AN ABSTRACT OF THE THESIS OF

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Lichen sensitivity to air quality has been recognized in Europe for over 125 years; recently Federal agencies in this country have begun using lichens as air quality bioindicators. This study presents the results of three different approaches to air quality biomonitoring using lichens: (1) a lichen community analysis, (2) an elemental analysis of lichen tissue content, and (3) the growth of removable lichen transplants. The lichen community and elemental tissue content analyses were part of an air quality baseline on the Tongass National Forest in southeast Alaska. The lichen transplant experiment compared the growth of three different lichen species and evaluated and refined a transplant technique in western Oregon.

Lichen communities were sampled on 50 *Pinus contorta* peatlands in southeast Alaska. These peatlands make good air quality biomonitoring sites because: (1) the trees are slow growing and provide stable substrates for lichen colonization; (2) many branches are at eye level, making the canopy epiphytes easily observable; (3) the scattered, open distribution of the trees allows for good air circulation on the sites; and (4) precipitation, light conditions, and relative humidity are high, which stimulate lichen growth.

A total of 100 lichen species were encountered during whole-plot ocular surveys of each plot. Multivariate ordination revealed what appears to be a successional gradient represented by high cover of *Bryoria* species at older sites and high cover of *Platismatia norvegica*, *P. glauca*, *Hypogymnia enteromorpha* sens. lat. and *H. inactiva* at younger sites. A second pattern revealed by ordination

analysis appears to be a climatic gradient with high Alectoria sarmentosa cover on moister, warmer sites, and high cover of Bryoria species on drier, colder sites. The first two gradients contained 35% and 21%, respectively, of the information in the analytical data set (cumulative r^2 = 56%).

Elemental tissue content of Alectoria sarmentosa was determined from 43 of the peatland plots in southeast Alaska. The range of values for 16 elements are reported and compared to other regional studies; the ranges of values for most elements were within normal background levels. Quality assurance techniques are described for separation of laboratory and field noise from elemental content signal. Principal components analysis was used to create three synthetic gradients of plot-level elemental content. The first three principal components captured 55% of the correlation structure among elements. Iron (r=-0.91), aluminum (r=-0.80) and chromium (r=-0.71) are all highly correlated with the first gradient. This gradient could represent sites enriched by elements from dirt; aluminum and iron silicates are both persistent and abundant components of weathered rock and soil. Potassium (r=-0.82), phosphorous (r=-0.63), zinc (r=-0.60), manganese (r=-0.58), magnesium (r=-0.51) and nickel (r=0.54) are correlated with the second gradient. Many of these elements are supplemented by salt water aerosols (Nieboer et al. 1978; Rhoades 1988). Lead (r=0.70) and cadmium (r=0.59) were correlated with the third axis. This gradients could represent enrichment from fossil fuel combustion. Recommendations for standardizing future regional studies of lichen elemental content are made.

Removable lichen transplants were constructed using live thalli of known weight, a 5 cm length of nylon monofilament, silicone glue, and reusable attachment mechanisms. Transplants were returned to several sites in Western Oregon and were weighed every several months for 13 months. Reference standards for each species were used to correct for changes in lichen water content due to changes in lab humidity. Despite apparent vigor, Alectoria proved unsuitable for repeated weighings because of biomass loss due to fragmentation (average of 9% biomass loss). Growth of Evernia and Lobaria transplants differed both between species and between sites. Average growth over the 13 months for _Evernia_ in the foothills and valley was 40% and 30% respectively; for _Lobaria_ it was 16% and 15%. Differences in growth between species could be due to different: (1) growth rates; (2) sensitivities to air quality; (3) sensitivities to microhabitat; and (4) sensitivities to transplant trauma. Differences in growth between valley and foothill sites could be due to differences in: (1) micro- or macrohabitat conditions; and (2) air quality.

Lichen Biomonitoring in Southeast Alaska and Western Oregon

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Chiska C. Derr, Author

DEDICATION

This thesis is dedicated to the memory of
Cindy Joy "Cyd" Brower, much loved friend and kindred spirit.

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Chapter I. Introduction

Lichens play many roles in ecosystems, providing food and nesting materials for vertebrates and invertebrates (Richardson & Young 1977) and contributing significantly to the nitrogen cycle in some systems (Pike 1978). Recently lichens have been recognized as important components of dwindling old-growth forests in the Pacific Northwest (FEMAT 1993; Neitlich 1993), and for their contribution to biodiversity (Pike et al. 1978; Geiser et al. 1994a). In addition to their vulnerability to habitat loss, some lichen species are highly sensitive to air pollution, becoming extinct in areas with poor air quality (Ferry et al. 1973; Gilbert 1993). This sensitivity makes lichens well suited to air quality biomonitoring techniques.

Lichens have been recognized in Europe as sensitive bioindicators of air quality for over 125 years (Nylander 1866). In the past decade several Federal agencies in this country have begun using lichens as air quality biomonitors, leading to the creation of a handbook compiled by the Forest Service, National Park Service, and University professionals (Stolte et al. 1993).

In 1989 the Tongass National Forest in southeast Alaska initiated an air quality biomonitoring program (AQBP) using lichens. The approach was two-fold: to document current elemental tissue content for several common lichen species on the forest (Geiser et al. 1994a), and to inventory the lichens of the Tongass and document their habitat (Geiser et al. 1994b). As a contribution to the Tongass AQBP, this thesis addressed three applications of biomonitoring with lichens: lichen community analysis and elemental tissue content analysis in southeast Alaska, and the growth of lichen transplants in western Oregon. The first, a description of lichen communities in _Pinus contorta_ peatlands under baseline conditions, provides a basis for comparison to detect changes in lichen communities over time (Smith et al. 1993). The second, elemental tissue content analyses, provides baseline levels of 16 elements for comparisons with other studies and with future conditions. Finally, the growth of lichen transplants refines a method for monitoring lichen growth under many different air quality and ecological conditions.

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Chapter II. Lichen Communities in Pinus contorta Peatlands in Southeast Alaska

Abstract

Lichen communities were sampled on 50 Pinus contorta peatlands in southeast Alaska. A total of 100 lichen species were encountered during whole-plot ocular surveys of each plot. Ordination revealed what appears to be a successional gradient represented by high cover of Bryoria species at older sites and high cover of Platismatia norvegica, P. glauca, Hypogymnia enteromorpha and H. inactiva at younger sites. A second pattern revealed by ordination analysis appears to be a climatic gradient with high Alectoria sarmentosa cover on moister, warmer sites and high cover of Bryoria species on drier, colder sites. The first two gradients contained 35% and 21%, respectively, of the information in the analytical data set (cumulative r^2 = 56%).

Introduction

With the advent of the Industrial Revolution and the burning of large quantities of fossil fuels, air pollution has become a significant problem in developed countries. Concern about air quality degradation prompted the United States to enact the 1970 Clean Air Act (CAA), which was amended in 1977 and 1990. Under the CAA, the Forest Service is mandated to monitor air quality and effects of air pollution on the National Forests, and to provide leadership and direction in air resource management in an integrated ecosystem management context (U.S. Forest Service 1988).

Lichens have long been recognized for their value as bioindicators of air quality (Ferry et al. 1973; Nash and Wirth 1988; Stolte et al. 1993). They are typically used in several ways: (1) pre-impact inventories are compared with existing lichen flora to evaluate losses due to changes in air quality; (2) lichen tissue samples are collected and analyzed for elemental content; (3) lichen distributions are mapped around recognized point sources; and (4) lichen community data are collected from baseline and impacted sites, and are analyzed to determine the range of variability in community composition under both conditions. All of these methods are significantly less expensive than employing instrumental monitors at each collection site.

In 1989, the Tongass National Forest in southeast Alaska initiated an Air Quality Biomonitoring Project (AQBP) using lichens (Geiser et al. 1989). A forest-wide lichen inventory was conducted (Geiser et al. 1994b), and lichen tissue samples and community data were collected in two widespread forest habitat types. This study presents a lichen community analysis of the 50 permanent Tongass AQBP sites established in *Pinus contorta* peatlands across southeast Alaska. The objectives of the analyses were: (1) to describe the natural range of variability in lichen communities in these habitats under baseline conditions, and (2) to interpret the lichen community gradients using 46 measured environmental attributes.

Study Area

Southeast Alaska in general

Southeast Alaska is a narrow swath of land (about 75 km by 325 km) between 54°40'-60°30' N and 130°-140° W (Harris et al. 1974). It is part of the Pacific Mountain System principal physiographic unit, the northern extension of the western United States and Canada Coastal Mountain System (Hartman & Johnson 1978). Southeast Alaska consists primarily of the myriad mountainous islands of the Alexander Archipelago which range in size from less than a hectare to more than 1070 sq km. Some mainland peaks exceed 3000 m, while those on the islands are mostly less than 1200 m (Harris et al. 1974). Southeast

Alaska is bounded to the west by the Pacific Ocean, to the north by the Fairweather Range and to the east by the Coast Range.

Southeast Alaska's present day topography is relatively young, reflecting a combination of Tertiary uplift, Pleistocene glaciation and subsequent glacial retreat, and climate (Williams 1958). Huge trenches and deep fjords separate the major islands, and U-shaped valleys, till plains, hanging valleys, and outwash plains are common as are deep valleys, steep slopes, and narrow intervalley ridges (Harris et al. 1974). Today, most active glaciers are confined to the mainland and, with few exceptions, they are retreating. As a result of these geologic influences and climate, soils are youthful, shallow and poorly developed. The lack of weathering of bedrock and glacial till deposits results in low nutrient availability (Harris et al. 1974). While much of Southeast Alaska is rock and ice, the dominant forest types are Tsuga heterophylla old growth forests and open Pinus contorta/Sphagnum peatlands. Stands of large Picea sitchensis are found in glacial valley bottoms, riparian areas, and along beach fringes, while Thuja plicata, Chamaecyparis nootkatensis, and Tsuga mertensiana occur on more poorly drained sites. Southeast Alaska experiences a typical maritime climate: cool and moist with small temperature fluctuations. Average annual precipitation ranges from 152 to 508 cm; 40% occurs in October while only 1% occurs in April, May, and June (Harris et al. 1974). Average monthly temperatures range from -3 to 3° C in January and 10 to 18° C in July (Leslie 1989).

Pinus contorta/Sphagnum peatlands

Approximately 24% of the forested portion of southeast Alaska consists of open Pinus contorta/Sphagnum peatlands or "muskegs" that developed during the late Pleistocene over granitic bedrock and impermeable soil layers (Harris et al. 1974). These peatlands are very nutrient poor Sphagnum-dominated wetlands with low pH and saturated, anaerobic organic soils (Histosols). They are typically distributed as wet pockets in the Tsuga heterophylla forest varying in size from 100 m^2 to many hectacres. Their drier fringes are forested with tree species intolerant of wetter conditions but which cannot compete on drier sites (Chamaecyparis nootkatensis, Tsuga mertensiana and Thuja plicata). Pinus contorta, which can't reproduce under the shade of the faster growing fringe species, are restricted to the drier microsites in the peatlands (Sphagnum hummocks). Even Pinus contorta are incapable of growing in the wettest portions of the peatland, so the slow-growing, stunted trees tend to be sparsely distributed in these open-canopy wetlands. These habitats have some of the highest vascular plant biodiversity on the Tongass, and are used extensively as wildlife corridors (Alaback 1991). P. contorta peatlands make good air quality biomonitoring sites because: (1) the trees are slow growing and provide stable substrates for lichen colonization; (2) many branches are at eye level, making the canopy epiphytes easily observable; (3) the scattered, open distribution of the trees allows for good air circulation on the sites; and 4) precipitation, light conditions, and relative humidity are high, which stimulate lichen growth.

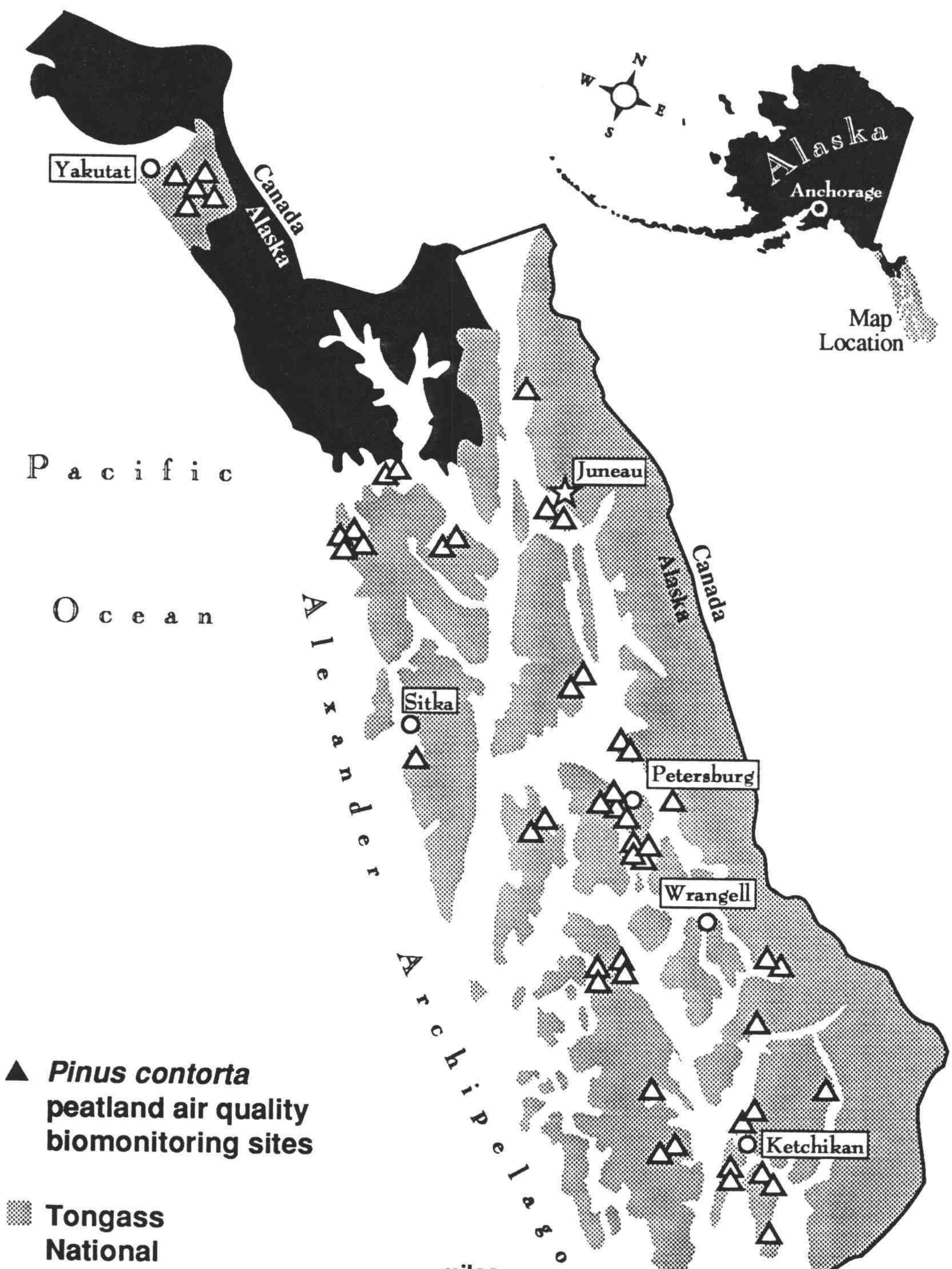
Methods

Between 1990 and 1992, 50 permanent plots were established in Pinus contorta peatlands across the Tongass National Forests (Fig. II.1). All 50 sites were in pristine areas of the forest, and were assumed to represent baseline conditions (Geiser et al. 1994a). The plots were then ordinated using multivariate techniques to express the data set's correlation structure in as few axes as possible.

Air Quality

Given the sparse population of humans in southeast Alaska, low levels of industrialization, frequent oceanic breezes, and high lichen diversity and cover, air quality on the Tongass National Forest is assumed to generally be very good (Geiser et al. 1994a). Two significant point sources of air pollution are the pulp mills in Sitka and Ketchikan. Very little air quality data are available from the Tongass, but recent data do exist for the Alaska Pulp Company mill near Sitka, including data from SO_2 monitors, wind data, and models of likely dispersion (Alaska Dept. of Environmental Conservation 1989-1992). Unfortunately, lichen data collection was not possible near either of these point sources because they were administratively excluded from this study.

Figure II.1 **Permanent *Pinus contorta* peatland air quality biomonitoring sites in the Tongass National Forest, southeast Alaska**



Sampling Design

Methods of permanent plot establishment and data collection were designed to: (1) represent the range of variation in Pinus contorta peatlands at lower elevations in southeast Alaska; (2) characterize lichen communities easily and objectively while capturing scarce lichens; and (3) make plots easy to relocate and resample in the future.

Fifty 500 m^2 circular permanent plots (radius = 42 m) were distributed across the Tongass National Forest to represent a broad range of latitudinal, topographic, elevational, vascular plant, and lichen variation in the peatlands (Appendix A). Plots were geographically distributed by dividing the Tongass into a grid of 26 1° latitude x 1° longitude units with at least two plots per unit, where possible. Because of the difficulty in accessing most sites, plots were often within a few kilometers of each other, however only one plot per site was sampled. Site selection criteria were: (1) each peatland was at least 1500 m^2 to minimize edge effects; (2) P. contorta was the dominant tree species; (3) there were a minimum of 10 dominant P. contorta over 2 m tall per site; (4) site elevation ranged from sea level to 333 m; and (5) site slopes were as close to zero as possible. Plot placement was somewhat subjective in that 500 m^2 plots with 10 qualifying trees were difficult to locate, so once ten trees were identified the plot was delineated around them. Each plot center was permanently marked with an orange-tipped 1.3 m length of aluminum conduit, a prominent snag or large tree was marked with flagging tape, the plot was photo-documented and directions for relocation recorded, and all plots were recorded in the Tongass National Forest Geographical Information System (GIS) database in Petersburg.

Choice of an epiphyte sampling method varies depending on objectives. Visual integration of one large plot yields high species capture and coarse cover estimates, while subsampling many small subplots has more accurate cover estimates but sacrifices species capture (McCune & Lesica 1992). Since the Tongass AQBP objectives included a forest-wide lichen inventory as well as documentation of lichen species abundances, it was important to document rare lichens and those with low cover. To meet those objectives, ocular whole-plot estimates of each lichen species were combined with a large number of subsamples.

Epiphytic lichen communities were characterized by evaluating lichen cover on 40 P. contorta branches per plot; only one tree species was used to minimize substrate variation (McCune 1988). Ten trees were selected using the following criteria: (1) trees were open grown; (2) trees ranged in height from 3.5 to 6 m; and (3) each tree had at least four branches below eye level (a suitable branch being at least 100 cm long and $\geq$1 cm in diameter at the base). The trees were marked with lengths of knotted nylon seine twine whose knot numbers correspond with the tree's number.

Four branches at or below eye level and oriented toward the four primary compass directions were selected and marked with nylon seine twine. When a tree had fewer than four branches, additional branches on other trees were sampled to reach a sum of 40. Branch segments 100 cm long and closest to the tree trunk were evaluated for percent cover of every non-crustose lichen species using the scale: 0 = 0%, 1 = 0-1% (0-3 mm of branch length), 2 = 1-5% (3-15 mm), 3 = 5-25% (15-75 mm), 4 = 25-50% (75-150 mm), 5 = 50-75% (150-225 mm), 6 = 75-95% (225-285 mm), 7 = 95-99% (285-299 mm) and 8 = 99-100% (299-300 mm of branch length). These cover classes approximate an arc-sine square root transformation. This method is sensitive to infrequent species and those with low cover (McCune 1990). Appendix B contains the branch cover data matrix, aggregated to a single value per species per plot.

