30"	1920	PSME bark
GU1	<i>Umbilicaria hyperborea</i>	111° 52' 52", 46° 54' 53"	1570	rocks

sample then consisted of a homogenous sample made up of all the thalli collected at the site. Up to five grams of ground sample for each site was obtained.

A one gram portion of each site sample was given to the Soils Testing Laboratory at Montana State University for analysis of sulfur and nitrogen. Nitric-perchloric acid wet ash digests were prepared for each sulfur quantification. Procedures were modified from Kresge (1977). Five ml of concentrated nitric acid and several 2-3 mm glass beads were added to 0.25 g of ground sample in digester tubes and let set overnight. One ml of perchloric acid was then added to the mixture and sample tubes were placed into the digester. Samples were brought to volume with 2 percent nitric acid and digested at 30 minute intervals at increasing temperatures from 137°C to 210°C. After the digestion was complete and cooled, the samples were read with an inductive coupled plasma spectrometer (ICP).

For nitrogen analysis, Total Kjeldahl Nitrogen was used, which converts organic nitrogen to ammonium. Two hundred fifty mg of dry lichen sample and 2.1 g of catalyst mixture (100 g K_2SO_4 + 10 g $Cu SO_4$ + 1 g Se, and 30% hydrogen peroxide) were placed in a digestion tube. Seven ml of concentrated H_2SO_4 was added and the mixture sat over night. Tubes were then placed into the digester for one hour and cooled. Samples were read with a Technicon Auto Analyzer II. An average percent was given from three readings of one digest per site for each sulfur and nitrogen, resulting in only one value per site.

A 100 mg portion from each ground sample from each site was sent in one ml polypropylene microcentrifuge tubes with snap-shut tops to the Laboratory of Biomedical Sciences at University of California, Los Angeles, for optic emission spectrometry (OES) with the arc emission spectrometer (ARC) (Alexander and McAnulty, 1981) of 26

inorganic elements (P, Na, K, Ca, Mg, Zn, Cu, Fe, Mn, B, Al, Si, Ti, V, Co, Ni, Mo, Cr, Sr, Ba, Li, Ag, Sn, Pb, Cd, and As). The University of California, Los Angeles (UCLA) laboratory was chosen because they are familiar with lichen tissues. Dr. Phil Rundel, UCLA and Dr. Tom Nash, Arizona State University, have used this facility extensively for lichen analysis. OES was the selected method because only a very small sample is needed, samples can be analyzed dry with no elaborate preparation, good elemental coverage is available, and it is of relatively low cost.

An Applied Research Laboratories 1.5 meter grating spectrometer was used. Standards were run along with the lichen samples for accuracy. The electronics and software were all built in-house at UCLA Biomedical Laboratory. All elements were determined simultaneously. All computations and reports were made with a Digital Equipment Corporation computer. Six different 10 mg portions of each site sample were run separately through the OES/ARC system to obtain six values per site.

Statistical Analysis

Only *one* value per sample for each sulfur and nitrogen analysis was obtained, limiting the number of statistical tests possible. No statistical tests were possible involving sulfur and nitrogen for *Bryoria fremontii* because only one sample was collected from each study area. The sample values of *L. vulpina* and *U. hyperborea* were averaged within each study area and either an ANOVA or *t*-test was performed for between and among study area comparisons.

Six values for each element at each of the 21 collection sites were obtained through OES/ARC analysis. These six replicates represent instrumental error since the samples were homogenous, but they were treated as sample variation in order to perform

statistics within study areas. Means and standard deviations of each sample for 15 elements (with values falling above lowest detection limits of the OES/ARC) were used to test differences between and among means *within* study areas for each species, using analysis of variance (ANOVA) and *t*-tests (GraphPad InStat, tm., 1993). ANOVA's were used to compare more than two groups of values and *t*-tests were used when only two groups were being compared. ANOVA's indicated significant differences between means ($P < 0.05$) when one or more of the sites were different from each other. In these cases, Student-Newman-Kuels (SNK) post-tests were applied. The SNK is an all pair-wise comparison of every combination of group pairs, giving P-values for each comparison.

Among and between study area variabilities for each element were tested with ANOVA's, Student-Newman-Kuels post-tests, and *t*-tests, using means and standard deviations from combined OES/ARC data of each species-- *Bryoria fremontii*, *Letharia vulpina*, and *Umbilicaria hyperborea*--for each study area.

Analysis of variance and Dunnett's post-test (Jandel Scientific SigmaStat for Windows, 1994) were used to compare my data to those of others for similar or identical lichen species collected from various locations within the United States. Dunnett's test is a multiple comparison test analogous to the SNK test but compares only a control group to all other groups. When the ANOVA results indicated significant differences ($p < 0.05$), a Dunnett's post-test was applied. The other data from the United States were used as the control group with which the three study areas were compared using the Dunnett's test.

RESULTS AND DISCUSSION

Sulfur and Nitrogen Analyses

Only one value per sample for each sulfur and nitrogen analysis was obtained (Appendix B, Table 21) limiting the number of statistical tests possible. Within study area statistics could not be performed, and no statistics with *Bryoria fremontii* could be performed. For between study area comparisons, *L. vulpina* data was analyzed for differences among the APW, Elkhorns, and GMW, although the number of samples (n) is small, six, three, and three respectively. *U. hyperborea* values were only compared between the APW and the Elkhorn Mountains (GMW had only one value) in which the samples were even smaller with two and three respectively.

The sulfur content of *L. vulpina* was significantly higher in the three samples collected from the GMW than the six samples collected from the APW. All other statistical tests performed on the sulfur and nitrogen data showed no significant differences among the three study areas (Table 7).

None of the nitrogen or sulfur values are above expected background levels reported from other areas in North America (Nash, 1990). St. Clair and Newberry (1993) report a value of 0.07 percent sulfur in the APW, which has a very high standard deviation of 0.03 percent, indicating high sample variability. Their value is not significantly different from the values for the Elkhorn Mountains or the GMW in this study. With such a small number of constituents being analyzed, conclusions cannot be drawn about anthropogenic influences on sulfur and nitrogen levels in the three study areas.

Table 7. Analysis of variance results for study area comparisons of sulfur and nitrogen data. Means and (standard deviations) for *Letharia vulpina* and *Umbilicaria hyperborea* were computed by combining sample values from each study area where more than one sample was collected. Values are in percent.

	% S	% N
<i>Letharia vulpina</i>		
Anaconda-Pintlers (n=6)	0.061 (0.007)	0.61 (0.05)
Elkhorn Mountains (n=3)	0.077 (0.017)	0.73 (0.22)
Gates of the Mountains (n=3)	0.084 (0.014)	0.75 (0.14)
ANOVA P-value	*0.04	0.26
<i>Umbilicaria hyperborea</i>		
Anaconda-Pintlers (n=2)	0.099 (<0.0001)	1.13 (0.11)
Elkhorn Mountains (n=3)	0.101 (0.015)	1.08 (0.15)
t-test P-value	0.89	0.70

* P<0.05

Other Elemental Analyses

Fifteen elements, P, Na, K, Ca, Mg, Zn, Cu, Fe, Mn, B, Al, Si, Ti, Sr, and Ba, of the 26 elements which were analyzed, fell above minimum detection limits (Table 8) of the OES/ARC system. Replicate values for each sample (Appendix B, Table 22) were used to calculate means and standard deviations for the 15 elements analyzed for all of the within study area comparisons (Table 9).

Nearly all of the samples fall within baseline, not elevated, levels for all elements analyzed as described by Nash (1990), who compiled lists of baseline and elevated levels of elements in lichens from several studies of different geographical areas in North America. One exception is the Mn level in the *B. fremontii* sample from the APW which falls into the elevated quantity class (>300 ppm) with a mean of 370 ppm. The Mn level in

Table 8. Minimum detectable amount for each element analyzed with the OES/ARC system.

Element	P	Na	K	Ca	Mg	Zn	Cu	Mn	Fe
Lower Limit (ppm)	50.0	10.0	500.0	50.0	50.0	5.0	1.0	4.0	9.0
Element	B	Al	Si	Ti	V	Co	Ni	Mo	Cr
Lower Limit (ppm)	1.5	10.0	2.0	3.5	1.0	2.0	2.0	1.0	1.3
Element	Sr	Ba	Li	Ag	Sn	Pb	Cd	As	
Lower Limit (ppm)	0.5	1.0	1.0	5.0	2.0	5.0	6.0	5.0	

the *B. fremontii* sample from the Elkhorns is also high (187 ppm) but not near the elevated range for Mn. Both the APW and the Elkhorn samples of *B. fremontii* have significantly higher levels of Mn than the *B. fremontii* sample from the GMW (43 ppm). The APW and Elkhorn Mountain samples were both collected from bark of *Picea sp.* The GMW sample was collected from *Pseudotsuga menseizii* bark. Sloof and Wolterbeek (1993a) found that the translocation of Mn in trees from wood to bark can influence Mn content in lichens. Perhaps spruce species have a greater translocation of elements than Douglas fir trees, resulting in the higher Mn levels in the APW and Elkhorn *B. fremontii* samples.

All three of the *Umbilicaria hyperborea* samples from the Elkhorn sites fall into the elevated range for Cu (20-4900 ppm Nash, 1990) with a mean value of 47 ppm (Table 9). One sample (EU2) also has an elevated level of Al (1500+ppm Nash, 1990) with a value of 2039 and an elevated level of Ti (150+ppm Nash, 1990) with a value of 202.

Comparisons to Other Studies

The range of values for each element reported appear to fall within typical limits as compared to other studies for similar lichens in the United States (Wetmore, 1985;

Table 9. Means and standard deviations of elements found in replicate homogenized samples of *Bryoria fremontii* (labeled AB, EB, and GB), *Letharia vulpina* (labeled AL, EL, and GL), and *Umbilicaria hyperborea* (labeled AU, EU, and GU) from the Anaconda-Pintler Wilderness (samples AB1-AU2), the Elkhorn Mountains (samples EB1-EU3), and the Gates of the Mountains Wilderness (samples GB1-GU1). Only those elements falling above minimum detection limits of the OES/ARC system are reported. For all samples, n=6. Values are in parts per million.

Sample		P	Na	K	Ca	Mg	Zn	Cu	Fe	Mn	B	Al	Si	Ti	Sr	Ba
AB1	mean	2230	59	5114	1109	271	26	6	463	371	21	267	1387	8	6	28
	SD	193	9	428	101	29	3	0	48	22	1	27	112	5	0	3
AL1	mean	2252	61	3968	602	150	18	2	665	135	6	474	2968	43	4	11
	SD	186	9	377	59	27	2	0	67	19	1	54	338	17	1	2
AL2	mean	2027	73	4021	1843	431	21	3	456	300	6	332	2330	47	11	33
	SD	133	13	154	100	28	1	0	38	31	0	29	129	13	1	5
AL3	mean	1852	54	3843	1455	197	22	3	497	100	6	333	2482	38	6	13
	SD	167	17	91	145	42	3	1	36	17	0	35	112	13	1	2
AL4	mean	2152	85	4053	2994	385	23	3	578	84	7	441	3110	84	6	20
	SD	244	7	432	230	36	4	0	67	10	1	47	117	15	1	2
AL5	mean	2204	71	4288	2222	261	21	3	514	121	7	343	2727	62	13	33
	SD	194	25	360	184	31	3	1	52	11	0	30	246	10	2	3
AL6	mean	2214	72	3992	997	307	18	2	616	74	6	282	2720	55	4	18
	SD	240	15	222	86	45	4	1	62	12	1	41	261	12	1	3
AU1	mean	5232	111	4856	83	548	42	15	1752	63	8	1428	5167	107	5	27
	SD	281	20	395	30	57	7	1	78	9	0	159	375	14	1	1
AU2	mean	4840	128	4638	236	340	56	16	1752	68	7	1187	4521	80	7	33
	SD	438	18	227	24	60	6	2	149	8	1	136	442	13	2	2
EB1	mean	2047	28	5662	1682	305	26	6	477	187	14	161	1149	5	17	27
	SD	210	9	350	209	23	1	1	27	15	2	27	73	3	4	5

Table 9. (Continued)

Sample		P	Na	K	Ca	Mg	Zn	Cu	Fe	Mn	B	Al	Si	Ti	Sr	Ba
EL1	mean	1538	41	4610	3625	287	26	3	230	175	7	198	1520	21	31	36
	SD	90	11	383	147	24	2	1	22	17	1	31	175	2	6	3
EL2	mean	1816	64	4272	3307	165	23	3	457	104	7	343	2544	59	14	34
	SD	132	14	258	286	34	3	0	48	7	1	51	269	16	1	4
EL3	mean	2090	69	4669	3779	291	30	6	498	122	6	429	2984	67	12	27
	SD	154	7	224	179	22	3	0	48	11	1	50	156	12	1	2
EU1	mean	6168	126	5148	351	647	48	45	2140	105	8	1494	5406	115	9	43
	SD	472	16	326	105	43	6	3	203	14	1	161	553	17	2	4
EU2	mean	6558	228	5469	341	832	36	40	2067	130	9	2039	6872	202	12	42
	SD	418	26	332	71	68	3	4	83	9	1	174	386	19	2	6
EU3	mean	6237	190	5170	409	523	44	56	1874	83	8	1588	6036	153	12	53
	SD	398	19	485	63	32	6	7	178	11	1	145	400	13	3	9
GB1	mean	1871	25	4472	1229	192	25	6	456	43	14	233	1310	14	3	9
	SD	167	10	235	74	31	2	0	42	5	1	32	95	5	0	1
GL1	mean	2113	77	4548	3422	341	25	5	420	116	6	340	2661	49	6	36
	SD	148	6	107	164	46	2	1	44	11	1	35	218	9	0	3
GL2	mean	1707	63	3992	4756	65	26	3	412	48	6	368	2550	60	8	17
	SD	117	4	232	365	21	3	0	38	3	1	41	212	11	1	2
GL3	mean	1902	81	4476	3011	228	23	5	378	85	6	346	2909	52	9	32
	SD	147	8	240	181	27	2	0	40	9	0	33	262	14	1	3
GU1	mean	4935	164	4853	173	597	32	20	1626	70	8	1375	5902	116	5	39
	SD	457	22	245	48	59	3	4	165	13	0	145	393	12	1	5

Wetmore, 1987; Crock *et al.* 1992; St. Clair and Newberry, 1993). But, statistical differences are numerous.

Although no other element quantification studies exist to date for *B. fremontii*, Wetmore (1987) analyzed another pendulous lichen species, *Usnea tristis*, from Saguaro National Monument (SNM), Arizona. Straight ANOVA's and Dunnet's *t*-tests were performed comparing the *B. fremontii* data from the three study areas (Table 10) to the SNM *U. tristis* data. Wetmore used an analysis technique called Inductive Coupled Plasma Atomic Emission Spectrometry (ICP/AES).

Table 10. *Usnea tristis* data from Saguaro National Monument (Wetmore, 1987) compared to *Bryoria fremontii* data from the Anaconda-Pintler Wilderness (A), the Elkhorn Mountains (E), and the Gates of the Mountains Wilderness (G). Means and (standard deviations) are in parts per million.

Element	<i>U. tristis</i> n=15	<i>B. fremontii</i> (A) n=6	<i>B. fremontii</i> (E) n=6	<i>B. fremontii</i> (G) n=6	P-value
P	843.6 (477.9)	*2229.9 (192.7)	*2047.5 (209.7)	*1871.1 (167.1)	<0.00001
K	3137.8 (543.0)	*5114.2 (428.2)	*5661.7 (349.7)	*4472.2 (234.9)	<0.00001
Ca	4294.8 (1607.8)	*1109.0 (100.3)	*1682.1 (208.7)	*1229.2 (74.4)	<0.00001
Mg	536.0 (63.9)	*270.9 (28.7)	*304.7 (22.5)	*192.0 (31.4)	<0.00001
Al	625.0 (274.3)	*266.9 (26.6)	*160.7 (27.3)	*233.1 (31.9)	<0.00001
Fe	408.6 (197.8)	463.0 (47.7)	476.6 (27.3)	455.9 (41.6)	0.71
Na	98.9 (33.2)	*59.2 (9.0)	*28.2 (9.1)	*25.2 (10.1)	<0.00001
Mn	46.8 (16.2)	*370.6 (22.4)	*187.2 (14.7)	43.4 (4.6)	<0.00001
Zn	26.2 (2.5)	25.5 (3.1)	25.6 (1.4)	25.1 (1.8)	0.77
Cu	15.4 (3.9)	*5.9 (0.3)	*5.8 (0.9)	*5.9 (0.4)	<0.00001
B	2.5 (0.5)	*21.2 (0.6)	*13.9 (2.3)	*14.3 (0.7)	<0.00001

* Values that Dunnet's test showed to be significantly different ($p < 0.05$) from the Saguaro National Monument *U. tristis* data.

Eleven elements (P, Na, K, Ca, Mg, Zn, Cu, Fe, Mn, B, and Al) of Wetmore's *U. tristis* data could be compared to the *B. fremontii* data in this study. Phosphorus, K, and B were statistically higher in *B. fremontii* from all three study areas than in *U. tristis* from SNM. Calcium, Mg, Al, Na and Cu are all statistically lower in the samples of *B. fremontii* from all three study areas than in *U. tristis* from SNM.

I was able to directly compare *Letharia vulpina* data to two other studies: *L. vulpina* from Sequoia National Park (SNP) (Wetmore, 1985) and *L. vulpina* data from the Anaconda-Pintler Wilderness (St. Clair and Newberry, 1993). St. Clair and Newberry's *Letharia vulpina* data offers a unique opportunity to test repeatability of data obtained for the same area.

Again, Wetmore used Inductive Coupled Plasma spectrometry with atomic emission spectrometer (ICP/AES) for analysis while St. Clair and Newberry used photon induced X-ray emission (PIXE) for analysis. I used ANOVA's and Dunnet's tests to compare 11 elements with Wetmore's data (Table 11) and 7 elements with St. Clair and Newberry's data (Table 12).

Phosphorus, K, Fe, and B were significantly higher in *L. vulpina* from all three study areas than in *L. vulpina* from SNP. Manganese was statistically lower in *L. vulpina* in all three areas than *L. vulpina* samples from SNP.

Numerous statistical differences are indicated when comparing St. Clair and Newberry's (1993) *L. vulpina* data from the APW to this study's *L. vulpina* data (Table 12). Iron was higher in *L. vulpina* samples from all three areas of this study compared to *L. vulpina* samples from St. Clair and Newberry (1993). Copper and Zn levels were lower in all three areas of this study. Manganese levels are lower in all three study areas, but only statistically for GMW. The *L. vulpina* samples from the GMW and APW from this study

had significantly less Sr than those of St. Clair and Newberry (1993). Titanium and percent S did not differ between SC&N's *L. vulpina* samples and the *L. vulpina* samples in this study.

Table 11. *Letharia vulpina* data from Sequoia National Park (SNP) (Wetmore, 1985) compared to *L. vulpina* data from the Anaconda-Pintler Wilderness (APW), the Elkhorn Mountains (Elkhorn), and the Gates of the Mountains Wilderness (GMW). Means and (standard deviations) are in parts per million.

Element	SNP n=27	APW n=36	Elkhorn n=18	GMW n=18	P-value
P	952.4 (470.0)	*2116.6 (230.6)	*1814.5 (261.3)	*1907.4 (214.3)	<0.00001
K	3352.8 (640.8)	*4027.4 (308.9)	*4516.9 (331.4)	*4339.0 (317.2)	<0.00001
Ca	1986.4 (503.9)	1685.6 (810.4)	*3570.5 (284.2)	*3729.9 (802.3)	<0.00001
Mg	648.0 (158.8)	*288.4 (105.3)	**247.8 (65.4)	*211.4 (120.8)	<0.00001
Al	361.8 (72.7)	367.6 (77.5)	323.1 (106.8)	351.3 (36.5)	0.24
Fe	265.6 (63.5)	*544.3 (89.1)	*394.7 (127.0)	*403.1 (42.5)	<0.00001
Na	52.4 (12.6)	*69.3 (17.3)	58.0 (16.4)	*73.7 (9.6)	<0.00001
Mn	93.5 (74.9)	*135.7 (79.3)	133.8 (33.0)	83.0 (29.6)	0.008
Zn	18.8 (4.7)	20.6 (3.4)	*26.2 (4.1)	*24.3 (2.6)	<0.00001
Cu	2.4 (0.4)	2.7 (0.8)	*3.8 (1.5)	*4.3 (0.9)	<0.00001
B	4.9 (0.5)	*6.5 (0.7)	*6.8 (1.1)	*5.6 (0.5)	<0.00001

* Values that Dunnet's test showed to be significantly different ($p < 0.05$) from the SNP *L. vulpina* values.

Repeatability of lichen composition data, as indicated from the differences between St. Clair and Newberry's data from this study's data, is questionable. It is important to resample from the exact locations in the future if comparisons to past data are desired. This will minimize variability through eliminating differences between sites. Future studies must indicate whether values are from samples that were homogenized from many thalli, or from individual thalli and also provide data on analytical, sample and instrumental error.

Table 12. St. Clair and Newberry's (SN&N) (1993) *Letharia vulpina* data from the Anaconda-Pintler Wilderness (APW) compared to this study's *L. vulpina* data from the (APW), the Elkhorn Mountains (Elkhorn), and the Gates of the Mountains Wilderness (GMW). Means and (standard deviations) are in parts per million for Mn, Fe, Sr, Ti, Cu, and Zn and percent for S.

Element	SC&N APW n=6	APW n=36	Elkhorn n=18	GMW n=18	P-value
Mn	192.8 (95.1)	135.7 (79.3)	133.8 (33.0)	*83.0 (29.6)	0.0022
Fe	341.7 (205.4)	*554.3 (89.1)	*394.7 (127.0)	*403.1 (42.5)	<0.00001
Sr	16.3 (5.8)	*7.3 (3.7)	18.9 (9.2)	*7.5 (1.6)	<0.00001
Ti	75.3 (46.1)	54.7 (19.9)	49.0 (23.4)	53.6 (11.9)	0.1002
Cu	11.7 (4.0)	*2.7 (0.8)	*3.8 (1.5)	*4.3 (0.9)	<0.00001
Zn	42.2 (9.3)	*20.6 (3.4)	*26.2 (4.1)	*24.3 (2.6)	<0.00001
%S	0.07 (0.03)	0.06 (0.01)	0.08 (0.02)	0.08 (0.01)	<0.0001

* Values that the Dunnet's test showed to be significantly different ($p < 0.05$) from SC&N's data.

Many factors could be involved in creating such different values of these data as compared to those of others in the United States. The variability between Wetmore's (1987) *U. tristis* data and the *B. fremontii* data could indicate that these two species can not be validly compared, despite similar habits, since the physiology of lichens varies greatly between species (Sloof and Wolterbeek, 1993b). Folkson (1979) found that interspecies element composition varies greatly and concluded that different species should not be compared without calibration between those species. Differences could also be a result of incompatible analysis methods (OES/ARC vs. ICP/AES). The vast differences between Wetmore's (1985) *L. vulpina* data and these data (Table 11) could be attributed to different methods, to air chemistry differences between the Sequoia National Park and southwestern Montana, or to a large inherent variability in *L. vulpina* samples. Even when the samples were collected from the same area (APW) as in St. Clair and Newberry's data, results showed high variability in samples. Perhaps the different

analytical methods produced different values, but most likely they were due to the high variability in *L. vulpina* thalli, sampling and analytical error.

Several methods have been used to evaluate element data from lichens.

Numerous papers have reported straight arithmetic means directly from the analysis procedure measurements (Wetmore, 1985, 1987, and 1989; Walther *et al.*, 1990b; Crock *et al.*, 1992; Crete *et al.*, 1992; Pfeiffer and Barclay-Estrup, 1992; St. Clair and Newberry, 1993; Takala *et al.*, 1994). Other studies, however, have gone beyond simply obtaining measurements and have calculated percent variance attributed to sampling and analytical error (Gough *et al.*, 1988a, 1988b; Frenzel *et al.*, 1990; Sloof and Wolterbeek, 1991, 1993b). When the laboratory error is large with respect to natural variability, it is unreasonable to report a baseline range (Jackson *et al.*, 1993).

Gough *et al.* (1988b) sampled *Hypogymnia enteromorpha* and *Usnea sp.* at Redwood National Park, California. They determined that over 50% of the variance for their *H. enteromorpha* data was attributed to within site and laboratory error for 13 elements. For their *Usnea sp.* data only five elements had a total variance of over 50% attributed to within site and analytical error. They chose not to express a baseline range for those elements. They concluded that only for certain elements should these species be used as bioindicators to document element concentrations of the park.

Gough *et al.* (1988a) analyzed *Parmelia sulcata* at Roosevelt National Park. Their data indicated that *P. sulcata* had less than 10% of its variability attributed to sampling and analytical error, and were therefore chemically similar throughout the park.

Rope and Pearson (1990) performed the identical statistical procedures as found in this paper (ANOVA's and Student-Newman-Kuels tests) and also calculated geometric means (which are used to standardize data) for the same data. The results of the two

procedures were "essentially identical" thus they only reported arithmetic means.

It is clear that in some cases, determination of variance attributed to within site, sampling and analytical error proves valuable. Perhaps if partitioning variance statistics were applied to the data presented in this paper, some of the values from the 15 elements that were above the OES/ARC detection limits could not be used for analysis.

Within Study Area Sample Comparisons

The values (means and standard deviations) for each sample used to calculate within study area statistical comparisons (Table 9) actually represent instrumental error and not sample variability. They had to be used in order to conduct any within study area statistics and the results are still indicative of within study area differences and similarities of samples.

Bryoria fremontii

Bryoria fremontii was collected only three time, once in each study area, because it was not usually found in exposed areas, therefore, no statistics were performed for within study area comparisons using *Bryoria fremontii*.

Letharia vulpina

APW: ANOVA's for the six sites of *L. vulpina* within the APW showed extremely variable results, with each site having a highest and/or lowest value in some element, and all elements except K and Zn being statistically different among the six samples (Figure 8). Post-test analysis of the *L. vulpina* samples from the APW (Table 13) indicates that Ca and Mg are the most variable with P-values of <0.001 for nearly all possible combinations of site comparisons. No other statistical trends are evident.

