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
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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 Iignicolous 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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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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STATEMENT OF PERMISSION TO USE

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TABLE OF CONTENTS

TABLE OF CONTENTS--Continued

LIST OF TABLES

LIST OF TABLES--Continued

LIST OF TABLES--Continued

LIST OF FIGURES

LIST OF FIGURES--Continued

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 though 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 form 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.

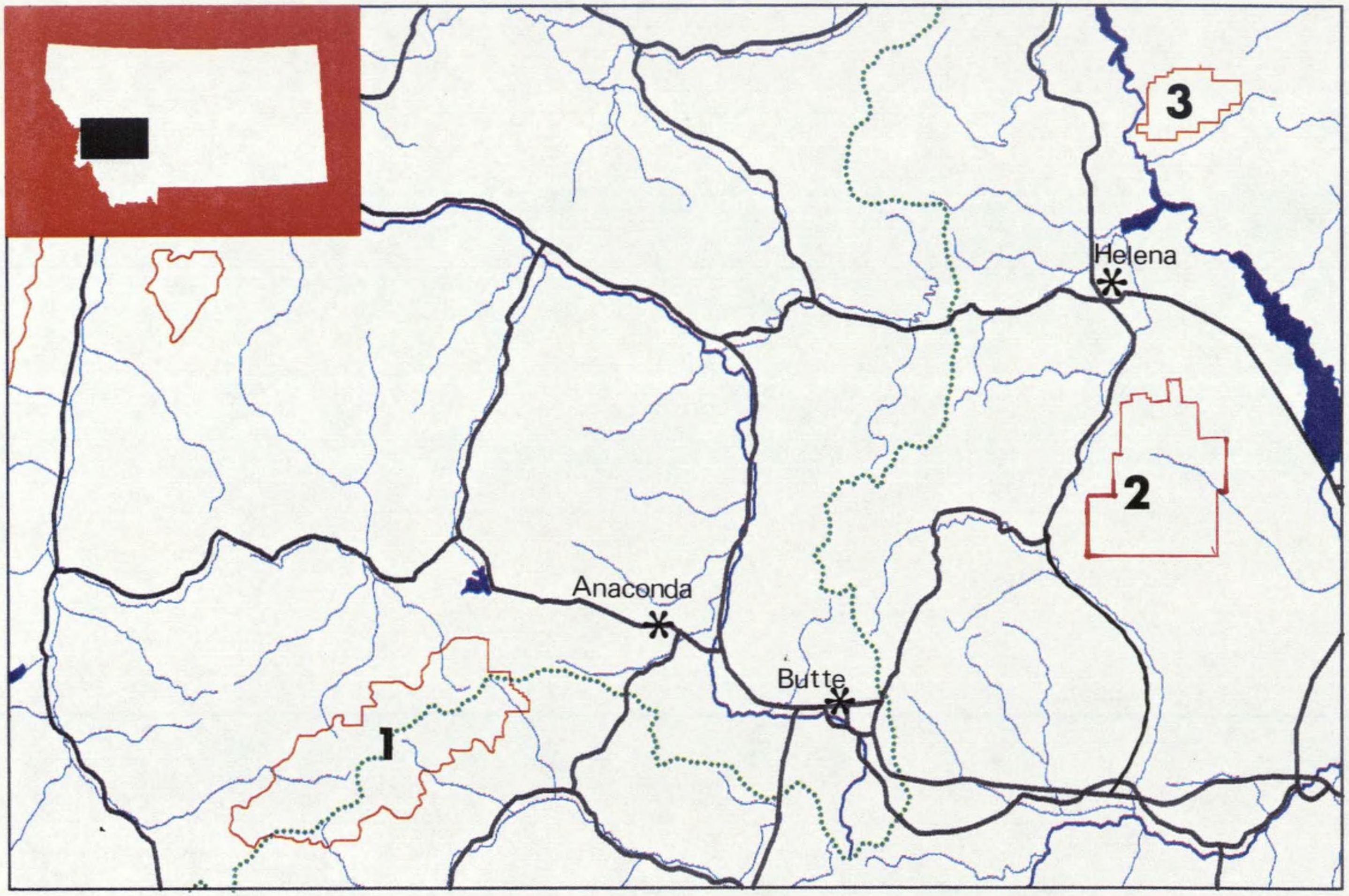

Figure 1. Study areas: 1) Anaconda-Pintler Wilderness, 2) Elkhorn Mountains, 3) Gates of the Mountains Wilderness. Major roads are black, waterways are blue, and the Continental Divide is green.

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