Whole-plot ocular estimates of lichen abundance for all non-crustose species on all substrates (including the ground) were made as follows, based on the number of individuals sighted per plot: class 1 = 1 individual; 2 = 2-5; 3 = 6-15; 4 = 16-40; and 5 = >40 individuals. For lichen species that occurred in mats or clumps where individuals were impossible to distinguish (Cladonia and Cladina species), each clump was recorded as a single individual (Geiser et al. 1994a). Voucher specimens were deposited at CANL, OSC, US, WIS, with the most complete set in the Tongass National Forest Herbarium in Petersburg, Alaska. Several genera (Bryoria, Cladonia, and Usnea) were not identified to species in the field; voucher specimens were collected to contribute to the species inventory, but were analyzed at the generic level. To characterize each plot physical attributes such as percent slope, aspect, percent cover of standing water, elevation, latitude, and longitude were recorded (Table II.4). Vascular plant cover was estimated using a modified Daubenmire method (1959). Appendix C contains the data matrix of physical attributes per plot.

For lichen tissue analysis samples of three species were collected at each site to determine the range of baseline lichen tissue concentrations of 16 elements. Three 1 g samples each of *Alectoria sarmentosa*, *Cladina rangiferina*, and *Hypogymnia enteromorpha* were collected off plot, to minimize disturbance on the permanent plot. *Alectoria* and *Hypogymnia* were collected from *Pinus contorta*, while *Cladina* was collected from the ground. Each sample was air dried and carefully cleaned and sorted to remove all visible foreign debris and dead tissue. Tissue samples were dried, ground and analyzed for parts per million (ppm) of 15 elements (potassium, calcium, magnesium, sodium, aluminum, iron, manganese, zinc, copper, boron, lead, nickel, chromium, cadmium, and sulfur) (Table III.4 reports observed average values, $\pm$ 2 standard deviations) using inductively coupled plasma atomic emission spectrometry (ICP-AES) (Geiser et al. 1994a). The ICP standard was NIST #1575 pine needles. Total sulphur was determined by dry combustion followed by measurement of evolved sulfur dioxide on a LECO Sulfur Determinator by infra red absorption (Geiser et al. 1994a). Standards for sulfur were commercially prepared Peach Leaves and NIST #1572 citrus leaves. Lichen tissue analyses were performed by the University of Minnesota Research Analytical Lab. See Chapter III for more details.

Lichen nomenclature followed Egan (1987); vascular plant nomenclature followed Hulten (1968) and Hitchcock and Cronquist (1973).

Data Analysis

If lichen community data are to be useful as indicators of air quality, the first step is to determine the natural range of variability for communities under current baseline conditions. One approach is to use multivariate techniques to reduce the dimensionality of the data. The resultant axes (gradients) can be interpreted by evaluating lichen species' responses along the gradients, and by examining correlations between plot gradient scores and environmental data.

To describe the overall abundance of lichens on the plots, total lichen cover values were calculated by summing the branch-level cover classes of all lichen species on a plot. This total lichen cover value has the following characteristics: (1) it cannot be back-transformed into a percent cover value; (2) it includes a species richness component and a total percent cover component; and (3) its distribution, compared to that of percent lichen cover, is more sensitive to low cover values when lichen cover is sparse (McCune 1988).

Although some plots had high total lichen branch cover and some had low cover, for community analysis purposes it was desirable to compare the proportions of total lichen cover by species. To equalize the weight of each plot in the analysis, the data were relativized by plot totals, i.e. each species value was divided by the sum of all species values on that plot. This transformed each lichen cover class value to a relative proportion of cover on each site.

Outliers were screened by examining the frequency distribution of values representing average distance from a plot to every other plot (program ROWCOL in McCune 1993). Using a cutoff value of 2 standard deviations (sd) from the overall average distance between plots, one site was identified as an outlier with an average distance over 4 standard deviations from the mean. This site had an unusually high cover of Sphaerophorus globosus (83% relative cover, $\bar{x}$ = 10%, sd = 12%). Field notes revealed that we appear to have combined its cover with that of an undescribed species of Loxospora; based on this error, the plot was removed. Subsequent outlier analyses identified two other sites (sd = 3.1 and 2.67 respectively). The second outlier had the lowest Alectoria sarmentosa relative cover (3%, $\bar{x}$ = 30% relative cover), and the highest Platismatia glauca relative cover (28%, $\bar{x}$ = 7%) of all plots, which suggested that this plot was uncharacteristically younger than the other plots (Esseen et al. 1994). This plot was subsequently removed. The third outlier had a low species richness (S = 4 as compared to an average of 11); this was probably a drier site with faster growing trees whose younger branches had not been fully colonized by lichens. Two sites lacking vascular plant data were also removed, leaving 45 sites. There were no species outliers, but species which occurred on less than 10% of the plots were removed.

Dimensionality of the final matrix of 45 plots by 21 lichen species was determined using Non-metric Multidimensional Scaling (NMS) (Kruskal 1964; Mather 1976) as implemented in PC-ORD (McCune 1993a); NMS is an ordination technique well suited to non-normal data (McCune 1993a). Lichen species and environmental variables were compared to the ordination results by means of graphical overlays and correlations with axis scores.

Alpha diversity was measured as the average number of species per plot. Gamma diversity was the total number of species accumulated across all plots. Beta diversity was calculated as total number of species divided by the average number of species, or gamma/alpha (Whittaker 1972).

Results and Discussion

Species diversity

A total of 100 lichen species were encountered during ocular surveys of 50 plots (Table II.1). By comparison, only 29 epiphytic macrolichens were encountered on the branch quadrats. It should be noted that not all plots received the same level of scrutiny during ocular estimates, due to different numbers and level of expertise of observers, and length of time on a plot. At some plots there were up to four observers; on those occasions many more lichens, especially crustose, were identified or collected. Vouchers of "lumped" groups which were subsequently identified also contributed to the large whole-plot ocular species list. Those species recorded on only a few plots were not necessarily "rare" but were under-represented in the sampling. The ocular species list was not analyzed quantitatively because of these methodological inconsistencies.

Table II.1. Lichens found on 50 *Pinus contorta* peatland plots

Lichen species	No. of Plots	Lichen species	No. of Plots
Alectoria sarmentosa	50	*C. maxima*	23
Arctomia delicatula	1	*C. ochrochlora*	2
Bryocaulon pseudosatoanum	24	*C. pyxidata*	1
Bryoria bicolor	19	*C. subfurcata*	7
B. capillaris	1	*C. squamosa*	17
B. carlottae	15	*C. sulphurina*	6
B. cervinula	9	*C. umbricola*	8
B. friabilis	3	*C. umbricola v. columbia*	1
B. fuscescens	2	*C. cf. umbricola* "sp. #2"	2
B. glabra	14	*C. uncialis*	48
B. lanestris	3	*C.* sp	8
B. nadvornikiana	1	*Coccotrema pocillarium*	1
B. oregana	2	*Coelocaulon aculeatum*	4
B. subcana	1	*C. muricatum*	4
B. tenuis	15	*Diplotomma alboatrum*	1
B. trichodes	18	*Hypogymnia apinnata*	1
B. trichodes ssp americana	27	*H. duplicata*	38
B. trichodes ssp trichodes	9	*H. enteromorpha*	41
Cavernularia hultenii	33	*H. inactiva*	30
C. lophyrea	13	*H. oceanica*	29
Cetraria californica	9	*H. physodes*	3
C. sp.	1	*H. vittata*	15
C. islandica	2	*Icmadophila ericetorum*	1
Cladina arbuscula	29	*Lepraria* sp.	1
C. arbuscula ssp. beringiana	11	*Lobaria linita*	1
C. ciliata	1	*Loxospora* sp.	11
C. ciliata f. tenuis	1	*Mycoblastus sanguinarius*	5
C. portentosa	8	*Ochrolechia frigida*	2
C. portentosa f. grisea	1	*O. laevigata*	3
C. rangiferina	45	*O. oregonensis*	2
Cladonia amaurocraea	2	*Parmelia hygrophila*	6
C. bellidiflora	24	*P. kerguelensis*	9
C. borealis	5	*P. saxatilis*	30
C. carneola	3	*P. squarrosa*	5
C. chlorophaea group	5	*P. sulcata*	14
C. coniocraea	1	*Parmeliopsis ambigua*	1
C. cornuta	9	*P. hyperopta*	24
C. cornuta ssp cornuta	2	*Peltigera neopolydactyla*	1
C. cornuta ssp groenlandica	8	*P. scabrosa*	1
C. crispata	9	*Pertusaria subambigens*	1
C. decorticata	14	*Platismatia glauca*	43
C. deformis	4	*P. herrei*	36
C. ecmocyna	1	*P. lacunosa*	15
C. fimbriata	6	*P. norvegica*	43
C. furcata	3	*Ramalina roesleri*	1
C. gracilis	2	*Siphula ceratites*	7
C. gracilis ssp gracilis	2	*Sphaerophorus globosus*	49
C. gracilis ssp. vulnerata	1	*Tuckermannopsis chlorophylla*	11
C. grayi	1	*Usnea longissima*	9
C. macroptera	1	*U.* species	1

Lichen species beta diversity was lower for branch quadrats than for whole-plot ocular estimates (Table II.2), illustrating the relative homogeneity (short ecological gradient) of the data set. Diversity indices for the whole-plot ocular estimates reflected the unevenness in sampling intensity. Beta diversity for epiphytes in particular was unnaturally high because of the skew imposed by the large species list as compared to the low alpha diversity. Had all plots been equally sampled (i.e. no lumping) alpha diversity would be higher and therefore beta would be smaller.

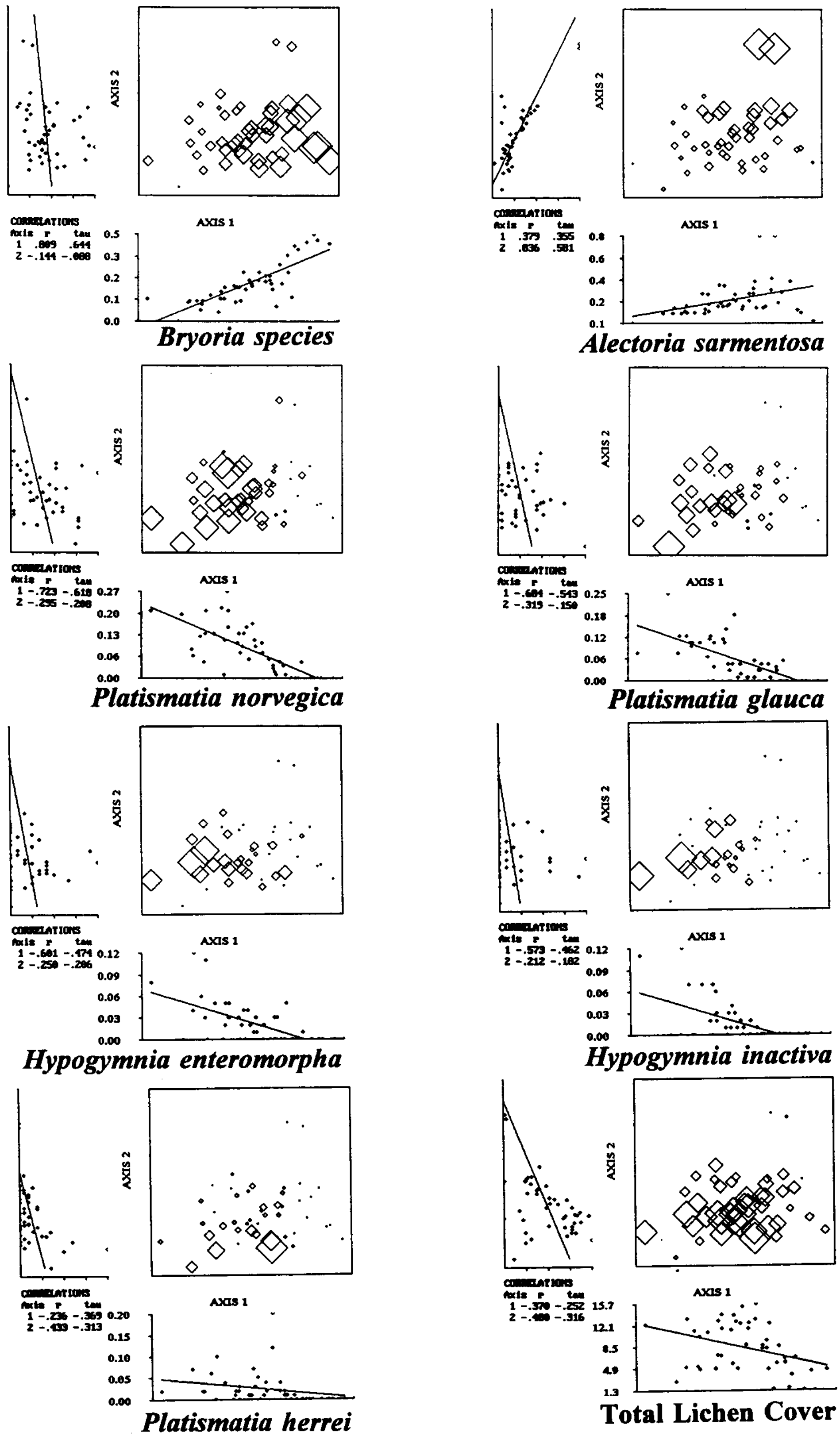
Table II.2. Total species diversity for all lichens encountered

	Diversity Measure		
	alpha	beta	gamma
Whole-plot ocular estimates:			
Epiphytes	17.3	4.1	71
Ground layer	4.4	6.4	28
Quadrat sampling for epiphytes:			
Complete data set (50 plots x 29 sp)	9.3	3.1	29
45 plots x 21 lichens data set	10.3	1.9	21

Community gradient variation

Stress values for a preliminary 6-axis run of NMS revealed that two ordination axes captured most of the variation in the lichen communities. The first two gradients contained 34.8% and 20.6%, respectively, of the information in the analytical data set (cumulative r^2 = 55.4%). Overlays (Fig. II.2) were examined to determine which lichen species and environmental variables were correlated with the two axes, and the nature of those relationships. Tables II.3 and II.4 list correlations between axis scores and lichen species abundance and environmental variables respectively.

Figure II.2. Overlays of lichen species on 2-dimensional ordination (size of box indicates amount of cover per species per plot)



First gradient

Bryoria had a strong positive correlation with the first axis (r = .809), while Platismatia norvegica (r = -.723), P. glauca (r = -.684), Hypogymnia enteromorpha (r = -.601) and H. inactiva (r = -.573) had strong negative correlations (Table II.3).

One possible explanation of the first axis is that it represents a successional gradient. Although Alectoria is not strongly correlated with this axis, the overlays reveal that Alectoria and Bryoria both tend to increase along the axis while the other species decrease (Fig. II.2). In a study of epiphyte biomass on different aged stands in western Oregon and Washington, McCune (1993b) found that "alectorioid" lichens (Alectoria, Bryoria and Usnea species) tended to be more dominant in older stands than "other" lichens (Hypogymnia and Platismatia). Further, this pattern was repeated as one moved up the canopy onto younger substrates. Similar patterns have been revealed in Oregon (Neitlich 1993) and Sweden (Esseen et al. 1994).

Bryoria are dark brown, tangled, filamentous lichens that tend to be rather long and drape over branches. Bryoria may physically reduce the presence of the other species because: (1) high Bryoria cover physically inhibits establishment of the other species; (2) Bryoria draped over other lichens may trap moisture and cause them to rot; (3) the darker, matted Bryoria may excessively shade species it drapes over; and (4) Bryoria, which produces a number of different lichen substances (Brodo & Hawksworth 1979), may have a chemical inhibition effect on other species.

A second explanation for the first axis is that it also represents a moisture gradient. A combined moisture and successional gradient has been suggested by McCune's "similar gradient hypothesis" (1993b). In that study, comparisons of epiphyte biomass at different locations in the canopy revealed that "alectoriod" lichens tended to be more abundant in the lower, moister, older positions while the "other" lichens tended to be more abundant in the higher, drier and younger positions. In the Pinus contorta peatlands, the two groups of lichens appeared to be responding to the moisture gradient at the plot level; plots where Alectoria and Bryoria cover was higher are probably wetter than those where Platismatia and Hypogymnia cover was high. It is interesting to note that the "other" species whose cover is converse to that of Bryoria all tend to have a more or less appressed habit, which could be better adapted to drier conditions.

Table II.3. Correlation coefficients (r) between lichen branch species and ordination axes

LICHEN SPECIES ON BRANCHES	AXIS #1 r	AXIS #2 r
Alectoria sarmentosa	0.379	0.836
Bryocaulon pseudosatoanum	0.198	0.044
Bryoria species	0.809	-0.144
Cavernularia hultenii	-0.351	-0.183
C. lophyrea	0.068	-0.008
Cetraria californica	-0.329	-0.162
C. chlorophylla	-0.145	-0.261
Cladonia species	0.212	-0.249
Hypogymnia duplicata	0.033	-0.040
H. enteromorpha	-0.601	-0.250
H. inactiva	-0.573	-0.212
H. oceanica	-0.396	-0.296
H. vittata	-0.143	-0.067
Parmelia saxatilis	-0.210	-0.300
Parmeliopsis hyperopta	-0.264	0.142
Platismatia glauca	-0.684	-0.319
P. herrei	-0.236	-0.433
P. lacunosa	-0.367	-0.052
P. norvegica	-0.723	-0.295
Sphaerophorus globosus	0.362	-0.117
Usnea species	-0.115	-0.111

Second gradient

Alectoria sarmentosa was the only lichen species strongly correlated with the second axis ($r = 0.84$), while Platismatia herrei had a weak negative correlation ($r = -0.43$; Table II.3). Examination of the overlays suggests that this gradient represents an opposition of Alectoria and Bryoria, who tend to dominate on different ends of this axis (Fig. II.2). Although Bryoria shows only a weak correlation with the second axis, the strength of that correlation is weakened by low abundance at the left end of the first axis (plots dominated by "other" lichens).

The second axis suggests species response to a climatic gradient. Athough Alectoria and Bryoria are both typical of moist habitats at the continental scale (Brodo and Hawksworth 1979), in some areas of the Pacific Northwest Alectoria is absent at drier sites while some Bryoria species thrive at those sites (McCune pers. comm.). Further, Bryoria tends to be more abundant in colder, slightly more continental sites while Alectoria is favored in warmer more oceanic sites. For example, as one travels east out of the dry Willamette Valley into the Cascade foothills, Alectoria is more abundant on the warmer, wetter sites. Alectoria begins to taper off as Santiam Pass is approached, with Bryoria increasing and continuing down the east side of the Cascades in the colder, drier sites where Alectoria disappears.

Environmental variables

Although environmental factors probably underlie the relative abundances of these lichen species along both gradients, none of the recorded environmental parameters were highly correlated with either axis (Table II.4.). This is often the case in community ecology studies where the most readily measured environmental variables are not necessarily the most important causal factors.