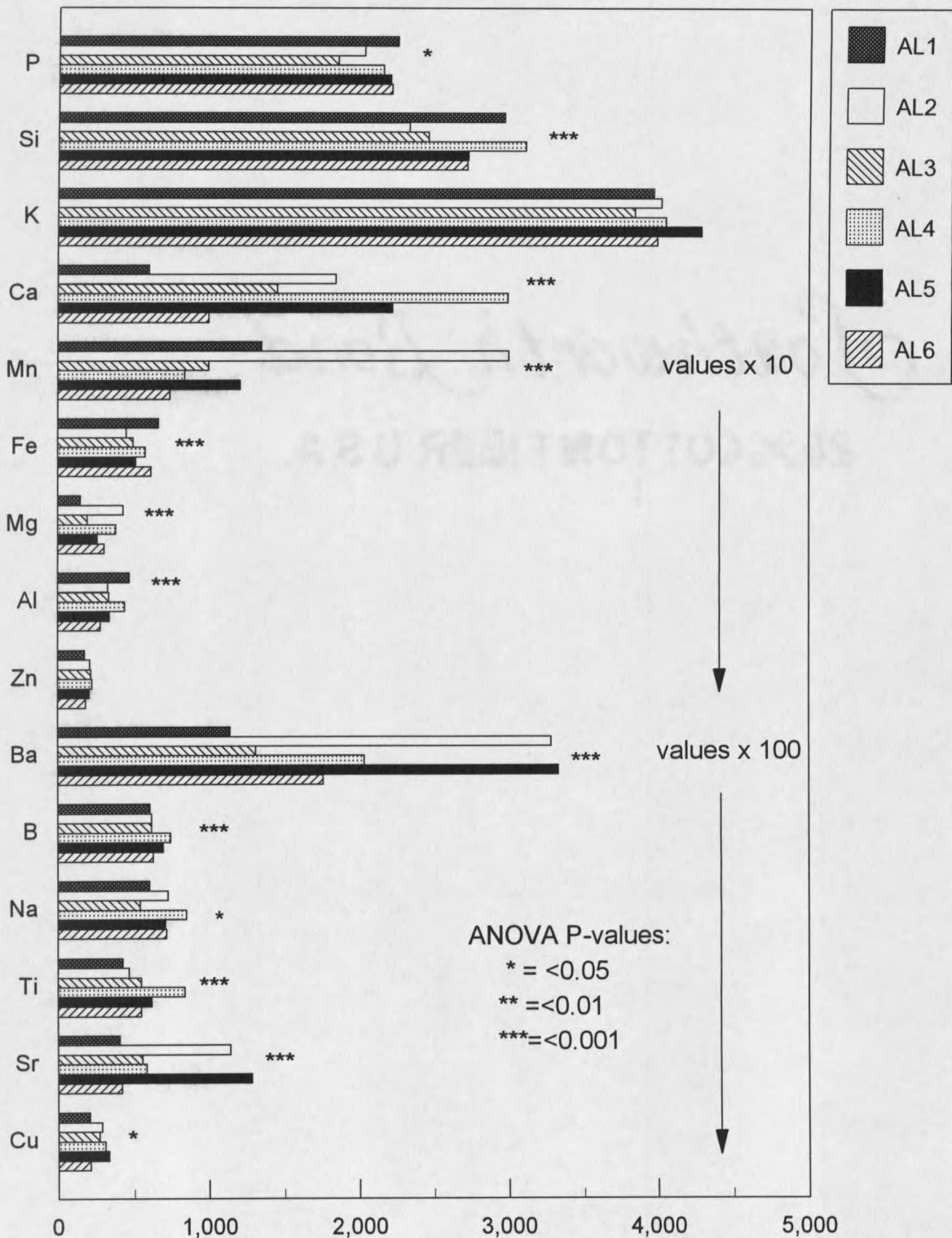


Figure 8. Analysis of Variance (ANOVA) results for six *Letharia vulpina* samples (AL1, AL2, AL3, AL4, AL5, and AL6) collected from the Anaconda-Pintler Wilderness. Values are in parts per million.

Table 13. Multiple comparison test results for *Letharia vulpina* samples collected from six sites (AL1, AL2, AL3, AL4, AL5, and AL6) within the Anaconda-Pintler Wilderness. Elements shown fell within OES/ARC detection limits.

Sites	P	Na	K	Ca	Mg	Zn	Cu	Fe	Mn	B	Al	Si	Ti	Sr	Ba
AL1 vs AL2	ns	ns	ns	***	***	ns	ns	***	***	ns	***	***	ns	***	***
AL1 vs AL3	*	ns	ns	***	*	ns	ns	***	**	ns	***	**	ns	ns	ns
AL1 vs AL4	ns	ns	ns	***	***	ns	ns	*	***	***	ns	ns	***	ns	***
AL1 vs AL5	ns	ns	ns	***	***	ns	*	***	ns	*	***	ns	ns	***	***
AL1 vs AL6	ns	ns	ns	***	***	ns	ns	ns	***	ns	***	ns	ns	ns	**
AL2 vs AL3	ns	ns	ns	***	***	ns	ns	ns	***	ns	ns	ns	ns	***	***
AL2 vs AL4	ns	ns	ns	***	*	ns	ns	**	***	***	***	***	***	***	***
AL2 vs AL5	ns	ns	ns	***	***	ns	ns	ns	***	*	ns	*	ns	ns	ns
AL2 vs AL6	ns	ns	ns	***	***	ns	ns	***	***	ns	ns	*	ns	***	***
AL3 vs AL4	*	*	ns	***	***	ns	ns	*	ns	***	***	***	***	ns	***
AL3 vs AL5	*	ns	ns	***	***	ns	ns	ns	ns	*	ns	ns	*	***	***
AL3 vs AL6	*	ns	ns	***	***	ns	ns	**	*	ns	ns	ns	ns	ns	*
AL4 vs AL5	ns	ns	ns	***	***	ns	ns	ns	**	ns	***	***	**	***	***
AL4 vs AL6	ns	ns	ns	***	***	ns	ns	ns	ns	***	***	***	**	ns	ns
AL5 vs AL6	ns	ns	ns	***	*	ns	*	**	***	*	ns	ns	ns	***	***

ns = not significant; (P>0.05), * = P<0.05, ** = P<0.01, *** = P<0.001

Elkhorn Mountains: For the *L. vulpina* site comparisons in the Elkhorns, ANOVA's demonstrated high variability with 13 elements having significant differences with K and B being the only elements not significantly different (Figure 9). Sample EL3 values were statistically higher than site EL1 and/or EL2 for P, Na, Ca, Mg, Zn, Cu, Fe, Mn, Al, Si, and Ti as indicated through post-tests (Table 14).

GMW: ANOVA results showed ten of 15 elements in *L. vulpina* samples from GMW to be significantly different; Fe, Al, Ti, Zn, and B were not significantly different (Figure 10). Post-tests for the GMW *L. vulpina* samples (Table 14) calculated site GL2 to be significantly lower in P, Na, K, Mg, Mn, and Ba while being extremely high (relative to GL1 and GL3) in Ca. The GL2 sample was the only one taken from *Pinus contorta* bark.

Umbilicaria hyperborea

APW: *U. hyperborea* samples in the APW came from two sites (AU1 and AU2), both from granite. Statistics show no consistency in comparing these sites. Sample AU1 is significantly higher in Al, Si, Mg, Ti, and B while sample AU2 is higher in Ca, Zn, and Ba (Figure 11). The elements P, K, Fe, Na, Mn, Cu, and Dr were not significantly different.

Elkhorn Mountains: ANOVA results for samples collected from the Elkhorns show that the sites vary dramatically (Figure 12). The only consistency is that EU2 is higher than one or both of EU1 and EU3 in Na, Mg, Mn, Al, Si, and Ti (Table 14). Phosphorus, K, Ca, Sr and B had no significant differences.

GMW: *U. hyperborea* was sampled from only one site in the GMW because it was not usually found in great abundance. No statistical comparisons were possible for within GMW.

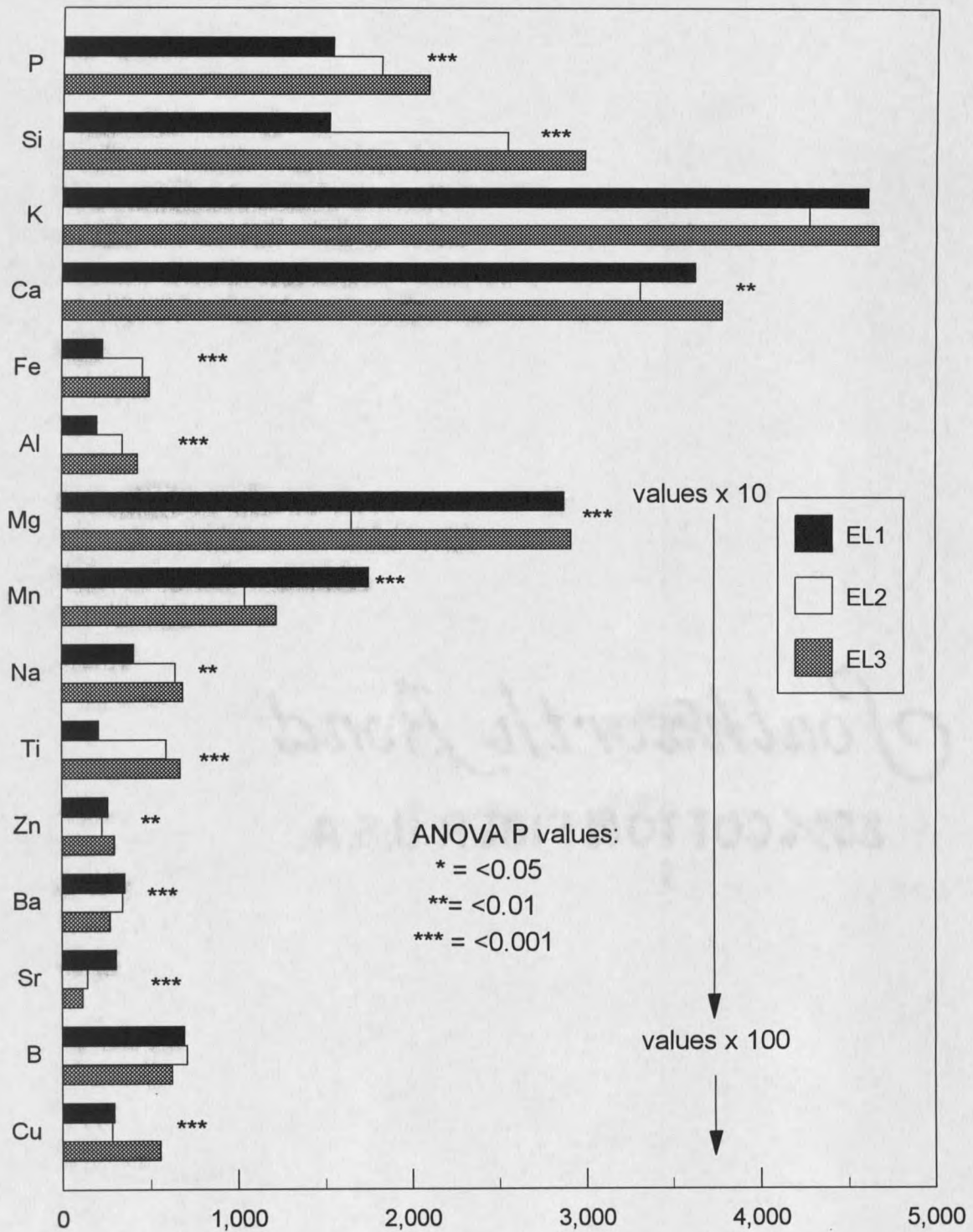


Figure 9. Analysis of variance (ANOVA) results for three *Letharia vulpina* samples (EL1, EL2, and EL3) from the Elkhorn Mountains. Values are in parts per million.

Table 14. Post-test results for three *Letharia vulpina* samples collected from the Elkhorn Mountains (EL1, EL2, EL3), for three *L. vulpina* samples collected from the Gates of the Mountains (GL1, GL2, GL3), and for three *Umbilicaria hyperborea* samples collected from the Elkhorn Mountains (EU1, EU2, EU3). Elements shown fell within OES/ARC detection limits.

Element	EL1 vs EL2	EL1 vs EL3	EL2 vs EL3	Rank(H to L)
Elkhorn Mountains <i>Letharia vulpina</i>				
P	**	***	**	EL3, EL2, EL1
Na	**	**	ns	EL3, EL2, EL1
K	ns	ns	ns	
Ca	*	ns	**	EL3, EL1, EL2
Mg	***	ns	***	EL3, EL1, EL2
Zn	ns	ns	**	EL3, EL1, EL2
Cu	ns	***	***	EL3, EL1, EL2
Fe	***	***	ns	EL3, EL2, EL1
Mg	***	***	*	EL1, EL3, EL2
B	ns	ns	ns	
Al	***	***	**	EL3, EL2, EL1
Si	***	***	***	EL3, EL2, EL1
Ti	***	***	ns	EL3, EL2, EL1
Sr	***	***	ns	EL1, EL2, EL3
Ba	ns	***	***	EL1, EL2, EL3
Gates of the Mountains Wilderness <i>Letharia vulpina</i>				
	<u>GL1 vs GL2</u>	<u>GL1 vs GL3</u>	<u>GL2 vs GL3</u>	
P	***	*	*	GL1, GL3, GL2
Na	**	ns	***	GL3, GL1, GL3
K	***	ns	***	GL1, GL3, GL2
Ca	***	*	***	GL2, GL1, GL3
Mg	***	***	***	GL1, GL3, GL2
Zn	ns	ns	ns	
Cu	**	ns	**	GL1, GL3, GL2
Fe	ns	ns	ns	
Mn	***	***	***	GL1, GL3, GL2
B	ns	ns	ns	
Al	ns	ns	ns	
Si	ns	ns	*	GL3, GL1, GL2
Ti	ns	ns	ns	
Sr	**	***	ns	GL3, GL2, GL1
Ba	***	*	***	GL1, GL3, GL2
Elkhorn Mountains <i>Umbilicaria hyperborea</i>				
	<u>EL1 vs EL2</u>	<u>EL1 vs EL3</u>	<u>EL2 vs EL3</u>	
P	ns	ns	ns	
Na	***	***	**	EU2, EU3, EU1
K	ns	ns	ns	
Ca	ns	ns	ns	
Mg	***	***	***	EU2, EU3, EU1
Zn	**	ns	*	EU1, EU3, EU2
Cu	ns	**	***	EU3, EU1, EU2
Fe	ns	*	ns	EU1, EU2, EU3
Mn	**	**	***	EU2, EU1, EU3
B	ns	ns	ns	
Al	***	ns	***	EU2, EU3, EU1
Si	***	*	**	EU2, EU3, EU1
Ti	***	**	***	EU2, EU3, EU1
Sr	ns	ns	ns	
Ba	ns	*	*	EU3, EU1, EU2

ns = not significant; (P>0.05); * = P<0.05; ** = P<0.01; *** = P<0.001

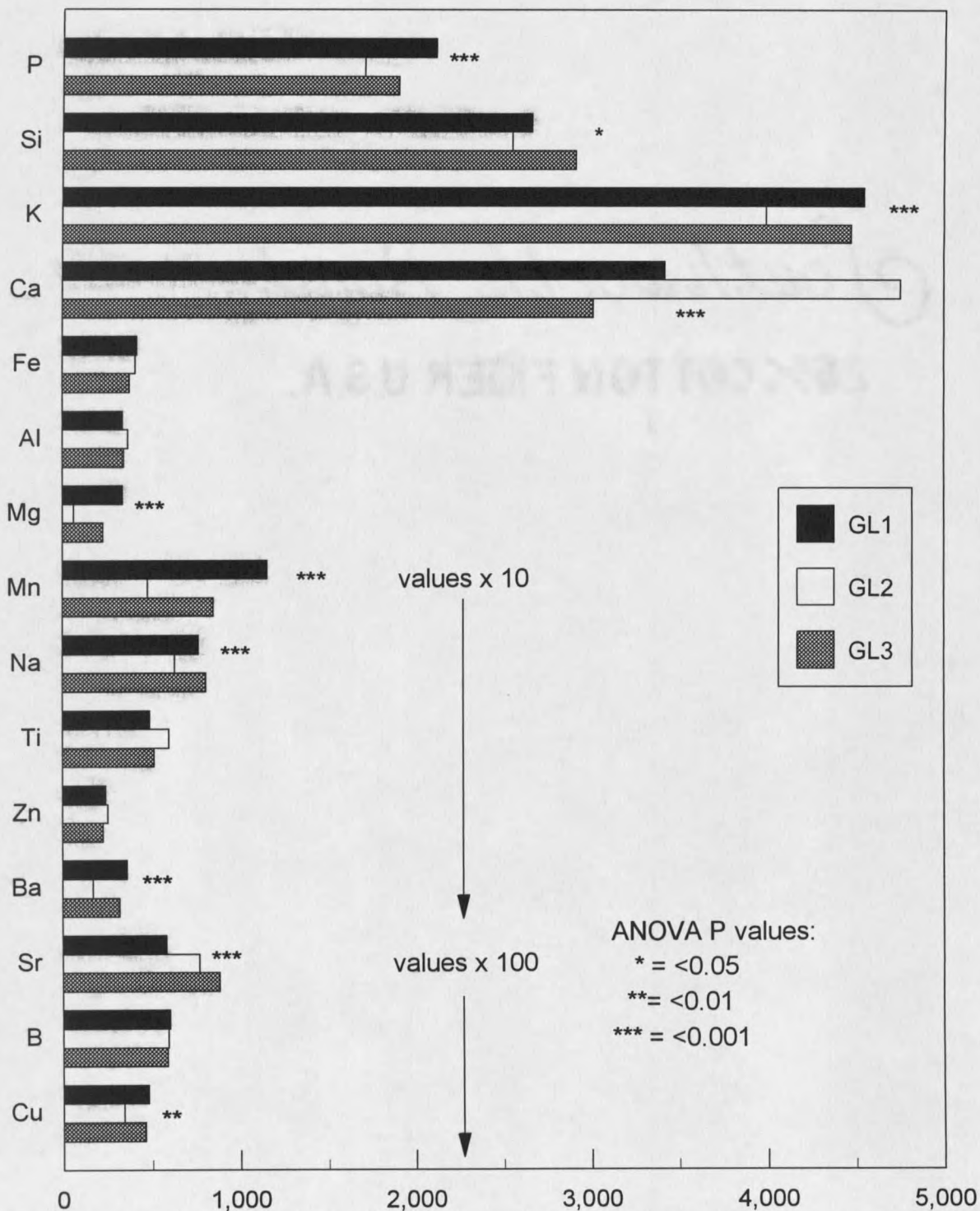


Figure 10. Analysis of variance (ANOVA) results for three *Letharia vulpina* samples (GL1, GL2, and GL3) from the Gates of the Mountains Wilderness. Values are in parts per million.

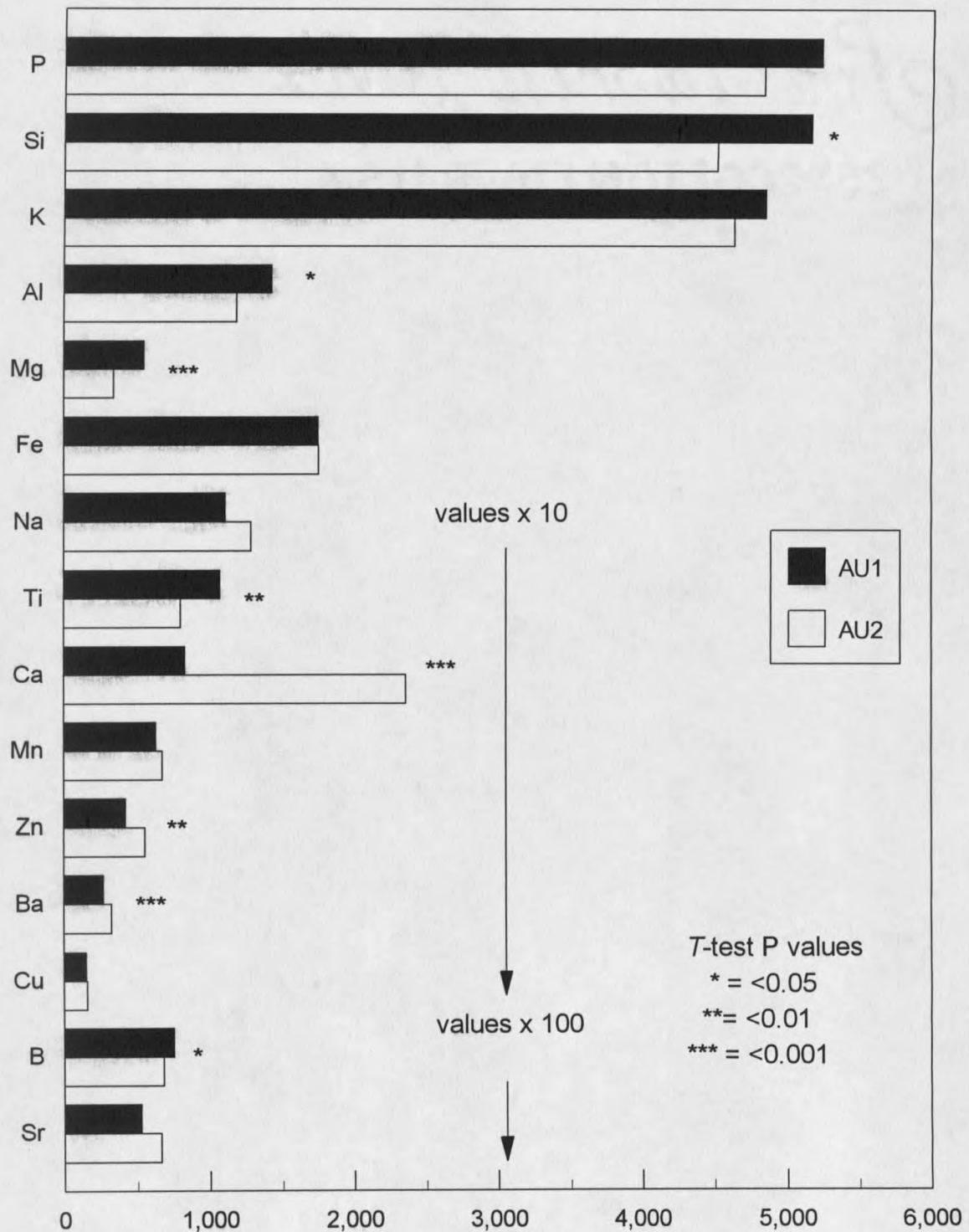


Figure 11. T-test results for two *Umbilicaria hyperborea* samples (AU1 and AU2) from the Anaconda-Pintler Wilderness. Values are in parts per million.

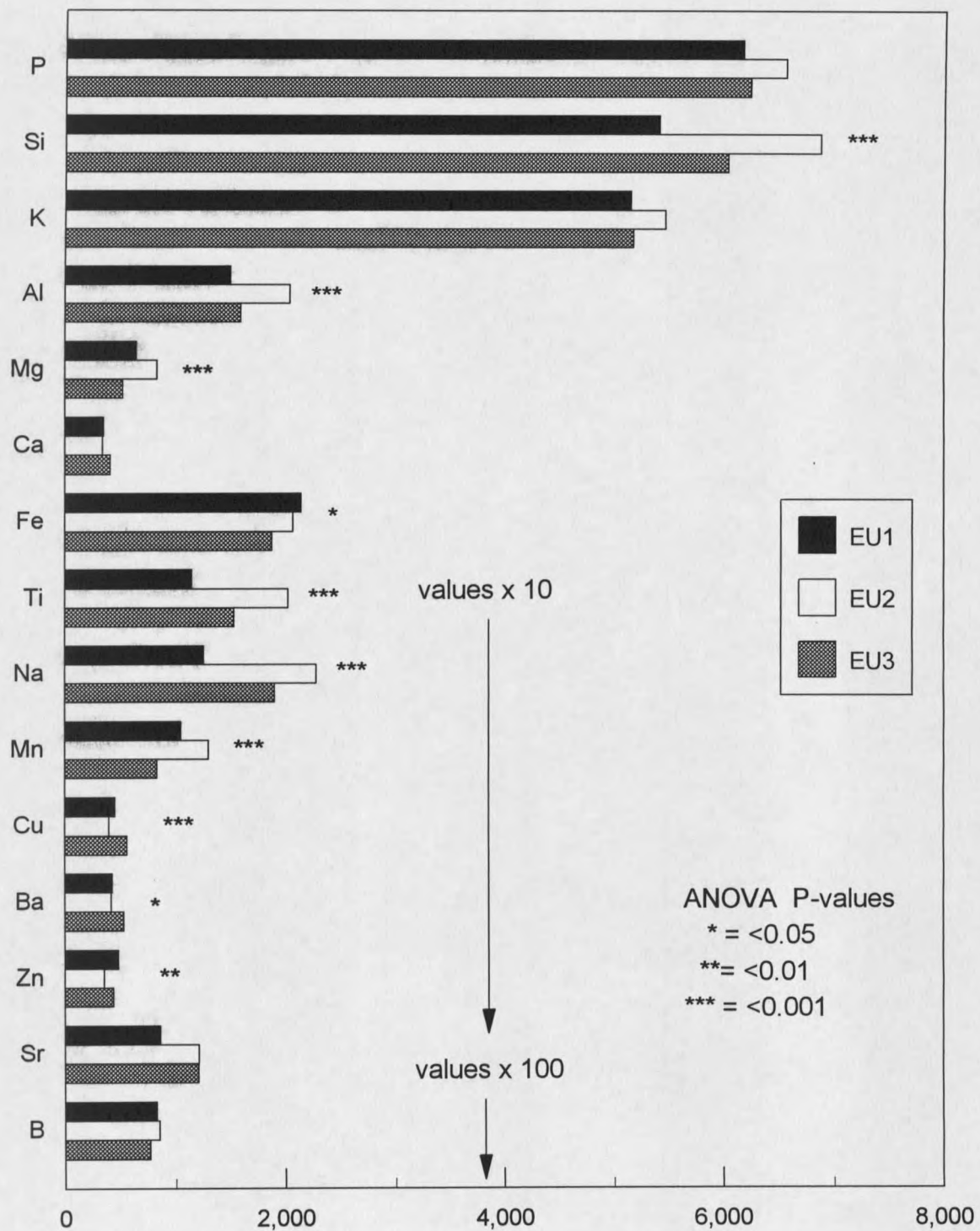


Figure 12. Analysis of variance (ANOVA) results for three *Umbilicaria hyperborea* samples (EU1, EU2, and EU3) from the Elkhorn Mountains. Values are in parts per million.