Table II.4. Correlations (r) between environmental variables and ordination axes

ENVIRONMENTAL VARIABLE	AXIS #1 r	AXIS #2 r
Latitude	-0.070	0.260
Longitude	0.114	0.352
Average Overstory Height	-0.179	-0.002
Avg. Overstory Diameter Breast Height	0.018	0.164
Average Understory Height	0.037	0.060
Average Overstory Cover	-0.058	-0.111
Average Understory Cover	-0.010	-0.001
Elevation (meters)	-0.214	0.172
% Slope	-0.073	0.232
Aspect	0.205	0.244
Landform	-0.150	0.239
Total Number of Lichen Species on Branches	-0.355	-0.237
% Overstory _Chamaecyparis_ _nootkatensis_	-0.063	0.195
% Overstory _Pinus_ _contorta_	-0.086	-0.131
% Overstory _Tsuga_ _heterophylla_	0.119	-0.068
% Overstory _T._ _mertensiana_	-0.090	0.035
% Understory _C._ _nootkatensis_	-0.092	0.016
% Understory _Pinus_ _contorta_	0.149	-0.106
% Understory _Picea_ _sitchensis_	-0.082	0.060
% Understory _Thuja_ _plicata_	-0.034	-0.008
% Understory _Tsuga_ _heterophylla_	-0.089	0.138
% Understory _T._ _mertensiana_	-0.006	0.107
% Cover _Menziesia_ _ferruginea_	0.073	0.219
% Cover _Empetrum_ _nigrum_	0.223	-0.216
% Cover _Carex_ _sitchensis_	-0.176	-0.186
% Cover _Fauria_ _crista-galli_	-0.320	-0.062
% Cover _Lysichitum_ _americanum_	-0.074	0.040
% Cover _Ledum_ _groenlandicum_	0.038	-0.336
% Cover _Vaccinium_ species	-0.136	-0.303
Phosphorous parts per million (ppm)	0.057	0.263
Potassium ppm	0.040	0.284
Calcium ppm	0.041	0.274
Magnesium ppm	0.028	0.254
Sodium ppm	-0.034	0.124
Aluminum ppm	-0.068	0.293
Iron ppm	-0.039	0.282
Manganese ppm	0.103	0.254
Zinc ppm	0.018	0.281
Copper ppm	-0.111	0.031
Boron ppm	0.208	0.279
Lead ppm	-0.098	-0.021
Nickel ppm	-0.154	-0.219
Chromium ppm	-0.156	-0.065
Cadmium ppm	-0.158	-0.330
% Total Sulphur	-0.060	-0.324
Total lichen branch cover	-0.370	-0.480

Conclusions

Lichen communities in southeast Alaskan peatlands show considerable variation in lichen abundance and species composition. Some communities are dominated by _Platismatia_ and _Hypogymnia_ species, while _Bryoria_ or _Alectoria_ dominate in other cases. Although the underlying causes for this variation remains obscure, there are several promising avenues of explanation.

The suggestion that the first gradient represents a successional trend could be further explored in southeast Alaska several ways. Additional _Pinus contorta_ plots could be sampled with tree cores taken from each tree. This could reveal a direct relationship between tree age and species composition and lichen abundance. Also, it is interesting to note that the lichen species most strongly correlated with the gradients in this study were also common on the Tongass Air Quality Biomonitoring _Tsuga heterophylla_ plots (Geiser et al. 1994a). It would be useful to test the applicabilities of the "similar gradient hypothesis" (McCune 1993b) in southeast Alaska. Specifically, one could determine if lichen species respond similarly to successional and moisture gradients.

If lichen communities are to be useful indicators of species compositional trends along air pollution gradients, it is essential that sites near areas impacted by air quality be sampled. Despite the history of studies of epiphyte ecology in the Pacific Northwest, we still know little about the response of the common southeast Alaskan species to air pollutants.

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Chapter III. Elemental Analysis of Lichens from _Pinus_ _contorta_ Peatlands in Southeast Alaska

Abstract

As part of an Air Quality Biomonitoring Program on the Tongass National Forest, elemental tissue content of the lichen _Alectoria sarmentosa_ was determined from 43 _Pinus_ _contorta_ peatland plots in southeast Alaska. The range of values for 16 elements are reported and compared to other regional studies; the ranges of values for most elements are within normal background levels. Quality assurance techniques are described for separation of laboratory and field noise from elemental content signal. Principal components analysis is used to create three synthetic gradients of plot-level elemental content. The first three principal components captured 55% of the correlation structure among elements. Iron (r=-0.91), aluminum (r=-0.80) and chromium (r=-0.71) are all highly correlated with the first gradient. This gradient could represent sites enriched by elements from soil; aluminum and iron silicates are both persistent and abundant components of weathered rock and soil. Potassium (r=-0.82), phosphorous (r=-0.63), zinc (r=-0.60), manganese (r=-0.58), magnesium (r=-0.51) and nickel (r=0.54) are correlated with the second gradient. Many of these elements are supplemented by salt water aerosols. Lead (r=0.70) and cadmium (r=0.59) were correlated with the third axis. These could possibly be due to enrichment from fossil fuel combustion. Suggestions are given to improve the compatibility of regional studies in the future.

Introduction

Rationale for elemental analysis of lichens

Lichens have long been used as sensitive indicators of air quality (Hale 1983). In addition to being sensitive to air quality directly, lichens can accumulate and concentrate many elements, toxic compounds and radioactivity in their tissue (Pearson 1993) while remaining metabolically active (Hawksworth & Rose 1976; Nieboer et al. 1978). This ability to accumulate substances makes lichens useful registers of elemental content. Lichens are also conspicuous components of many ecosystems and play important ecological roles.

Because lichens lack the waxy cuticle of vascular plants they function like little sponges accumulating matter through wet and dry deposition. Nieboer et al. (1978) provide an overview of the mechanics of lichen mineral uptake. Structural characteristics combined with the frequent cycles of wetting and drying that lichens experience allow for the concentration of substances that can be measured in the lab (Rhoades 1988). Elemental analyses of lichens are relatively inexpensive; 16 elements can be measured for under $30.00 per sample (University of Minnesota Research Analytical Lab 1994), while a single sulfur dioxide monitor can cost tens of thousands of dollars. Lichens can not be used to provide a record of levels of deposition (like an instrument can), but they are effective cumulative registers of elemental levels, which they integrate over a number of years.

Not all lichens have the same sensitivity to air quality; some are extremely sensitive and disappear from impacted areas, while others can tolerate higher concentrations of elements (Rhoades 1988). A pollution tolerant species is especially useful because it can persist in an impacted area and build up concentrations of elements; studies have correlated the amounts in lichen tissues with levels in the nearby environment (Rhoades 1988). Unfortunately, the pollution tolerance of relatively few lichens in the Pacific Northwest is known. For elemental analysis it is most useful to carefully select a few lichen species based on the following criteria: (1) the lichens have broad distributions and ecological amplitudes, making comparisons across broad geographic areas possible; (2) when possible, select species with known levels of sensitivity to air pollution; and (3) select species that have been used in other elemental analyses studies.

Different lichen species accumulate elements at different rates (Nieboer et al. 1978), making comparisons between species difficult. Different elements also accumulate at different rates. Given these constraints however, comparisons of the same elements in the same species from different areas can provide a meaningful picture of regional ranges of atmospheric deposition (McCune et al. 1993).

Because laboratory analytical procedures can vary, it is wisest to select a lab that has experience with lichen tissues in particular, and to use that lab for the duration of the study and for follow-up studies in the future.

Lichen elemental tissue content is measured as either parts per million (ppm) or as a percent of dry weight. Each tissue sample must contain only one lichen species and be free of contaminants such as soil, bark, or other foreign matter. Elements of interest are typically those with known or suspected toxicity from anthropogenic sources. Tissue analyses can be tailored to target elements associated with emissions from local or suspected point sources.

Elemental content of lichens is currently being used to monitor air quality by several Federal agencies (Hale 1982; Wetmore 1985; Wetmore 1987; Rhoades 1988; Ryan 1990; McCune et al. 1993; Geiser et al. 1994). A handbook for the use of lichens as biomonitors was recently compiled by a team of Forest Service, National Park Service, and University professionals (Stolte et al. 1993), and includes a section on lichen tissue analysis (Jackson et al. 1993).

Scope of present work

In 1989 the USDA Forest Service Tongass National Forest initiated an Air Quality Biomonitoring Program (AQBP) using lichens. The approach was two-fold: (1) to establish a baseline of lichen elemental content (Geiser et al. 1994a); and (2) to conduct a forest-wide lichen inventory (Geiser et al. 1994b). As part of the baseline permanent plots were established in two forested habitats: <u>Pinus contorta</u> peatlands and <u>Tsuga heterophylla</u> old-growth. The results reported here are from the <u>Pinus contorta</u> peatlands.

Objectives

The objectives of these analyses are to: (1) determine the range of values for 16 elements on 43 plots with "pristine" air quality; (2) describe the correlation structure among elements; and (3) compare these values with results from other regional studies.

Methods

Field

Study area, field methods, and sampling design are described in detail in Derr (1994) and in Geiser et al. (1994a). Briefly, between 1989 and 1992, 50 permanent plots were established in Pinus contorta peatlands and samples of up to three target lichen species (Alectoria sarmentosa, Hypogymnia enteromorpha sens. lat., and Cladina rangiferina) were collected per plot. Because Alectoria had the broadest coverage across the region, it was the only species analyzed in 1991 and 1992. While Alectoria was present at all 50 permanent Pinus contorta plots, it was only collected on 43. This was due to one or more of the following: (a) lack of enough material to make an adequate sample, (b) lack of time at a site, or (c) contamination of the sample in transit from the field. Lichen tissue was collected from several off-plot trees to maintain lichen cover integrity on the permanent plot, and to capture the range in variability of elemental concentration between individual lichens. Lichens were collected into 100% cotton herbarium paper envelopes; gloves were not worn. After air drying overnight in a lab free of smoke and other contaminants, dirt, bark, and pieces of other lichens were hand-picked from the tissue sample. The cleaned lichen samples were stored in 6 x 11 cm Kraft coin envelopes.

The results of analyses of Alectoria sarmentosa growing on Pinus contorta collected in 43 peatlands are presented here. These data were used to establish the range of regional baseline values for 16 elements in this specific habitat type. This baseline could be used for comparison with currently impacted areas and with conditions in the future.

Laboratory analysis

124 one-gram samples (1 to 3 samples per plot) of cleaned and air-dried Alectoria tissue were sent to the University of Minnesota Research Analytical Lab where samples were oven dried and ground. Two separate analyses were performed; 15 elements were simultaneously determined by inductively coupled plasma atomic emission spectrophotometry (ICP-AES), and percent total sulfur was determined by infrared absorption.

Calcium, magnesium, sodium, potassium, phosphorous, iron, manganese, aluminum, copper, zinc, cadmium, chromium, nickel, lead, and boron were determined simultaneously by ICP. Roughly one gram of each ground sample was dry ashed in a 20 ml high-form quartz crucible in a 485°C circulating-air muffle furnace for ten to twelve hours; crucibles were covered during ashing to prevent contamination. The ash was dissolved in 5 ml of 20% HCl for fifteen minutes, then 5 ml of deionized water was added and the ash allowed to settle for 3 hours. The resulting decanted supernatant was run through the ICP in 7 ml plastic disposable tubes. Results were expressed on a ppm (ug/g) basis by element.

Percent total sulfur was determined from a 100-150 mg portion of each ground sample. Each sample was dry ashed, then evolved sulfur dioxide was measured on a LECO Sulfur Determinator by infrared absorption. Sulfur values were converted from percent total weight to ppm because it standardized the units for all elements. Appendix D contains the raw data matrix of 124 lichen samples by 16 elements.

The analytical lab routinely used lab splits and a "peat" standard to ensure that variance in instrumental readings was less than 5%. The peat standard was prepared by the lab, and contains approximately the same proportions of elements as typical natural peat. If the reading for any given element "drifted" beyond 5% of the actual concentration of the peat standard, or the difference between the lab split readings was greater than 5%, the instrument was recalibrated against all elements in the peat standard (R. Eliason, University of Minnesota, pers. comm.).

Data analysis

Data screening

Raw data were averaged by plot to give a single value per element per plot, then screened for skewness to determine if transformations were necessary. Averaged values were $\log_{10}$ transformed to correct for the strong positive skew in the data. Multivariate outliers were sought for both elements and plots using a city-block distance measure in the program ROWCOL in PCORD (McCune 1993a).

Element selection

Initial data summaries were done for all elements on all plots. Interpretation of these summaries and comparisons of reported elemental values with in-house lab calibration standards indicated that all elements were suitable for inclusion in subsequent analyses.

Plot-level indices

Each plot was assigned a score on each of several gradients in elemental content. These gradients were generated using Principal Components Analysis (PCA; McCune 1993), the basic eigenanalysis technique first used in ecology by Goodall (1954). Elements were combined into three plot-level indices, or "principal components", based on the strongest correlation structure among elements, using correlations among elements as the cross-products matrix. PCA constructs linear combinations of elements that best represent the correlation structure among those elements. The resulting linear equations were used to calculate scores, or plot-level indices, for each sample unit. The scores indicate the position of individual samples on synthetic gradients in elemental content, and can be listed in a table, plotted as an ordination, or both. These synthetic gradients often represent different classes of sources of elemental deposition (e.g. road dust, fossil fuel combustion, saltwater aerosols) (McCune et al. 1993).

Results and Discussion

Skewness and transformation

Summarization of raw averaged data indicated a strong positive skew in elements across all plots. Log_{10} transformation largely corrected this skewness and reduced the most extreme cases of positive kurtosis (Table III.1).

Table III.1. Effect of $\log_{10}$ transformation on skewness and kurtosis by element (all samples combined)

	Raw Data		Log-transformed	
	Skewness	Kurtosis	Skewness	Kurtosis
1 P	0.991	1.824	0.219	0.643
2 K	-0.560	0.263	-1.070	1.119
3 CA	3.403	15.861	-0.515	0.989
4 MG	0.587	-0.045	-0.367	-0.080
5 NA	5.160	27.760	1.175	2.053
6 AL	2.593	8.288	0.555	1.093
7 FE	2.710	7.967	0.401	0.629
8 MN	0.560	-0.804	-0.696	-0.359
9 ZN	0.520	0.311	-0.142	-0.335
10 CU	-0.226	0.960	-1.778	4.865
11 B	2.440	5.125	0.514	0.658
12 PB	1.721	3.543	0.252	-0.263
13 NI	0.617	-1.155	0.379	-1.473
14 CR	1.200	0.363	0.410	-0.783
15 CD	0.936	0.728	-0.271	-0.301
16 S	0.767	0.053	0.300	-0.367

Quality Assurance

Variability in reported values of elemental content in Alectoria sarmentosa can stem from a variety of different sources (Rhoades 1988; R. Eliason pers. comm.). These include: (1) variability of elemental content within plots, (2) variability of elemental content between plots, (3) variability introduced by the drying, grinding, and ashing of samples prior to instrumental analysis, and (4) variability due to procedural errors associated with calibration of the detection instruments. There are also recognized constraints on the accuracy of reported values based on the detection limitations of lab equipment (Rhoades 1988; Geiser et al. 1994). A number of quality assurance (QA) checks were used to examine the different levels of sample variability and procedural error.

Lab detection limits

The University of Minnesota Soil Testing and Research/Analytical Laboratory has specific detection limits for ICP-AES analyses (R. Eliason, pers. comm.). These detection limits are presented in Table III.2.

Table III.2. Detection limits for ICP-AES at University of Minnesota Soil Testing and Analytical Laboratory

Element	ppm	Element	ppm	Element	ppm
P	0.228	Al	0.040	B	0.006
K	0.311	Fe	0.008	Pb	0.089
Ca	0.048	Mn	0.002	N	0.029
Mg	0.033	Zn	0.007	Cr	0.005
Na	0.094	Cu	0.007	Cd	0.006

Within-plot and instrumental calibration variability

The following calculations were used to estimate what proportion of the total variation in reported elemental values (S_T^2) was due to: (a) noise associated with precision limitations due to calibration of lab instruments (S_L^2), (b) noise associated with variability in elemental content of individual lichen thalli on a plot (S_F^2), and (c) noise associated with sample preparation (S_B^2). Every tenth field sample was analyzed twice ("lab splits") to evaluate lab noise. Field replications were used to evaluate within-plot variation. A "bulk sample" (see following section on bulk sample) was analyzed periodically to evaluate error associated with sample preparation. The 1990 data for lab splits were used as a representative subsample; all values for the bulk sample and field measurements were used. Calculations for each element were based on total variance and mean-square error (MSE) values from analysis of variance.

Total variance (S_T^2) = Total sum of squares / n-1 degrees freedom
Estimated % lab (S_L^2) = (MSE within lab splits / S_T^2) * 100
Estimated % field (S_F^2) = (MSE within plots / S_T^2) * 100
Estimated % bulk sample (S_B^2) = (bulk sample variance / S_T^2) * 100

To accurately detect the signal representing variation in elemental concentration of lichen samples, lab and bulk sample variance should be minimal. The percent of total variance associated with lab error and with sample preparation was very low for most elements (Table III.3). Lead, nickel, chromium, and cadmium, however, were more variable because they were measured in amounts very close to the detection limits of the instrument. The percent of total variance due to within-plot differences was considerably higher than lab error for all elements except chromium. This is probably an artifact of the proximity of measured amounts of chromium to detection limits, and not an indication of high within-plot variance, as evidenced by the one-way ANOVA F-ratio and probability statistic for chromium (Table III.4).

Table III.3. Laboratory error, within plot variance, and variance from sample preparation. These estimates are based on lab splits, field splits, and a bulk sample of Alectoria sarmentosa, respectively, and are expressed as a percent of the total variance

Elements	Total Variance ($\log_{10}$ ppm)	Lab Error, % of Total	Within-plot Variance, % of Total	Bulk Sample Variance, % of Total
P	0.0382	0.3	92.4	5.5
K	0.0283	0.4	93.3	3.2
Ca	0.1313	0.2	34.0	7.2
Mg	0.0334	0.3	35.3	4.8
Na	0.1857	0.2	22.3	0.8
Al	0.0463	1.3	20.1	2.8
Fe	0.0837	0.4	18.9	5.0
Mn	0.1834	0.1	23.6	1.5
Zn	0.0163	0.6	41.7	8.0
Cu	0.0436	0.7	68.3	2.1
B	0.1505	0.5	35.3	1.5
Pb	0.0855	28.6	42.0	18.0
Ni	0.0254	33.1	17.7	51.2
Cr	0.0659	67.5	60.4	183.3
Cd	0.0720	14.4	58.1	97.5
S	0.0096	5.2	29.2	6.3

Comparisons with NIST standards

Standard samples were analyzed during lichen tissue analysis to assess the combined error associated with preparation of the sample and instrumental analysis. Because at present there are no NIST lichen standards, NIST 1575 pine needles were used for ICP, and commercially prepared peach leaves from Alpha Resources, Stevensville, MI and NIST 1572 citrus leaves were used as sulfur standards. The operating assumption is that if the lab techniques work on NIST pine needles, they should work on lichens (R. Eliason, pers. comm.). Observed averages $\pm$ 2 standard deviations are reported. The range of most observed values was within the range reported by NIST except for low values for aluminum, iron, manganese, and nickel, and the highly variable values of lead (Table III.4). Of these, iron was most problematic with values about half of those published by NIST.

Table III.4. Comparison of observed elemental contents with reported values from NIST pine needles for 15 ICP-AES elements, and peach leaves and NIST citrus leaves for S ("Standard Range" refers to the upper and lower limits provided by NIST; sulfur standards are reported as certified ppm)

Element	Standard Range ug/g	Observed Values -2 sd	x ug/g	+2 sd
P	1000-1400	1121	1205	1290
K	3500-3900	3611	3752	3894
Ca	3900-4300	4034	4233	4431
Mg	unknown	-189	832	1853
Na	unknown	6	15	23
Al	515-575	267	299	331
Fe	190-210	77	88	99
Mn	660-690	493	556	620
Zn	unknown	62	71	80
Cu	2.7-3.3	2.2	2.7	3.2
B	unknown	15.9	17.1	18.2
Pb	10.3-11.3	7.1	11.3	15.6
Ni	2.8-4.2	1.7	2.3	2.8
Cr	2.4-2.8	0.9	2.0	3.1
Cd	unknown	-0.2	0.4	1.0
S (peach)	2130	1937	2079	2221
S (citrus)	4070	3754	3926	4098

Bulk samples

Due to the lack of NIST lichen standards, an in-house lichen standard (bulk sample) was periodically analyzed along with the NIST pine needles. The bulk sample consisted of a 100 g sample of <u>Alectoria</u> <u>sarmentosa</u> that was collected at a single site in southeast Alaska; 1 g samples of the bulk were analyzed. The bulk sample, like the NIST standard, is used between different lab "runs" and also between different years. The percent of total variance associated with the bulk sample is presented in Table III.3.

Data screening results

Plots #5, #18 and #9 were identified as outliers with standard deviations (sd) of 2.8, 2.5 and 2.1 respectively, as was the element lead (sd = 2.9). Because none of the outliers were extreme, and because they potentially express variation of interest, they were included in the analysis.

Basic summary statistics

Table III.5 lists the basic summary statistics for elemental content in Alectoria. The raw median value for each element was reported, as opposed to a raw average, because the median is a better estimator of central tendency than the mean when data are skewed.

Table III.5. Elemental content (log of ppm except median & range) of 16 elements in 43 samples of Alectoria sarmentosa

#	Name	Raw Median	Raw Range	Mean	Stand. Dev.	Sum	Min	Max
1	P	185	121-312	2.275	0.083	97.840	2.081	2.494
2	K	1047	624-1372	3.009	0.075	129.385	2.795	3.134
3	CA	5082	603-29156	3.654	0.304	157.133	2.780	4.465
4	MG	353	122-601	2.515	0.164	108.139	2.087	2.820
5	NA	105	30-3948	2.112	0.423	90.803	1.476	3.596
6	AL	32	12-144	1.536	0.205	66.035	1.083	2.158
7	FE	24	6-165	1.417	0.294	60.926	0.752	2.217
8	MN	48	6-150	1.637	0.382	70.390	0.766	2.175
9	ZN	22	13-39	1.343	0.107	57.754	1.108	1.596
10	CU	0.90	0.26-1.48	-0.047	0.135	-2.022	-0.580	0.169
11	B	1.63	0.21-16.33	0.296	0.388	12.716	-0.678	1.221
12	PB	2.20	0.85-8.84	0.366	0.229	15.735	-0.073	0.946
13	NI	0.29	0.22-0.59	-0.501	0.153	-21.536	-0.658	-0.227
14	CR	0.25	0.11-0.82	-0.556	0.233	-23.903	-0.959	-0.086
15	CD	0.21	0.07-0.60	-0.673	0.215	-28.955	-1.155	-0.223
16	S	257	28-433	2.427	0.089	104.375	2.230	2.637

ANOVAs of elements

One-way ANOVAs were performed on each of the log-transformed elements to compare within plot variability (or noise) with between plot variability (the elemental content signal). The F ratio of between plot to within plot variability (Table III.6) can be interpreted as an indicator of the signal to noise ratio: the lower the ratio, the more noise. The probability statistic (p) evaluates the significance of the F ratio.

Table III.6. One-way ANOVAs of 16 log-transformed elements in Alectoria sarmentosa tissue

Element	F ratio	p	Element	F ratio	p
P	1.3	0.198	Zn	5.1	0.000
K	1.2	0.228	Cu	2.4	0.001
Ca	6.7	0.000	B	6.4	0.000
Mg	6.4	0.000	Pb	5.0	0.000
Na	11.2	0.000	Ni	14.5	0.000
Al	12.1	0.000	Cr	2.9	0.000
Fe	13.6	0.000	Cd	3.1	0.000
Mn	10.5	0.000	S	8.1	0.000

Comparisons with other studies

Unfortunately there are few studies of lichen elemental content in the Pacific Northwest. Studies that do exist suggest that the ranges of values for most elements in Alectoria in Pinus contorta peatlands are within normal background levels (Table III.7). Some calcium, magnesium, and sodium values were higher than those reported from Olympic National Park (Rhoades 1988); this is most likely due to the strong maritime influence in southeast Alaska and enhancement by salt spray. Chromium was slightly higher in peatlands than in Olympic National Park, but this could be an artifact of the detection limits. Note that differences in reported ranges between this study and Geiser et al. (1994) were probably due to the inclusion of 31 peatland plots not included in Geiser et al.

Table III.7. Range of raw elemental content of Alectoria sarmentosa in the Pacific Northwest and Alaska (* = value below detection limit)

Element	Raw Range (ppm)		
	Pinus contorta Peatlands	Tongass National Forest (Geiser et al. 1994)	Olympic National Park (Rhoades 1988)
P	121-312	93-1068	327-1150
K	624-1372	221-2500	1450-2700
Ca	603-29156	238-11825	930-4210
Mg	122-601	112-854	232-453
Na	30-3948	12-1532	33-119
Al	12-144	6-65	20-108
Fe	6-165	4-250	63-221
Mn	3-287	51-302	38-268
Zn	13-39	5-49	18-45
Cu	0.26-1.48	0.23-1.99	1.02-1.37
B	0.21-16.33	0.06-7.15	0.95-2.92
Pb	0.85-8.84	n/a	3.26-14.4
Ni	0.22-0.59	n/a	* -1.17
Cr	0.11-0.82	n/a	0.26-0.64
Cd	0.07-0.60	n/a	* - *
S	28-433	140-670	243-592

Correlations among elements

It can be expected that some elements will tend to be correlated with each other if the sources of those elements are shared (McCune et al. 1993). For example, calcium, magnesium, sodium, manganese, zinc, and cadmium all tend to be elevated in areas subjected to salt water spray (Nieboer et al. 1978; Rhoades 1988; see Table III.10, axis #2). The correlation structure among elements in the peatlands was examined in two ways; (1) a correlation coefficient matrix comparing all pairs of elements was calculated (Table III.8), and (2) this correlation structure was subsequently analyzed using PCA as described below.

Table III.8. Correlations among elements in <u>Alectoria</u> <u>sarmentosa</u> (r >0.5 are highlighted)

	P	K	Ca	Mg	Na	Al	Fe	Mn	Zn	Cu	B	Pb	Ni	Cr	Cd	S
P	1															
K	**.69**	1														
CA	-.06	.25	1													
MG	.32	.35	.25	1												
NA	.34	.25	.05	**.75**	1											
AL	-.07	-.00	-.08	.15	.32	1										
FE	.22	.19	-.25	.21	.25	**.78**	1									
MN	.11	.46	.34	.05	-.24	-.07	.06	1								
ZN	.28	.45	.19	.02	-.17	-.24	-.18	.40	1							
CU	-.01	.19	.23	.10	-.08	.29	**.51**	.22	.20	1						
B	.21	.06	-.03	.29	.19	.02	.31	.01	.07	.42	1					
PB	-.21	-.10	**.53**	.05	-.11	-.01	-.15	.08	.01	.15	-.14	1				
NI	-.30	-.32	-.12	-.15	-.13	.36	.23	-.33	-.30	-.07	-.13	.37	1			
CR	.09	.14	-.14	.08	.01	**.51**	**.65**	.18	-.06	.45	.23	.14	**.52**	1		
CD	-.16	.19	.41	.05	-.14	-.05	-.26	.36	.29	-.01	-.29	.33	.11	-.09	1	
S	-.12	-.18	-.35	.03	.19	.41	.28	-.21	-.36	-.14	-.17	-.01	.36	.09	.14	1

Principal components

Principal components analysis (PCA) was used to partition the strongest multivariate correlation structure in the data along a small number of synthetic gradients, or components (Table III.9). Synthetic scores were calculated for each of the 43 plots according to their position along each of the gradients (Appendix E). These scores can be used as plot-level indices of elemental content, and scores for plots sampled in the future can be compared with this index. Eigenvectors (Appendix F), coefficients of the linear equations produced by PCA, are used to calculate these scores.

The first three principal components captured 55% of the correlation structure among elements. Interpretation of those gradients was enhanced by the correlation coefficients between concentrations of each element and plot scores on the gradient (Table III.10). While correlation coefficients contain the same information as the eigenvectors, correlation coefficients are scaled from -1 to 1 and are thus more easily interpretable.

Table III.9. Variance extracted from first 5 principal components for separate analyses for Alectoria sarmentosa

VARIANCE EXTRACTED, FIRST 10 AXES			
AXIS	EIGENVALUE	% OF VARIANCE	CUM. % OF VAR.
1	3.271	20.442	20.442
2	3.128	19.549	39.991
3	2.315	14.472	54.462
4	1.780	11.127	65.589
5	1.384	8.648	74.237

Correlations between each element and the principal components are presented in Table III.10. Iron (r = -0.91), aluminum (r = -0.80) and chromium (r = -0.71) are all highly correlated with the first gradient. This gradient could represent sites enriched by elements from dirt; aluminum and iron silicates are both persistent and abundant components of weathered rock and soil. Potassium (r = -0.82), phosphorous (r = -0.63), zinc (r = -0.60), manganese (r = -0.58), magnesium (r = -0.51) and nickel (r = 0.54) are correlated with the second gradient. Many of these elements are supplemented by salt water aerosols (Nieboer et al. 1978; Rhoades 1988). Lead (r = 0.70) and cadmium (r = 0.59) were correlated with the third axis. These could possibly be due to enrichment from fossil fuel combustion.

Table III.10. Pearson correlation coefficients (r) between individual elements and scores on principal components for Alectoria sarmentosa elemental content. Correlations with r $\geq$ 0.5 are highlighted in bold

Element	Axis 1 r	Axis 1 r^2	Axis 2 r	Axis 2 r^2	Axis 3 r	Axis 3 r^2
P	-0.174	0.030	**-0.633**	**0.401**	-0.402	0.162
K	-0.069	0.005	**-0.819**	**0.671**	-0.018	0.000
CA	0.312	0.097	-0.428	0.183	0.509	0.259
MG	-0.335	0.113	-0.512	0.262	-0.169	0.028
NA	-0.451	0.204	-0.281	0.079	-0.414	0.172
AL	**-0.797**	**0.635**	0.093	0.009	0.240	0.058
FE	**-0.906**	**0.821**	-0.148	0.022	0.090	0.008
MN	0.177	0.031	**-0.580**	**0.337**	0.406	0.165
ZN	0.338	0.114	**-0.603**	**0.364**	0.156	0.024
CU	-0.394	0.156	-0.401	0.161	0.420	0.176
B	-0.356	0.127	-0.355	0.126	-0.183	0.033
PB	0.115	0.013	0.040	0.002	**0.699**	**0.488**
NI	-0.385	0.149	0.544	0.296	0.471	0.222
CR	**-0.705**	**0.497**	-0.091	0.008	0.425	0.181
CD	0.320	0.103	-0.147	0.022	**0.582**	**0.339**
S	-0.421	0.177	0.432	0.187	0.022	0.000

Enhancing comparisons among studies

An important objective for establishing lichen elemental content baselines is to create a basis for comparison of spatial and temporal elemental concentrations. To enhance regional comparisons, it would be useful for different studies to adopt a common format for reporting results so that meaningful comparisons between studies and between points in time could easily be created. Some suggestions include: (a) elemental data should be log transformed to correct for the positive skew in elemental values; (b) median, mean and min-max ranges of raw data for each element should be reported; (c) Tyvec bags should be used for field collection and transport of lichen tissue samples, to avoid potential contamination by sulfur in Kraft envelopes or bags; (d) sterile gloves should be worn to prevent contamination during handling; and (e) a suite of regionally common lichens should be used in subsequent studies. These could include (but not be limited to):

Alectoria sarmentosa, *Cladina rangiferina*, *Sphaerophorus globosus* and *Platismatia glauca*.

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Chapter IV. Growth of Transplants of Alectoria sarmentosa, Evernia prunastri, and Lobaria pulmonaria in Western Oregon

Abstract

Removable lichen transplants were constructed using live thalli of known weight, a 5 cm length of monofilament and silicone glue, and reusable attachment mechanisms. Transplants were weighed every several months for 13 months, and reference standards for each species were used to correct for changes in lichen water content due to changes in lab humidity. Alectoria sarmentosa transplants were grown in their original noble fir (Abies procera) stand in the Coast Range; despite apparent vigor, Alectoria proved unsuitable for repeated weighings because of biomass loss due to fragmentation (average of 9% biomass loss), although it remained healthy. Evernia prunastri and Lobaria pulmonaria were grown in their original habitat in a scattered Oregon white oak stand (Quercus garryana) in the Willamette Valley foothills, and on open-grown oaks on the valley floor. Average growth during 13 months for Evernia in the foothills and valley was 40% and 30% respectively; for Lobaria it was 16% and 15%. Differences in growth between species could be due to differences in: (1) growth rates; (2) sensitivities to air quality; (3) sensitivities to microhabitat; and (4) sensitivities to transplant trauma. Differences in growth between valley and foothill sites could be due to differences in: (1) micro- or macrohabitat conditions; and (2) air quality.

Introduction

Why do we care about lichen growth rates/transplants?

Lichens play many roles in ecosystems; they provide food for wildlife and bird nesting material (Richardson & Young 1977), can be significant contributors to the nitrogen cycle (Pike 1978), and are bioindicators of air quality (Hart et al. 1988; Stolte et al. 1993), forest health (Stolte et al. 1993), and biodiversity (Nitare & Noren 1992; Tibell 1992). Despite their importance, little is known about their basic biology. The development of reliable techniques for lichen transplants will facilitate studies of basic lichen biology. Transplants are also useful tools for air quality biomonitoring (Pearson 1993).

What are lichen transplants?

Lichens are usually securely attached to their substrate, making removal and transplant difficult. While transplants of lichens attached to their branch (Nash et al. 1990) or bark (Brodo 1961) substrate have been made, the attached substrate can be unwieldy and suitable lichen species are limited. Lichen fragments have been glued to slate rock in new habitats (e.g. Armstrong 1982), but unfortunately these transplants are permanently attached and can't easily be removed and weighed. The construction of lightweight removable pendants expands the range of potential species and habitats for transplant studies. Furthermore, these transplants are easily portable which facilitates reweighing.

Lichen transplants consist of a live lichen thallus of known weight, an artificial substrate, glue and a reusable attachment mechanism. They are easily assembled in the lab and can be transported to original and new habitats. Other types of pendulous lichen transplants have been constructed (Denison 1988; Stone 1986), but their tiered multiple thalli can increase microhabitat modification and make it difficult to assess growth of individual thalli; transplants using single thalli reduce these effects. The tiered thallus method, and the method developed by Sillett (1994) require that a hole be punched in the thallus, limiting this technique to large foliose species.

How are they useful?

Transplants can be used to study basic lichen biology, addressing issues such as: (1) average growth rates of different species; (2) seasonality of growth; (3) growth rates in different microhabitats; and (4) growth rates when transplanted into non-native habitats. They also have management applications as air pollution bioindicators (Palomaki et al. 1992; Pearson 1993). Some applications are: (1) determining growth rates of sensitive and tolerant species along air pollution gradients so that indicator species can be used to monitor air quality; (2) calibration of lichen transplant elemental uptake with instrumental monitors of sulfur and other pollutants of concern; and (3) using transplants as air quality bioindicators in former habitats where air quality has improved.

Transplant Species

Alectoria sarmentosa is a pendulous fruticose lichen that grows on trees and woody shrubs. While some populations commonly produce apothecia, its typical mode of reproduction appears to be by fragmentation. In North America it is widespread in moist coastal, mountainous and boreal areas from the Seward Peninsula in Alaska south to central California, in the Canadian and American Rocky Mountains, and in Eastern Canada (Brodo & Hawksworth 1979). It also occurs in Greenland, Scandinavia, Scotland, and in boreal and subalpine forests in mountainous regions of Europe (Brodo & Hawksworth 1979). *Alectoria*, along with the closely related genus *Bryoria*, is an important winter forage species for black-tailed deer (Hanley et al. 1985) and mountain goats (Fox et al. 1989).

Alectoria is currently being used as an air quality bioindicator by several Federal agencies, who analyze tissue samples for levels of selected elements (Geiser et al. 1994; Stolte et al. 1993). Given its importance to wildlife, and its usefulness as an air quality biomonitor, it would be especially useful to develop a transplant method for this species.

Evernia prunastri, a dorsi-ventrally differentiated fruticose lichen that produces annual dichotomous branches (Stone & McCune 1990), is common on trees and fenceposts from British Columbia south to California, and in Europe; it is rare in Eastern North America, where it is replaced by E. mesomorpha (Hale 1979). Although some European studies have shown E. prunastri to be pollution tolerant (Pearson 1993), others have found it to be moderately sensitive to sulphur dioxide (Pearson & Henriksson 1981). Its relatively thin cortex leaves the phycobiont vulnerable to chlorophyll damage, resulting in electrolyte leakage (Pearson & Henriksson 1981) and reduced photosynthesis (Sanz et al. 1992). In the Willamette Valley however it can be common even in industrialized areas. Its widespread distribution in the Northern Hemisphere, pollution tolerance compared to cyanolichens and tough thallus make this a desirable transplant species. Its annual branching pattern could also be utilized in transplant studies.

Lobaria pulmonaria, a foliose epiphyte, is frequent on conifers and hardwoods in coastal and montane North America (Hale 1979). Due to its sensitivity to air pollution (Pearson 1993; Wetmore 1983) and habitat destruction, it is now absent from many former habitats in Europe (Rose 1987) and the Pacific Northwest of North America, where it is less abundant in managed second-growth stands than in old-growth (Lesica et al. 1991; Neitlich 1993). Its role as a nitrogen fixer makes it an important component of the ecosystem; damage to the nitrogen-fixing mechanism of other cyanolichens has been demonstrated with increased exposure to sulphur dioxide (Henriksson & Pearson 1981). L. pulmonaria's widespread distribution, suitability as an air quality bioindicator and leathery thallus make this a good transplant species.

Study Sites

Four study sites were selected to represent a range of climatic and air quality conditions in the Willamette Valley and Coast Range of Oregon (Table IV.1). Lichens were also transplanted from Alaska to Oregon to determine how well one species could withstand transplanting over a large distance.

Marys Peak

Marys Peak, at 1249 m, is the highest peak in the Oregon Coast Range. Lichens were cultured in a noble fir (Abies procera) stand at 1097 m, and a Douglas fir (Pseudotsuga menziesii) stand at 791 m. At the City of Corvallis Rock Creek water treatment plant meteorological site (7 km up Highway 34 west of the junction with Highway 20, at 137 m elevation on the east flank of Marys Peak), average annual temperature is 10.6°C, with January and July means of 3.6 and 18°C respectively (Taylor & Bartlett 1993). Average annual precipitation is 165 cm with 77% occurring from November to March.