Causes of Variability

Samples within the study areas were extremely variable as shown by element analysis figures for all three species. This is not surprising considering all of the factors which could make collection sites different. Kral *et al.* (1989) found that Pb and Cd in *Hypogymnia physodes* increased with elevation in Bohemia. They suggested that climatic factors such as incidence of fog, hoar frost and icing could influence element composition in lichens. Crete *et al.* (1992) reported differences in levels of Cs, Pb, and Hg among samples collected from different elevations in northern Quebec. Markert and Weckert (1989) reported seasonal variation in element concentrations in moss species, in which the highest concentrations were found in winter and suggested that the same could be for lichens.

In the Elkhorn Mountains, *Letharia vulpina* and *Umbilicaria hyperborea* were each collected at two sites. This provides a way to evaluate interspecies chemical composition in the same place. Samples EL2 (*L. vulpina*) and EU2 (*U. hyperborea*) were collected within 2 meters of each other and samples EL3 (*L. vulpina*) and EU3 (*U. hyperborea*) were collected approximately 3 meters from each other. These two locations did not produce the same composition data for the two species. *Umbilicaria hyperborea* from site EU2 had significantly higher values of Na, Mg, Mn, Ag, Si, and Ti than *L. vulpina* (site EL2) (Table 13). *L. vulpina* from site EL3 had higher levels of P, Na, Ca, Mg, Z, Cu, Fe, Al, Si, and Ti than *U. hyperborea* (site EU3) (Table 13). So, at a given site, species do not have similar patterns in element chemistry, leading strongly to the assumption of microhabitat and substrate influence. Sloof and Wolterbeek (1993a) examined the influence of substrate on epiphytic lichens. They found that Cd, Mn, and Zn levels in trees can be translocated into bark and can potentially contribute to the levels of these

elements in lichens.

For an umbilicate species such as *U. hyperborea*, it is much more likely that rock and dirt particles have become trapped in the thallus convolutions, despite careful cleaning. Like *Rhizoplaca melanophthalma* which has a well-developed lower cortex to protect its inner cortex from substrate contamination, its convoluted surface could trap wind blown particles and soil could accumulate around the umbilicus (Rope and Pearson, 1990).

Another component of variability could be the average age of thallus collected at each site. Even though each ground sample consisted of a range of lichen ages, the average age could vary. If the thalli sampled from one site were older on the average, than another, the composition data could have higher values for the older site since contaminant accumulation has a basis in time. This potential factor alone could contribute to much of the variability within a study area.

Study Area Comparisons

Means and standard deviations for between and among study area comparisons of *B. fremontii*, *L. vulpina*, and *U. hyperborea* are in Table 15.

The *B. fremontii* statistics show numerous statistical differences with no apparent patterns (Figure 13). Even the post-tests reveal no consistencies (Table 16).

It was thought that the *L. vulpina* data would produce the least variable data due to its larger number of constituents, but it turned out to be the most variable. Figure 14 shows the inconsistencies clearly with the ANOVA results in which 13 elements were statistically different among the study areas. Table 16 demonstrates that the post-tests are just as inconsistent.

Table 15. *Bryoria fremontii*, *Letharia vulpina*, and *Umbilicaria hyperborea* data used for among and between study area comparisons of the Anaconda-Pintler Wilderness (A), the Elkhorn Mountains (E), and the Gates of the Mountains Wilderness (G). Only the 15 elements falling above minimum detection limits of the OES/ARC are included. Values are in parts per million.

Area	Lichen species	n	P	Na	K	Ca	Mg	Zn	Cu	Fe	Mn	B	Al	Si	Ti	Sr	Ba
A	<i>B. fremontii</i>	6 mean SD	2230 193	59 9	5114 428	1109 101	271 29	26 3	6 0	463 48	371 22	21 1	267 27	1387 112	8 5	6 0	28 3
E	<i>B. fremontii</i>	6 mean SD	2047 210	28 9	5662 350	1682 209	305 23	26 1	6 1	477 27	187 15	14 2	161 27	1149 73	5 3	17 4	27 5
G	<i>B. fremontii</i>	6 mean SD	1871 167	25 10	4472 235	1229 74	192 31	25 2	6 0	456 42	43 5	14 1	233 32	1310 95	14 5	3 0	9 1
A	<i>L. vulpina</i>	36 mean SD	2117 231	69 17	4027 309	1686 810	288 105	21 3	3 1	554 89	136 79	7 1	368 78	2723 336	55 20	7 4	21 9
E	<i>L. vulpina</i>	18 mean SD	1814 261	58 16	4517 331	3570 284	248 65	26 4	4 1	395 127	134 33	7 1	323 107	2349 660	49 23	19 9	32 5
G	<i>L. vulpina</i>	18 mean SD	1907 214	74 10	4339 317	3730 802	211 121	24 3	4 1	403 42	83 30	6 0	351 37	2707 267	54 12	7 2	29 9
A	<i>U. hyperborea</i>	12 mean SD	5036 406	120 21	4747 328	160 84	444 122	49 9	16 2	1752 113	65 8	7 1	1308 189	4844 516	94 19	6 2	30 3
E	<i>U. hyperborea</i>	18 mean SD	6321 440	181 48	5262 394	367 83	667 139	43 7	47 8	2027 192	106 22	8 1	1707 287	6105 750	157 40	11 3	46 8
G	<i>U. hyperborea</i>	6 mean SD	4935 457	164 22	4853 245	173 48	597 59	32 3	20 4	1626 165	70 13	8 0	1375 145	5902 393	116 12	5 1	39 5

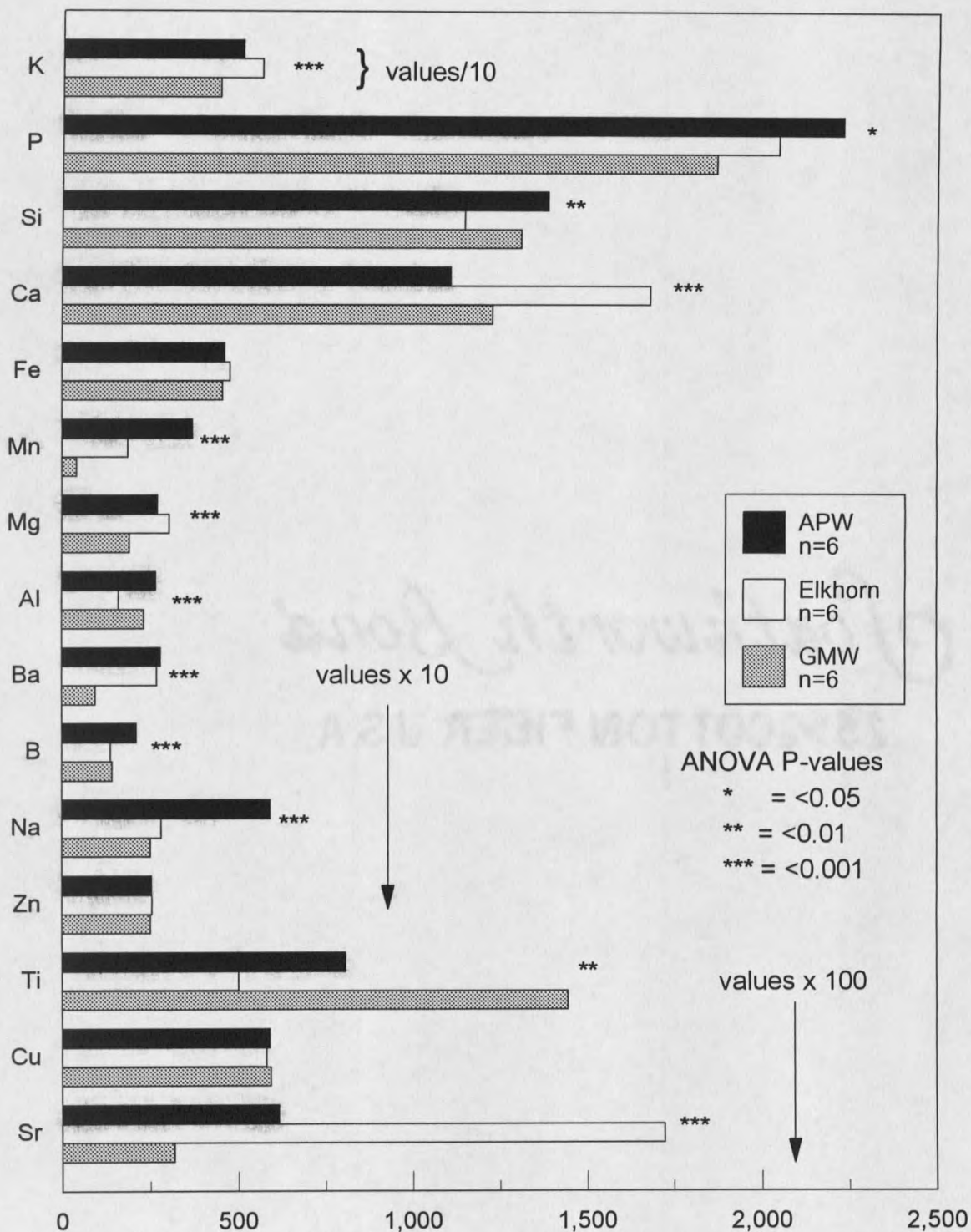


Figure 13. Analysis of variance (ANOVA) results for *Bryoria fremontii* samples collected from the Anaconda-Pintler Wilderness (APW), the Elkhorn Mountains (Elkhorn), and the Gates of the Mountains Wilderness (GMW). Values are in parts per million.

Table 16. Post-test results for *Bryoria fremontii*, *Letharia vulpina*, and *Umbilicaria hyperborea* samples collected from the Gates of the Mountains Wilderness (G), the Anaconda-Pintler Wilderness (A), and the Elkhorn Mountains (E). Elements shown fell above minimum detection limits of the OES/ARC.

Element	G vs A	G vs E	E vs A	Rank (High to Low)
<i>Bryoria fremontii</i>				
P	*	ns	ns	AEG
Na	***	ns	***	GEA
K	**	***	*	EAG
Ca	ns	***	***	EGA
Mg	***	***	ns	EAG
Zn	ns	ns	ns	
Cu	ns	ns	ns	
Fe	ns	ns	ns	
Mn	***	***	***	AGE
B	***	ns	***	AGE
Al	ns	***	***	AGE
Si	ns	*	**	AGE
Ti	*	**	ns	GAE
Sr	*	***	***	EAG
Ba	***	***	ns	AEG
<i>Letharia vulpina</i>				
P	**	ns	***	AGE
Na	ns	***	***	AGE
K	**	ns	***	EGA
Ca	***	ns	***	GEA
Mg	*	ns	ns	AEG
Zn	***	ns	***	EGA
Cu	***	ns	***	GEA
Fe	***	ns	***	AGE
Mn	*	*	ns	AEG
B	*	**	ns	EAG
Al	ns	ns	ns	
Si	ns	*	**	AGE
Ti	ns	ns	ns	
Sr	ns	***	***	EGA
Ba	**	ns	***	EGA
<i>Umbilicaria hyperborea</i>				
P	ns	***	***	EAG
Na	*	ns	***	EGA
K	ns	*	**	EGA
Ca	ns	***	***	EGA
Mg	*	ns	***	EGA
Zn	***	**	*	AEG
Cu	ns	***	***	EGA
Fe	ns	***	***	EAG
Mn	ns	***	***	EGA
B	ns	ns	**	EGA
Al	ns	**	***	EGA
Si	**	ns	***	EGA
Ti	ns	**	***	EGA
Sr	ns	***	***	EAG
Ba	*	*	***	EGA

ns = not significant; (P>0.05); * = P<0.05; ** = P<0.01; *** = P<0.001

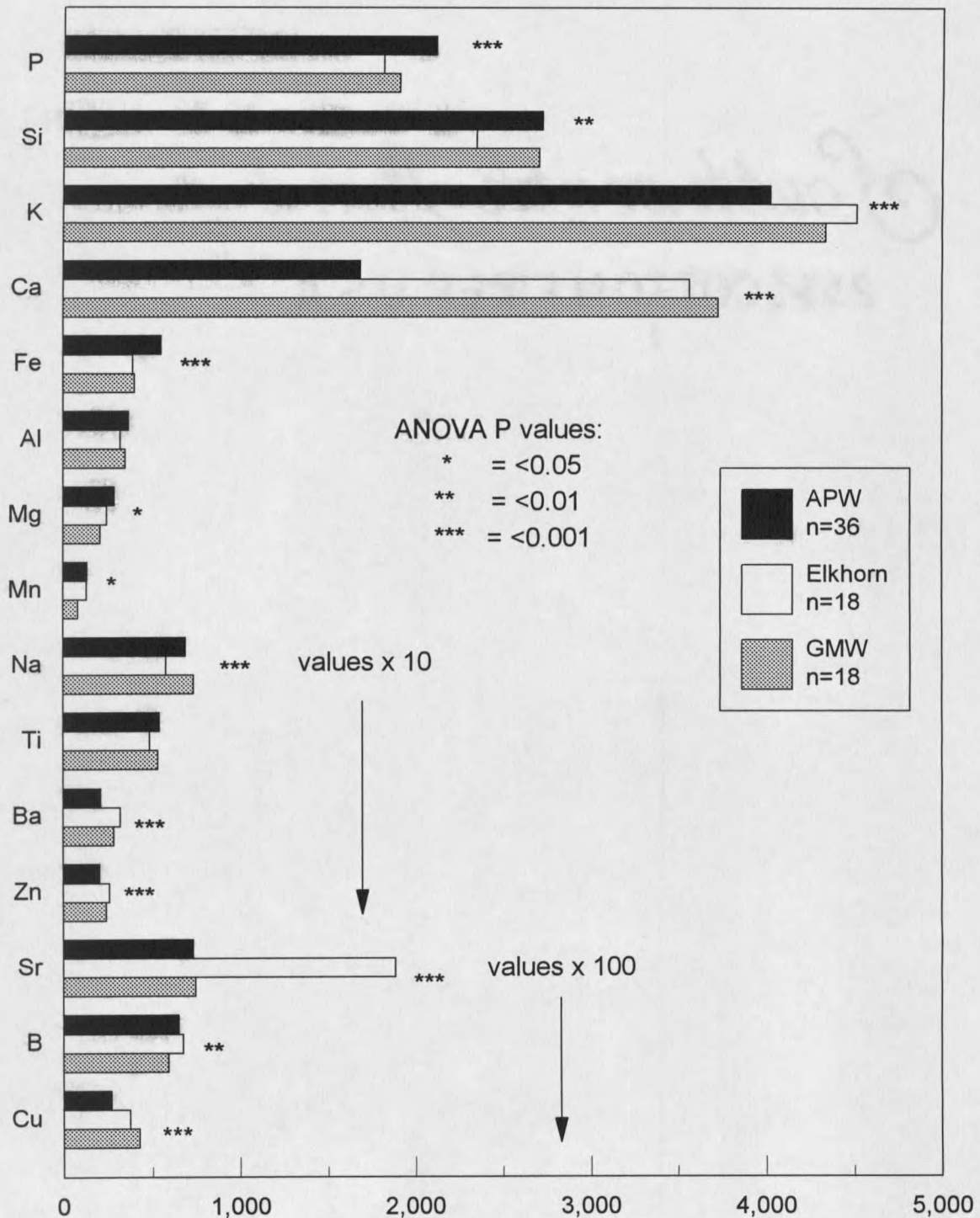


Figure 14. Analysis of variance (ANOVA) results for *Letharia vulpina* samples collected from the Anaconda-Pintler Wilderness (APW), the Elkhorn Mountains (Elkhorn), and the Gates of the Mountains Wilderness (GMW). Values are in parts per million.

Distribution of elements in *U. hyperborea* data, of which fewer samples were available for analysis, showed the most consistent results. The Elkhorn samples had significantly higher levels of P, K, Ca, Cu, Fe, Mn, Al, Ti, Sr, and Ba than both the APW and GMW *U. hyperborea* samples (Figure 15).

Both the *B. fremontii* results and the *L. vulpina* results are so inconsistent, no conclusions can be drawn about element composition for these species between the study areas. If, however, we look at *U. hyperborea* data individually, it could be concluded that the Elkhorn Mountains were affected and are still being affected by air pollution, when in fact the higher levels of P, K, Ca, Cu, Fe, Mn, Al, Ti, Sr, and Ba in the Elkhorn *U. hyperborea* samples is most likely influenced by its rock substrate. These data clearly point out the importance of sampling more than one species in an area.

Taking all the analyses into consideration, no evidence of impacts from historical and present mining and smelting activities are indicated by these data. This is not surprising because the turnover rate for many elements in lichens is relatively short. Nieboer and Richardson (1981) calculated the mean residence time for elements to be two to five years. Pike (1978) found that lichens in hardwood forests of New Hampshire have rapid turnover rates, calculated at five years. Therefore, lichens would be expected to show reductions in levels of elements within five years of a decrease in emissions from a pollution source. Walther *et al.* (1990a) found that when metal concentrations in lichens were plotted against time, the effects of an industrial zone in southwest Louisiana had all but disappeared within five years as indicated by reductions of certain elements.

In studies using lichens for mapping dispersal zones of pollution sources, the use of lichen mineral content can be an effective biological index (Nieboer *et al.*, 1978).

When using elemental concentrations in lichens for long-term studies, however, attention

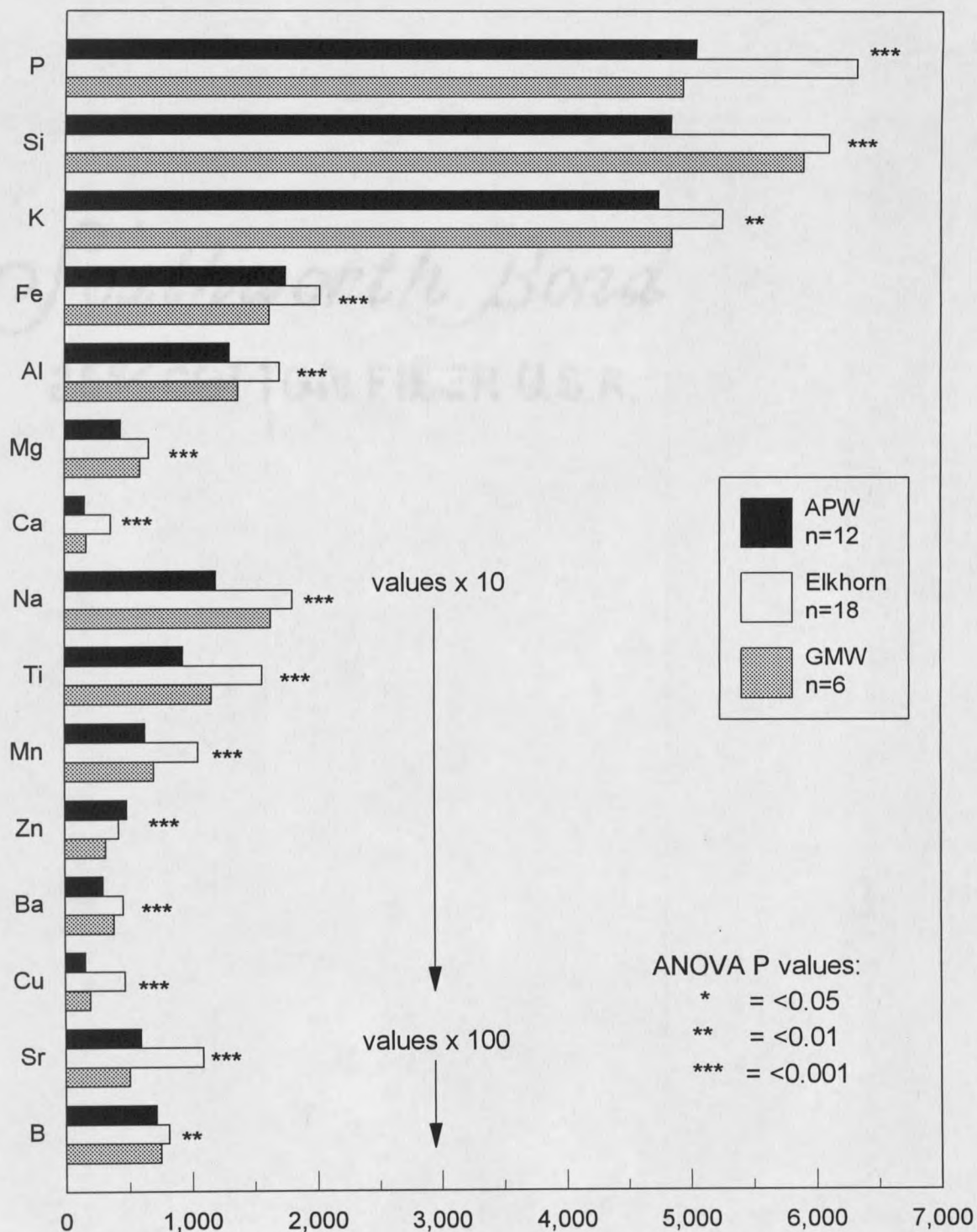


Figure 15. Analysis of variance (ANOVA) results for *Umbilicaria hyperborea* samples collected from the Anaconda-Pintler Wilderness (APW), the Elkhorn Mountains (Elkhorn), and the Gates of the Mountains Wilderness (GMW). Values are in parts per million.

should be paid to which species are the best at retaining elements. The studies successful at showing decreased quantities through time as related to pollution source output have demonstrated that certain species are better bioaccumulators than others. Schwartzman *et al.* (1991) showed that *Flavoparmelia baltimorensis* was successful for retrospective quantitative monitoring of Pb. Brown *et al.* (1994) demonstrated that *Xanthoria parietina* in Italy does not invariably accumulate elements, while Rope and Pearson (1990) found *Rhizoplaca melanophthalma* had less membrane leakage than in other species, indicating that it may accumulate elements. Brown and Brown (1991) suggest that future investigations should consider carefully the possibility that individual atoms are only temporarily retained in a lichen. Metal accumulation and retention may be influenced by microclimate, rainfall, solubility of pollutants, tolerance, and age, growth rate, and physiology of the lichen species (Sloof and Wolterbeek, 1993b).

Most of the studies of element uptake and release by lichens have been performed in the laboratory and not in a field situation which emphasizes the need for detailed field studies of mineral cycling in lichens. The rate of accumulation, redistribution or loss of elements should be studied further because they vary based on the nature of the elements, the lichen species involved and the environmental conditions (Brown and Brown (1991).

SUMMARY

No evidence of air pollution in the three study areas is evident from these data. They do, however, provide valuable information about how different species can vary in chemical composition within a given area, and support the idea that more than one species should be sampled in an area.

The comparisons of identical lichen species within the APW show that the repeatability of lichen composition data needs to be investigated further.

Same-site comparisons through time can be made with these data to gain knowledge of whether these species are good bioaccumulators or if they recycle elements quickly. The determination of baseline element composition of these lichen species in these areas give a snapshot of the chemistry of lichens against which future element concentration changes can be assessed.

CONCLUSIONS

Diversity of lichen flora is highest in the APW, lowest in the GMW, and intermediate in the Elkhorn Mountains. The differences in species diversity are most likely attributed to differences in climate, plant communities (vascular vegetation) present, and available rock substrates. The APW receives the most precipitation of the three study areas and has the most diverse vascular vegetation. This recorded climatic gradient is substantiated biologically by the presence of four species in the genus *Cladonia* in the APW not present in the other two areas. Also, two more species with oceanic affinities were found in the APW than the Elkhorn Mountains or the GMW. More rock substrate is exposed in the APW than the other two areas. The number of crustose rock lichens reflects this with 50 identified from the APW, 33 in the Elkhorn Mountains, and 32 in the GMW.

Comparison of species identified from each area shows that the lichen flora of the APW is most similar to that of the Elkhorn Mountains (53%) and the lichen flora of the GMW is 39% similar to the APW and Elkhorn Mountains. Differences in size of the lichen floras contribute to the low similarity of the GMW to the other areas.

A relationship between dominant vascular vegetation and lichen flora present in a site has been shown through data matrices of lichen species occurring in the collection sites. The sites with the most similar vascular vegetation had the most similar lichen flora. For example, the sites across the study areas with spruce/fir forest types were more similar to each other than to sites across the study areas with Douglas fir or lodgepole pine forests.

Lichen floristics do not indicate damage by air pollution in the APW, the Elkhorn

Mountains, or the GMW. Numerous lichen species with known sensitivities to pollutants have been found throughout the areas. In particular, *Usnea* species were collected in abundance from all three study areas.

Elemental analyses of lichen thalli likewise indicate no effect of past and present mining and smelting activities in Anaconda, Butte, and Helena. Only three of 21 individual samples had one or more elements with elevated levels as indicated by baseline data compiled from element composition studies from other geographical regions in North America. The range of quantities given for elevated quantities overlaps with the range of background quantities for some elements. Therefore, it is safe to assume that the elevated quantities measured in the three samples from this study may be background levels for southwestern Montana.

Element analysis data from *Letharia vulpina* and *Bryoria fremontii* indicate that these species are not useful as bioindicators because of their high sample variability. *Umbilicaria hyperborea*, however, may be a useful indicator for some elements. Research on how *U. hyperborea* uptakes and releases elements, and how much substrate influences its element composition should be conducted before action is taken to use this species in future studies.