Willamette Valley Foothills

Chip Ross Park is a prairie bald in the foothills north of Corvallis. This site (referred to as the foothill site) has large, open-grown Oregon white oak (Quercus garryana) with a healthy epiphytic lichen population including abundant cyanolichens typical of Willamette Valley foothills Oregon white oaks (Denison & Palmer-Muller 1993; Pike 1973).

Willamette Valley Floor

A Willamette Valley transect consisted of five sites beginning in Millersburg, 19 km NE of Corvallis, and running 18 km NW towards

Monmouth. The transect was originally planned to study growth response to a perceived air quality gradient with varying distances to a Kraft-process pulp mill. Because the sites also differed from each other in factors other than air quality (discussed below), the transect design was abandoned and the valley sites were considered to represent varying levels of several different stresses. The first site was 0.8 km from the pulp mill; the second in an overgrown pasture 1.5 km from the mill; the third along railroad tracks 2 km from the mill; the fourth in a lawn next to a heavily grazed and manure-fertilized cow pasture 4.4 km from the mill; and the fifth was 18 km from the mill on Cemetery Hill, a low, open hill surrounded by agricultural fields. At each site large, open-grown oaks similar in habitat to those in the foothills were selected. While epiphytes were present on all oaks, cyanolichens were absent. All sites in the valley transect were at about 60 m elevation.

Willamette Valley and foothills weather is monitored at the Hyslop Experimental Station on the northern edge of Corvallis. Average annual temperature is 12°C, with January and July means of 4 and 19°C respectively (Taylor & Bartlett 1993). Average annual precipitation is 107 cm; 72% occurs between November and March.

Cloudwater data from Mary's Peak suggest that air quality on the peak is good (Muir and Bohm 1989). Air quality data for the Willamette Valley study sites are sparse, but air quality is generally considered good (no non-compliance days near the study sites in 1992; Oregon Dept. Environmental Quality 1992). There are some air pollution sources in the valley that could inhibit lichen growth, such as sulphur dioxide from automobiles, farm equipment and the pulp mill, hydrochloric gas from a zirconium plant (Denison pers. comm.), and nitrogenous and other chemical compounds used in farm fields. Inhalable particulates of 10 micron diameter or less (PM10) are also present from field burning, wood stoves and blowing dust; some of these may cause chemical reactions that inhibit plant (Oregon Dept. Environmental Quality 1992) and lichen growth.

Petersburg, Alaska

Petersburg is a small coastal island community in southeast Alaska that experiences a typical temperate maritime climate. The collection site was a beach-fringe stand of western hemlock (Tsuga heterophylla) and Sitka spruce (Picea sitchensis). Average annual temperature is 5°C with January and July means of -3° and 13° respectively (National Climatic Center 1983). Average annual precipitation is 260 cm, but it is distributed fairly evenly throughout the year; only 45% occurs between November and March. Air quality in the Petersburg area is excellent (Geiser 1994); there are no Prevention of Significant Deterioration (PSD) permitted sites and the air is continually refreshed by ocean breezes.

Table IV.1. Locations and elevations of transplant study sites.

Site Location	Latitude/Longitude	Elevation
Mary's Peak Noble Fir	44°30'N, 123°33'W	1097 m
Mary's Peak Douglas Fir	44°29'N, 123°33'W	791 m
Petersburg, Alaska	56°48'W, 132°00'W	sea level
Chip Ross Park (Foothills)	44°37'N, 123°18'W	183 m
Willamette Valley Transect: (Pulp Mill-Cemetery Hill)	44°39'N, 123°04'W - 44°48'N, 123°11'W	60 m

Methods

Weight change used as measure of growth

Because lichen transplants can be grown and measured for years, a non-destructive, repeatable measure of growth was desirable. Changes in air-dried weight were used as a measure of growth.

Collection of each species

Alectoria thalli averaging 0.5 g in weight were collected from the noble fir and second-growth Douglas fir stand on Mary's Peak, and from beach-fringe in southeast Alaska; only individuals with a single holdfast were selected. *Evernia* and *Lobaria* thalli were collected from open-grown Oregon white oaks in the foothill site. Individual *Evernia* thalli about 0.2 g in weight were carefully separated from the substrate to minimize lichen injury. Distal lobes averaging 0.5 g were gently torn from robust *Lobaria* thalli. All lichens were collected from microhabitats as similar to their transplant microhabitats as possible with respect to height on tree, location on branch and position in the canopy. Only healthy individuals free of necrotic tissue were selected.

Reference standards

Lichens respond to slight changes in humidity by passively absorbing or losing water; some species can absorb up to 300 times their dry weight in water (Blum 1973). This creates a problem for reweighing transplants under different humidities. To adjust for changes in lab humidity, permanent reference samples of each species were created. These 2 g samples were wetted, oven dried at 94°C for 1.5 hour to end metabolic activity (Stone 1986). At each round of transplant weighing, the reference standards were equilibrated with ambient lab humidity for the same length of time as the transplants (typically 24 hours). Any weight change (to nearest 0.0001 g) in the standards was assumed proportional to the change in transplant water content; a multiplier was calculated and used to adjust the transplant weights at each weighing. Between weighings, the standards were stored in air tight plastic containers in the lab.

Construction of transplants

Thalli were collected and transported when air dry; dry lichens are presumed to be less vulnerable to unfavorable conditions than moist ones (Denison 1988). Lichens were cleaned of any debris and air-dried overnight in the laboratory, along with the humidity reference standards. After the initial weighing a 5 cm length of 5 pound test monofilament with a loop at the end was glued to either the holdfast or the torn end of the thallus with a dab of inert silicone sealant. The lichens and their artificial substrates were air-dried overnight, then reweighed. Finally, Goody "ponytailers", elastic bands with plastic beads at each end and a silicone-covered metal crimp in the center, were numbered with an indelible marker and slipped through the loop on their corresponding transplant. The transplants were returned to the field immediately, where the ponytailers were fastened to branches in the lower canopy of the selected trees.

Redistribution of transplants in field and weighings

The Alaska <u>Alectoria</u> transplants were placed in the noble fir stand on Mary's Peak. <u>Alectoria</u> collected from the two sites on Mary's Peak were split between their site of origin and the other habitat site, to see if there were any differences in growth between transplants in original sites and new ones (transplants went from noble fir to noble fir, noble fir to Douglas fir, Douglas fir to Douglas fir and Douglas fir to noble fir). <u>Lobaria</u> and <u>Evernia</u> transplants were evenly distributed between their site of origin and along the 5 sites on the 19 km valley transect. <u>Alectoria</u> transplants were initiated in January 1991 and reweighed in March 1991, May 1991, November 1991 and January 1992. <u>Evernia</u> and <u>Lobaria</u> transplants were placed in the field in May 1992, and reweighed in October 1992, February 1993, and June 1993. Ponytailers were detached from the transplants at each weighing, and transplant location was marked on each branch with a numbered piece of masking tape.

Results

After 12 months, 22% of the Alectoria thalli had detached or been removed by animals, and 13% of the remainder had obviously fragmented (>25% weight loss). Because of this reduction in transplant numbers, data from each of the Alectoria transplant sites were combined. Although all thalli appeared healthy and robust, including the Alaska material, they averaged a 9% weight loss (standard deviation, sd = 9). Since Alectoria apparently reproduces largely by fragmentation, this species was found to be unsuitable for transplant experiments where repeated measures are desirable. Also, Alectoria is consumed by some animals in preference to other lichens (McCune & Daly 1994), and is likely to be gathered by animals for nesting materials (Sharnoff 1992). Given its apparent heartiness and habitat plasticity, however, it may be suitable for transplant into areas where periodic or episodic elemental absorption by lichens was being monitored.

During the first five months (the dry season) Evernia transplants in the foothills and along the valley transect showed very little increase in biomass (Table IV.2). Over the entire 13 months, however, the transplants in the foothills gained weight by an average of 40% (sd = 3%), while those in the valley averaged 30% (sd = 15%).

Like Evernia, the Lobaria transplants grew primarily during the wet portion of the year. They had virtually no growth from May through October, but over the year they averaged 16% (sd = 8) and 15% (sd = 10) in the foothills and along the valley transplant respectively (Table IV.2).

Table IV.2. Cumulative growth (% by weight) of _Evernia_ _prunastri_ and _Lobaria_ _pulmonaria_ transplants in the Willamette Valley, Oregon (x=mean, sd=standard deviation, n=sample size)

Time Interval		_Evernia prunastri_ VALLEY	_Evernia prunastri_ FOOTHILLS	_Lobaria pulmonaria_ VALLEY	_Lobaria pulmonaria_ FOOTHILLS
May 92-Oct 92	x	0.2	-0.9	-0.3	-0.9
	sd	6.3	1.3	3.3	0.8
	n	48	9	46	7
May 92-Feb 93	x	11.9	16.4	6.1	8.9
	sd	9.0	4.1	7.8	2.7
	n	47	6	37	4
May 92-June 93	x	30.0	39.7	14.5	16.0
	sd	14.9	3.5	10.0	7.9
	n	34	4	23	2

Some transplants of all species were rendered useless due to fragmentation, detachment of the thallus, or because they disappeared, however rates of transplant attrition differed between species (Table IV.3). While 13% of the _Alectoria_ fragmented, neither the _Evernia_ nor the _Lobaria_ in the foothills did, and in the valley only 6% and 4% (respectively) of the individuals fragmented. None of the _Evernia_ became detached from the silicone gel, yet 50% of the foothill and 18% of the valley _Lobaria_ and 22% of the _Alectoria_ did. The disappearance of transplants seemed to be related more to the site, rather than the species. None of the _Alectoria_ was lost, yet 60% and 30% of the _Evernia_ and _Lobaria_ in the foothills, and 26% and 32% respectively in the valley disappeared. Transplants near the pulp mill vanished when branches with transplants were apparently selectively pruned. I suspect that transplants at the foothill site, a well-used park, were removed by curious passersby.

Table IV.3. Summary of lichen transplant growth (% by weight) and attrition by species (x=mean, sd=standard deviation, n=sample size)

	Alectoria	Evernia Foothills	Evernia Valley	Lobaria Foothills	Lobaria Valley
x	-9	40	30	16	14
sd	9	4	15	8	10
n	46	10	50	10	50
% Fragmented	13	0	6	0	4
% Detached	22	0	0	50	18
% Lost or Vandalized	0	60	26	30	32
# Months	14	13	13	13	13
1st Month	Jan '91	May '92	May '92	May '92	May '92

Discussion

Air quality

Although air quality in the Willamette Valley in general is considered to be good (Oregon Dept. of Environmental Quality 1992), there are at least two point-sources near the transect and the valley is visibly impacted by a combination of smoke from field and firewood burning, chemical compounds used in agricultural fields, industrial pollutants and vehicle emissions. Surveys of the valley lichen flora suggest that some sites in the valley are more depauperate than others (Denison & Palmer-Muller 1993; Pike 1973). In particular, the absence of air pollution-sensitive cyanolichens and their abundance in similar habitats in the less developed foothills suggests that air quality in the valley may not be as good as that in the foothills. The lack of *Lobaria pulmonaria* and other cyanolichens could also be due to the lack of propagule sources, or altered bark chemistry from years of accumulated pollutants. Unfortunately, there are little data on air quality in the valley to support or refute these hypotheses. Further studies with lichen flora and transplants could be informative.

Perhaps the selected sites were too dry, although there are Lobaria at similar valley sites (Denison pers. comm.).

Differences between species

While all of the lichens tested were transplantable using this method, some species were more suitable than others. Because 25% of the *Alectoria sarmentosa* transplants either fragmented or detached, this species is not recommended for transplants where repeated weights are desired. However, since it did remain healthy and vigorous even when moved from Alaska to Oregon, it could have other transplant applications. For example, it could be transplanted in bulk to bioaccumulate in areas where air quality is a concern, or to an instrumental monitoring site. Samples for tissue analysis could be collected at intervals to determine either the rate of bioaccumulation or correlation between bioaccumulation and pollutant levels recorded by the instrumental monitors.

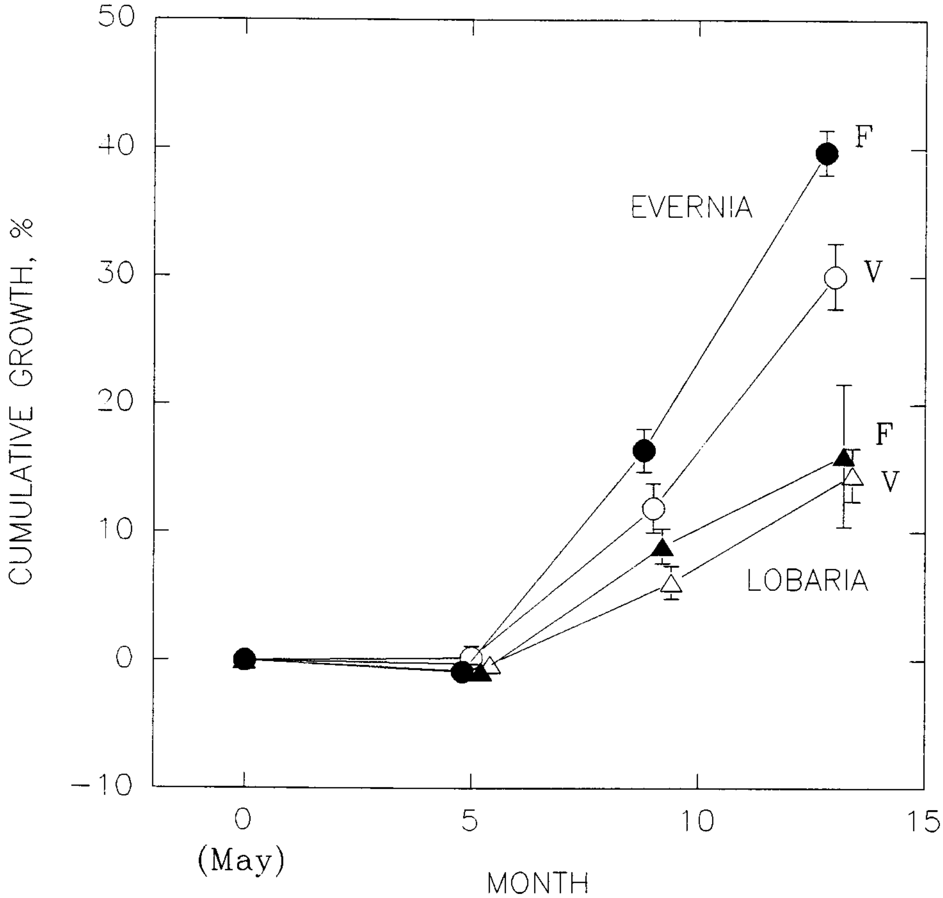
Fragmentation was not a serious problem with *Evernia prunastri* or *Lobaria pulmonaria*, but detachment of the thallus from the silicone caused substantial loss of *Lobaria* at both sites. Differences in detachment between species was probably due to differences in their respective morphologies, and how they were influenced by wind; the *Lobaria* thalli were solid pieces about 5 cm in diameter, and were probably buffeted more than the relatively dissected *Evernia* thalli. The high rate of *Lobaria* detachment doesn't seem to be indicative of some inherent tendency to come unglued, but rather indicates vulnerability of single thalli in wind. In one study in the Willamette Valley using similar transplants of *Lobaria pulmonaria* in a closed Oregon ash (*Fraxinus latifolia* L.) grove, less than 0.5% of the transplants detached (McCune et al. 1994). When *Lobaria* were transplanted using 25 tiered cuttings on one string, little if any loss was reported despite their exposure to wind and weather for three years (Denison 1988). Although this site was more sheltered than valley sites, the low thallus loss rates could also be because the stacked thalli deflected wind better than a single thallus. This effect could probably be moderated by: (a) placing the transplants in microsites more sheltered from the wind; and (b) making the monofilament lanyards shorter, to minimize movement in the wind.

Evernia transplants at both sites grew over twice as much as *Lobaria* transplants, which could be due to a number of physiological factors. Perhaps *Evernia* naturally grows faster than *Lobaria*; even though *Lobaria* thalli get much larger than *Evernia*, suggesting faster growth, it could be that individuals of *Lobaria* simply live longer. Faster growth and a relatively short life would be expected of a "weedy" species like *Evernia*. While there are no data to support this observation, perhaps *Lobaria* is more sensitive to transplant shock or to being torn. The injury site where the *Lobaria* lobe was detached from the parent thallus is considerably larger than that on *Evernia*, 2-5 cm as opposed to 2-4 mm! Perhaps once *Lobaria* recover from transplant shock, they would grow more quickly. Alternately, *Lobaria* may be more sensitive to microhabitat modifications than *Evernia*. In nature, *Lobaria* tend to be more pendulous than *Evernia*. Shorter lanyards might correct this problem.

Differences between sites

The lack of naturally occurring *Lobaria* at valley floor sites suggested that there were dissimilarities between the foothill and valley sites that would be expected to influence *Lobaria* transplant growth rates. However, there were no statistically significant differences in growth rates between these two sites (Fig. IV.1). This seemed unusual given the considerable differences between the growth rates of these *Lobaria* transplants compared to two other studies conducted in the area; Denison (1988) reported an average of 8% increase per year and McCune et al. (199) reported 34%, while this study averaged about 15%. Perhaps the difference in evapo-transpiration rates between sites could account for the differences in growth rates between studies. The site with the best growth was a closed Oregon ash grove, where the transplants had the least exposure to wind (McCune et al. 1994); the site with the lowest growth consisted of uncovered racks placed in an open lawn in the foothills (Denison 1988). The lower canopy of open-grown oaks both in the foothills and on the valley floor would probably fall somewhere between the other two sites in terms of relative humidity. Another possible factor contributing to the relatively low growth rate of the tiered transplants (Denison 1988) could be that shading of the middle thalli inhibited photosynthesis.

Figure IV.1. Growth of Evernia prunastri and Lobaria pulmonaria transplants in the Willamette Valley and in the foothills. Error bars indicate ±1 standard error.



It is also possible that the growth rate of the valley transplants was artificially enhanced by the accumulation of foreign matter. There were several unforeseen sources of foreign matter. At the two sites closest to the pulp mill a sooty smelling, gritty dark particulate coated the transplants and host trees. Also, at the site next to the cow pasture, a liquid cow manure slurry was sprayed over the field as a fertilizer; unfortunately, some of the transplants were sprayed as well, and were coated with the dried slurry. It is difficult to estimate how much this slurry increased the transplant weights, but it was obvious on all the transplants. It may have actually enhanced growth as well.

There was a significant difference between Evernia growth at the valley and foothill sites, with transplants at the valley sites growing less than those in the foothills (Table IV.2; Fig. IV.1). This could be a reflection of reduced air quality in the valley; several studies have found this species to be moderately sensitive to sulphur dioxide (Pearson & Henrikkson 1981), which can reduce the rate of photosynthesis (Sanz et al. 1992). As with Lobaria, the decreased growth rate of Evernia valley transplants may have been partially masked by particulate accumulation.

Seasonality of lichen growth

Lichens are similar to vascular plants in that they require water and sunlight to photosynthesize. Lacking the waxy cuticle of vascular plants to aid in water retention, they can only photosynthesize when liquid or high concentrations of gaseous water are present. Therefore, lichens grow more during wet periods of the year when water is readily available from precipitation, dew, fog, and relative humidity. In a study of factors determining lobe growth in two species of the foliose lichen Parmelia, rainfall and frequency of sunshine hours had the highest correlation with radial growth of lichen lobes (Armstrong 1993).