The recycling of elements through a lichen is highly variable for different species and environmental factors. Investigations of element accumulation and release for any lichen species considered for long-term environmental assessment using element composition should be performed. Sampling procedures should then incorporate the particular features of the actual lichen and environmental conditions considered.

These data provide a temporal view of element composition in lichen thalli for the three study areas. If element composition data of lichens is desired from these three

areas in the future, it is recommended that collection and analysis procedures be comparable to those used in this study in order to make accurate comparisons to these data.

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APPENDICES

APPENDIX A

Lichen Species

Appendix A. Species identified in the Anaconda-Pintler Wilderness (sites with A), the Elkhorn Mountains (sites with E), and the Gates of the Mountains Wilderness (sites with G). The most common substrate for each species and collection site(s) are listed after species name.

Acarospora cervina Massal. var. ***glaucocharpa*** (Wahlenb. in Ach.) Körber--Rock: G12

A. chlorophana (Wahleng. ex Ach.) Massal.--Rock: A8, E1, E4

A. fuscata (Nyl.) Arnold--Rock: A2, A14, A17, A20, A21, A22, E1, E8, E11, G7

A. strigata (Nyl.) Jatta--Rock: G7

Alectoria imshaugii Brodo and D. Hawksw.--Branches: A15

A. sarmentosa (Ach.) Ach. subsp. ***sarmentosa*** --Conifer branches: A15, A16, A19, E3, E9

Aspicilia caesiocinerea (Nyl. ex Malbr.) Arnold--Rock: A1, A4, A7, A17, A18, A21, E1, E8, E10, E11, G2, G3, G7

A. calcarea (L.) Mudd--Rock: A23

A. cinerea (L.) Körber--Rock: A2, A4, A8, A18, A22, E1, E6, E8, E10, E11, G7

A. supertegens Arnold--Rock: A1

Bellemerea alpina (Sommerf.) Clauz. & Roux--Rock: A4, A9, A12, A22, A23, A24, E3, E11

B. cinereorufescens (Ach.) Clauz. & Roux--Rock: A12, A22

Bryoria abbreviata (Müll.Arg.) Brodo & D.Hawksw.--Conifer branches: A6, A10, A16, A17, A19, A22, A23, E3, E4, E7, E9, E10, G2, G5, G6, G8, G10

B. capillaris (Ach.) Brodo & D.Hawksw.--Conifer branches: G9

B. fremontii (Tuck.) Brodo & D.Hawksw.--Conifer branches: A1, A3, A11, A13, A15, A16, A19, A20, E3, E7, E9, E10, G2, G11, G6, G10

B. fuscescens (Gyelnik) Brodo & D.Hawksw.--Conifer branches: A(1, 3, 10, 11, 15, 16, 17, 19, 20, 22, 23, 24), E3, E6, E9, G(2, 5, 8, 9, 10, 12)

B. glabra (Mot.) Brodo & D.Hawksw.--Bark: A19, E2, E9, E11, G5

B. lanestrus (Ach.) Brodo & D.Hawksw.--Conifer branches: A17, A23, E9

Appendix A. (Continued)

- B. pseudofuscescens* (Gyelnik) Brodo & D.Hawksw.--Conifer branches: E9
- B. simplicior* (Vainio) Brodo & D.Hawksw.--Conifer branches: E9
- Buellia lepidastr* (Tuck.) Tuck.--Rotting wood: A4
- B. punctata* (Hoffm.) Massal.--Rotting wood: A6
- Caloplaca arenaria* (Pers.) Müll. Arg.--Rock: A17
- C. epithallina* Lynge--Rocks, lichens: A21, E4, E10
- C. saxicola* (Hoffm.)--Rocks: A2, E10
- Candelariella aurella* (Hoffm.) Zahlbr.--Rocks: E5, G7
- C. vitellina* (Hoffm.) Müll. Arg.--Rocks: A12, A17, A18, A21, A22, E1, E6, E10, E11, G3
- C. xanthostigma* (Ach.) Lettau--Aspen bark: G4
- Catapyreneum lachneum* (Ach.) R. Sant.--Soil, rocks: A7, A14, A18, A22
- Catillaria chalybeia* (Borrer) Massal.--Rocks: G2, G6
- Chrysothrix chlorina* (Ach.) Laundon--Aspen bark, rocks: A14, G4
- Cladonia bacillaris* Nyl.--Soil: E4
- C. cariosa* (Ach.) Sprengel--Soil: A17, A18, A24, E7, E11, G6
- C. carneola* (Fr.) Fr.--Forest floor: A3, A4, A6, A12, A22, A24, E2, E3, E9, E10, E11, G2, G9, G10
- C. cenotea* (Ach.) Schaerer--Forest floor: A1, A3, A5, A11, A15, A16, A20, E7, E8, E9, E10, E11, G12
- C. cervicornis* (Ach.) Flotow subsp. *verticillata* (Hoffm.) Ahti--Forest floor: A7, A9, A22, A23, E8, E3
- C. chlorophaea* (Flörke ex Sommerf.)--Forest floor: A11, A12, A15, A16, E1, E2, E3, E6, E9, E11, G9, G10, G12
- C. coccifera* (L.) Willd.--Soil: A6, G11

Appendix A. (Continued)

- C. coniocraea* auct. (fide Ahti)--Forest floor: A3, A9, A13, A15, A16, A19, E3, E6, E8, E9, E10, E11, G2, G6, G9, G10, G11, G12
- C. cornuta* (L.) Hoffm. subsp. *cornuta*--Forest floor: A22
- C. deformis* (L.) Hoffm.--Forest floor: A6, A9, A10, A11, A13, A16, A20, E9, G9, G10
- C. ecmocyna* Leighton subsp. *ecmocyna*--Forest floor: A1, A2, A3, A4, A6, A9, A10, A11, A13, A15, A16, A19, A20, A23, A24, E3
- C. fimbriata* (L.) Fr.--Forest floor: A1, A3, A5, A6, A9, A10, A11, A13, A16, A18, A19, A22, A23, A24, E2, E4, E6, E7, E8, E10, E11, G4, G5, G6, G8, G10
- C. macrophylla* (Schraerer) Stenh.--Soil: A22
- C. merochlorophaea* Asah.--Detritus, soil: A9
- C. multiformis* G. K. Merr.--Forest floor: A15, A18, A20, E2, G12
- C. ochrochlora* Flörke--Detritus: A1, G2
- C. pyxidata* (L.) Hoffm.--Forest floor: A1, A5, A7, A15, E2, E4, E7, E8, G9, G10
- C. subulata* (L.) Weber ex Wigg.--Forest floor: A5, E2, E7, E9, E11
- C. sulphurina* (Michaux) Fr.--Forest floor: A1, A3, A4, A13, A15, A20, E4, G11
- C. symphycarpa* (Ach.) Fr.--Forest floor: A21, G5, G12
- C. umbricola* Tønssb. & Ahti--Detritus, soil: A11, A19, A20
- Coelocaulon aculeatum* (Schreber) Link--Soil: A8
- Collema coccophorum* Tuck.--Sandy soil: G1
- C. furfuraceum* (Arnold) Du Rietz--Rock: G12
- Dermatocarpon intestiniforme* (Korber) Hasse--Rock: A18
- D. luridum* (With.) Laundon--On rock in seep: G2
- D. miniatum* (L.) Mann--Rocks: G1
- D. moulinsii* (Mont.) Zahlbr.--Rocks: E1

Appendix A. (Continued)

Dimelaena oreina (Ach.) Norman--Rocks: A21, E1, E6, G7

Diploschistes canadensis Räsänen--Rocks: A14

D. scruposus (Schreber) Norman--Soil: A14, A21

Diplotomma penichrum (Tuck.) Szat.--Bark: A15

Hypogymnia austerodes (Nyl.) Räsänen--Bark, branches, logs, rocks: A3, A5, A11, A12, A20, A22, A23, A24, E2, E4, E7, E9

H. bitteri (Lyngé) Ahti--Branches: A16, A20

H. imshaugii Krog--Branches: A1, A6, A13, A15, A16, A17, A19, A20, A22, A23, A24, E3, E4, E7, E9, E10, G1, G2, G5, G6, G8, G9, G10, G12

H. metaphysodes (Asah.) Rass.--Branches: A15

H. occidentalis Pike--Branches: A16, A19

H. physodes (L.) Nyl.--Branches, bark: A1, A15, A10, A16, A19, A20, E2, E6, E7, E8, E9, E10, E11, G2, G5, G9, G10, G11, G12

H. tubulosa (Schraerer) Havaas--Branches: A15, A19, A20, A24, E7, E9, E11

Icmadophila ericetorum (L.) Zahlbr.--Lignum: A3, G9

Imshaugii aleurites (Ach.) S. F. Meyer--Lignum: A3, G9

Lecanora allophana Nyl.--Bark: A24

L. argopholis (Ach.) Ach.--Rocks: A12

L. cenisia (Sm.) Ach.--Rocks: A14, E8

L. crenulata Hook.--Rock: G1

L. dispersa (Pers.) Sommerf.--Rocks: A9, E4, E8, E11, G7

L. hagenii (Ach.) Ach.--Rocks: A6, A7, A17, A22, E1, E3, E4, G1, G8

L. muralis (Schreber) Rabenh.--Rocks: A8, G1, G7

L. novomexicana (B. de Lesd.) Zahlbr.--Rocks: A2, A8, A21, E4, E5, E6, G3

Appendix A. (Continued)

- L. piniperda* Körber--Rocks: A10
- L. polytropa* (Hoffm.) Rabenh.--Rocks: A2, A4, A7, A8, A9, A12, A17, A18, A19, A22, A23, E3, E8, E10, E11, G3, G6
- L. pulicaris* (Pers.) Ach.--Lignum: A1, A3, A5, A10, A11, A20, A23, E9
- L. rupicola* (L.) Zahlbr.--Rocks: A2, A8, A14, E4, E5, E10, G3
- L. symmicta* (Ach.) Ach.--Rocks: E9
- Lecidea atrobrunnea* (Ramond in Lam. & DC.) Schaerer--Rocks: A(1, 2, 4, 7, 8, 9, 12, 17, 18, 21, 22, 23); E(1, 4, 5, 8, 11), G1, G3, G7
- L. auriculata* Th. Fr. --Rocks: A4, A17, A18, E1, E11, G1
- L. berengeriana* (Massal.) Nyl.--Soil with moss, duff: A3, A23, E10
- L. elabens* Fr.--Bark: E2
- L. lapicida* (Ach.) Ach.--Rocks: E3
- L. leucophaea* (Flörke ex Rabenh.) Nyl.--Rocks: A17
- L. lithophila* (Ach.) Ach.--Rocks: E8
- L. plana* (Lahm in Körber) Nyl.--Rocks: A18, G7
- L. tessellata* Flörke--Rocks: A1, A2, A21, E2, E4, E11, G7
- Lecidella euphorea* (Flörke) Hertel--Lignum, soil: A6, A7, A9, A10, A12, A15, A23, E4, G4
- L. stigmathea* (Ach.) Hertel & Leuck.--Rocks: A8, A17, A18, E1, G12
- Lepraria incana* (L.) Ach.--Rocks, soil: A14, A17, A22, E3
- L. membranacea* auct.--Rocks, soil: A6, A8, A12, A21, A23, E5, E8, E10
- L. neglecta* (Nyl.) Lettau --Rocks: A14, A23, E4
- Letharia columbiana* (Nutt.) Thomson--Lignum: A1, A3, A4, A5, A6, A7, A12, A17, A22, A23, A24, E3, G2, G5, G10

Appendix A. (Continued)

L. vulpina (L.) Hue--Lignum: A(1, 3, 6, 10, 11, 12, 13, 15, 16, 19, 20, 22, 23, 24); E(1, 2, 3, 4, 6, 7, 8, 9, 10, 11); G(1, 2, 5, 6, 8, 9, 10, 11, 12)

Massalongia carnosia (Dickson) Körber--Detritus: A17

Melanelia exasperatula (Nyl.) Essl.--Bark: A20, A23, A24, E7, E10

M. granulosa (Lyng.) Essl.--Rock: A14, A22, E10

m. incolorata (Parr.) Essl.--Bark: E7

M. infumata (Nyl.) Essl.--Rocks, bark, soil: A2, A21, E6, E9, E10

M. sorediata (Ach.) Goward & Ahti --Rock: E10

M. stygia (L.) Essl.--Rock: A2, A21

M. subelegantula (Essl.) Essl. --Bark, branches: A3, A16, A19, G5

M. subolivacea (Nyl. in Hasse) Essl.--Bark, branches: E1, E2, E7, G8, G12

M. substygia (Räsänen) Essl.--Rocks: E1

Nephroma parile (Ach.) Ach. --Soil, rock: A14, A15

Pannaria leucosticta (Tuck. in Darl.) Tuck. ex Nyl.--Soil, moss: A3

Parmelia saxatilis (L.) Ach.--Rocks, bark: A15, E6, E7, E10, E11

P. sulcata Taylor--Lignum: A(1, 14, 15, 16, 19, 20); E(2, 6, 7, 9, 10, 11); G(4, 5, 6, 8, 9, 10, 11, 12)

Parmeliopsis ambigua (Wulfen in Jacq.) Nyl.--Lignum: A(1, 3, 5, 6, 9, 10, 11, 12, 13, 15, 16, 19, 20, 22, 23, 24); E(1, 2, 3, 4, 7, 8, 9, 10, 11); G(2, 5, 6, 8, 9, 10, 11, 12)

P. hyperopta (Ach.) Arnold--Lignum: A(1, 2, 3, 5, 6, 9, 10, 11, 12, 13, 15, 16, 19, 20, 22, 23); E(2, 4, 7, 8, 9, 10, 11); G(2, 6, 10)

Peltigera aphthosa (L.) Willd.--Forest floor: A(1, 5, 10, 11, 13, 15, 16, 19, 20, 22, 24); E(2, 3, 9, 10, 11); G(6, 9, 10)

P. canina (L.) Willd.--Forest floor: A(1, 5, 11, 15, 16, 17, 19, 20, 22, 23, 24); E(2, 3, 4, 7, 9, 10, 11); G(5, 8, 9, 10, 11)

Appendix A. (Continued)

- P. collina* (Ach.) Schrader--Moss on rock: A16
- P. degenii* Gyelnik--Moss on rock, soil: A1, A3
- P. didactyla* (With.) Laundon--Forest floor: E7, E10
- P. horizontalis* (Huds.) Baumg.--Forest floor: G12
- P. malacea* (Ach.) Funck--Forest floor: A5, A9, E6, E8, G2, G3, G6
- P. membranacea* (Ach.) Nyl.--Soil with moss: A19
- P. neckeri* Hepp ex Müll. Arg.--Moss on soil: E11
- P. polydactyla* (Necker) Hoffm.--Forest floor: A9, A13, G8
- P. rufescens* (Weis) Humb.--Soil, forest floor: A(4, 8, 10, 12, 18, 21); E(1, 2, 4, 8); G(1, 3, 9, 12)
- P. venosa* (L.) Hoffm.--Soil: A(1, 5, 13, 20, 24); E3, E8
- Phaeophyscia constipata* (Norrin & Nyl.) Moberg--Rocks: A14
- P. endococcinea* (Körber) Moberg--Rocks: E10
- P. sciastra* (Ach.) Moberg--Rocks; E6
- Physcia adscendens* (Fr.) H. Olivier--Aspen bark: G4
- P. caesia* (Hoffm.) Fűrnr.--Rocks: A2, A17, A18, A21, E4, E10, G1, G7
- P. dubia* (Hoffm.) Lettau--Rocks: A2, A8, A17, A22
- P. stellaris* (L.) Nyl.--Aspen bark: G4
- Physconia muscigena* (Ach.) Poelt--Rocks: E1, E10
- Platismatia glauca* (L.) Culb. & C. Culb.--Lignum: A(1, 10, 15, 16, 19, 20); E(1, 6, 7, 8, 9, 10, 11); G(6, 9, 10, 11, 12)
- Porpidia crustulata* (Ach.) Hertel & Knoph--Rocks: A1, A17
- P. macrocarpa* (DC. *in* Lam. & DC.) Hertel & Schwab--Rocks: A10, A19

Appendix A. (Continued)

Pseudephebe pubescens (L.) M. Choisy--Rocks: A(2, 8, 12, 14, 21, 22); E(5, 6, 10, 11); G3, G6

Psora decipiens (Hedwig) Hoffm. --Rocks: G12

Psoroma hypnorum (Vahl) Gray --Soil: A1, A15, A23, E2, E3, E4

Rhizocarpon concentricum (Davies) Beltram. --Rocks: G7

R. disporum (Naeg. ex Hepp) Mull. Arg. --Rocks: A(2, 12, 14, 18, 21, 22); E(1, 8, 10, 11); G7

R. geographicum (L.) DC. Rocks: A1, A2, A7, A8, A18, A22

R. grande (Flörke ex Flowtow) Arnold --Rocks: A9, A18, E6, E10

R. riparium Räsänen --Rocks: A(4, 8, 9, 10, 12, 14, 17, 19, 21, 22, 23); E(3, 4, 5, 8, 11); G2

R. sphaerosporum Räsänen --Rocks: A14, E12

R. superficiale (Schaerer) Vainio --Rocks: A21

Rhizoplaca chrysoleuca (Sm.) Zopf --Rocks: A21, E(1, 5, 6, 9, 10, 11); G7

R. melanophthalma (DC. in Lam. & DC.) Leuck & Poelt --A2, A21, E(1, 5, 6, 8, 10); G7

R. peltata (Ramond) Leuck & Poelt --Rocks: A8, G1, G7, G12

Rimularia insularis (Nyl.) Rambold & Hertel --Rocks: E11

Solorina crocea (L.) Ach. --Soil: E3, E9

Sporastatia testudinea (Ach.) Massal. --Rocks: A2, A8, A19, E4

Staurothele fuscocuprea (Nyl.) Zsch. --Rocks: G7

Stereocaulon paschale (L.) Hoffm. --Forest floor: A24

S. tomentosum Fr. --Forest floor: A10, E3

Tephromela armeniaca (DC.) Hertel & Rambold --Rocks: E4

Thyrea pulvinata (Schaerer) Massal.--Rocks: G12

Appendix A. (Continued)

Trapeliopsis granulosa (Hoffm.) Lumbsch.--Soil, detritus: A(1, 4, 6, 7, 11, 12, 17, 22, 24); E(3, 4, 8, 10)

Tuckermannopsis chlorophylla (Willd. in Humb.) Hale --Lignum: A15, A16, A19, E(2, 6, 7, 9, 11); G(5, 6, 8, 9, 11, 12)

T. merrillii (Du Rietz) Hale --Bark: A13, A22, E3, G2

T. pinastri (Scop.) Hale --Lignum: A5, A20, E(2, 4, 6, 7, 11); G(2, 5, 6, 9, 11, 12)

T. platyphylla (Tuck.) Hale --Lignum: A15, A19, A20, E10, G2, G10

Umbilicaria americana (L.) Ach.--Rocks: A14, E6

U. hyperborea (Ach.) Hoffm. var. *hyperborea* --Rocks: A(2, 4, 8, 12, 14, 18, 21, 22); E(1, 3, 4, 5, 6, 8, 9, 10, 11); G7

U. kraschennikovii (Savicz) Zahlbr. --Rocks: A8, A18, A22, E4, E5, E11

U. phaea Tuck. --Rocks: G7

U. vellea (L.) Ach. --Rocks: E1

U. virginis Schraerer --Rocks: A8, A22, E5

Usnea cavernosa Tuck. --Branches: G11

U. filipendula Stirton --Branches: G11

U. hirta (L.) Weber ex Wigg. --Branches: E(1, 2, 7, 10); G(1, 2, 5, 6, 8, 9, 10, 11)

U. lapponica Vainio --Branches: A(3, 13, 19, 20,); E2, E3, E9, G9, G11, G12

U. scabrata Nyl. --Branches: G10, G12

U. subfloridana Stirton --Branches, bark: E4, E7, E9, E11, G(4, 5, 6, 8, 9, 12)

Verrucaria glaucovirens Grumm. --Rocks: A17, G7

Xanthoparmelia chlorochroa (Tuck.) Hale --Loose on soil: E1

X. coloradoensis (Gyelnik) Hale --Rocks: A8, A21

X. conspersa (Ehrh. ex Ach.) Hale --Rocks: E1

Appendix A. (Continued)

X. cumberlandia (Gyelnik) Hale --Rocks: E5, E10

X. lineola (Berry) Hale --Rocks: E4

X. mexicana (Gyelnik) Hale --Rocks: E1, E6

X. novomexicana (Gyelnik) Hale --Rocks: E10

X. plittii (Gyelnik ex D. Dietr.) Hale --Rocks: G7

X. subdicipiens (Vainio) Hale --Rocks: G7

X. wyomingica (Gyelnik) Hale--Soil: A21

Xanthoria elegans (Link) Th. Fr. --Rocks: A2, A8, E5, E10, G4, G7, G12

X. polycarpa (Hoffm.) Rieber --Aspen bark: G4

X. sorediata (Vainio) Poelt --Rocks: A8, E4, E5

APPENDIX B

Tables

Table 17. Data matrix of species occurring at each collection site. Sites are arranged according to vegetation present within each study area. Species are grouped by common substrate. X=present, --=absent

Vegetation Collection Sites	ROCKS (talus & outcrops)			<i>Juniperus communis</i>		MEADOW	<i>Pseudotsuga menziesii</i>			<i>Potr</i>	<i>Pinus contorta</i>			<i>Abies lasiocarpa/Picea</i>		<i>Pinus albicaulis</i>			
	Gates	Elkhorn	Pintlers	Gates	Elkhorn	Gates	Gates	Elkhorns	Pintlers	Gates	Gates	Elkhorns	Pintlers	Elkhorns	Pintlers	Pintlers			
	G7	E5	A2,A14,A21	G1	E1	G3	G(5,8,9,- 10,11,12)	E(2,6,7, 10,11)	A15	G4	G2, G6	E3, E8	A(4,9,13,18,22)	E4, E9	A(1,3,5,6,10,11,16, 19,20,23,24)	A7	A12	A17	A8
SPECIES																			
Lichens found on rocks																			
<i>Acarospora cervina</i>	--	--	--	--	--	--	X	--	--	--	--	--	--	--	--	--	--	--	--
<i>Acarospora chlorophana</i>	--	--	--	--	X	--	--	--	--	--	--	--	--	X	--	--	--	--	X
<i>Acarospora fuscata</i>	X	--	--	--	X	--	--	X	--	--	--	X	X	--	--	--	--	X	--
<i>Acarospora strigata</i>	X	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
<i>Aspicilia caesiocinerea</i>	X	--	X	--	X	X	--	X	--	--	X	X	X	--	X	X	--	X	--
<i>Aspicilia calcarea</i>	--	--	--	--	--	--	--	--	--	--	--	--	--	--	X	--	--	--	--
<i>Aspicilia cinerea</i>	X	--	--	--	X	--	--	X	--	--	--	X	X	--	--	--	--	--	X
<i>Aspicilia supertegens</i>	--	--	--	--	--	--	--	--	--	--	--	--	--	--	X	--	--	--	--
<i>Bellemeria alpina</i>	--	--	--	--	--	--	--	X	--	--	--	X	X	--	X	--	X	--	--
<i>Bellemeria cinereorufescens</i>	--	--	--	--	--	--	--	--	--	--	--	--	X	--	--	--	X	--	--
<i>Buellia lepidastr</i>	--	--	--	--	--	--	--	--	--	--	--	--	X	--	--	--	--	--	--
<i>Caloplaca arenaria</i>	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	X	--
<i>Caloplaca epithallina</i>	--	--	X	--	--	--	--	X	--	--	--	--	--	X	--	--	--	--	--
<i>Caloplaca saxicola</i>	--	--	X	--	--	--	--	X	--	--	--	--	--	--	--	--	--	--	--
<i>Candelariella aurella</i>	X	X	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
<i>Candelariella vitellina</i>	X	--	X	--	X	X	--	X	--	--	--	--	X	--	--	--	X	X	--
<i>Catapyrenium lachneum</i>	--	--	X	--	--	--	--	--	--	--	--	--	X	--	--	--	X	--	--
<i>Catillaria chalybeia</i>	--	--	--	--	--	--	--	--	--	--	X	--	--	--	--	--	--	--	--
<i>Collema furfuraceum</i>	--	--	--	--	--	--	X	--	--	--	--	--	--	--	--	--	--	--	--
<i>Dermatocarpon intestineforme</i>	--	--	--	--	--	--	--	--	--	--	--	--	X	--	--	--	--	--	--
<i>Dermatocarpon luridum</i>	--	--	--	--	--	--	--	--	--	--	X	--	--	--	--	--	--	--	--
<i>Dermatocarpon miniatum</i>	--	--	--	X	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
<i>Dermatocarpon moulinsii</i>	--	--	--	--	X	--	--	--	--	--	--	--	--	--	--	--	--	--	--
<i>Dimelaena oreina</i>	X	--	X	--	X	--	--	X	--	--	--	--	--	--	--	--	--	--	--
<i>Diploschistes canadensis</i>	--	--	X	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
<i>Diploschistes scruposus</i>	--	--	X	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
<i>Lecanora argopholis</i>	--	--	X	--	--	--	--	--	--	--	--	--	--	--	--	--	X	--	--
<i>Lecanora cenisia</i>	--	--	X	--	--	--	--	--	--	--	--	X	--	--	--	--	--	--	--
<i>Lecanora crenulata</i>	--	--	--	X	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
<i>Lecanora dispersa</i>	X	--	--	--	--	--	--	X	--	--	--	X	X	X	--	--	--	--	--
<i>Lecanora muralis</i>	X	--	--	X	--	--	--	--	--	--	--	--	--	--	--	--	--	--	X
<i>Lecanora novomexicana</i>	--	X	X	--	--	X	--	X	--	--	--	--	--	X	--	--	--	--	X
<i>Lecanora piniperda</i>	--	--	--	--	--	--	--	--	--	--	--	--	--	--	X	--	--	--	--
<i>Lecanora polytropa</i>	--	--	X	--	--	X	--	X	--	--	X	X	X	--	X	X	X	X	X
<i>Lecanora rupicola</i>	--	X	X	--	--	X	--	X	--	--	--	--	--	X	--	--	--	--	X
<i>Lecidea atrobrunnea</i>	X	X	X	X	X	X	--	X	--	--	--	X	X	X	X	X	X	X	X