Growth of Evernia and Lobaria transplants was strongly seasonal. Virtually no growth was experienced by either species during the dry summer (Table IV.2 and Fig. IV.1); McCune et al. (1994) report a similar lack of growth during the same period the subsequent year. Both species began to grow during the wet season and they experienced their greatest growth during the moist spring, when daylight hours were increasing, and there was still residual soil moisture to contribute to morning and evening dew on rainless days.

Recommendations for future transplant studies

In future studies, more than 10 transplants should be used at each site to compensate for attrition. As suggested earlier, shorter monofilament lanyards and placement of transplants in more sheltered microsites would probably reduce loss due to wind. Having the thalli closer to the branch would more accurately mimic lichen microhabitat, and could result in increased lichen growth; the thallus would probably stay hydrated and photosynthesizing longer if it were closer to moss-covered branches rather than blowing in the wind.

Given the unanticipated accumulation of foreign matter at several sites, I would recommend the use of blanks to determine percentage weight gain from this source. Perhaps rubber casts of live lichens, or pieces of rigid plastic with the same approximate surface area could be used. These would be expected to accumulate foreign matter at the same rate as live lichens. In previous studies (Stone 1986; McCune et al. 1994) blanks consisted only of monofilament and silicone and showed no significant weight changes, perhaps due to their small size.

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Chapter V. Summary

Three methods of applying lichens to air quality biomonitoring were implemented in this study: lichen community analysis, lichen tissue elemental content analysis, and transplant of three lichen species. Results are summarized and suggestions given for each of these three applications.

All three approaches to lichen biomonitoring yielded valuable information. The elemental analyses provided a basis of comparison with future and regional studies. Using lichen transplants is a promising method for evaluating lichen growth in a variety of different habitats. The lichen community analysis suggested possible trends in species composition in one habitat type. One drawback to this approach is that sophisticated multivariate data analysis techniques and interpretation skills are necessary for the information to be meaningful.

Lichen community analysis

Lichen communities were sampled on 50 _Pinus contorta_ peatlands in southeast Alaska. These peatlands make good air quality biomonitoring sites because: (1) the trees are slow growing and provide stable substrates for lichen colonization; (2) many branches are at eye level, making the canopy epiphytes easily observable; (3) the scattered, open distribution of the trees allows for good air circulation on the sites; and (4) precipitation, light conditions, and relative humidity are high, which stimulate lichen growth. Multivariate ordination of lichen branch cover estimates revealed two main gradients, one suggestive of a combined succession and moisture gradient, and one suggestive of lichen response along a climatic gradient. The hypothesis of lichen community variation along a successional gradient could be further explored in southeast Alaska several ways. One, additional _Pinus contorta_ plots could be sampled with tree cores taken from each tree. This could reveal a direct relationship between tree age and position of the plot along the gradient. Also, it is interesting to note that the lichen species most strongly correlated with the gradients in this study were also common in the Tongass Air Quality Biomonitoring Tsuga heterophylla plots (Geiser et al. 1994a). A second approach to the successional gradient hypothesis would be to do a study of the "similar gradient hypothesis" (McCune 1993b). This could be useful to determine if lichen species are responding to McCune's proposed successional and moisture gradients, and to compare the results of those analyses with the trends reported in this study. Finally, if lichen communities are to be useful indicators of species compositional trends along air pollution gradients, it is essential that sites near areas impacted by air quality be sampled.

Lichen elemental tissue content analysis

The range of values for 16 elements were reported and compared to other regional studies, and the values of most elements were found to be within normal background levels. Principal components analysis was used to create three gradients of plot-level elemental content. The first gradient may represent sites enriched by elements from dirt. The second may represent sites where elements were supplemented by salt water aerosols. The third gradient could represent enrichment from fossil fuel combustion.

An important objective for establishing lichen elemental content baselines is to create a basis for comparison of spatial and temporal elemental concentrations. To enhance regional comparisons, it would be useful for different studies to adopt a format for reporting results so that tables between studies and between points in time could easily be created. Some suggestions include: (a) elemental data be log transformed to correct for the positive skew in elemental values, (b) that median, mean and min-max ranges of raw data for each element be reported, and (c) a suite of regionally common lichens be used in subsequent studies. These could include (but not be limited to): Alectoria sarmentosa, Cladina rangiferina, Sphaerophorus globosus and Platismatia glauca.

Lichen transplants

Removable lichen transplants were used to determine growth of three lichen species in several different habitats. Despite apparent vigor, Alectoria proved unsuitable for repeated weighings because of biomass loss due to fragmentation. Growth of Evernia and Lobaria transplants differed both between species and between sites. Average growth for Evernia in the foothills and valley was 40% and 30% respectively; for Lobaria it was 16% and 15%. Differences in growth between species could be due to: (1) different growth rates; (2) different sensitivities to air quality; (3) different sensitivities to microhabitat; and (4) different sensitivities to transplant trauma. Differences in growth between valley and foothill sites could be due to: (1) different micro- or macrohabitat conditions; and (2) differences in air quality.

In future lichen transplant studies, more than 10 transplants should be used at each site to compensate for attrition. Shorter monofilament lanyards and placement of transplants in more sheltered microsites would probably reduce loss due to wind. Having the thalli closer to the branch would more accurately mimic lichen microhabitat, and could result in increased lichen growth; the thallus would probably stay hydrated and photosynthesizing longer if it were closer to moss-covered branches rather than blowing in the wind. Also, to mitigate for the accumulation of foreign matter on the transplants, the use of blanks to determine percentage weight gain from this source is recommended.

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APPENDICES

Appendix A Locations of 50 Permanent Air Quality Biomonitoring plots on the Tongass National Forest, southeast Alaska

Plot #	Date	Plot Location
1	11 Jul 90 #1	Old Toms Creek Research Natural Area
2	11 Jul 90 #2	Old Toms Creek Research Natural Area
3	13 Jul 90 #1	Dog Island Research Natural Area
4	20 Jul 90 #1	Petersburg Creek Wilderness Area
5	25 Jul 90 #1	Manzanita Lake Wilderness Area
6	2 Aug 90 #1	Dry Pass, Chichagof Island
7	2 Aug 90 #2	Dry Pass, Chichagof Island
8	2 Aug 90 #1	Myriad Islands
9	3 Aug 90 #1	Big Bay, Baranof Island
10	16 Aug 90 #1	Fish Creek, Douglas Island
11	17 Aug 90 #1	Berners Bay
12	17 Aug 90 #2	Petersburg Lake Wilderness Area
13	24 Jun 91 #1	Froot Loop Road, Mitkof Island
14	26 Jun 91 #1	Portage Bay, Kupreanof Island
15	26 Jun 91 #1	Hatchery Ck, Prince of Wales Island
16	26 Jun 91 #2	Hatchery Ck, Prince of Wales Island
17	3 Jul 91 #1	Froot Loop Road, Mitkof Island
18	4 Jul 91 #1	Ward Cove, Revillagigedo Island
19	5 Jul 91 #1	Naukati, Prince of Wales Island
20	5 Jul 91 #2	Naukati, Prince of Wales Island
21	8 Jul 91 #1	Lunch Creek, Revillagigedo Island
22	9 Jul 91 #1	Bostwick River, Gravina Island
23	9 Jul 91 #1	Bostwick River, Gravina Island
24	10 Jul 91 #1	Bold Island
25	10 Jul 91 #2	Bold Island
26	23 Jul 91 #1	Twin Creek, Mitkof Island
27	24 Jul 91 #1	Pavlof Lake, Chichagof Island
28	25 Jul 91 #1	Whitestone River, Chichagof Island
29	25 Jul 91 #2	Whitestone River, Chichagof Island
30	26 Jul 91 #1	Pleasant Island
31	26 Jul 91 #2	Pleasant Island
32	30 Jul 91 #1	Woewodski Island
33	6 Aug 91 #1	Karta Wilderness, Prince of Wales Island
34	7 Aug 91 #1	Lake McDonald
35	9 Aug 91 #1	Woodpecker Cove, Mitkof Island
36	12 Aug 91 #1	Cape Fanshaw
37	12 Aug 91 #2	Cape Fanshaw
38	14 Aug 91 #1	Gambier Bay, Admiralty I. Wilderness
39	14 Aug 91 #2	Gambier Bay, Admiralty I. Wilderness
40	15 Aug 91 #1	Pt. Agasiz
41	4 Sep 91 #2	Between Harding & Toms Creek
42	4 Sep 91 #4	Between Harding & Toms Creek
43	7 Jul 92 #1	Pike Lake Research Natural Area
44	7 Jul 92 #2	Pike Lake Research Natural Area
45	8 Jul 92 #1	Pike Lake Research Natural Area

Appendix A (continued) Locations of 50 Permanent Air Quality Biomonitoring plots on the Tongass National Forest, southeast Alaska

Plot #	Date	Plot Location
46	8 Jul 92 #2	Pike Lake Research Natural Area
47	8 Jul 92 #3	Pike Lake Research Natural Area
48	14 Aug 92 #1	Rowan Creek, Kuiu Island
49	15 Aug 92 #1	Crane Creek, Kuiu Island
50	27 Aug 92 #1	Fish Creek, Douglas Island

Appendix B Data matrix of epiphytic lichen cover estimates of 29 species on 50 <u>Pinus</u> <u>contorta</u> peatlands plots in southeast Alaska (summarized by lichen species per plot; note that lichen species wrap to next line on each plot)

Lichen Species: *Alectoria sarmentosa, Bryocaulon pseudosatoanum, Bryoria spp, Cavernularia hultenii, C. lophyrea, Cetraria californica, C. chlorophylla, Cladina rangiferina, Cladonia spp, Hypogymnia duplicata, H. enteromorpha sens. lat., H. imshaugii, H. inactiva, H. oceanica, H. vitatta, Parmelia saxatilis, P. hygrophylla, P. sulcata, P. squarrosa, P. spp., Parmeliopsis hyperopta, Platismatia glauca, P. herrei, P. lacunosa, P. norvegica, Ramalina roesleri, Sphaerophorous globosus, Usnea longissima, U. spp.*

Plot01	1.51	.00	.11	.11	.00	.00	.00	.00	.19	.35	.21	.00
	.00	.08	.00	.10	.00	.00	.00	.00	.39	1.35	.24	.06
	1.19	.00	.70	.00	.00							
Plot02	1.73	.00	.40	.08	.00	.00	.00	.00	.20	.25	.23	.00
	.00	.03	.00	.18	.00	.00	.00	.00	.07	1.20	.53	.00
	1.01	.00	1.05	.00	.00							
Plot03	.00	.00	.03	.00	.00	.00	.00	.08	.07	.00	.00	.00
	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.05	.00
	.00	.00	1.12	.00	.00							
Plot04	1.42	.67	1.17	.05	.00	.00	.00	.00	.53	.99	.13	.00
	.00	.06	.09	.05	.00	.00	.00	.00	.00	.91	.08	.00
	.06	.00	1.04	.04	.00							
Plot05	1.14	.03	.56	.00	.00	.00	.00	.00	.55	.14	.17	.00
	.00	.03	.00	.06	.00	.00	.00	.00	.73	.60	.00	.11
	.28	.00	.94	.00	.00							
Plot06	1.39	.00	2.00	.07	.00	.00	.07	.00	1.23	.00	.00	.00
	.00	.00	.00	.28	.00	.00	.00	.00	.07	.29	.04	.00
	.24	.00	.20	.00	.00							
Plot07	2.26	.07	1.15	.11	.10	.00	.03	.00	.25	.02	.00	.00
	.00	.00	.00	.18	.00	.00	.00	.00	.10	.17	.07	.00
	.10	.00	.26	.00	.00							
Plot08	1.01	.00	.75	.32	.00	.00	.03	.00	.03	.00	.00	.00
	.00	.00	.00	.49	.00	.00	.00	.00	.00	.57	.48	.00
	1.04	.09	.17	.03	.00							
Plot09	1.09	.09	1.73	.09	.24	.00	.00	.00	.18	.00	.00	.00
	.00	.00	.00	.00	.00	.00	.00	.00	.00	.24	.00	.00
	.00	.00	.27	.00	.00							
Plot10	2.90	.06	3.14	.00	.17	.00	.04	.00	.65	.19	.71	.08
	.30	.08	.15	.69	.00	.00	.00	.00	.11	1.52	.39	.00
	2.25	.01	.66	.00	.00							
Plot11	3.22	.00	3.73	.03	.09	.00	.06	.00	.16	.00	.56	.00
	.41	.05	.00	.16	.00	.03	.00	.00	.28	.64	.63	.00
	2.01	.00	.41	.00	.00							
Plot12	3.42	.36	2.74	.13	.00	.00	.00	.00	.55	.38	.26	.00
	.00	.00	.00	.17	.00	.00	.00	.00	.06	.25	.06	.00
	.40	.00	.85	.00	.00							

Appendix B (continued) Data matrix of epiphytic lichen cover estimates of 29 species on 50 Pinus contorta peatlands plots in southeast Alaska (summarized by lichen species per plot; note that lichen species wrap to next line on each plot)

Lichen Species: *Alectoria sarmentosa, Bryocaulon pseudosatoanum, Bryoria spp, Cavernularia hultenii, C. lophyrea, Cetraria californica, C. chlorophylla, Cladina rangiferina, Cladonia spp, Hypogymnia duplicata, H. enteromorpha sens. lat., H. imshaugii, H. inactiva, H. oceanica, H. vitatta, Parmelia saxatilis, P. hygrophylla, P. sulcata, P. squarrosa, P. spp., Parmeliopsis hyperopta, Platismatia glauca, P. herrei, P. lacunosa, P. norvegica, Ramalina roesleri, Sphaerophorous globosus, Usnea longissima, U. spp.*

Plot13	2.55	.05	1.15	.08	.00	.00	.00	.00	.00	.00	.20	.00
	.43	.08	.08	.05	.08	.00	.00	.00	.00	.00	.15	.00
	1.98	.00	.35	.00	.00							
Plot14	2.72	.00	1.33	.13	.03	.00	.00	.00	.00	.28	1.10	.00
	.00	.00	.00	.00	.00	.00	.00	.00	.73	.98	.00	.90
	1.40	.00	.70	.00	.00							
Plot15	3.00	.08	2.58	.00	.00	.00	.00	.00	.06	.28	.67	.00
	.86	.17	.00	.08	.00	.08	.00	.00	.00	1.72	.25	.36
	1.61	.00	1.19	.00	.00							
Plot16	2.85	.52	1.77	.00	.00	.00	.00	.00	.00	.00	.00	.00
	.00	.00	.00	.00	.00	.00	.00	.00	.00	.17	.00	.00
	.00	.00	.65	.00	.00							
Plot17	4.13	.00	2.88	.00	.00	.00	.00	.00	.17	.08	.40	.00
	.00	.00	.00	.00	.00	.10	.00	.17	.00	.57	.45	.00
	1.42	.00	1.48	.00	.00							
Plot18	2.55	.00	2.13	.00	.00	.00	.00	.00	.28	.25	.00	.00
	.00	.00	.00	.08	.00	.03	.00	.00	.00	.50	.15	.00
	.50	.00	1.92	.00	.00							
Plot19	2.78	.00	2.35	.20	.00	.00	.00	.00	.00	.47	.08	.00
	.15	.45	.00	.00	.00	.03	.00	.00	.00	.13	.10	.00
	1.52	.00	.63	.00	.00							
Plot20	2.22	.00	2.10	.00	.00	.00	.00	.00	.52	.88	.45	.00
	.00	.60	.00	.00	.00	.00	.00	.00	.08	.13	.00	.00
	.05	.00	1.70	.00	.00							
Plot21	2.13	.00	.77	.40	.00	.00	.00	.00	.08	.00	.00	.00
	.22	.00	.00	.15	.00	.00	.00	.00	.00	.17	.15	.00
	.73	.00	.25	.00	.00							
Plot22	1.02	.00	2.25	.00	.00	.00	.00	.00	.45	.00	.00	.00
	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
	.00	.00	.82	.00	.00							
Plot23	.64	.00	2.17	.00	.00	.00	.00	.12	.36	.14	.00	.00
	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
	.00	.00	1.38	.00	.00							
Plot24	.10	.00	.10	.22	.00	.05	.00	.00	.08	.00	.00	.00
	.32	.00	.00	.00	.00	.00	.00	.00	.08	.82	.30	.00
	.60	.00	.22	.00	.00							

Appendix B (continued) Data matrix of epiphytic lichen cover estimates of 29 species on 50 Pinus contorta peatlands plots in southeast Alaska (summarized by lichen species per plot; note that lichen species wrap to next line on each plot)

Lichen Species: *Alectoria sarmentosa, Bryocaulon pseudosatoanum, Bryoria spp, Cavernularia hultenii, C. lophyrea, Cetraria californica, C. chlorophylla, Cladina rangiferina, Cladonia spp, Hypogymnia duplicata, H. enteromorpha sens. lat., H. imshaugii, H. inactiva, H. oceanica, H. vitatta, Parmelia saxatilis, P. hygrophylla, P. sulcata, P. squarrosa, P. spp., Parmeliopsis hyperopta, Platismatia glauca, P. herrei, P. lacunosa, P. norvegica, Ramalina roesleri, Sphaerophorous globosus, Usnea longissima, U. spp.*

Plot25	.73	.00	.15	.24	.00	.00	.00	.00	.32	.00	.00	.00
	.00	.15	.00	.00	.00	.00	.00	.00	.00	.98	.27	.00
	.78	.00	.29	.00	.00							
Plot26	3.35	.00	2.17	.00	.00	.00	.00	.00	.13	.13	.00	.00
	.00	.00	.10	.00	.00	.00	.00	.00	.82	.28	.15	.00
	.28	.00	.93	.00	.00							
Plot27	2.20	.00	2.00	.25	.00	.05	.00	.00	.00	.35	.57	.00
	.75	.30	.00	.15	.00	.00	.08	.00	.52	1.17	.43	.00
	1.60	.00	.65	.00	.00							
Plot28	1.33	.00	1.92	.65	.15	1.25	.15	.00	.00	.08	1.02	.00
	1.33	.35	.00	.00	.00	.00	.15	.00	.00	1.02	.25	.08
	2.63	.00	.00	.00	.00							
Plot29	2.17	.00	1.70	.25	.00	.55	.30	.00	.13	.00	.70	.00
	.77	.52	.00	.08	.00	.00	.05	.00	.10	1.42	.73	.00
	1.52	.00	.28	.00	.00							
Plot30	2.53	.00	2.88	.43	.00	.38	.00	.00	.00	.00	.05	.00
	.00	.00	.00	.00	.00	.00	.00	.00	.10	.00	.00	.00
	.32	.00	.10	.00	.00							
Plot31	3.10	.25	2.53	.50	.00	.17	.00	.00	.00	.00	.38	.00
	.32	.88	.00	.15	.00	.00	.00	.00	.17	.50	.05	.15
	2.50	.00	.03	.00	.00							
Plot32	3.22	.00	2.47	.13	.00	.00	.00	.00	.35	.43	.00	.00
	.13	.08	.00	.05	.00	.00	.00	.00	.28	.05	.35	.00
	.52	.00	.70	.00	.08							
Plot33	.28	.13	.65	.00	.00	.00	.00	.00	.00	.05	.00	.00
	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
	.00	.00	.28	.00	.00							
Plot34	1.80	.00	.47	.08	.08	.00	.00	.00	.00	.05	.00	.00
	.10	.20	.00	.00	.00	.00	.00	.00	.22	.35	.00	.00
	1.10	.00	.55	.00	.00							
Plot35	3.75	.60	2.85	.17	.00	.00	.00	.00	.52	.80	.13	.00
	.08	.15	.00	.20	.00	.00	.00	.00	.63	.28	.28	.08
	1.23	.00	.80	.00	.00							
Plot36	3.88	.00	4.70	.00	.00	.13	.00	.00	.15	.20	.30	.00
	.38	.00	.00	.38	.00	.00	.00	.00	.38	.15	3.08	.00
	1.33	.00	.70	.00	.00							