Table 17. (Continued)

Vegetation	ROCKS			Juniperus communis		MEADOW	Pseudotsuga menziesii			Potr	Pinus contorta			Abies lasiocarpa/Picea			Pinus albicaulis				
Collection Sites	Gates	Elkhorn	Pintlers	Gates	Elkhorn	Gates	Gates	Elkhorns	Pintlers	Gates	Gates	Elkhorns	Pintlers	Elkhorns	Pintlers		Pintlers	A7	A12	A17	A8
	G7	E5	A2,A14,A21	G1	E1	G3	G(5,8,9,- 10,11,12)	E(2,6,7, 10,11)	A15	G4	G2, G6	E3, E8	A(4,9,13,18,22)	E4, E9	A(1,3,5,6,10,11,16, 19,20,23,24)						
SPECIES																					
Lecidea auriculata	--	--	--	X	X	--	--	X	--	--	--	--	X	--	--	--	--	X	--	--	
Lecidea lapicida	--	--	--	--	--	--	--	--	--	--	--	X	--	--	--	--	--	--	--	--	
Lecidea leucophaea	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	X	--	--	
Lecidea lithophila	--	--	--	--	--	--	--	--	--	--	--	X	--	--	--	--	--	--	--	--	
Lecidea plana	X	--	--	--	--	--	--	--	--	--	--	--	X	--	--	--	--	--	--	--	
Lecidea species (no apo)	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	
Lecidea tessellata	X	X	X	--	--	--	--	X	--	--	--	--	--	X	X	--	--	--	--	--	
Lecidella stigmata	--	--	--	--	X	--	X	--	--	--	--	--	X	--	--	--	--	X	X	--	
Lepraria incana	--	--	X	--	--	--	--	--	--	--	--	X	X	--	--	--	--	X	--	--	
Lepraria neglecta	--	--	X	--	--	--	--	--	--	--	--	--	--	X	X	--	--	--	--	--	
Melanelia granulosa	--	--	X	--	--	--	--	X	--	--	--	--	X	--	--	--	--	--	--	--	
Melanelia infumata	--	--	X	--	--	--	--	X	--	--	--	--	--	X	--	--	--	--	--	--	
Melanelia sorediata	--	--	--	--	--	--	--	X	--	--	--	--	--	--	--	--	--	--	--	--	
Melanelia stygia	--	--	X	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	
Melanelia substygia	--	--	--	--	X	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	
Nephroma parile	--	--	X	--	--	--	--	--	X	--	--	--	--	--	--	--	--	--	--	--	
Phaeophyscia constipata	--	--	X	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	
Phaeophyscia endococcinea	--	--	--	--	--	--	--	X	--	--	--	--	--	--	--	--	--	--	--	--	
Phaeophyscia orbicularis	--	--	X	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	
Phaeophyscia sciastra	--	--	--	--	--	--	--	X	--	--	--	--	--	--	--	--	--	--	--	--	
Physcia caesia	X	--	X	X	--	--	--	X	--	--	--	--	X	X	--	--	--	X	--	--	
Physcia dubia	--	--	X	--	--	--	--	X	--	--	--	--	X	--	--	--	--	X	X	--	
Physconia muscigena	--	--	--	--	X	--	--	X	--	--	--	--	--	--	--	--	--	--	--	--	
Porpidia crustulata	--	--	--	--	--	--	--	--	--	--	--	--	--	--	X	--	--	X	--	--	
Porpidia macrocarpa	--	--	--	--	--	--	--	--	--	--	--	--	--	--	X	--	--	--	--	--	
Pseudephebe pubescens	--	X	X	--	--	X	--	X	--	--	X	--	X	--	--	--	--	X	--	X	
Psora decipiens	--	--	--	--	--	--	X	--	--	--	--	--	--	--	--	--	--	--	--	--	
Rhizocarpon concentricum	X	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	
Rhizocarpon disporum	X	--	X	--	X	--	--	X	--	--	--	X	X	--	--	--	--	X	--	--	
Rhizocarpon geographicum	--	--	X	--	--	--	--	--	--	--	--	--	X	--	X	--	--	X	--	X	
Rhizocarpon grande	--	--	--	--	--	--	--	X	--	--	--	--	X	--	--	--	--	--	--	--	
Rhizocarpon riparium	--	X	X	--	--	--	--	X	--	--	X	X	X	X	X	--	X	X	X	X	
Rhizocarpon spaerosporum	--	--	X	--	--	--	--	--	--	--	--	X	--	--	--	--	--	--	--	--	
Rhizocarpon superficiale	--	--	X	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	

Table 17. (Continued)

Vegetation Collection Sites	ROCKS			<i>Juniperus communis</i>		MEADOW	<i>Pseudotsuga menziesii</i>			Potr	<i>Pinus contorta</i>			<i>Abies lasiocarpa/Picea</i>		<i>Pinus albicaulis</i>			
	Gates	Elkhorn	Pinliers	Gates	Elkhorn	Gates	Gates	Elkhorns	Pinliers	Gates	Gates	Elkhorns	Pinliers	Elkhorns	Pinliers	Pinliers			
	G7	E5	A2,A14,A21	G1	E1	G3	G(5,8,9, 10,11,12)	E(2,6,7, 10,11)	A15	G4	G2, G6	E3, E8	A(4,9,13,18,22)	E4, E9	A(1,3,5,6,10,11,16, 19,20,23,24)	A7	A12	A17	A8
SPECIES																			
<i>Rhizoplaca chryssoleuca</i>	X	X	X	-	X	-	-	X	-	-	-	-	-	X	-	-	-	-	-
<i>Rhizoplaca melanophthalma</i>	X	X	X	-	X	-	-	X	-	-	-	X	-	-	-	-	-	-	-
<i>Rhizoplaca peltata</i>	X	-	-	X	-	-	X	-	-	-	-	-	-	-	-	-	-	-	X
<i>Rimularia insularis</i>	-	-	-	-	-	-	-	X	-	-	-	-	-	-	-	-	-	-	-
<i>Sporastatia tesudinea</i>	-	-	X	-	-	-	-	-	-	-	-	-	-	X	X	-	-	-	X
<i>Staurothele clopima</i>	X	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
<i>Tephromela armeniaca</i>	-	-	-	-	-	-	-	-	-	-	-	-	-	X	-	-	-	-	-
<i>Thyrea pulvinata</i>	-	-	-	-	-	-	X	-	-	-	-	-	-	-	-	-	-	-	-
<i>Umbilicaria hyperborea</i>	X	X	X	-	X	-	-	X	-	-	-	X	X	X	-	-	X	-	X
<i>Umbilicaria kraschennikovii</i>	-	X	-	-	-	-	-	X	-	-	-	-	X	X	-	-	-	-	X
<i>Umbilicaria phaea</i>	X	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
<i>Umbilicaria vellea</i>	-	-	X	-	X	-	-	X	-	-	-	-	-	-	-	-	-	-	-
<i>Umbilicaria virginis</i>	-	X	-	-	-	-	-	-	-	-	-	-	X	-	-	-	-	-	X
<i>Verrucaria glaucovirens</i>	X	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	X	-
<i>Xanthoparmelia coloradoensis</i>	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	X
<i>Xanthoparmelia conspersa</i>	-	-	-	-	X	-	-	-	-	-	-	-	-	-	-	-	-	-	-
<i>Xanthoparmelia cumberlandia</i>	-	X	X	-	-	-	-	X	-	-	-	-	-	-	-	-	-	-	X
<i>Xanthoparmelia lineola</i>	-	-	-	-	-	-	-	-	-	-	-	-	-	X	-	-	-	-	-
<i>Xanthoparmelia mexicana</i>	-	-	-	-	X	-	-	X	-	-	-	-	-	-	-	-	-	-	-
<i>Xanthoparmelia novomexicana</i>	-	-	-	-	-	-	-	X	-	-	-	-	-	-	-	-	-	-	-
<i>Xanthoparmelia plittii</i>	X	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
<i>Xanthoparmelia subdecepiens</i>	X	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
<i>Xanthoria elegans</i>	X	X	X	-	-	-	X	X	-	X	-	-	-	-	-	-	-	-	X
<i>Xanthoria polycarpa</i>	-	-	-	-	-	-	-	-	-	X	-	-	-	-	-	-	-	-	-
<i>Xanthoria sorediata</i>	-	X	-	-	-	-	-	-	-	-	-	-	-	X	-	-	-	-	X
Lichens found on soil, detritis, duff																			
<i>Cladonia umbricola</i>	-	-	-	-	-	-	-	-	-	-	-	-	-	-	X	-	-	-	-
<i>Collema coccophorum</i>	-	-	-	X	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
<i>Lecidea berengeriana</i>	-	-	-	-	-	-	-	X	-	-	-	-	-	-	X	-	-	-	-
<i>Lepraria membranacea</i>	-	X	X	-	-	-	-	X	-	-	-	X	-	-	X	-	X	-	X
<i>Pannaria leucosticta</i>	-	-	-	-	-	-	-	-	-	-	-	-	-	-	X	-	-	-	-
<i>Psoroma hypnorum</i>	-	-	-	-	-	-	-	X	X	-	-	X	-	X	X	-	-	-	-
<i>Trapeliopsis granulosa</i>	-	-	-	-	-	-	-	X	-	-	-	X	X	X	X	X	X	X	-
<i>Xanthoparmelia chlorochroa</i>	-	-	-	-	X	-	-	-	-	-	-	-	-	-	-	-	-	-	-
<i>Xanthoparmelia wyomingica</i>	-	-	X	-	X	-	-	-	-	-	-	-	-	-	-	-	-	-	-

Table 17. (Continued)

Vegetation Collection Sites	ROCKS			<i>Juniperus communis</i>		MEADOW	<i>Pseudotsuga menziesii</i>			Potr	<i>Pinus contorta</i>			<i>Abies lasiocarpa/Picea</i>		<i>Pinus albicaulis</i>			
	Gates	Elkhorn	Pintlers	Gates	Elkhorn	Gates	Gates	Elkhorns	Pintlers	Gates	Gates	Elkhorns	Pintlers	Elkhorns	Pintlers	Pintlers			
	G7	E5	A2,A14,A21	G1	E1	G3	G(5,8,9, 10,11,12)	E(2,6,7, 10,11)	A15	G4	G2, G6	E3, E8	A(4,9,13,18,22)	E4, E9	A(1,3,5,6,10,11,16, 19,20,23,24)	A7	A12	A17	A8
SPECIES																			
Lichens found on rotting wood																			
<i>Buellia punctata</i>	-	-	-	-	-	-	-	-	-	-	-	-	-	-	X	-	-	-	-
<i>Cladonia ochrochlora</i>	-	-	-	-	-	-	-	-	-	-	X	-	-	-	X	-	-	-	-
<i>Immadophila ericetorum</i>	-	-	-	-	-	-	X	-	-	-	-	-	-	-	X	-	-	-	-
<i>Massalongia carnea</i>	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	X	-
Lichens found on the forest floor																			
<i>Cladonia bacillaris</i>	-	-	-	-	-	-	-	-	-	-	-	-	-	X	-	-	-	-	-
<i>Cladonia cariosa</i>	-	-	-	-	-	-	-	X	-	-	X	-	X	-	X	-	-	X	-
<i>Cladonia carneola</i>	-	-	-	-	-	-	X	X	-	-	X	X	X	X	X	-	X	-	-
<i>Cladonia cenotea</i>	-	-	-	-	-	-	X	X	X	-	-	X	-	X	X	-	-	-	-
<i>Cladonia cervicomis</i>	-	-	-	-	-	-	-	-	-	-	-	X	X	-	X	X	-	-	-
<i>Cladonia chlorophaea</i>	-	-	-	-	X	-	X	X	X	-	-	X	-	X	X	-	X	-	-
<i>Cladonia coccifera</i>	-	-	-	-	-	-	X	-	-	-	-	-	-	-	X	-	-	-	-
<i>Cladonia coniocraea</i>	-	-	-	-	-	-	X	X	X	-	X	X	X	X	X	-	-	-	-
<i>Cladonia cornuta</i>	-	-	-	-	-	-	-	-	-	-	-	-	X	-	-	-	-	-	-
<i>Cladonia deformis</i>	-	-	-	-	-	-	X	-	-	-	-	-	X	X	X	-	-	-	-
<i>Cladonia ecmocyna</i>	-	-	X	-	-	-	-	-	X	-	-	X	X	-	X	-	-	-	-
<i>Cladonia fimbriata</i>	-	-	-	-	-	-	X	X	-	X	X	X	X	X	X	-	-	-	-
<i>Cladonia macrophylla</i>	-	-	-	-	-	-	-	-	-	-	-	-	X	-	-	-	-	-	-
<i>Cladonia meroclrophaea</i>	-	-	-	-	-	-	-	-	-	-	-	-	X	-	-	-	-	-	-
<i>Cladonia multiformis</i>	-	-	-	-	-	-	X	X	X	-	-	-	X	-	X	-	-	-	-
<i>Cladonia pyxidata</i>	-	-	-	-	-	-	X	X	X	-	-	X	-	X	X	X	-	-	-
<i>Cladonia subulata</i>	-	-	-	-	-	-	-	X	-	-	-	-	-	X	X	-	-	-	-
<i>Cladonia sulphurina</i>	-	-	-	-	-	-	X	-	X	-	-	-	X	X	X	-	-	-	-
<i>Cladonia symphyocarpa</i>	-	-	X	-	-	-	X	-	-	-	-	-	-	-	-	-	-	-	-
<i>Coelocaulon aculeatum</i>	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	X
<i>Peltigera aphosa</i>	-	-	-	-	-	-	X	X	X	-	X	X	X	X	X	-	-	-	-
<i>Peltigera canina</i>	-	-	-	-	-	-	X	X	X	-	-	X	X	X	X	-	-	X	-
<i>Peltigera collina</i>	-	-	-	-	-	-	-	-	-	-	-	-	-	-	X	-	-	-	-
<i>Peltigera degenii</i>	-	-	-	-	-	-	-	-	-	-	-	-	-	-	X	-	-	-	-
<i>Peltigera didactyla</i>	-	-	-	-	-	-	-	X	-	-	-	-	-	-	-	-	-	-	-

Table 17. (Continued)

Vegetation Collection Sites	ROCKS			<i>Juniperus communis</i>		MEADOW	<i>Pseudotsuga menziesii</i>			Potr	<i>Pinus contorta</i>			<i>Abies lasiocarpa/Picea</i>		<i>Pinus albicaulis</i>			
	Gates	Elkhorn	Pinflers	Gates	Elkhorn	Gates	Gates	Elkhorns	Pinflers	Gates	Gates	Elkhorns	Pinflers	Elkhorns	Pinflers	Pinflers			
	G7	E5	A2,A14,A21	G1	E1	G3	G(5,8,9,- 10,11,12)	E(2,6,7, 10,11)	A15	G4	G2, G6	E3, E8	A(4,9,13,18,22)	E4, E9	A(1,3,5,6,10,11,16, 19,20,23,24)	A7	A12	A17	A8
SPECIES																			
<i>Peltigera horizontalis</i>	-	-	-	-	-	-	X	-	-	-	-	-	-	-	-	-	-	-	-
<i>Peltigera malacea</i>	-	-	-	-	-	X	-	X	-	-	X	X	X	-	X	-	-	-	-
<i>Peltigera membranacea</i>	-	-	-	-	-	-	-	-	-	-	-	-	-	-	X	-	-	-	-
<i>Peltigera neckeri</i>	-	-	-	-	-	-	-	X	-	-	-	-	-	-	-	-	-	-	-
<i>Peltigera polydactyla</i>	-	-	-	-	-	-	X	-	-	-	-	-	X	-	-	-	-	-	-
<i>Peltigera rufescens</i>	-	-	X	X	X	X	X	X	-	-	-	X	X	X	X	-	X	-	X
<i>Peltigera venosa</i>	-	-	-	-	-	-	-	-	-	-	-	X	X	-	X	-	-	-	-
<i>Solorina crocea</i>	-	-	-	-	-	-	-	-	-	-	-	X	-	X	-	-	-	-	-
<i>Stereocaulon tomentosum</i>	-	-	-	-	-	-	-	-	-	-	-	X	-	-	X	-	-	-	-
<i>Stereocaulon paschale</i>	-	-	-	-	-	-	-	-	-	-	-	-	-	-	X	-	-	-	-
Lichens found primarily on tree trunks, bark, downed logs																			
<i>Bryoria glabra</i>	-	-	-	-	-	-	X	X	-	-	-	-	-	X	X	-	-	-	-
<i>Candelariella xanthostigma</i>	-	-	-	-	-	-	-	-	-	X	-	-	-	-	-	-	-	-	-
<i>Chrysothrix chlorina</i>	-	-	X	-	-	-	-	-	-	X	-	-	-	-	-	-	-	-	-
<i>Diplocoma penicrum</i>	-	-	-	-	-	-	-	-	X	-	-	-	-	-	-	-	-	-	-
<i>Imshaugia aleurites</i>	-	-	-	-	-	-	X	X	-	-	-	-	-	-	-	-	-	-	-
<i>Lecanora allophana</i>	-	-	-	-	-	-	-	-	-	-	-	-	-	-	X	-	-	-	-
<i>Lecanora hageni</i>	-	-	-	X	X	-	X	-	-	-	-	X	X	X	X	X	-	X	-
<i>Lecanora pulicaris</i>	-	-	-	-	-	-	-	-	-	-	-	-	-	X	X	-	-	-	-
<i>Lecanora symmicta</i>	-	-	-	-	-	-	-	-	-	-	-	-	-	X	-	-	-	-	-
<i>Lecidea elabens</i>	-	-	-	-	-	-	-	X	-	-	-	-	-	-	-	-	-	-	-
<i>Lecidella euphorea</i>	-	-	-	-	-	-	-	-	X	X	-	-	X	X	X	X	X	-	-
<i>Melanelia exasperatula</i>	-	-	-	-	-	-	-	X	-	-	-	-	-	-	X	-	-	-	-
<i>Melanelia incolorata</i>	-	-	-	-	-	-	-	X	-	-	-	-	-	-	-	-	-	-	-
<i>Melanelia subelegantula</i>	-	-	-	-	-	-	X	-	-	-	-	-	-	-	X	-	-	-	-
<i>Melanelia subolivacea</i>	-	-	-	-	X	-	X	X	-	-	-	-	-	-	-	-	-	-	-
<i>Parmelia saxatilis</i>	-	-	-	-	-	-	-	X	X	X	-	-	-	-	-	-	-	-	-
<i>Parmelia sulcata</i>	-	-	X	-	-	-	X	X	X	X	X	-	-	X	X	-	-	-	-
<i>Parmeliopsis ambigua</i>	-	-	-	-	X	-	X	X	X	-	X	X	X	X	X	-	X	-	-
<i>Parmeliopsis hyperopta</i>	-	-	X	-	-	-	X	X	X	-	X	X	X	X	X	-	X	-	-
<i>Physcia adscendens</i>	-	-	-	-	-	-	-	-	-	X	-	-	-	-	-	-	-	-	-
<i>Physcia stellaris</i>	-	-	-	-	-	-	-	-	-	X	-	-	-	-	-	-	-	-	-
<i>Platismatia glauca</i>	-	-	-	-	-	-	X	X	X	-	X	X	-	X	X	-	-	-	-
<i>Tuckermanopsis chlorophylla</i>	-	-	-	-	-	-	X	X	X	-	X	-	-	X	X	-	-	-	-
<i>Tuckermanopsis merrillii</i>	-	-	-	-	-	-	-	-	-	-	X	X	X	-	-	-	-	-	-
<i>Tuckermanopsis pinastri</i>	-	-	-	-	-	-	X	X	-	-	X	-	-	X	X	-	-	-	-
<i>Tuckermanopsis platyphylla</i>	-	-	-	-	-	-	X	X	X	-	X	-	-	-	X	-	-	-	-

Table 17. (Continued)

Vegetation Collection Sites	ROCKS			<i>Juniperus communis</i>		MEADOW	<i>Pseudotsuga menziesii</i>			Potr	<i>Pinus contorta</i>			<i>Abies lasiocarpa/Picea</i>		<i>Pinus albicaulis</i>			
	Gates	Elkhorn	Pintlers	Gates	Elkhorn	Gates	Gates	Elkhorns	Pintlers	Gates	Gates	Elkhorns	Pintlers	Elkhorns	Pintlers	Pintlers			
	G7	E5	A2,A14,A21	G1	E1	G3	G(5,8,9,- 10,11,12)	E(2,6,7, 10,11)	A15	G4	G2, G6	E3, E8	A(4,9,13,18,22)	E4, E9	A(1,3,5,6,10,11,16, 19,20,23,24)	A7	A12	A17	A8
SPECIES																			
Lichens found on branches; with or without bark																			
<i>Alectoria imshaugii</i>	-	-	-	-	-	-	-	-	X	-	-	-	-	-	-	-	-	-	-
<i>Alectoria sarmentosa</i>	-	-	-	-	-	-	-	-	X	-	-	X	-	X	X	-	-	-	-
<i>Bryoria abbreviata</i>	-	-	-	-	-	-	X	X	-	-	X	X	X	X	X	-	-	X	-
<i>Bryoria capillaris</i>	-	-	-	-	-	-	X	-	-	-	-	-	-	-	-	-	-	-	-
<i>Bryoria fremontii</i>	-	-	-	-	-	-	X	X	X	-	X	X	X	X	X	-	-	-	-
<i>Bryoria fuscescens</i>	-	-	-	-	-	-	X	X	X	-	X	X	X	X	X	-	-	X	-
<i>Bryoria lanestrus</i>	-	-	-	-	-	-	-	-	-	-	-	-	-	X	X	-	-	X	-
<i>Bryoria pseudofuscescens</i>	-	-	-	-	-	-	-	-	-	-	-	-	-	X	-	-	-	-	-
<i>Bryoria simplicior</i>	-	-	-	-	-	-	-	-	-	-	-	-	-	X	-	-	-	-	-
<i>Hypogymnia austerodes</i>	-	-	-	-	-	-	-	X	-	-	-	-	X	X	X	-	X	-	-
<i>Hypogymnia bitteri</i>	-	-	-	-	-	-	-	-	-	-	-	-	-	-	X	-	-	-	-
<i>Hypogymnia imshaugii</i>	-	-	-	X	-	-	X	X	X	-	X	X	X	X	X	-	-	X	-
<i>Hypogymnia metaphysodes</i>	-	-	-	-	-	-	-	-	X	-	-	-	-	-	X	-	-	-	-
<i>Hypogymnia occidentalis</i>	-	-	-	-	-	-	-	-	-	-	-	-	-	-	X	-	-	-	-
<i>Hypogymnia physodes</i>	-	-	-	-	-	-	X	X	X	-	X	X	-	X	X	-	-	-	-
<i>Hypogymnia tubulosa</i>	-	-	-	-	-	-	-	X	X	-	-	-	-	X	X	-	-	-	-
<i>Letharia columbiana</i>	-	-	-	-	-	-	X	-	-	-	X	X	X	X	X	X	X	X	-
<i>Letharia vulpina</i>	-	-	-	X	X	-	X	X	X	-	X	X	X	X	X	-	X	-	-
<i>Usnea cavemosa</i>	-	-	-	-	-	-	X	-	-	-	-	-	-	-	-	-	-	-	-
<i>Usnea ceratina</i>	-	-	-	-	-	-	X	-	-	-	-	-	-	-	-	-	-	-	-
<i>Usnea filipendula</i>	-	-	-	-	-	-	X	-	-	-	-	-	-	-	-	-	-	-	-
<i>Usnea hirta</i>	-	-	-	X	X	-	X	X	-	-	X	-	-	-	-	-	-	-	-
<i>Usnea lapponica</i>	-	-	-	-	-	-	X	X	-	-	-	X	X	X	X	-	-	-	-
<i>Usnea subfloridana</i>	-	-	-	-	-	-	X	X	-	X	X	-	-	X	-	-	-	-	-

Table 18. Data matrix of species occurring at each collection site. Sites are arranged by a combination of elevation and moisture gradients (Pfister *et al.*, 1977). Species are grouped by common substrate. X=present, --=absent.

[illegible]

Table 18. (Continued)

[illegible]

Table 18. (Continued)

[illegible]

Table 19. Jaccard's similarity values for all combinations of site comparisons based on lichen occurrence at each site. See Table 1 for site details.

Sites	A1	A2	A3	A4	A5	A6	A7	A8	A9	A10	A11	A12	A13	A14	A15	A16	A17	A18	A19	A20	A21	A22	A23	A24
A1	1.00																							
A2	0.09	1.00																						
A3	0.22	0.09	1.00																					
A4	0.09	0.13	0.09	1.00																				
A5	0.22	0.09	0.29	0.09	1.00																			
A6	0.22	0.09	0.24	0.09	0.24	1.00																		
A7	0.09	0.13	0.09	0.21	0.09	0.09	1.00																	
A8	0.09	0.28	0.09	0.13	0.09	0.09	0.13	1.00																
A9	0.18	0.09	0.18	0.09	0.18	0.18	0.09	0.09	1.00															
A10	0.22	0.09	0.24	0.09	0.24	0.31	0.09	0.09	0.18	1.00														
A11	0.22	0.09	0.39	0.09	0.29	0.24	0.09	0.09	0.18	0.24	1.00													
A12	0.18	0.09	0.18	0.09	0.18	0.18	0.09	0.09	0.21	0.18	0.18	1.00												
A13	0.22	0.09	0.26	0.09	0.26	0.24	0.09	0.09	0.18	0.24	0.26	0.18	1.00											
A14	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	1.00										
A15	0.35	0.09	0.22	0.09	0.22	0.22	0.09	0.09	0.18	0.22	0.22	0.18	0.22	0.05	1.00									
A16	0.35	0.09	0.22	0.09	0.22	0.22	0.09	0.09	0.18	0.22	0.22	0.18	0.22	0.05	0.44	1.00								
A17	0.09	0.13	0.09	0.22	0.09	0.09	0.21	0.13	0.09	0.09	0.09	0.09	0.09	0.05	0.09	0.09	1.00							
A18	0.09	0.13	0.09	0.25	0.09	0.09	0.21	0.13	0.09	0.09	0.09	0.09	0.09	0.05	0.09	0.09	0.22	1.00						
A19	0.35	0.09	0.22	0.09	0.22	0.22	0.09	0.09	0.18	0.22	0.22	0.18	0.22	0.05	0.44	0.56	0.09	0.09	1.00					
A20	0.35	0.09	0.22	0.09	0.22	0.22	0.09	0.09	0.18	0.22	0.22	0.18	0.22	0.05	0.44	0.45	0.09	0.09	0.45	1.00				
A21	0.09	0.33	0.09	0.13	0.09	0.09	0.13	0.28	0.09	0.09	0.09	0.09	0.09	0.05	0.09	0.09	0.13	0.13	0.09	0.09	1.00			
A22	0.18	0.09	0.18	0.09	0.18	0.18	0.09	0.09	0.21	0.18	0.18	0.39	0.18	0.05	0.18	0.18	0.09	0.09	0.18	0.18	0.09	1.00		
A23	0.18	0.09	0.18	0.09	0.18	0.18	0.09	0.09	0.21	0.18	0.18	0.31	0.18	0.05	0.18	0.18	0.09	0.09	0.18	0.18	0.09	0.31	1.00	
A24	0.22	0.09	0.35	0.09	0.29	0.24	0.09	0.09	0.18	0.24	0.35	0.18	0.26	0.05	0.22	0.22	0.09	0.09	0.22	0.22	0.09	0.18	0.18	1.00
E1	0.09	0.15	0.09	0.13	0.09	0.09	0.13	0.15	0.09	0.09	0.09	0.09	0.09	0.05	0.09	0.09	0.13	0.13	0.09	0.09	0.15	0.09	0.09	0.09
E2	0.31	0.09	0.22	0.09	0.22	0.22	0.09	0.09	0.18	0.22	0.22	0.18	0.22	0.05	0.31	0.31	0.09	0.09	0.31	0.31	0.09	0.18	0.18	0.22
E3	0.18	0.09	0.18	0.09	0.18	0.18	0.09	0.09	0.21	0.18	0.18	0.31	0.18	0.05	0.18	0.18	0.09	0.09	0.18	0.18	0.09	0.31	0.33	0.18
E4	0.18	0.09	0.18	0.09	0.18	0.18	0.09	0.09	0.21	0.18	0.18	0.25	0.18	0.05	0.18	0.18	0.09	0.09	0.18	0.18	0.09	0.25	0.25	0.18
E5	0.09	0.28	0.09	0.13	0.09	0.09	0.13	0.43	0.09	0.09	0.09	0.09	0.09	0.05	0.09	0.09	0.13	0.13	0.09	0.09	0.28	0.09	0.09	0.09
E6	0.09	0.15	0.09	0.13	0.09	0.09	0.13	0.15	0.09	0.09	0.09	0.09	0.09	0.05	0.09	0.09	0.13	0.13	0.09	0.09	0.15	0.09	0.09	0.09
E7	0.31	0.09	0.22	0.09	0.22	0.22	0.09	0.09	0.18	0.22	0.22	0.18	0.22	0.05	0.31	0.31	0.09	0.09	0.31	0.31	0.09	0.18	0.18	0.22
E8	0.09	0.15	0.09	0.13	0.09	0.09	0.13	0.15	0.09	0.09	0.09	0.09	0.09	0.05	0.09	0.09	0.13	0.13	0.09	0.09	0.15	0.09	0.09	0.09
E9	0.35	0.09	0.22	0.09	0.22	0.22	0.09	0.09	0.18	0.22	0.22	0.18	0.22	0.05	0.40	0.40	0.09	0.09	0.40	0.40	0.09	0.18	0.18	0.22
E10	0.09	0.15	0.09	0.13	0.09	0.09	0.13	0.15	0.09	0.09	0.09	0.09	0.09	0.05	0.09	0.09	0.13	0.13	0.09	0.09	0.15	0.09	0.09	0.09
E11	0.09	0.15	0.09	0.13	0.09	0.09	0.13	0.15	0.09	0.09	0.09	0.09	0.09	0.05	0.09	0.09	0.13	0.13	0.09	0.09	0.15	0.09	0.09	0.09
G1	0.09	0.10	0.09	0.10	0.09	0.09	0.10	0.10	0.09	0.09	0.09	0.09	0.09	0.05	0.09	0.09	0.10	0.10	0.09	0.09	0.10	0.09	0.09	0.09
G2	0.27	0.09	0.22	0.09	0.22	0.22	0.09	0.09	0.18	0.22	0.22	0.18	0.22	0.05	0.27	0.27	0.09	0.09	0.27	0.27	0.09	0.18	0.18	0.22
G3	0.09	0.21	0.09	0.13	0.09	0.09	0.13	0.21	0.09	0.09	0.09	0.09	0.09	0.05	0.09	0.09	0.13	0.13	0.09	0.09	0.21	0.09	0.09	0.09
G4	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.07	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
G5	0.31	0.09	0.22	0.09	0.22	0.22	0.09	0.09	0.18	0.22	0.22	0.18	0.22	0.05	0.31	0.31	0.09	0.09	0.31	0.31	0.09	0.18	0.18	0.22
G6	0.31	0.09	0.22	0.09	0.22	0.22	0.09	0.09	0.18	0.22	0.22	0.18	0.22	0.05	0.31	0.31	0.09	0.09	0.31	0.31	0.09	0.18	0.18	0.22
G7	0.09	0.15	0.09	0.13	0.09	0.09	0.13	0.15	0.09	0.09	0.09	0.09	0.09	0.05	0.09	0.09	0.13	0.13	0.09	0.09	0.15	0.09	0.09	0.09
G8	0.31	0.09	0.22	0.09	0.22	0.22	0.09	0.09	0.18	0.22	0.22	0.18	0.22	0.05	0.31	0.31	0.09	0.09	0.31	0.31	0.09	0.18	0.18	0.22
G9	0.31	0.09	0.22	0.09	0.22	0.22	0.09	0.09	0.18	0.22	0.22	0.18	0.22	0.05	0.31	0.31	0.09	0.09	0.31	0.31	0.09	0.18	0.18	0.22
G10	0.31	0.09	0.22	0.09	0.22	0.22	0.09	0.09	0.18	0.22	0.22	0.18	0.22	0.05	0.31	0.31	0.09	0.09	0.31	0.31	0.09	0.18	0.18	0.22
G11	0.31	0.09	0.22	0.09	0.22	0.22	0.09	0.09	0.18	0.22	0.22	0.18	0.22	0.05	0.31	0.31	0.09	0.09	0.31	0.31	0.09	0.18	0.18	0.22
G12	0.26	0.09	0.22	0.09	0.22	0.22	0.09	0.09	0.18	0.22	0.22	0.18	0.22	0.05	0.26	0.26	0.09	0.09	0.26	0.26	0.09	0.18	0.18	0.22

Table 19. (Continued)

Sites	E1	E2	E3	E4	E5	E6	E7	E8	E9	E0	E11	G1	G2	G3	G4	G5	G6	G7	G8	G9	G10	G11	G12
E1	1.00																						
E2	0.09	1.00																					
E3	0.09	0.18	1.00																				
E4	0.09	0.18	0.25	1.00																			
E5	0.15	0.09	0.09	0.09	1.00																		
E6	0.19	0.09	0.09	0.09	0.15	1.00																	
E7	0.09	0.38	0.18	0.18	0.09	0.09	1.00																
E8	0.19	0.09	0.09	0.09	0.15	0.24	0.09	1.00															
E9	0.09	0.31	0.18	0.18	0.09	0.09	0.31	0.09	1.00														
E10	0.19	0.09	0.09	0.09	0.15	0.24	0.09	0.30	0.09	1.00													
E11	0.19	0.09	0.09	0.09	0.15	0.24	0.09	0.35	0.09	0.30	1.00												
G1	0.10	0.09	0.09	0.09	0.10	0.10	0.09	0.10	0.09	0.10	0.10	1.00											
G2	0.09	0.27	0.18	0.18	0.09	0.09	0.27	0.09	0.27	0.09	0.09	0.09	1.00										
G3	0.15	0.09	0.09	0.09	0.21	0.15	0.09	0.15	0.09	0.15	0.15	0.10	0.09	1.00									
G4	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	1.00								
G5	0.09	0.36	0.18	0.18	0.09	0.09	0.36	0.09	0.31	0.09	0.09	0.09	0.27	0.09	0.05	1.00							
G6	0.09	0.38	0.18	0.18	0.09	0.09	0.42	0.09	0.31	0.09	0.09	0.09	0.27	0.09	0.05	0.36	1.00						
G7	0.24	0.09	0.09	0.09	0.15	0.19	0.09	0.19	0.09	0.19	0.19	0.10	0.09	0.15	0.05	0.09	0.09	1.00					
G8	0.09	0.36	0.18	0.18	0.09	0.09	0.36	0.09	0.31	0.09	0.09	0.09	0.27	0.09	0.05	0.52	0.36	0.09	1.00				
G9	0.09	0.46	0.18	0.18	0.09	0.09	0.38	0.09	0.31	0.09	0.09	0.09	0.27	0.09	0.05	0.36	0.38	0.09	0.36	1.00			
G10	0.09	0.46	0.18	0.18	0.09	0.09	0.38	0.09	0.31	0.09	0.09	0.09	0.27	0.09	0.05	0.36	0.38	0.09	0.36	0.59	1.00		
G11	0.09	0.33	0.18	0.18	0.09	0.09	0.33	0.09	0.31	0.09	0.09	0.09	0.27	0.09	0.05	0.33	0.33	0.09	0.33	0.33	0.33	1.00	
G12	0.09	0.26	0.18	0.18	0.09	0.09	0.26	0.09	0.26	0.09	0.09	0.09	0.26	0.09	0.05	0.26	0.26	0.09	0.26	0.26	0.26	0.26	1.00

Table 20. Dice's similarity values for all combinations of site comparisons based on lichen occurrence at each site. See Table 1 for site details.

Sites	A1	A2	A3	A4	A5	A6	A7	A8	A9	A10	A11	A12	A13	A14	A15	A16	A17	A18	A19	A20	A21	A22	A23	A24
A1	1.00																							
A2	0.13	1.00																						
A3	0.36	0.13	1.00																					
A4	0.13	0.21	0.13	1.00																				
A5	0.36	0.13	0.45	0.13	1.00																			
A6	0.36	0.13	0.38	0.13	0.38	1.00																		
A7	0.13	0.21	0.13	0.35	0.13	0.13	1.00																	
A8	0.13	0.43	0.13	0.21	0.13	0.13	0.21	1.00																
A9	0.31	0.13	0.31	0.13	0.31	0.31	0.13	0.13	1.00															
A10	0.36	0.13	0.38	0.13	0.38	0.47	0.13	0.13	0.31	1.00														
A11	0.36	0.13	0.56	0.13	0.45	0.38	0.13	0.13	0.31	0.38	1.00													
A12	0.31	0.13	0.31	0.13	0.31	0.31	0.13	0.13	0.33	0.31	0.31	1.00												
A13	0.36	0.13	0.40	0.13	0.40	0.38	0.13	0.13	0.31	0.38	0.40	0.31	1.00											
A14	0.13	0.14	0.13	0.14	0.13	0.13	0.14	0.14	0.13	0.13	0.13	0.13	0.13	1.00										
A15	0.52	0.13	0.36	0.13	0.36	0.36	0.13	0.13	0.31	0.36	0.36	0.31	0.36	0.13	1.00									
A16	0.52	0.13	0.36	0.13	0.36	0.36	0.13	0.13	0.31	0.36	0.36	0.31	0.36	0.13	0.61	1.00								
A17	0.13	0.21	0.13	0.36	0.13	0.13	0.35	0.21	0.13	0.13	0.13	0.13	0.13	0.14	0.13	0.13	1.00							
A18	0.13	0.21	0.13	0.40	0.13	0.13	0.35	0.21	0.13	0.13	0.13	0.13	0.13	0.14	0.13	0.13	0.36	1.00						
A19	0.52	0.13	0.36	0.13	0.36	0.36	0.13	0.13	0.31	0.36	0.36	0.31	0.36	0.13	0.61	0.72	0.13	0.13	1.00					
A20	0.52	0.13	0.36	0.13	0.36	0.36	0.13	0.13	0.31	0.36	0.36	0.31	0.36	0.13	0.61	0.62	0.13	0.13	0.62	1.00				
A21	0.13	0.50	0.13	0.21	0.13	0.13	0.21	0.43	0.13	0.13	0.13	0.13	0.13	0.14	0.13	0.13	0.21	0.13	0.13	0.13	1.00			
A22	0.31	0.13	0.31	0.13	0.31	0.31	0.13	0.13	0.33	0.31	0.31	0.56	0.31	0.13	0.31	0.31	0.13	0.13	0.31	0.31	0.13	1.00		
A23	0.31	0.13	0.31	0.13	0.31	0.31	0.13	0.13	0.33	0.31	0.31	0.47	0.31	0.13	0.31	0.31	0.13	0.13	0.31	0.31	0.13	0.47	1.00	
A24	0.36	0.13	0.51	0.13	0.45	0.38	0.13	0.13	0.31	0.38	0.51	0.31	0.40	0.13	0.36	0.36	0.13	0.13	0.36	0.36	0.13	0.31	0.31	1.00
E1	0.13	0.26	0.13	0.21	0.13	0.13	0.21	0.26	0.13	0.13	0.13	0.13	0.13	0.14	0.13	0.13	0.21	0.21	0.13	0.13	0.26	0.13	0.13	0.13
E2	0.47	0.13	0.36	0.13	0.36	0.36	0.13	0.13	0.31	0.36	0.36	0.31	0.36	0.13	0.47	0.47	0.13	0.13	0.47	0.47	0.13	0.31	0.31	0.36
E3	0.31	0.13	0.31	0.13	0.31	0.31	0.13	0.13	0.33	0.31	0.31	0.47	0.31	0.13	0.31	0.31	0.13	0.13	0.31	0.31	0.13	0.47	0.50	0.31
E4	0.31	0.13	0.31	0.13	0.31	0.31	0.13	0.13	0.33	0.31	0.31	0.40	0.31	0.13	0.31	0.31	0.13	0.13	0.31	0.31	0.13	0.40	0.40	0.31
E5	0.13	0.43	0.13	0.21	0.13	0.13	0.21	0.60	0.13	0.13	0.13	0.13	0.13	0.14	0.13	0.13	0.21	0.21	0.13	0.13	0.43	0.13	0.13	0.13
E6	0.13	0.26	0.13	0.21	0.13	0.13	0.21	0.26	0.13	0.13	0.13	0.13	0.13	0.14	0.13	0.13	0.21	0.21	0.13	0.13	0.26	0.13	0.13	0.13
E7	0.47	0.13	0.36	0.13	0.36	0.36	0.13	0.13	0.31	0.36	0.36	0.31	0.36	0.13	0.47	0.47	0.13	0.13	0.47	0.47	0.13	0.31	0.31	0.36
E8	0.31	0.13	0.31	0.13	0.31	0.31	0.13	0.13	0.33	0.31	0.31	0.36	0.31	0.13	0.31	0.31	0.13	0.13	0.31	0.31	0.13	0.36	0.36	0.31
E9	0.52	0.13	0.36	0.13	0.36	0.36	0.13	0.13	0.31	0.36	0.36	0.31	0.36	0.13	0.57	0.57	0.13	0.13	0.57	0.57	0.13	0.31	0.31	0.36
E10	0.31	0.13	0.31	0.13	0.31	0.31	0.13	0.13	0.33	0.31	0.31	0.36	0.31	0.13	0.31	0.31	0.13	0.13	0.31	0.31	0.13	0.36	0.36	0.31
E11	0.31	0.13	0.31	0.13	0.31	0.31	0.13	0.13	0.33	0.31	0.31	0.36	0.31	0.13	0.31	0.31	0.13	0.13	0.31	0.31	0.13	0.36	0.36	0.31
G1	0.13	0.21	0.13	0.22	0.13	0.13	0.22	0.21	0.13	0.13	0.13	0.13	0.13	0.14	0.13	0.13	0.22	0.22	0.13	0.13	0.21	0.13	0.13	0.13
G2	0.41	0.13	0.36	0.13	0.36	0.36	0.13	0.13	0.31	0.36	0.36	0.31	0.36	0.13	0.41	0.41	0.13	0.13	0.41	0.41	0.13	0.31	0.31	0.36
G3	0.13	0.35	0.13	0.21	0.13	0.13	0.21	0.35	0.13	0.13	0.13	0.13	0.13	0.14	0.13	0.13	0.21	0.21	0.13	0.13	0.35	0.13	0.13	0.13
G4	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09
G5	0.47	0.13	0.36	0.13	0.36	0.36	0.13	0.13	0.31	0.36	0.36	0.31	0.36	0.13	0.47	0.47	0.13	0.13	0.47	0.47	0.13	0.31	0.31	0.36
G6	0.47	0.13	0.36	0.13	0.36	0.36	0.13	0.13	0.31	0.36	0.36	0.31	0.36	0.13	0.47	0.47	0.13	0.13	0.47	0.47	0.13	0.31	0.31	0.36
G7	0.13	0.26	0.13	0.21	0.13	0.13	0.21	0.26	0.13	0.13	0.13	0.13	0.13	0.14	0.13	0.13	0.21	0.21	0.13	0.13	0.26	0.13	0.13	0.13
G8	0.47	0.13	0.36	0.13	0.36	0.36	0.13	0.13	0.31	0.36	0.36	0.31	0.36	0.13	0.47	0.47	0.13	0.13	0.47	0.47	0.13	0.31	0.31	0.36
G9	0.47	0.13	0.36	0.13	0.36	0.36	0.13	0.13	0.31	0.36	0.36	0.31	0.36	0.13	0.47	0.47	0.13	0.13	0.47	0.47	0.13	0.31	0.31	0.36
G10	0.47	0.13	0.36	0.13	0.36	0.36	0.13	0.13	0.31	0.36	0.36	0.31	0.36	0.13	0.47	0.47	0.13	0.13	0.47	0.47	0.13	0.31	0.31	0.36
G11	0.47	0.13	0.36	0.13	0.36	0.36	0.13	0.13	0.31	0.36	0.36	0.31	0.36	0.13	0.47	0.47	0.13	0.13	0.47	0.47	0.13	0.31	0.31	0.36
G12	0.42	0.13	0.36	0.13	0.36	0.36	0.13	0.13	0.31	0.36	0.36	0.31	0.36	0.13	0.42	0.42	0.13	0.13	0.42	0.42	0.13	0.31	0.31	0.36

Table 20. (Continued)

Sites	E1	E2	E3	E4	E5	E6	E7	E8	E9	E10	E11	G1	G2	G3	G4	G5	G6	G7	G8	G9	G10	G11	G12
E1	1.00																						
E2	0.13	1.00																					
E3	0.13	0.31	1.00																				
E4	0.13	0.31	0.40	1.00																			
E5	0.26	0.13	0.13	0.13	1.00																		
E6	0.39	0.13	0.13	0.13	0.26	1.00																	
E7	0.13	0.54	0.31	0.31	0.13	0.13	1.00																
E8	0.13	0.31	0.36	0.36	0.13	0.13	0.31	1.00															
E9	0.13	0.47	0.31	0.31	0.13	0.13	0.47	0.31	1.00														
E10	0.13	0.31	0.36	0.36	0.13	0.13	0.31	0.46	0.31	1.00													
E11	0.13	0.31	0.36	0.36	0.13	0.13	0.31	0.52	0.31	0.46	1.00												
G1	0.21	0.13	0.13	0.13	0.21	0.21	0.13	0.13	0.13	0.13	0.13	1.00											
G2	0.13	0.41	0.31	0.31	0.13	0.13	0.41	0.31	0.41	0.31	0.31	0.13	1.00										
G3	0.26	0.13	0.13	0.13	0.35	0.26	0.13	0.13	0.13	0.13	0.13	0.21	0.13	1.00									
G4	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	1.00								
G5	0.13	0.52	0.31	0.31	0.13	0.13	0.52	0.31	0.47	0.31	0.31	0.13	0.41	0.13	0.09	1.00							
G6	0.13	0.54	0.31	0.31	0.13	0.13	0.60	0.31	0.47	0.31	0.31	0.13	0.41	0.13	0.09	0.52	1.00						
G7	0.32	0.13	0.13	0.13	0.26	0.32	0.13	0.13	0.13	0.13	0.13	0.21	0.13	0.26	0.09	0.13	0.13	1.00					
G8	0.13	0.52	0.31	0.31	0.13	0.13	0.52	0.31	0.47	0.31	0.31	0.13	0.41	0.13	0.09	0.69	0.52	0.13	1.00				
G9	0.13	0.63	0.31	0.31	0.13	0.13	0.54	0.31	0.47	0.31	0.31	0.13	0.41	0.13	0.09	0.52	0.54	0.13	0.52	1.00			
G10	0.13	0.63	0.31	0.31	0.13	0.13	0.54	0.31	0.47	0.31	0.31	0.13	0.41	0.13	0.09	0.52	0.54	0.13	0.52	0.74	1.00		
G11	0.13	0.49	0.31	0.31	0.13	0.13	0.49	0.31	0.47	0.31	0.31	0.13	0.41	0.13	0.09	0.49	0.49	0.13	0.49	0.49	0.49	1.00	
G12	0.13	0.42	0.31	0.31	0.13	0.13	0.42	0.31	0.42	0.31	0.31	0.13	0.41	0.13	0.09	0.42	0.42	0.13	0.42	0.42	0.42	0.42	1.00

Table 21. Inductive Coupled Plasma Spectrometry data for sulfur and nitrogen content of 21 lichen samples collected from the Anaconda-Pintler Wilderness, the Gates of the Mountains Wilderness, and the Elkhorn Mountains. Values are in percent. See Table 6 for site details.

		Total Kjeldahl Nitrogen (TKN)	Nitric-Perchloric Acid Digest
Site	Species	ICP %N	ICP %S
Anaconda-Pintler Wilderness			
AB1	<i>Bryoria fremontii</i>	0.720	0.081
AL1	<i>Letharia vulpina</i>	0.530	0.056
AL2	<i>Letharia vulpina</i>	0.600	0.060
AL3	<i>Letharia vulpina</i>	0.600	0.062
AL4	<i>Letharia vulpina</i>	0.690	0.070
AL5	<i>Letharia vulpina</i>	0.600	0.066
AL6	<i>Letharia vulpina</i>	0.630	0.052
AU1	<i>Umbilicaria hyperborea</i>	1.210	0.099
AU2	<i>Umbilicaria hyperborea</i>	1.050	0.099
Elkhorn Mountains			
EB1	<i>Bryoria fremontii</i>	0.820	0.084
EL1	<i>Letharia vulpina</i>	0.490	0.058
EL2	<i>Letharia vulpina</i>	0.780	0.081
EL3	<i>Letharia vulpina</i>	0.920	0.091
EU1	<i>Umbilicaria hyperborea</i>	1.090	0.111
EU2	<i>Umbilicaria hyperborea</i>	1.220	0.108
EU3	<i>Umbilicaria hyperborea</i>	0.920	0.083
Gates of the Mountains Wilderness			
GB1	<i>Bryoria fremontii</i>	1.420	0.122
GL1	<i>Letharia vulpina</i>	0.910	0.098
GL2	<i>Letharia vulpina</i>	0.640	0.071
GL3	<i>Letharia vulpina</i>	0.700	0.082
GU1	<i>Umbilicaria hyperborea</i>	1.180	0.115

Table 22. Raw data, means and standard deviations for 26 elements found in lichen samples of *Bryoria fremontii* (labeled with AB, EB, and GB), *Letharia vulpina* (labeled AL, EL, and GL) and *Umbilicaria hyperborea* (labeled AU, EU, and GU) from the Anaconda-Pintler Wilderness (samples AB1-AU2), the Elkhorn Mountains (samples EB1-EU2) and the Gates of the Mountains Wilderness (samples GB1-GU1). Values are in parts per million.