Appendix B (continued) Data matrix of epiphytic lichen cover estimates of 29 species on 50 Pinus contorta peatlands plots in southeast Alaska (summarized by lichen species per plot; note that lichen species wrap to next line on each plot)

Lichen Species: *Alectoria sarmentosa, Bryocaulon pseudosatoanum, Bryoria spp, Cavernularia hultenii, C. lophyrea, Cetraria californica, C. chlorophylla, Cladina rangiferina, Cladonia spp, Hypogymnia duplicata, H. enteromorpha sens. lat., H. imshaugii, H. inactiva, H. oceanica, H. vitatta, Parmelia saxatilis, P. hygrophylla, P. sulcata, P. squarrosa, P. spp., Parmeliopsis hyperopta, Platismatia glauca, P. herrei, P. lacunosa, P. norvegica, Ramalina roesleri, Sphaerophorous globosus, Usnea longissima, U. spp.*

Plot37	3.05	1.16	3.47	.16	.00	.00	.16	.00	.47	.00	.00	.00
	.00	.00	.00	.42	.00	.00	.00	.00	.21	.16	1.53	.00
	1.42	.00	.95	.00	.00							
Plot38	2.95	.43	2.65	.00	.00	.00	.43	.00	.52	1.83	.38	.00
	.00	.05	.00	.25	.00	.00	.00	.00	.00	.65	.08	.00
	.13	.00	2.08	.08	.00							
Plot39	2.85	.08	2.60	.17	.08	.00	.05	.00	.28	1.08	.35	.00
	.15	.30	.08	.08	.00	.00	.00	.00	.00	1.38	.15	.00
	1.25	.00	.43	.00	.03							
Plot40	3.17	.00	2.88	.00	.00	.00	.00	.00	.22	.38	.45	.00
	.13	.35	.45	.47	.00	.00	.00	.00	.00	.70	.95	.15
	1.30	.00	1.08	.17	.00							
Plot41	4.20	.00	3.25	.00	.00	.00	.10	.05	.82	.00	.38	.00
	.10	.15	.22	.38	.00	.00	.00	.00	.03	2.85	.00	.00
	.95	.00	1.85	.00	.00							
Plot42	3.88	.10	3.10	.10	.00	.00	.00	.00	.52	.17	.32	.00
	.43	.00	.45	.75	.00	.00	.00	.00	.00	2.03	.08	.00
	1.08	.00	.85	.00	.00							
Plot43	1.59	.00	.32	.00	.00	.00	.00	.00	.00	.00	.00	.00
	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
	.00	.00	.00	.00	.00							
Plot44	.25	.00	.00	.00	.00	.00	.08	.00	.00	.00	.00	.00
	.00	.00	.00	.08	.00	.00	.00	.00	.00	.00	.00	.00
	.00	.00	.08	.00	.00							
Plot45	1.35	.00	.20	.00	.00	.00	.00	.00	.00	.00	.00	.00
	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
	.08	.00	.00	.00	.00							
Plot46	.68	.00	.68	.00	.00	.00	.00	.00	.00	.00	.00	.00
	.00	.00	.00	.00	.00	.00	.00	.00	.08	.00	.00	.00
	.00	.00	.05	.00	.00							
Plot47	2.50	.00	.82	.00	.00	.00	.08	.00	.08	.13	.00	.00
	.00	.00	.00	.08	.00	.00	.00	.00	.00	.65	.08	.00
	.82	.00	.57	.00	.00							
Plot48	2.62	.00	2.62	.15	.00	.00	.00	.00	.36	.00	.00	.00
	.00	.00	.00	.05	.00	.00	.00	.00	.00	.28	.00	.00
	.00	.00	.56	.00	.08							

Appendix B (continued) Data matrix of epiphytic lichen cover estimates of 29 species on 50 <u>Pinus</u> <u>contorta</u> peatlands plots in southeast Alaska (summarized by lichen species per plot; note that lichen species wrap to next line on each plot)

Lichen Species: *Alectoria sarmentosa, Bryocaulon pseudosatoanum, Bryoria spp, Cavernularia hultenii, C. lophyrea, Cetraria californica, C. chlorophylla, Cladina rangiferina, Cladonia spp, Hypogymnia duplicata, H. enteromorpha sens. lat., H. imshaugii, H. inactiva, H. oceanica, H. vitatta, Parmelia saxatilis, P. hygrophylla, P. sulcata, P. squarrosa, P. spp., Parmeliopsis hyperopta, Platismatia glauca, P. herrei, P. lacunosa, P. norvegica, Ramalina roesleri, Sphaerophorous globosus, Usnea longissima, U. spp.*

Plot49	1.02	.00	.75	.05	.00	.00	.00	.00	.00	.10	.22	.00
	.00	.08	.00	.08	.00	.00	.00	.00	1.50	.40	.13	.00
	.47	.00	.45	.00	.00							
Plot50	3.17	.00	1.95	.10	.00	.25	.00	.00	.00	.00	1.58	.00
	1.58	.15	.08	.32	.00	.00	.00	.00	.03	1.70	.25	1.00
	.88	.00	.30	.00	.00							

Appendix C Data matrix of site description variables measured on 50 *Pinus contorta* peatland plots in southeast Alaska (note that site variables wrap to next line for each plot)

Site description variables measured: Ovserver, latitude, longitude, overstory height, overstory diameter breast height, understory height, total % overstory cover of conifers, total % understory cover of conifers, elevation, slope, aspect, landform, number of lichen species; following attributes were measured as percent cover: overstory *Chamaecyparis nootkatensis*, overstory *Pinus contorta*, overstory *Tsuga heterophylla*, overstory *T. mertensiana*, understory *C. nootkatensis*, understory *P. contorta*, understory *Picea sitchensis*, understory *Thuja plicata*, understory *T. heterophylla*, understory *T. mertensiana*, *Menziesii ferruginea*, *Empetrum nigrum*, *Cassiope stelleriana*, *Fauria crista-galli*, *Lysichitum americanum*, *Ledum groenlandicum*, *Vaccinium* spp.

PLOT01	3	55.3614	132.4414	3.96	33.02	1.21	10	18	311	5	50	4					
28	0	19	0	3	0	0	0	0	0	0	0	0	0	0	0	0	
PLOT02	3	55.3672	132.4431	4.57	40.64	1.21	8	18	323	8	70	4					
25	0	19	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
PLOT03	3	54.8183	131.3278	8.23	15.24	1.21	20	75	12	12	360	1					
10	0	19	0	0	3	25	0	50	0	0	0	40	0	2	0	10	5
PLOT04	1	56.8414	133.0675	6.10	13.67	1.21	20	30	15	12	14	2					
22	21	20	0	1	0	25	0	0	2	5	5	15	15	10	10	18	1
PLOT05	3	55.5861	131.1028	7.62	20.32	3.66	28	63	183	30	270	4					
24	28	25	0	3	50	10	0	0	2	0	0	0	0	0	0	0	0
PLOT06	2	57.7694	136.2917	3.05	12.70	1.21	15	11	12	15	0	2					
26	15	15	0	0	0	10	0	0	1	0	0	20	0	0	0	75	4
PLOT07	2	57.7708	136.2953	5.79	10.16	0.61	30	17	46	15	5	2					
29	30	30	0	0	1	5	0	0	1	10	10	90	0	5	0	0	6
PLOT08	1	57.6289	136.2139	6.10	12.70	1.21	50	1	15	20	280	2					
25	0	50	0	0	0	0	1	0	0	0	1	20	2	10	0	0	0
PLOT09	2	56.8078	135.3225	4.57	12.70	0.61	35	50	61	20	332	2					
22	2	30	1	0	25	20	0	0	2	0	0	85	0	15	0	3	0
PLOT10	3	58.3336	134.5617	3.35	12.70	1.52	50	30	43	5	90	1					
34	0	50	0	10	0	10	0	0	0	20	0	8	0	0	0	75	38
PLOT11	1	58.7783	135.0317	4.68	13.67	1.21	19	18	79	5	240	3					
21	0	19	0	0	0	18	0	0	0	0	0	37	20	0	0	0	11
PLOT12	3	56.8639	133.1631	6.10	25.40	1.21	20	38	46	3	15	1					
23	0	20	2	0	0	30	0	0	7	0	1	40	6	0	1	18	17
PLOT13	3	56.6597	132.8644	2.13	7.62	1.21	20	7	76	5	270	2					
22	6	20	0	0	1	5	0	0	0	1	0	80	70	0	0	5	10
PLOT14	1	56.9097	133.0889	7.62	15.24	0.91	25	14	488	10	42	4					
36	0	25	0	0	10	2	0	0	0	2	1	20	3	15	2	0	15
PLOT15	2	55.8667	132.9525	3.35	10.68	0.61	25	20	274	6	294	3					
23	0	25	0	0	0	20	0	0	0	0	0	50	75	1	10	5	25
PLOT16	2	55.8675	132.9500	3.35	10.41	0.91	15	5	274	4	248	3					
19	0	15	0	0	0	5	0	0	0	0	0	37	0	2	0	5	5
PLOT17	1	56.6797	132.7892	3.66	15.24	0.61	10	5	305	6	94	4					
32	1	8	0	1	1	2	0	0	1	1	1	0	5	40	1	0	1

Appendix C (continued) Data matrix of site description variables measured on 50 Pinus contorta peatland plots in southeast Alaska (note that site variables wrap to next line for each plot)

Site description variables measured: Ovserver, latitude, longitude, overstory height, overstory diameter breast height, understory height, total % overstory cover of conifers, total % understory cover of conifers, elevation, slope, aspect, landform, number of lichen species; following attributes were measured as percent cover: overstory Chamaecyparis nootkatensis, overstory Pinus contorta, overstory Tsuga heterophylla, overstory T. mertensiana, understory C. nootkatensis, understory P. contorta, understory Picea sitchensis, understory Thuja plicata, understory T. heterophylla, understory T. mertensiana, Menziesii ferruginea, Empetrum nigrum, Cassiope stelleriana, Fauria crista-galli, Lysichitum americanum, Ledum groenlandicum, Vaccinium spp.

PLOT18	2	55.4067	131.7008	3.12	10.16	0.91	30	12	15	5	186	2					
25	1	30	0	1	0	10	0	1	0	1	0	50	0	25	0	30	
0PLOT19	2	55.8964	133.1403	4.57	8.38	1.22	10	20	30	0	0	1					
19	0	10	0	0	0	15	0	0	0	5	0	60	20	25	8	0	10
PLOT20	2	55.8997	133.1342	3.66	7.62	1.22	15	20	46	4	210	1					
21	0	15	0	0	0	20	0	0	0	0	0	60	20	0	0	0	8
PLOT21	2	55.5067	131.7031	3.35	6.35	1.22	10	28	76	1	90	2					
20	0	10	0	0	3	15	0	0	5	5	0	30	30	0	0	0	25
PLOT22	2	55.2572	131.7725	3.05	7.62	0.91	10	21	6	2	160	2					
14	0	10	0	0	1	15	0	0	0	5	0	80	20	0	1	30	23
PLOT23	2	55.2689	131.7742	4.57	11.43	3.05	15	13	6	0	160	1					
16	0	13	0	0	0	8	0	2	0	3	0	75	10	0	1	10	11
PLOT24	2	55.2561	131.4369	2.44	8.89	0.91	10	18	30	3	85	3					
26	1	9	0	0	1	15	0	0	0	2	0	40	75	0	0	25	21
PLOT25	2	55.2500	131.4389	3.66	7.62	1.22	15	38	30	1	0	3					
21	0	10	0	0	0	8	0	30	0	0	0	10	5	0	0	5	10
PLOT26	1	56.7342	132.8428	6.10	17.78	1.22	15	10	335	12	180	4					
21	0	12	0	0	3	5	0	0	0	2	1	1	0	20	1	18	2
PLOT27	2	57.8358	135.0753	4.88	7.62	0.91	15	10	122	4	48	2					
30	0	15	0	0	0	8	0	0	0	2	0	55	0	60	1	20	20
PLOT28	2	58.0581	135.1097	4.57	10.16	0.91	11	8	30	0	0	1					
24	0	11	0	1	0	5	1	0	0	2	0	15	0	40	0	0	25
PLOT29	2	58.0536	135.1508	3.66	7.62	1.21	10	11	61	5	10	1					
21	0	10	0	0	0	8	0	0	2	1	0	75	0	15	0	25	15
PLOT30	2	58.3508	135.6511	6.10	10.16	1.83	20	31	168	1	180	3					
15	0	20	0	0	0	30	0	0	1	0	0	20	0	8	0	8	15
PLOT31	2	58.3564	135.6433	4.57	10.16	1.52	10	25	168	1	0	3					
22	0	10	0	0	0	15	0	0	0	10	0	40	8	10	0	15	11
PLOT32	1	56.5697	133.0531	4.57	12.70	1.22	35	20	76	0	0	2					
35	0	35	0	0	5	15	0	0	0	0	1	15	0	1	0	18	11
PLOT33	2	55.5767	132.6286	4.57	7.62	0.61	20	22	76	0	0	2					
27	0	20	0	0	0	20	0	1	0	1	0	75	0	2	0	15	27
PLOT34	2	55.9322	131.8108	5.49	10.16	1.22	25	19	61	0	0	3					
25	0	25	0	0	8	10	0	0	0	1	0	30	0	10	0	20	11

Appendix C (continued) Data matrix of site description variables measured on 50 Pinus contorta peatland plots in southeast Alaska (note that site variables wrap to next line for each plot)

Site description variables measured: Ovserver, latitude, longitude, overstory height, overstory diameter breast height, understory height, total % overstory cover of conifers, total % understory cover of conifers, elevation, slope, aspect, landform, number of lichen species; following attributes were measured as percent cover: overstory Chamaecyparis nootkatensis, overstory Pinus contorta, overstory Tsuga heterophylla, overstory T. mertensiana, understory C. nootkatensis, understory P. contorta, understory Picea sitchensis, understory Thuja plicata, understory T. heterophylla, understory T. mertensiana, Menziesii ferruginea, Empetrum nigrum, Cassiope stelleriana, Fauria crista-galli, Lysichitum americanum, Ledum groenlandicum, Vaccinium spp.

PLOT35	1	56.5342	132.9272	6.10	15.24	1.83	45	36	213	5	108	4					
35	15	20	0	10	20	10	1	0	0	5	2	0	0	25	2	2	21
PLOT36	1	57.1897	133.5517	3.66	13.97	1.22	15	18	15	4	325	1					
19	1	13	2	0	10	7	0	0	1	0	0	40	0	20	0	25	10
PLOT37	1	57.1833	133.5497	4.69	13.67	1.21	10	14	15	0	0	1					
12	0	10	0	0	0	13	0	0	1	0	0	0	0	1	0	25	5
PLOT38	1	57.4994	134.0558	12.19	20.32	1.22	40	10	30	0	0	1					
25	0	40	0	0	0	10	0	0	0	0	3	0	40	8	5	0	1
PLOT39	1	57.5008	134.0581	4.57	12.70	0.91	15	5	30	0	0	1					
24	0	15	0	0	0	5	0	0	0	0	0	37	1	0	0	30	2
PLOT40	1	56.9611	132.9008	9.14	10.03	0.91	25	26	30	5	200	1					
21	0	25	0	0	20	5	1	0	0	0	0	35	2	0	8	20	5
PLOT41	1	56.2083	131.6522	7.62	17.78	0.91	25	78	46	0	0	1					
24	2	20	0	3	60	15	0	0	0	3	2	35	0	0	0	15	35
PLOT42	1	56.2072	131.6511	3.66	10.16	1.18	15	11	46	0	0	1					
30	0	15	0	0	0	10	0	0	1	0	0	35	0	2	0	15	10
PLOT43	2	59.4842	139.1367	3.66	10.1	1.18	7	6	46	15	285	2					
13	0	15	0	1	0	3	1	0	0	2	1	10	0	0	0	1	1
PLOT44	2	59.4897	139.1394	14.54	40.64	1.83	8	18	46	5	240	2					
10	0	8	1	1	0	15	1	0	1	1	0	5	5	0	0	3	2
PLOT45	2	59.4958	139.1533	1.68	17.78	1.21	21	9	61	5	260	2					
18	0	20	0	1	0	3	0	0	0	6	0	3	1	3	1	0	2
PLOT46	2	59.4947	139.0667	4.88	15.24	1.18	9	21	61	5	260	2					
12	0	8	0	1	0	15	1	0	0	5	1	2	2	15	1	4	4
PLOT47	2	59.4989	139.1581	3.05	10.92	1.21	7	4	61	5	130	2					
16	0	6	1	1	0	1	0	0	0	3	1	3	0	2	0	18	5
PLOT48	2	56.7011	134.2300	3.66	10.16	0.91	15	10	15	0	0	1					
16	0	15	0	0	0	10	0	0	0	0	0	80	0	0	0	5	2
PLOT49	2	56.7022	134.0206	7.62	17.78	1.18	15	30	305	4	180	3					
18	0	14	0	0	0	20	0	5	5	0	0	50	0	50	0	0	2
PLOT50	2	58.3150	134.5531	3.35	10.16	0.91	20`	20	168	1	0	2					
24	0	20	0	0	0	20	0	0	0	0	0	5	0	0	0	1	1

Appendix D Raw data matrix of 16 elements (ppm) from 124 lichen tissue samples on 43 Pinus contorta peatland plots in southeast Alaska