Sample	P	Na	K	Ca	Mg	Zn	Cu	Fe	Mn
AB1 rep 1	2246.97	47.62	4517.38	1019.94	260.79	26.31	6.03	437.57	387.29
AB1 rep 2	2547.31	73.64	5082.33	1031.93	252.01	26.74	6.11	498.54	347.33
AB1 rep 3	2227.54	54.53	4981.65	1188.39	241.67	30.81	5.63	411.91	343.47
AB1 rep 4	2036.95	58.73	5661.58	1161.07	276.15	22.38	5.43	432.03	362.30
AB1 rep 5	2297.66	64.62	5552.23	1242.69	271.06	23.18	6.11	539.54	389.79
AB1 rep 6	2023.03	55.96	4889.70	1009.90	323.70	23.80	6.12	458.43	393.48
mean	2229.91	59.18	5114.14	1108.99	270.90	25.64	5.91	463.00	370.61
SD	192.70	8.99	428.18	100.68	28.74	3.11	0.30	47.66	22.44
AL1 rep 1	1997.97	51.05	3762.94	598.47	137.15	17.05	2.98	571.83	165.00
AL1 rep 2	2172.42	55.09	3983.72	591.94	160.24	15.18	2.23	616.37	141.28
AL1 rep 3	2165.54	54.05	3524.05	525.03	125.66	15.79	1.90	651.33	124.25
AL1 rep 4	2331.97	72.30	4258.69	559.61	192.64	20.66	2.04	681.61	142.41
AL1 rep 5	2294.97	69.13	3733.40	683.31	122.43	18.29	1.86	755.00	117.67
AL1 rep 6	2546.56	62.22	4543.12	655.43	159.41	20.51	1.62	716.20	117.06
mean	2251.57	60.64	3967.65	602.30	149.59	17.91	2.10	665.39	134.61
SD	186.20	8.68	376.75	58.82	26.56	2.33	0.47	66.68	18.61
AL2 rep 1	1907.53	88.37	4003.73	1843.50	439.94	20.31	3.32	406.68	300.80
AL2 rep 2	2013.90	72.85	3842.41	1878.69	466.47	21.81	3.30	485.16	309.47
AL2 rep 3	2079.78	48.89	4240.14	1648.11	411.36	22.21	2.82	477.10	240.77
AL2 rep 4	1858.35	70.59	4169.41	1930.10	386.25	20.29	2.44	470.49	308.01
AL2 rep 5	2073.06	82.11	3971.89	1900.07	442.87	22.65	2.94	487.26	329.83
AL2 rep 6	2228.63	73.20	3900.20	1860.23	439.44	20.38	2.52	409.26	313.21
mean	2026.88	72.67	4021.30	1843.45	431.06	21.27	2.89	455.99	300.35
SD	133.00	13.46	164.43	100.39	28.07	1.07	0.37	37.68	30.75
AL3 rep 1	1852.65	50.09	3741.29	1341.78	160.25	23.39	3.34	481.76	109.80
AL3 rep 2	2146.05	56.07	3942.23	1642.79	262.11	28.02	3.68	538.23	86.56
AL3 rep 3	1887.37	26.76	3782.99	1357.66	192.34	18.81	2.04	484.92	72.73
AL3 rep 4	1804.40	50.41	3759.39	1582.61	182.66	21.63	2.53	543.86	104.31
AL3 rep 5	1645.11	69.35	3903.37	1518.22	153.13	19.49	2.17	456.25	107.63
AL3 rep 6	1775.63	73.80	3927.89	1287.92	230.91	21.54	2.50	477.56	118.90
mean	1851.87	54.41	3842.86	1455.16	196.90	22.15	2.71	497.10	99.99
SD	166.50	16.74	91.25	145.43	42.17	3.31	0.66	35.53	17.05
AL4 rep 1	2555.65	90.59	3993.45	3072.59	343.97	28.51	3.42	637.87	76.09
AL4 rep 2	2040.99	79.94	3551.38	3281.67	396.07	20.10	2.81	564.61	81.29
AL4 rep 3	2035.16	85.90	3961.38	3123.33	341.55	26.00	3.32	481.67	79.14
AL4 rep 4	2135.32	90.78	3898.47	2819.54	408.02	20.71	3.06	630.89	78.45
AL4 rep 5	2290.50	89.22	4855.65	3025.56	391.72	21.19	3.49	632.05	102.25
AL4 rep 6	1852.72	74.47	4058.39	2638.48	430.14	19.53	2.64	519.81	87.04
mean	2151.72	85.15	4053.12	2993.53	385.25	22.67	3.12	577.82	84.04
SD	244.11	6.63	431.68	229.56	35.51	3.68	0.35	66.55	9.66
AL5 rep 1	2509.15	79.67	4273.01	2259.49	290.61	21.90	5.13	476.71	120.93
AL5 rep 2	2185.02	83.00	4391.04	2123.00	236.85	21.66	4.43	447.29	130.96
AL5 rep 3	2267.81	66.67	4748.51	2563.24	252.50	26.98	2.93	533.69	126.81
AL5 rep 4	2014.72	22.71	4467.68	2164.49	229.42	18.83	2.03	589.23	102.03
AL5 rep 5	2267.28	90.68	3672.48	2029.40	305.81	19.23	3.27	492.20	129.53
AL5 rep 6	1978.94	82.59	4175.71	2191.50	249.67	17.76	2.36	544.74	113.51
mean	2203.82	70.89	4288.07	2221.85	260.81	21.06	3.36	513.98	120.63
SD	193.92	24.87	359.63	183.84	30.55	3.33	1.20	51.59	11.14
AL6 rep 1	2272.95	65.64	4224.11	968.66	261.69	15.48	2.11	544.29	68.77
AL6 rep 2	2151.78	62.35	4147.51	872.54	324.85	26.45	3.32	602.20	88.07
AL6 rep 3	2523.27	51.07	3879.13	1032.26	304.47	18.85	1.82	687.43	55.98
AL6 rep 4	2410.89	90.99	4021.15	1091.80	248.98	16.96	1.90	688.55	75.14
AL6 rep 5	2058.60	82.05	4070.68	937.25	368.28	17.39	2.06	615.67	84.73
AL6 rep 6	1865.65	78.98	3606.95	1081.49	333.78	15.83	1.63	555.00	73.16
mean	2213.86	71.85	3991.69	997.33	307.01	18.49	2.14	615.52	74.31
SD	239.69	14.71	221.86	86.29	45.20	4.08	0.60	62.32	11.55

Table 22. (Continued)

Sample	P	Na	K	Ca	Mg	Zn	Cu	Fe	Mn
AU1 rep 1	5645.47	89.90	4700.96	97.69	534.15	39.62	15.57	1886.17	63.71
AU1 rep 2	5160.05	122.10	4891.07	130.31	482.12	46.51	14.47	1662.76	57.12
AU1 rep 3	5350.83	85.02	5192.87	62.85	584.66	51.99	16.82	1705.57	72.67
AU1 rep 4	4784.84	127.09	4380.61	92.39	531.28	35.39	14.12	1785.46	51.95
AU1 rep 5	5267.94	107.23	5421.91	69.73	640.74	44.65	17.42	1721.33	74.70
AU1 rep 6	5182.27	134.18	4547.53	47.33	512.28	35.71	14.13	1749.24	57.48
mean	5231.90	110.92	4855.82	83.38	547.54	42.31	15.42	1751.76	62.94
SD	280.70	20.27	395.01	29.65	56.62	6.57	1.43	77.70	9.14
AU2 rep 1	4315.34	103.73	4899.06	225.53	246.81	58.44	16.28	1600.20	58.49
AU2 rep 2	4966.13	129.49	4796.45	209.17	296.29	61.29	16.49	1721.57	68.65
AU2 rep 3	4906.30	110.77	4527.95	263.34	362.16	44.85	17.01	1835.65	63.82
AU2 rep 4	5523.49	134.64	4503.35	260.31	412.82	58.61	18.11	1975.43	78.46
AU2 rep5	4403.24	139.27	4305.97	212.11	340.32	55.84	13.16	1585.51	62.14
AU2 rep6	4927.55	153.03	4794.92	246.10	380.29	53.98	15.32	1794.95	74.44
mean	4840.34	128.49	4637.95	236.09	339.78	55.50	16.06	1752.22	67.67
SD	438.44	18.35	227.32	23.84	60.02	5.79	1.69	148.63	7.65
EB1 rep 1	2198.86	14.35	5216.63	1535.45	282.53	27.27	5.69	451.34	208.05
EB1 rep 2	2203.56	37.72	6023.09	1852.78	337.04	25.17	7.63	508.38	192.16
EB1 rep 3	2297.61	19.62	5852.11	1420.71	300.18	27.45	5.33	466.69	184.16
EB1 rep 4	1798.24	32.42	5983.69	1531.23	304.68	25.14	5.38	442.88	172.92
EB1 rep 5	1879.98	31.11	5607.18	1895.17	279.99	24.24	5.24	485.84	169.32
EB1 rep 6	1906.70	34.02	5287.56	1857.35	323.83	24.28	5.61	504.25	196.77
mean	2047.49	28.21	5661.71	1682.12	304.71	25.59	5.81	476.56	187.23
SD	209.68	9.12	349.74	208.73	22.51	1.43	0.91	27.32	14.72
EL1 rep 1	1563.93	21.80	4069.43	3817.69	285.04	28.22	3.12	244.56	165.21
EL1 rep 2	1692.31	51.68	4815.11	3759.45	328.11	28.41	4.79	223.79	202.49
EL1 rep 3	1501.28	46.00	4270.83	3569.19	254.04	23.66	3.46	203.21	155.98
EL1 rep 4	1428.35	37.30	4675.62	3421.79	287.80	23.19	1.88	211.34	163.69
EL1 rep 5	1491.74	36.68	4695.77	3535.21	288.14	25.41	2.11	233.83	180.54
EL1 rep 6	1547.50	50.99	5131.09	3648.23	280.49	28.58	2.19	263.72	182.05
mean	1537.52	40.74	4609.64	3625.26	287.27	26.25	2.92	230.08	174.99
SD	89.54	11.31	382.76	147.12	23.77	2.48	1.10	22.22	16.86
EL2 rep 1	1642.16	54.22	3817.53	3276.15	153.34	21.29	2.69	392.11	96.02
EL2 rep 2	1930.78	54.16	4352.85	3158.62	147.58	26.19	2.46	461.03	116.62
EL2 rep 3	1835.45	49.43	4132.08	3758.73	117.39	18.32	2.68	451.89	97.51
EL2 rep 4	1677.01	74.14	4485.68	3068.18	163.53	21.60	2.96	428.78	103.48
EL2 rep 5	1966.38	84.83	4351.88	3538.81	206.84	26.15	3.18	535.02	104.51
EL2 rep 6	1844.12	70.17	4492.46	3040.26	201.82	22.02	2.86	470.93	106.61
mean	1815.98	64.49	4272.08	3306.79	165.08	22.59	2.81	456.63	104.13
SD	131.53	13.99	258.19	285.99	34.10	3.06	0.25	47.60	7.38
EL3 rep 1	2348.68	72.54	4311.26	3875.47	314.08	33.18	6.41	544.72	117.33
EL3 rep 2	2049.88	70.57	4507.34	3486.07	290.18	28.37	5.45	472.35	111.30
EL3 rep 3	2184.19	56.77	4677.08	4017.86	270.93	34.78	5.48	537.51	140.57
EL3 rep 4	1912.12	74.47	4808.95	3829.93	278.47	26.68	5.05	419.18	123.54
EL3 rep 5	2028.99	72.42	4920.64	3747.31	322.13	27.23	5.65	487.91	127.01
EL3 rep 6	2015.66	66.21	4787.63	3719.14	270.52	27.46	5.19	523.37	114.06
mean	2089.92	68.83	4668.82	3779.30	291.05	29.62	5.54	497.51	122.30
SD	153.81	6.54	224.12	178.52	22.28	3.46	0.48	47.66	10.69
EU1 rep 1	6847.41	137.28	5309.44	488.49	644.76	54.65	48.20	2407.86	120.48
EU1 rep 2	6531.22	141.79	5666.30	364.98	586.79	52.30	46.25	2080.89	101.83
EU1 rep 3	5906.42	99.35	4835.32	259.83	699.14	51.82	42.96	1870.04	115.66
EU1 rep 4	6058.85	117.36	4798.29	283.14	610.86	46.05	45.58	2346.81	92.09
EU1 rep 5	6157.08	121.36	5232.81	461.27	652.66	46.20	48.74	2024.85	113.89
EU1 rep 6	5506.48	135.96	5048.04	246.71	687.15	39.40	39.63	2107.48	86.08
mean	6167.91	125.52	5148.37	350.74	646.89	48.40	45.23	2139.65	105.00
SD	471.51	16.00	326.17	104.93	43.13	5.61	3.43	202.59	13.91

Table 22. (Continued)

Sample	P	Na	K	Ca	Mg	Zn	Cu	Fe	Mn
EU2 rep 1	7181.10	245.70	5228.66	460.46	765.53	37.37	39.48	2071.72	126.51
EU2 rep 2	6922.95	196.29	5269.73	278.07	874.29	34.53	38.12	2190.75	119.18
EU2 rep 3	6418.58	206.54	5264.65	363.89	767.67	31.31	35.58	2111.36	120.76
EU2 rep 4	6518.08	261.84	5783.84	366.81	809.16	36.52	36.84	2027.33	139.31
EU2 rep 5	6114.86	240.99	5993.00	290.23	833.94	39.57	46.79	1942.59	138.83
EU2 rep 6	6190.70	215.34	5273.34	286.66	941.89	34.04	42.63	2058.31	133.52
mean	6557.71	227.78	5468.87	341.02	832.08	35.56	39.91	2067.01	129.69
SD	418.03	25.51	332.03	70.64	67.74	2.89	4.15	82.98	8.84
EU3 rep 1	6170.48	192.88	5747.60	360.72	513.01	53.17	56.24	1780.69	84.80
EU3 rep 2	6239.31	184.30	4645.87	493.97	553.94	47.18	68.10	1811.10	101.31
EU3 rep 3	6296.32	156.07	4828.68	401.60	530.52	42.41	51.53	2145.78	84.39
EU3 rep 4	6711.91	213.71	5797.42	336.86	468.27	38.03	49.99	1677.10	73.58
EU3 rep 5	5528.70	199.32	4998.01	476.29	555.88	41.20	49.60	1789.29	70.07
EU3 rep 6	6472.69	193.92	5002.95	387.52	515.51	39.85	59.77	2037.28	84.24
mean	6236.57	190.03	5170.09	409.49	522.86	43.64	55.87	1873.54	83.06
SD	397.67	19.27	484.97	62.92	32.39	5.60	7.18	178.40	10.93
GB1 rep 1	2080.35	13.57	4421.78	1125.11	248.39	27.69	5.92	529.63	49.05
GB1 rep 2	1902.55	18.49	4498.99	1288.55	187.15	22.83	6.51	444.52	47.25
GB1 rep 3	1985.73	17.73	4209.46	1271.09	192.00	25.42	6.06	471.31	43.05
GB1 rep 4	1883.05	28.29	4676.54	1291.84	177.22	24.53	5.59	417.36	43.60
GB1 rep 5	1603.50	34.94	4231.72	1145.16	153.43	23.82	5.32	419.19	36.00
GB1 rep 6	1771.11	38.08	4794.56	1253.68	194.01	26.46	6.22	453.17	41.67
mean	1871.05	25.18	4472.18	1229.24	192.03	25.13	5.94	455.86	43.44
SD	167.13	10.06	234.86	74.43	31.35	1.78	0.43	41.58	4.67
GL1 rep 1	2301.19	70.18	4696.74	3479.61	330.41	24.09	6.24	426.02	130.71
GL1 rep 2	2140.53	87.05	4485.45	3534.87	337.14	25.51	5.54	366.02	107.16
GL1 rep 3	2244.13	78.70	4540.01	3268.83	270.18	22.92	4.42	457.63	110.62
GL1 rep 4	1933.27	74.50	4404.41	3271.38	409.48	27.80	4.67	372.22	129.33
GL1 rep 5	2101.48	72.47	4647.45	3313.32	330.38	23.50	4.27	473.73	108.49
GL1 rep 6	1957.37	78.16	4516.54	3666.34	369.09	23.25	3.57	421.72	107.82
mean	2112.99	76.84	4548.43	3422.39	341.11	24.51	4.79	419.66	115.69
SD	148.34	5.97	107.33	163.53	46.33	1.85	0.96	43.68	11.17
GL2 rep 1	1564.41	67.91	3732.12	4144.48	67.94	24.29	2.93	348.30	48.72
GL2 rep 2	1835.88	63.42	4119.00	4831.60	54.54	24.65	3.49	409.23	50.52
GL2 rep 3	1833.34	61.19	4199.55	5261.81	31.05	31.82	3.13	427.58	51.90
GL2 rep 4	1737.79	65.63	4135.75	4907.31	82.81	23.72	3.79	444.41	45.77
GL2 rep 5	1590.70	64.43	4105.29	4706.83	62.80	23.94	3.37	390.65	45.69
GL2 rep 6	1681.31	57.26	3663.07	4682.68	89.81	24.58	3.89	450.47	45.83
mean	1707.24	63.31	3992.46	4755.78	64.83	25.50	3.43	411.77	48.07
SD	116.65	3.71	231.70	365.02	21.01	3.12	0.37	38.19	2.72
GL3 rep 1	1816.79	75.80	4165.80	2995.06	235.66	20.17	5.35	335.29	90.06
GL3 rep 2	1974.47	77.81	4315.64	2977.45	191.54	20.34	4.53	372.22	89.66
GL3 rep 3	1874.53	72.69	4335.23	3071.23	210.72	21.30	4.52	369.82	66.61
GL3 rep 4	1718.80	87.69	4624.70	2958.91	219.21	25.42	3.98	340.96	86.80
GL3 rep 5	1878.26	78.78	4617.88	2754.32	243.14	25.28	4.68	436.25	91.44
GL3 rep 6	2148.85	92.86	4797.86	3311.58	268.67	24.07	4.60	413.25	86.49
mean	1901.95	80.94	4476.18	3011.43	228.16	22.76	4.61	377.97	85.18
SD	147.19	7.70	239.83	181.08	27.01	2.44	0.44	39.83	9.30
GU1 rep 1	5148.37	171.11	4847.37	220.67	652.3	36.66	26.64	1518.05	93.56
GU1 rep 2	5544.74	149.68	4867.60	141.69	536.92	32.11	15.11	1872.38	62.78
GU1 rep 3	4542.82	136.81	4567.16	208.19	590.16	28.17	20.13	1609.41	70.09
GU1 rep 4	5314.31	199.12	5094.91	150.96	676.56	32.20	21.00	1763.02	74.22
GU1 rep 5	4582.84	151.44	4589.39	102.77	529.50	32.76	18.55	1419.36	59.16
GU1 rep 6	4479.46	175.01	5154.30	211.58	594.86	30.03	17.76	1573.05	62.96
mean	4935.42	163.86	4853.46	172.64	596.72	31.99	19.87	1625.88	70.46
SD	467.60	22.39	245.25	47.74	59.34	2.86	3.90	165.47	12.58

Table 22. (Continued)

Sample	B	Al	Si	Ti	V	Co	Ni	Mo	Cr
AB1 rep 1	20.01	232.52	1408.76	10.58	0.34	0.70	2.46	0.07	0.82
AB1 rep 2	21.56	253.96	1501.03	6.79	0.29	0.43	1.73	0.09	0.95
AB1 rep 3	21.21	291.04	1386.19	15.51	0.00	0.30	1.58	0.16	0.86
AB1 rep 4	21.69	265.34	1212.29	8.10	0.38	0.66	2.55	0.12	0.82
AB1 rep 5	21.40	304.72	1502.04	1.42	0.32	0.61	2.22	0.16	0.75
AB1 rep 6	21.22	253.76	1311.03	5.99	0.21	0.72	1.39	0.17	0.73
mean	21.18	266.89	1386.89	8.06	0.26	0.57	1.99	0.13	0.82
SD	0.60	26.60	112.26	4.73	0.14	0.17	0.49	0.04	0.08
AL1 rep 1	5.95	425.09	2486.61	28.43	0.62	0.66	3.63	0.05	0.99
AL1 rep 2	5.93	495.09	3032.37	47.05	0.13	0.34	2.99	0.06	1.17
AL1 rep 3	5.31	415.08	2922.02	32.06	0.42	0.55	3.52	0.05	1.16
AL1 rep 4	6.00	441.58	2811.04	25.44	0.83	0.71	2.26	0.10	1.03
AL1 rep 5	6.51	533.22	3040.13	68.10	0.53	0.67	2.32	0.13	1.20
AL1 rep 6	6.82	533.41	3518.57	54.55	1.16	0.65	2.90	0.13	1.32
mean	6.09	473.91	2968.46	42.60	0.61	0.60	2.94	0.09	1.16
SD	0.52	53.66	337.92	16.85	0.35	0.14	0.58	0.04	0.12
AL2 rep 1	6.24	299.93	2249.02	55.01	0.36	0.70	2.65	0.13	1.16
AL2 rep 2	5.70	350.56	2182.11	46.03	0.00	0.49	2.21	0.10	0.91
AL2 rep 3	6.40	300.03	2344.82	27.32	0.00	0.19	1.94	0.01	0.88
AL2 rep 4	5.81	347.15	2386.57	36.82	0.94	0.64	2.93	0.09	1.04
AL2 rep 5	6.37	327.18	2268.88	49.81	0.72	0.65	2.64	0.11	1.15
AL2 rep 6	6.76	369.83	2547.03	64.69	0.75	0.78	3.25	0.16	1.17
mean	6.21	332.45	2329.74	46.61	0.46	0.57	2.60	0.10	1.05
SD	0.40	28.56	128.60	13.24	0.40	0.21	0.47	0.05	0.13
AL3 rep 1	5.89	340.37	2414.87	31.31	0.33	0.54	1.87	0.07	0.93
AL3 rep 2	6.58	348.82	2676.07	50.35	0.09	0.73	5.93	0.22	1.24
AL3 rep 3	6.10	280.19	2481.24	42.64	0.17	0.44	2.00	0.07	1.05
AL3 rep 4	5.83	381.85	2516.48	21.72	0.59	0.60	1.69	0.10	0.91
AL3 rep 5	6.19	340.34	2461.21	54.77	0.79	0.57	2.34	0.08	1.18
AL3 rep 6	5.96	307.16	2343.87	29.05	0.43	0.71	2.60	0.14	0.88
mean	6.09	333.12	2482.29	38.31	0.04	0.60	2.74	0.11	1.03
SD	0.27	35.22	112.13	13.00	0.26	0.11	1.60	0.06	0.15
AL4 rep 1	7.57	511.94	3263.02	86.03	0.33	0.54	2.32	0.19	1.31
AL4 rep 2	7.38	429.81	3079.55	105.00	0.24	0.51	1.82	0.19	1.14
AL4 rep 3	7.08	410.26	3197.24	95.06	0.75	0.50	2.09	0.17	1.21
AL4 rep 4	7.47	423.34	2949.24	77.60	1.13	0.67	2.76	0.18	1.15
AL4 rep 5	8.37	389.43	3152.08	79.89	0.93	0.57	2.44	0.08	1.28
AL4 rep 6	6.79	482.69	3016.92	61.42	0.85	0.59	2.06	0.04	1.06
mean	7.44	441.24	3109.67	84.17	0.70	0.56	2.25	0.14	1.19
SD	0.54	46.50	116.82	15.07	0.35	0.06	0.33	0.06	0.09
AL5 rep 1	6.47	328.94	2920.66	63.19	0.18	0.63	2.93	0.14	1.38
AL5 rep 2	7.13	310.04	2408.97	54.36	0.26	0.67	6.56	0.20	4.19
AL5 rep 3	6.61	371.70	3073.21	76.90	0.00	0.00	2.83	0.06	1.03
AL5 rep 4	7.81	385.95	2680.41	59.25	1.13	0.53	1.20	0.05	1.11
AL5 rep 5	7.03	333.63	2756.24	68.22	0.86	0.56	1.73	0.13	1.19
AL5 rep 6	6.77	325.05	2523.59	47.53	0.75	0.62	1.39	0.09	1.00
mean	6.97	342.55	2727.18	61.58	0.53	0.50	2.77	0.11	1.65
SD	0.48	29.53	246.13	10.36	0.45	0.25	1.99	0.06	1.25
AL6 rep 1	6.12	306.83	2783.23	42.95	0.34	0.50	3.09	0.10	2.09
AL6 rep 2	5.70	218.92	2434.49	51.32	0.25	0.66	4.09	0.07	0.83
AL6 rep 3	5.46	267.15	2932.88	60.36	0.06	0.51	2.31	0.12	1.17
AL6 rep 4	6.64	259.90	3096.73	75.31	0.94	0.71	2.73	0.18	1.27
AL6 rep 5	7.19	315.07	2548.74	47.28	0.69	0.64	3.14	0.11	1.01
AL6 rep 6	6.66	327.10	2525.96	52.18	0.71	0.68	2.42	0.15	1.00
mean	6.29	282.50	2720.34	54.90	0.60	0.62	2.96	0.12	1.23
SD	0.65	41.06	260.67	11.55	0.33	0.09	0.65	0.04	0.45

Table 22. (Continued)

Sample	B	Al	Si	Ti	V	Co	Ni	Mo	Cr
AU1 rep 1	8.14	1697.61	5829.63	129.10	0.74	0.31	5.85	0.37	2.48
AU1 rep 2	7.77	1343.23	4875.97	107.02	0.27	0.60	5.33	0.43	1.86
AU1 rep 3	7.48	1461.84	5217.95	114.58	0.05	0.82	3.75	0.39	1.75
AU1 rep 4	7.07	1392.71	4780.96	96.71	1.40	0.78	3.86	0.42	1.47
AU1 rep 5	7.67	1220.29	5263.00	89.67	1.26	0.82	3.84	0.39	1.63
AU1 rep 6	7.09	1453.19	5035.51	105.83	0.88	0.82	3.84	0.43	1.63
mean	7.54	1428.14	5167.17	107.15	0.77	0.69	4.41	0.41	1.80
SD	0.41	158.77	374.67	13.81	0.53	0.21	0.93	0.03	0.36
AU2 rep 1	6.26	992.19	3996.16	66.31	0.87	0.82	3.86	0.26	1.33
AU2 rep 2	7.66	1274.66	4931.84	88.68	1.40	0.75	4.04	0.57	3.48
AU2 rep 3	7.43	1234.32	4886.10	73.35	0.13	0.00	7.57	0.42	1.59
AU2 rep 4	6.73	1358.30	4852.95	89.69	1.11	0.88	4.17	0.55	1.80
AU2 rep5	6.13	1065.86	3987.57	67.24	0.75	0.94	3.45	0.46	1.34
AU2 rep6	6.63	1197.36	4472.26	95.09	1.03	0.96	3.73	0.57	1.63
mean	6.81	1187.12	4521.15	80.06	0.88	0.72	4.47	0.47	1.86
SD	0.62	135.65	441.51	12.58	0.43	0.36	1.54	0.12	0.81
EB1 rep 1	15.49	171.64	1099.77	6.54	0.00	0.67	4.13	0.12	0.97
EB1 rep 2	17.47	209.87	1187.29	7.91	0.00	0.82	3.89	0.18	1.23
EB1 rep 3	11.33	150.65	1044.72	0.32	0.00	0.41	1.92	0.01	0.90
EB1 rep 4	12.01	135.87	1119.88	3.58	0.57	0.06	0.03	0.06	0.79
EB1 rep 5	13.18	139.23	1204.10	8.16	0.36	0.63	1.47	0.15	0.98
EB1 rep 6	13.91	157.13	1237.00	3.58	0.39	0.58	0.92	0.10	0.86
mean	13.90	160.73	1148.79	5.01	0.22	0.53	2.06	0.10	0.95
SD	2.28	27.31	72.65	3.06	0.25	0.27	1.64	0.06	0.15
EL1 rep 1	7.32	227.64	1557.84	22.44	0.00	0.03	5.01	0.26	0.90
EL1 rep 2	9.08	182.83	1559.93	25.06	0.00	0.41	4.04	0.73	1.01
EL1 rep 3	7.47	168.07	1281.55	20.33	0.26	0.80	2.89	0.17	1.04
EL1 rep 4	5.95	165.19	1465.81	19.23	0.82	0.47	1.24	0.09	0.93
EL1 rep 5	5.73	201.40	1443.94	19.39	0.61	0.50	1.29	0.09	1.06
EL1 rep 6	6.04	240.28	1809.92	18.44	0.78	0.47	1.24	0.09	0.99
mean	6.93	197.57	1519.83	20.82	0.41	0.45	2.62	0.24	0.99
SD	1.29	31.24	174.73	2.49	0.38	0.25	1.64	0.25	0.06
EL2 rep 1	7.51	271.73	2155.11	51.06	0.00	0.53	1.74	0.10	1.06
EL2 rep 2	7.90	333.75	2358.34	54.66	1.65	0.49	1.72	0.08	1.11
EL2 rep 3	8.63	364.58	2748.94	67.72	0.00	0.06	1.16	0.08	1.25
EL2 rep 4	6.08	317.93	2622.15	56.22	0.97	0.52	1.51	0.13	1.14
EL2 rep 5	6.45	423.52	2898.01	85.01	0.83	0.52	0.92	0.20	1.30
EL2 rep 6	5.98	347.06	2481.83	39.13	0.78	0.49	1.43	0.12	1.20
mean	7.09	343.10	2544.06	58.97	0.70	0.43	1.41	0.12	1.18
SD	1.08	50.52	269.44	15.73	0.63	0.18	0.32	0.04	0.09
EL3 rep 1	7.62	454.64	2751.88	73.89	0.41	0.78	2.19	0.32	1.26
EL3 rep 2	5.68	417.51	3051.28	61.67	0.19	0.67	1.78	0.11	1.15
EL3 rep 3	5.93	504.69	3178.89	88.73	0.24	0.09	0.87	0.12	1.36
EL3 rep 4	5.83	377.76	2855.70	58.80	1.08	0.51	1.10	0.11	1.15
EL3 rep 5	6.02	373.61	2986.58	60.77	1.06	0.52	1.42	0.11	1.21
EL3 rep 6	6.23	444.23	3077.71	58.93	0.98	0.47	0.42	0.18	1.13
mean	6.22	428.74	2983.67	67.13	0.66	0.51	1.30	0.16	1.21
SD	0.71	49.89	155.97	11.99	0.42	0.24	0.64	0.08	0.09
EU1 rep 1	9.65	1718.79	5978.03	127.09	0.00	0.90	3.01	0.81	2.29
EU1 rep 2	9.27	1370.90	5459.13	115.53	0.00	0.86	3.65	0.78	2.47
EU1 rep 3	8.25	1475.49	4665.41	96.88	0.19	0.17	1.99	0.40	1.84
EU1 rep 4	7.21	1535.32	5441.43	140.80	1.18	0.71	2.84	0.42	1.50
EU1 rep 5	8.17	1593.77	6014.56	103.28	1.51	0.80	3.56	0.75	2.02
EU1 rep 6	7.14	1267.19	4876.17	104.55	1.05	0.76	2.49	0.55	1.49
mean	8.28	1493.58	5405.79	114.69	0.66	0.70	2.92	0.62	1.94
SD	1.03	160.70	553.32	16.65	0.67	0.27	0.63	0.19	0.40

Table 22. (Continued)

Sample	B	Al	Si	Ti	V	Co	Ni	Mo	Cr
EU2 rep 1	8.91	2079.09	7261.01	196.51	1.28	1.31	4.28	0.73	4.45
EU2 rep 2	9.35	1982.26	7002.00	183.87	0.49	0.99	3.36	0.66	3.55
EU2 rep 3	9.20	1908.05	6512.84	201.38	1.46	1.20	3.45	0.65	3.66
EU2 rep 4	7.64	2313.10	7331.11	187.08	2.18	0.93	3.48	0.57	2.93
EU2 rep 5	8.14	1824.06	6409.14	207.13	2.30	1.06	5.04	0.64	3.02
EU2 rep 6	7.95	2124.77	6715.19	236.99	2.29	1.02	4.07	0.84	2.93
mean	8.53	2038.56	6871.88	202.16	1.67	1.08	3.95	0.68	3.42
SD	0.71	173.59	386.48	19.14	0.73	0.14	0.65	0.09	0.60
EU3 rep 1	9.11	1687.53	6729.26	163.11	0.48	0.85	3.17	0.85	2.20
EU3 rep 2	7.09	1340.95	6002.01	162.38	0.97	1.03	3.52	0.87	2.32
EU3 rep 3	7.61	1586.64	6176.28	136.29	0.17	0.79	2.60	0.75	2.17
EU3 rep 4	6.87	1533.42	5574.99	136.12	1.81	0.73	2.12	0.62	2.07
EU3 rep 5	7.45	1614.45	5987.64	163.12	2.00	0.96	3.28	1.06	2.12
EU3 rep 6	7.87	1764.67	5748.53	156.59	2.43	0.91	3.37	1.03	2.15
mean	7.67	1587.94	6036.45	152.94	1.31	0.88	3.01	0.86	2.17
SD	0.79	145.49	399.74	13.19	0.90	0.11	0.54	0.17	0.09
GB1 rep 1	14.36	291.40	1435.66	16.91	0.00	0.02	0.92	0.03	0.97
GB1 rep 2	14.03	249.25	1364.63	17.17	0.00	0.08	1.04	0.05	0.94
GB1 rep 3	13.36	218.96	1361.22	6.63	0.00	0.60	1.84	0.02	0.79
GB1 rep 4	15.35	213.84	1292.46	16.48	0.21	0.64	0.88	0.13	0.86
GB1 rep 5	14.34	216.43	1181.05	10.97	0.49	0.61	0.88	0.22	0.85
GB1 rep 6	14.58	208.77	1227.83	18.51	0.53	0.60	0.66	0.12	0.83
mean	14.34	233.11	1310.47	14.45	0.21	0.42	1.04	0.10	0.87
SD	0.65	31.94	94.96	4.63	0.25	0.29	0.41	0.08	0.07
GL1 rep 1	6.35	327.46	2492.68	54.46	0.00	0.66	2.01	0.14	1.27
GL1 rep 2	6.31	304.28	2588.89	38.60	0.38	0.84	2.44	0.12	1.33
GL1 rep 3	6.87	325.45	2744.40	47.14	0.13	0.68	2.33	0.12	1.48
GL1 rep 4	5.24	314.26	2466.47	40.00	0.88	0.66	1.27	0.17	1.15
GL1 rep 5	6.02	381.25	3058.76	60.67	1.11	0.57	1.16	0.15	1.06
GL1 rep 6	5.34	386.90	2616.57	53.92	0.71	0.51	1.01	0.13	1.14
mean	6.02	339.93	2661.30	49.13	0.54	0.65	1.70	0.14	1.24
SD	0.63	35.24	218.41	8.75	0.44	0.11	0.63	0.02	0.15
GL2 rep 1	5.11	335.01	2192.55	44.86	0.19	0.61	1.72	0.12	0.96
GL2 rep 2	6.78	405.33	2464.23	60.41	0.00	0.43	1.67	0.16	1.09
GL2 rep 3	6.15	405.42	2734.74	61.19	0.00	0.38	1.46	0.09	1.11
GL2 rep 4	6.14	404.27	2697.85	79.93	1.14	0.48	0.97	0.14	1.20
GL2 rep 5	5.90	317.98	2486.22	55.31	1.03	0.47	0.84	0.14	1.14
GL2 rep 6	5.64	340.82	2723.20	59.13	1.28	0.47	0.54	0.06	1.13
mean	5.95	368.14	2549.80	60.14	0.61	0.47	1.20	0.12	1.10
SD	0.56	41.08	212.22	11.41	0.60	0.08	0.49	0.04	0.08
GL3 rep 1	6.09	322.95	2927.14	43.63	0.00	0.62	2.14	0.06	1.15
GL3 rep 2	5.71	346.36	3011.37	52.23	0.00	0.59	2.04	0.10	2.45
GL3 rep 3	6.00	367.78	2568.91	59.38	0.00	0.43	1.61	0.12	1.21
GL3 rep 4	5.48	294.79	2865.89	31.09	0.83	0.59	0.79	0.15	1.13
GL3 rep 5	5.75	355.28	2739.71	51.65	0.79	0.56	1.15	0.14	1.14
GL3 rep 6	6.21	386.96	3341.80	71.86	0.87	0.56	1.06	0.19	1.46
mean	5.87	345.69	2909.14	51.64	0.41	0.56	1.47	0.13	1.42
SD	0.27	32.84	262.41	13.82	0.46	0.07	0.55	0.04	0.52
GU1 rep 1	7.33	1204.04	5415.28	101.65	0.25	0.93	2.98	0.55	2.49
GU1 rep 2	7.93	1498.35	6198.55	113.22	0.00	0.95	2.70	0.47	2.08
GU1 rep 3	7.14	1413.77	5886.64	133.60	0.60	0.82	2.66	0.51	2.26
GU1 rep 4	7.79	1361.85	6435.48	119.09	1.47	0.91	3.07	0.63	2.24
GU1 rep 5	7.07	1216.86	5504.19	104.64	1.24	0.83	2.17	0.55	2.15
GU1 rep 6	7.81	1557.50	5974.60	126.75	1.65	0.73	2.01	0.64	1.95
mean	7.51	1375.39	5902.46	116.49	0.87	0.86	2.60	0.56	2.19
SD	0.38	144.52	393.24	12.46	0.68	0.08	0.43	0.07	0.18

Table 22. (Continued)

Sample	Sr	Ba	Li	Ag	Sn	Pb	Cd	As
AB1 rep 1	6.19	25.27	0.10	0.97	0.18	5.44	0.00	0.18
AB1 rep 2	5.69	24.82	0.07	1.04	0.28	4.75	5.59	0.23
AB1 rep 3	6.75	28.06	0.11	0.89	0.26	5.29	7.97	0.21
AB1 rep 4	6.39	31.60	0.16	1.12	0.25	4.66	0.00	0.20
AB1 rep 5	6.07	30.48	0.16	1.08	0.14	4.58	0.00	0.19
AB1 rep 6	5.95	28.33	0.17	1.05	0.25	5.03	0.00	0.18
mean	6.17	28.09	0.13	1.03	0.23	4.94	2.26	0.20
SD	0.37	2.71	0.04	0.08	0.05	0.37	3.68	0.02
AL1 rep 1	3.80	10.14	0.08	0.91	0.19	5.74	0.00	0.19
AL1 rep 2	4.59	10.59	0.07	0.83	0.27	5.37	0.00	0.20
AL1 rep 3	4.38	11.20	0.08	0.81	0.20	6.14	0.00	0.18
AL1 rep 4	2.80	9.73	0.11	0.99	0.15	5.71	0.00	0.19
AL1 rep 5	3.98	12.97	0.02	0.91	0.23	5.45	0.00	0.18
AL1 rep 6	5.01	13.89	0.10	1.03	0.21	5.87	0.00	0.20
mean	4.09	11.42	0.08	0.91	0.21	5.71	0.00	0.19
SD	0.77	1.66	0.03	0.09	0.04	0.28	0.00	0.01
AL2 rep 1	11.03	34.57	0.14	0.96	0.22	5.52	0.00	0.19
AL2 rep 2	10.55	33.04	0.07	0.78	0.28	5.62	0.00	0.18
AL2 rep 3	9.90	24.22	0.07	0.79	0.22	4.97	0.00	0.20
AL2 rep 4	12.76	32.83	0.18	0.95	0.20	5.41	0.00	0.19
AL2 rep 5	11.80	34.59	0.17	0.93	0.23	5.23	0.00	0.18
AL2 rep 6	12.54	37.65	0.16	0.97	0.23	5.23	0.00	0.18
mean	11.43	32.82	0.13	0.90	0.23	5.33	0.00	0.19
SD	1.13	4.65	0.05	0.09	0.03	0.24	0.00	0.01
AL3 rep 1	5.21	11.02	0.12	0.84	0.25	5.58	0.00	0.19
AL3 rep 2	8.22	17.19	0.13	0.97	0.30	5.75	0.00	0.19
AL3 rep 3	5.00	12.81	0.12	0.85	0.23	5.26	1.07	0.20
AL3 rep 4	6.29	13.87	0.17	0.90	0.27	5.14	0.00	0.18
AL3 rep 5	4.59	12.16	0.10	0.87	0.32	4.96	0.00	0.18
AL3 rep 6	4.23	11.67	0.17	0.99	0.35	5.11	0.00	0.19
mean	5.59	13.12	0.14	0.90	0.29	5.30	0.18	0.19
SD	1.47	2.22	0.03	0.06	0.05	0.30	0.44	0.01
AL4 rep 1	6.05	20.11	0.15	0.93	0.32	6.30	0.00	0.20
AL4 rep 2	7.39	23.00	0.19	0.80	0.28	5.66	0.00	0.18
AL4 rep 3	6.75	21.65	0.16	0.90	0.29	5.80	5.97	0.20
AL4 rep 4	4.70	19.10	0.27	0.93	0.27	5.27	0.00	0.19
AL4 rep 5	5.08	20.44	0.11	0.98	0.28	5.09	0.00	0.20
AL4 rep 6	5.19	17.77	0.13	0.84	0.23	4.78	0.00	0.18
mean	5.86	20.34	0.17	0.90	0.28	5.48	0.99	0.19
SD	1.06	1.84	0.06	0.07	0.03	0.65	2.44	0.01
AL5 rep 1	13.26	35.02	0.12	1.00	0.34	7.09	7.15	0.20
AL5 rep 2	11.50	30.19	0.13	1.04	0.58	6.81	8.99	0.21
AL5 rep 3	15.00	38.05	0.11	0.75	0.20	7.14	0.66	0.22
AL5 rep 4	10.71	31.96	0.18	0.92	0.11	5.07	0.00	0.19
AL5 rep 5	15.46	34.72	0.22	0.89	0.20	5.93	0.00	0.18
AL5 rep 6	11.02	29.89	0.18	0.92	0.27	5.28	0.00	0.19
mean	12.82	33.30	0.16	0.92	0.28	6.22	2.80	0.20
SD	2.07	3.18	0.04	0.10	0.16	0.92	4.13	0.01
AL6 rep 1	4.79	18.75	0.07	0.92	0.26	6.10	6.89	0.21
AL6 rep 2	3.06	11.14	0.04	0.99	0.29	5.64	0.00	0.20
AL6 rep 3	4.73	18.69	0.09	0.88	0.23	6.89	8.38	0.20
AL6 rep 4	5.27	18.26	0.17	0.97	0.33	5.78	0.00	0.19
AL6 rep 5	3.45	19.00	0.15	0.90	0.27	4.94	0.00	0.19
AL6 rep 6	4.04	19.71	0.19	0.91	0.30	5.73	0.00	0.18
mean	4.22	17.59	0.12	0.93	0.28	5.85	2.54	0.20
SD	0.86	3.20	0.06	0.04	0.03	0.64	3.97	0.01

Table 22. (Continued)

Sample	Sr	Ba	Li	Ag	Sn	Pb	Cd	As
AU1 rep 1	6.11	28.06	0.11	0.84	0.20	10.16	0.00	0.20
AU1 rep 2	5.18	26.57	0.05	0.97	0.31	8.66	0.00	0.20
AU1 rep 3	5.68	28.20	0.06	1.06	0.25	9.97	0.00	0.19
AU1 rep 4	4.10	25.84	0.15	0.99	0.17	8.07	0.00	0.18
AU1 rep 5	5.74	28.55	0.10	1.19	0.23	10.97	0.00	0.20
AU1 rep 6	4.81	26.18	0.07	1.04	0.30	9.07	0.00	0.19
mean	5.27	27.23	0.09	1.01	0.24	9.48	0.00	0.19
SD	0.73	1.17	0.04	0.12	0.06	1.07	0.00	0.01
AU2 rep 1	5.70	30.93	0.02	0.98	0.32	8.45	0.00	0.20
AU2 rep 2	3.94	31.26	0.14	0.92	0.19	11.21	0.00	0.21
AU2 rep 3	6.27	31.57	0.09	0.79	0.16	8.27	4.46	0.21
AU2 rep 4	8.31	34.56	0.11	1.03	0.21	10.84	0.00	0.19
AU2 rep5	6.39	32.69	0.13	1.03	0.16	9.10	0.00	0.18
AU2 rep6	9.30	35.68	0.13	1.08	0.33	8.16	0.00	0.19
mean	6.65	32.78	0.10	0.97	0.23	9.34	0.74	0.20
SD	1.91	1.94	0.04	0.10	0.08	1.35	1.82	0.01
EB1 rep 1	15.76	24.01	0.11	1.02	0.23	5.68	0.00	0.20
EB1 rep 2	21.72	35.12	0.13	1.16	0.35	5.42	0.00	0.21
EB1 rep 3	12.13	21.62	0.02	0.95	0.28	5.51	0.00	0.22
EB1 rep 4	15.20	24.48	0.13	0.96	0.18	5.37	0.00	0.19
EB1 rep 5	18.37	27.80	0.17	1.03	0.26	5.23	0.00	0.20
EB1 rep 6	20.29	29.01	0.19	1.00	0.21	5.24	0.00	0.18
mean	17.25	27.01	0.13	1.02	0.25	5.41	0.00	0.20
SD	3.55	4.79	0.06	0.08	0.06	0.17	0.00	0.01
EL1 rep 1	25.71	32.87	0.20	0.68	0.17	5.55	0.00	0.19
EL1 rep 2	39.88	38.02	0.18	1.00	0.39	6.03	0.00	0.22
EL1 rep 3	26.80	34.01	0.21	1.08	0.35	6.50	0.00	0.20
EL1 rep 4	33.52	33.01	0.27	0.95	0.32	5.26	0.00	0.19
EL1 rep 5	25.30	35.29	0.25	0.96	0.35	5.98	1.77	0.19
EL1 rep 6	32.40	39.98	0.21	1.05	0.22	5.85	1.23	0.20
mean	30.60	35.53	0.22	0.95	0.30	5.86	0.50	0.20
SD	5.73	2.89	0.03	0.14	0.09	0.43	0.79	0.01
EL2 rep 1	12.41	29.18	0.20	0.90	0.21	6.10	0.00	0.19
EL2 rep 2	14.11	34.35	0.23	1.02	0.30	6.36	0.00	0.21
EL2 rep 3	15.85	33.22	0.19	0.76	0.16	6.13	0.00	0.20
EL2 rep 4	14.61	33.87	0.22	1.01	0.31	6.27	0.00	0.20
EL2 rep 5	12.93	40.94	0.25	1.04	0.34	6.90	0.00	0.19
EL2 rep 6	15.97	33.60	0.23	0.99	0.27	5.64	0.00	0.20
mean	14.31	34.19	0.22	0.95	0.27	6.23	0.00	0.20
SD	1.47	3.80	0.02	0.11	0.07	0.41	0.00	0.01
EL3 rep 1	10.67	26.62	0.23	1.17	0.21	9.12	0.00	0.20
EL3 rep 2	11.06	24.29	0.17	1.09	0.30	7.48	0.00	0.20
EL3 rep 3	12.72	27.92	0.21	0.86	0.16	8.62	2.80	0.21
EL3 rep 4	10.61	28.33	0.23	1.03	0.17	7.27	0.00	0.20
EL3 rep 5	13.20	29.96	0.25	1.02	0.24	8.15	0.00	0.19
EL3 rep 6	11.70	25.78	0.27	1.03	0.10	8.57	2.62	0.19
mean	11.66	27.15	0.23	1.03	0.20	8.20	0.90	0.20
SD	1.09	2.01	0.03	0.10	0.07	0.71	1.40	0.01
EU1 rep 1	10.15	46.34	0.05	1.34	0.38	24.11	5.40	0.21
EU1 rep 2	9.23	47.65	0.05	1.31	0.40	24.00	1.57	0.21
EU1 rep 3	5.99	35.07	0.06	0.95	0.16	15.94	0.00	0.21
EU1 rep 4	8.08	41.46	0.16	1.38	0.27	20.50	3.34	0.20
EU1 rep 5	10.77	43.04	0.15	1.38	0.18	21.87	5.93	0.20
EU1 rep 6	7.31	43.93	0.14	1.29	0.32	20.71	3.22	0.19
mean	8.59	42.91	0.10	1.27	0.29	21.19	3.24	0.20
SD	1.80	4.45	0.05	0.16	0.10	3.01	2.24	0.01

Table 22. (Continued)

Sample	Sr	Ba	Li	Ag	Sn	Pb	Cd	As
EU2 rep 1	15.35	39.57	0.08	1.41	0.44	12.86	0.00	0.21
EU2 rep 2	12.06	42.56	0.10	1.30	0.29	11.73	0.00	0.20
EU2 rep 3	7.91	39.54	0.06	1.40	0.31	12.03	0.00	0.21
EU2 rep 4	12.56	32.09	0.13	1.40	0.20	13.11	0.00	0.20
EU2 rep 5	12.22	48.90	0.13	1.46	0.39	14.02	0.00	0.21
EU2 rep 6	12.63	47.76	0.17	1.35	0.30	12.31	0.00	0.19
mean	12.12	41.74	0.11	1.39	0.32	12.68	0.00	0.20
SD	2.39	6.18	0.04	0.06	0.08	0.83	0.00	0.01
EU3 rep 1	16.96	60.30	0.07	1.26	0.37	17.48	0.00	0.20
EU3 rep 2	9.68	44.34	0.11	1.43	0.31	15.49	9.83	0.21
EU3 rep 3	9.46	43.43	0.06	1.18	0.36	12.82	0.00	0.20
EU3 rep 4	10.66	49.33	0.12	1.31	0.39	16.59	0.00	0.20
EU3 rep 5	11.24	55.87	0.14	1.24	0.29	12.02	0.00	0.19
EU3 rep 6	14.28	65.41	0.14	1.30	0.31	15.81	9.87	0.19
mean	12.06	53.11	0.11	1.29	0.34	15.04	3.28	0.20
SD	2.97	8.89	0.03	0.08	0.04	2.15	5.09	0.01
GB1 rep 1	3.71	9.03	0.07	0.62	0.17	5.09	0.00	0.19
GB1 rep 2	3.74	8.23	0.08	0.68	0.20	5.24	0.00	0.19
GB1 rep 3	3.12	8.01	0.07	0.85	0.20	5.31	0.00	0.18
GB1 rep 4	2.93	9.97	0.12	1.02	0.26	5.25	0.00	0.19
GB1 rep 5	2.68	10.72	0.15	0.94	0.17	4.81	0.00	0.18
GB1 rep 6	2.96	10.78	0.14	0.98	0.19	5.32	0.00	0.19
mean	3.19	9.46	0.11	0.85	0.20	5.17	0.00	0.19
SD	0.44	1.22	0.04	0.16	0.03	0.19	0.00	0.01
GL1 rep 1	6.12	37.08	0.16	1.21	0.35	7.55	0.00	0.21
GL1 rep 2	6.40	36.30	0.20	1.09	0.19	6.42	0.00	0.19
GL1 rep 3	5.64	32.01	0.09	1.17	0.28	7.58	0.00	0.21
GL1 rep 4	5.82	35.50	0.23	1.05	0.18	8.89	0.00	0.18
GL1 rep 5	5.53	39.65	0.31	1.04	0.08	6.08	0.00	0.20
GL1 rep 6	5.66	37.29	0.25	1.00	0.30	7.32	0.00	0.19
mean	5.86	36.30	0.21	1.09	0.23	7.31	0.00	0.20
SD	0.33	2.52	0.08	0.08	0.10	0.99	0.00	0.01
GL2 rep 1	5.71	13.17	0.26	0.97	0.20	6.99	0.00	0.19
GL2 rep 2	7.60	17.74	0.25	0.94	0.30	6.72	0.00	0.21
GL2 rep 3	7.73	16.96	0.21	0.93	0.25	7.96	0.00	0.21
GL2 rep 4	9.26	19.67	0.31	0.93	0.32	6.45	0.00	0.19
GL2 rep 5	6.97	16.32	0.32	0.91	0.28	7.03	0.00	0.19
GL2 rep 6	8.95	18.59	0.29	0.85	0.07	6.58	0.00	0.18
mean	7.70	17.07	0.27	0.92	0.24	6.96	0.00	0.20
SD	1.30	2.25	0.04	0.04	0.09	0.54	0.00	0.01
GL3 rep 1	9.39	31.04	0.15	0.96	0.20	6.21	0.00	0.19
GL3 rep 2	8.88	31.46	0.15	0.97	0.26	6.44	0.00	0.19
GL3 rep 3	7.35	29.31	0.19	0.98	0.27	6.13	0.00	0.20
GL3 rep 4	9.78	35.86	0.24	1.03	0.22	6.23	0.00	0.19
GL3 rep 5	7.34	29.55	0.22	1.09	0.25	7.09	0.00	0.20
GL3 rep 6	10.24	36.03	0.20	1.14	0.39	6.45	0.00	0.20
mean	8.83	32.21	0.19	1.03	0.27	6.42	0.00	0.20
SD	1.23	3.01	0.04	0.07	0.07	0.35	0.00	0.01
GU1 rep 1	5.70	41.50	0.14	1.34	0.44	12.76	0.39	0.22
GU1 rep 2	5.04	33.56	0.06	1.12	0.34	9.17	0.00	0.19
GU1 rep 3	5.40	36.18	0.13	1.15	0.32	9.92	0.00	0.20
GU1 rep 4	5.13	44.69	0.11	1.29	0.35	10.48	0.00	0.20
GU1 rep 5	4.03	33.01	0.16	1.18	0.19	9.25	0.00	0.19
GU1 rep 6	5.13	44.08	0.12	1.13	0.25	7.97	0.00	0.20
mean	5.07	38.84	0.12	1.20	0.32	9.93	0.07	0.20
SD	0.56	5.25	0.03	0.09	0.09	1.62	0.16	0.01

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