SITE	P	K	Ca	Mg	Na	Al	Fe	Mn
1	163.10	917.94	2088.00	262.20	100.46	28.81	22.98	22.34
1	178.00	1051.00	3197.00	403.40	150.69	34.69	23.19	64.70
1	174.20	991.20	5168.00	394.00	127.98	42.22	19.14	68.98
2	337.90	1355.00	6920.00	1188.00	128.50	218.60	221.80	202.80
2	121.40	847.70	4683.90	323.80	181.88	39.71	22.21	25.52
2	139.70	947.03	5786.00	307.50	118.60	45.90	250.44	51.87
3	120.60	719.80	9508.00	262.50	114.80	50.55	8.02	18.50
4	157.90	1036.00	7939.00	164.10	45.56	39.74	11.38	78.83
4	181.40	1324.10	3580.00	228.96	54.20	30.87	15.05	81.67
5	135.40	784.11	6043.60	252.31	36.26	32.65	5.32	38.75
5	123.30	820.80	2223.00	261.60	23.60	17.54	5.99	19.40
8	128.91	706.29	5622.00	314.15	335.58	46.23	21.92	4.82
8	161.80	846.82	5034.00	325.00	358.42	42.10	19.32	4.38
8	136.10	813.31	11825.00	505.91	531.58	64.45	23.00	8.32
9	120.40	699.63	1752.00	255.40	324.10	22.36	15.94	7.97
9	645.71	1787.00	3557.00	652.00	1532.00	31.97	19.97	7.76
9	138.31	827.03	1503.00	359.00	530.59	26.96	23.71	10.12
10	167.90	934.80	1305.00	178.10	34.34	27.66	31.10	50.10
10	168.97	43.10	941.46	161.82	26.31	27.15	37.50	37.26
10	147.19	895.19	4679.70	156.65	36.96	44.68	32.51	78.06
11	151.93	961.53	2213.00	299.99	159.28	30.94	18.50	30.14
11	157.16	901.64	1682.50	272.19	100.15	23.17	18.69	24.03
11	140.50	732.55	1901.00	437.70	165.20	36.78	31.88	24.03
12	172.60	1053.00	2524.60	238.60	16.58	21.67	9.52	110.10
12	165.30	834.40	1470.00	204.20	38.06	27.42	23.71	33.16
12	175.70	908.55	1025.70	228.80	95.84	18.54	17.63	54.26
13	192.70	1142.78	6805.35	279.75	54.09	42.15	33.57	104.65
13	177.19	1127.90	7146.03	354.36	62.92	32.45	29.43	142.50
13	185.69	1167.42	7664.94	445.12	189.27	32.04	31.65	87.26
14	179.53	1044.18	759.08	380.12	128.82	47.49	44.67	44.57
14	178.30	1048.06	1305.96	331.00	107.97	49.53	45.87	36.11
14	173.79	1024.57	1238.10	292.69	117.18	47.39	40.79	35.08
15	164.18	1018.67	2870.45	355.21	93.22	21.10	17.82	98.29
15	177.18	1068.51	4462.41	442.17	140.89	22.07	21.24	98.00
15	145.88	981.64	9568.74	343.59	91.66	23.51	17.89	143.93
16	155.54	1000.89	5350.86	396.75	86.79	30.54	20.91	82.66
16	210.64	1142.45	6210.45	437.69	196.82	38.46	30.00	122.62
17	174.95	943.78	14546.43	161.74	104.13	65.32	25.57	49.26
17	158.03	838.49	4925.88	118.20	76.82	42.64	28.48	7.23
17	165.51	848.63	4427.34	166.16	87.03	55.06	26.69	17.38
18	195.80	1100.72	865.70	128.26	32.00	32.30	45.80	6.27
18	185.76	984.61	77.69	114.56	33.25	35.42	52.80	5.23
18	184.45	1042.65	865.45	123.93	34.71	27.45	39.68	6.58
19	206.35	1095.53	7523.03	223.29	100.47	36.43	24.53	133.05
19	180.71	1043.30	7341.76	250.32	76.23	39.51	25.99	130.95
19	184.73	1079.58	13216.03	317.59	77.59	34.04	21.75	143.45

Appendix D (continued) Raw data matrix of 16 elements (ppm) from 124 lichen tissue samples on 43 *Pinus contorta* peatland plots in southeast Alaska

SITE	P	K	Ca	Mg	Na	Al	Fe	Mn
21	138.62	911.74	33279.20	294.62	66.78	22.28	25.83	4.91
21	116.48	830.49	36838.70	395.89	77.07	20.49	24.24	4.12
21	160.35	1046.30	17349.44	386.59	66.73	25.59	33.05	54.45
22	292.18	1185.98	8312.94	488.89	125.53	14.27	10.68	39.06
22	349.47	1203.61	6589.53	300.09	105.03	10.23	8.57	40.29
22	293.39	1197.72	7493.30	270.19	65.28	11.81	7.90	18.77
23	228.12	1255.50	11188.46	591.12	103.44	11.91	8.01	99.83
23	212.06	1072.57	7753.33	249.31	65.79	15.56	10.34	79.95
23	175.00	956.96	8727.68	371.20	78.29	11.47	7.52	39.79
25	272.94	1045.63	1699.34	614.41	168.08	29.13	13.68	4.02
25	219.19	1191.94	6462.87	470.28	392.80	23.90	17.36	8.28
25	161.34	994.96	7539.99	466.60	218.05	19.64	13.13	8.54
26	220.55	1142.63	4072.53	278.16	48.20	27.78	22.75	93.36
26	160.57	1065.47	2589.92	273.76	81.43	26.98	21.66	96.38
26	209.76	1218.05	5900.57	280.84	80.02	31.94	27.60	123.82
28	218.82	1122.24	5228.33	600.36	327.59	44.79	39.73	41.74
28	209.70	1106.50	2071.36	585.88	6003.35	53.73	49.32	7.74
28	237.85	1176.10	3759.13	646.53	5514.38	43.82	37.31	50.83
29	217.09	1269.99	4623.96	694.17	2267.91	79.56	71.35	43.51
29	217.91	1254.25	5650.94	649.68	1778.78	73.50	64.30	48.35
29	226.59	1209.76	4359.12	638.17	275.27	73.49	68.59	66.40
30	178.03	991.48	2222.69	398.19	150.68	57.52	58.22	36.91
30	177.16	1046.51	3898.55	345.21	117.54	42.59	39.60	44.04
30	184.01	1077.35	3872.95	468.10	395.67	66.80	67.50	30.49
31	176.82	1178.60	2314.70	446.16	228.37	47.67	70.77	70.75
31	206.02	1203.85	5250.91	514.05	384.86	42.42	41.86	114.00
31	181.36	1091.73	4481.44	554.10	245.35	39.01	39.18	125.59
32	161.72	892.99	4852.43	238.34	37.98	36.93	26.70	42.88
32	177.22	897.69	4272.34	226.52	47.26	45.98	35.47	59.61
32	164.40	945.78	5665.11	279.95	80.96	32.05	25.93	86.23
33	186.81	1387.95	7507.92	556.04	360.79	20.49	16.43	106.60
33	221.22	1396.21	7523.21	642.45	369.20	22.91	19.51	120.88
33	212.06	1206.68	9731.95	655.57	378.11	25.31	19.73	129.07
34	159.95	1021.17	5091.65	218.86	85.56	27.75	18.68	71.46
34	164.51	959.74	9121.78	176.17	63.99	30.54	19.50	77.71
34	157.87	960.06	4538.12	229.64	89.27	33.24	22.89	79.85
35	164.65	1042.06	5482.89	225.21	59.11	26.91	17.62	82.09
35	183.49	996.11	8480.58	253.94	117.01	31.51	26.74	86.84
35	185.18	986.16	6686.95	223.73	56.88	22.27	14.55	103.41
36	187.52	868.85	1591.33	288.90	310.63	38.44	32.62	9.76
36	212.29	975.43	1391.07	329.99	358.29	45.11	36.26	12.27
36	211.64	985.81	2900.51	295.50	189.56	27.45	24.75	38.98
38	204.15	1102.61	4890.77	303.12	84.85	18.71	12.92	109.54
38	237.17	1313.84	15362.73	534.38	145.81	19.68	13.47	218.48
38	226.88	1202.40	7254.37	350.45	102.37	19.56	13.75	121.05

Appendix D (continued) Raw data matrix of 16 elements (ppm) from 124 lichen tissue samples on 43 Pinus contorta peatland plots in southeast Alaska

SITE	P	K	Ca	Mg	Na	Al	Fe	Mn
39	216.65	1292.39	9787.36	471.67	156.46	22.40	17.71	101.36
39	209.79	1080.89	9670.20	432.27	87.28	25.34	17.15	88.91
39	202.11	1118.61	3773.98	202.83	55.11	17.78	13.40	56.57
40	188.43	1149.44	6213.68	433.92	256.57	38.54	24.46	39.54
40	209.58	1021.40	7238.40	193.45	132.88	28.83	12.49	51.81
40	214.44	1032.75	3225.55	251.06	182.15	35.30	27.75	32.09
41	197.39	1128.25	1456.07	150.16	39.89	19.87	13.84	39.71
41	186.12	1082.00	2805.80	204.90	35.52	28.92	23.36	50.27
41	223.87	1198.44	3894.37	310.74	52.18	15.29	19.37	73.47
43	170.32	911.44	4116.15	352.41	139.86	37.43	41.04	10.55
43	182.21	958.32	1966.00	454.99	233.16	59.91	58.30	12.03
43	210.97	1012.76	5301.50	428.89	212.30	45.67	44.66	30.44
44	185.56	953.14	5504.99	486.44	186.71	33.64	32.80	36.63
44	214.39	1136.48	5267.59	307.73	155.90	25.24	24.60	33.75
44	201.62	988.19	5413.58	366.05	233.71	23.83	21.20	41.07
45	171.60	917.58	3442.80	268.93	59.48	30.02	27.76	46.43
45	181.22	1006.20	2914.51	381.83	94.42	29.87	30.06	49.72
45	176.31	954.73	2295.95	238.60	55.64	29.63	31.76	36.64
46	250.35	1184.25	4249.52	254.78	68.41	27.43	23.54	83.58
46	212.27	1023.03	3463.05	251.65	82.85	36.23	33.63	67.77
46	249.80	1093.74	3547.80	256.51	82.21	31.04	30.94	79.40
47	160.38	878.30	610.84	391.83	153.57	34.25	37.89	9.34
47	169.43	913.52	1031.21	336.88	86.12	30.89	32.34	7.54
47	179.20	10259.1	1603.42	380.44	110.59	32.73	35.49	11.93
48	285.21	1382.50	7633.06	534.32	354.00	155.80	143.68	47.28
48	186.87	988.34	2492.43	271.37	199.94	133.99	121.80	18.43
48	241.92	1297.75	6875.85	388.47	260.80	142.02	118.72	47.22
49	175.09	1041.43	9080.19	433.65	225.78	39.96	18.42	27.92
49	215.19	1294.35	9037.69	441.50	239.62	41.29	23.36	32.00
49	196.61	1060.88	6457.13	469.62	279.40	41.97	25.54	29.12
50	194.67	1184.96	2053.02	256.73	29.23	64.78	97.39	92.91
50	258.25	1303.81	9168.94	201.71	32.54	47.51	59.50	148.28
50	270.04	1626.49	5417.89	303.24	47.85	73.46	103.06	180.03

Appendix D (continued) Raw data matrix of 16 elements (ppm) from 124 lichen tissue samples on 43 <u>Pinus</u> <u>contorta</u> peatland plots in southeast Alaska

SITE	Zn	Cu	B	Pb	Ni	Cr	Cd	S
1	5.40	0.76	0.67	3.65	0.64	1.70	0.48	290
1	16.81	0.81	0.72	1.08	0.45	0.29	0.08	280
1	16.25	0.80	0.61	3.16	0.45	0.11	0.09	260
2	28.33	2.65	2.10	6.99	0.82	1.68	0.23	530
2	13.05	0.80	0.52	1.78	0.45	0.56	0.23	300
2	15.64	0.74	0.54	1.30	0.45	0.11	0.36	290
3	16.77	0.64	0.93	5.48	0.45	0.11	0.43	300
4	26.01	1.05	0.80	3.71	0.45	1.11	0.55	250
4	32.54	1.03	1.38	2.21	0.45	0.53	0.15	280
5	29.72	0.38	0.22	3.22	0.45	0.11	0.43	240
5	30.54	0.35	0.20	2.31	0.45	0.11	0.32	250
8	12.42	0.95	1.15	4.93	0.45	0.11	0.08	440
8	16.48	0.85	1.06	2.55	0.45	0.26	0.25	400
8	14.17	0.96	1.34	4.72	0.53	0.11	0.31	460
9	12.62	0.05	1.15	1.08	0.45	0.11	0.28	340
9	13.71	0.48	1.95	1.08	0.45	0.11	0.08	520
9	13.97	0.26	1.16	1.08	0.45	0.27	0.08	320
10	20.74	0.04	0.78	4.17	0.63	0.87	0.19	360
10	17.66	1.13	1.16	5.28	0.48	0.37	0.08	430
10	20.74	1.15	4.47	7.69	0.55	0.11	0.40	350
11	27.44	0.67	2.91	4.61	0.45	0.11	0.08	300
11	20.40	0.82	6.80	1.08	0.88	0.76	0.45	260
11	12.58	0.65	7.07	3.93	0.45	0.14	0.34	340
12	25.59	0.52	0.22	1.96	0.45	0.93	0.08	200
12	16.50	0.61	0.48	4.39	0.45	0.53	0.08	270
12	16.72	0.54	0.58	1.08	0.45	0.26	0.36	280
13	25.29	1.37	3.95	2.31	0.31	0.36	0.62	290
13	29.07	1.15	3.47	3.63	0.24	0.35	0.40	360
13	25.28	1.12	1.91	1.90	0.31	0.36	0.37	270
14	15.70	0.91	1.05	0.84	0.22	0.26	0.12	340
14	16.96	1.00	1.74	0.96	0.24	0.28	0.19	340
14	16.76	0.90	1.31	0.85	0.22	0.25	0.16	330
15	18.36	0.86	3.35	1.24	0.22	0.20	0.13	300
15	18.72	0.88	1.46	1.69	0.22	0.24	0.18	350
15	19.21	0.94	1.96	2.82	0.22	0.20	0.21	260
16	21.25	0.94	2.12	2.58	0.22	0.19	0.17	260
16	22.09	0.98	2.13	2.21	0.22	0.20	0.24	340
17	18.81	1.15	1.56	2.59	0.39	0.30	0.22	230
17	15.82	1.00	0.84	2.08	0.29	0.30	0.12	280
17	15.80	0.97	0.93	1.73	0.29	0.28	0.16	210
18	22.89	1.39	1.24	2.03	0.57	0.29	0.11	260
18	23.75	0.98	1.12	0.84	0.47	0.29	0.07	460
18	22.70	0.96	1.08	1.68	0.50	0.28	0.10	330
19	20.43	0.76	2.46	1.77	0.22	0.29	0.11	240
19	22.66	1.04	3.46	1.75	0.22	0.22	0.14	220
19	26.67	1.06	1.16	3.38	0.22	0.21	0.13	240

Appendix D (continued) Raw data matrix of 16 elements (ppm) from 124 lichen tissue samples on 43 <u>Pinus</u> <u>contorta</u> peatland plots in southeast Alaska

SITE	Zn	Cu	B	Pb	Ni	Cr	Cd	S
21	14.92	1.47	2.57	4.96	0.53	0.34	0.15	180
21	14.36	1.50	1.76	6.35	0.55	0.36	0.16	150
21	18.90	1.14	1.75	5.52	0.48	0.37	0.15	180
22	25.17	0.93	2.01	6.10	0.23	0.22	0.15	220
22	21.39	0.72	1.42	3.24	0.22	0.16	0.10	190
22	32.03	0.95	1.51	4.91	0.22	0.17	0.28	180
23	25.12	0.96	5.34	10.39	0.22	0.16	0.22	210
23	27.22	1.00	2.58	7.52	0.22	0.21	0.16	220
23	18.70	0.90	3.74	8.60	0.22	0.20	0.18	240
25	18.69	0.81	2.37	2.43	0.22	0.19	0.21	270
25	32.59	0.98	2.53	3.36	0.26	0.19	0.32	295
25	29.41	0.92	1.66	4.42	0.26	0.16	0.32	260
26	24.12	0.79	1.70	1.22	0.22	0.15	0.37	220
26	22.44	0.66	0.94	1.24	0.22	0.30	0.27	200
26	25.75	0.90	1.03	1.48	0.22	0.22	0.35	210
28	24.20	0.85	1.83	2.38	0.29	0.46	0.23	250
28	19.11	0.78	1.95	2.60	0.22	0.28	0.10	230
28	23.57	0.82	1.56	2.88	0.22	0.28	0.15	250
29	24.01	1.04	1.59	4.58	0.30	0.46	0.12	230
29	25.35	1.07	1.71	3.05	0.28	0.36	0.16	260
29	25.34	1.01	1.54	3.00	0.28	0.39	0.13	260
30	20.61	1.08	1.56	1.54	0.32	0.31	0.16	360
30	20.38	0.97	1.36	1.67	0.26	0.29	0.29	310
30	20.18	1.16	2.11	1.94	0.37	0.33	0.23	380
31	26.82	1.42	46.06	1.05	0.51	1.26	0.36	330
31	19.73	1.17	1.76	2.31	0.26	0.29	0.28	370
31	18.75	1.05	2.05	2.96	0.22	0.27	0.14	360
32	20.86	0.86	1.59	3.00	0.22	0.16	0.28	300
32	20.32	0.95	0.92	2.52	0.22	0.19	0.29	270
32	20.41	0.86	1.10	2.75	0.22	0.28	0.32	250
33	27.79	0.79	1.35	2.05	0.22	0.18	0.33	250
33	32.66	0.84	1.50	1.72	0.22	0.16	0.33	250
33	27.00	0.81	1.79	1.82	0.22	0.16	0.43	250
34	23.92	0.80	1.04	1.88	0.22	0.14	0.23	240
34	23.53	0.93	0.83	3.40	0.30	0.28	0.36	250
34	21.35	0.80	0.98	1.78	0.22	0.16	0.19	240
35	23.28	0.96	1.78	2.71	0.22	0.14	0.26	260
35	23.68	1.33	1.15	2.18	0.22	0.19	0.41	260
35	22.29	0.87	1.50	2.19	0.22	0.14	0.27	230
36	14.93	0.83	2.25	0.86	0.22	0.22	0.14	300
36	16.43	0.76	2.75	0.84	0.22	0.19	0.05	320
36	22.48	0.82	2.09	0.84	0.22	0.15	0.33	270
38	31.81	0.90	1.29	1.47	0.22	0.15	0.38	230
38	29.55	1.16	1.69	2.37	0.22	0.18	0.66	220
38	30.36	0.89	1.31	1.69	0.22	0.19	0.35	250

Appendix D (continued) Raw data matrix of 16 elements (ppm) from 124 lichen tissue samples on 43 <u>Pinus</u> <u>contorta</u> peatland plots in southeast Alaska

SITE	Zn	Cu	B	Pb	Ni	Cr	Cd	S
39	31.67	0.99	4.57	2.35	0.22	0.19	0.25	270
39	26.45	0.92	2.38	2.01	0.22	0.19	0.33	220
39	25.66	0.75	1.73	1.35	0.43	0.19	0.11	250
40	28.42	0.95	1.62	1.90	0.22	0.19	0.25	330
40	22.93	0.90	1.45	2.00	0.22	0.16	0.34	240
40	22.67	0.78	1.25	1.92	0.22	0.16	0.16	270
41	24.75	0.62	0.69	0.84	0.22	0.14	0.12	230
41	22.71	0.81	0.88	1.25	0.22	0.15	0.24	240
41	20.58	0.86	0.64	1.28	0.22	0.14	0.32	210
43	16.12	1.09	5.44	1.33	0.29	0.34	0.17	190
43	14.45	0.94	9.27	2.03	0.34	0.46	0.14	220
43	15.05	1.03	28.56	1.96	0.38	0.42	0.18	240
44	22.07	1.03	18.35	1.52	0.37	0.34	0.21	200
44	33.35	1.05	7.37	1.39	0.36	0.30	0.22	200
44	23.41	1.05	23.29	1.55	0.35	0.29	0.23	190
45	25.08	0.88	12.15	1.55	0.22	0.26	0.07	220
45	23.76	0.82	8.74	1.83	0.22	0.24	0.08	240
45	23.08	0.89	4.26	0.96	0.22	0.27	0.06	220
46	33.19	0.90	11.56	1.54	0.24	0.24	0.09	210
46	33.26	0.76	2.00	1.20	0.25	0.29	0.08	190
46	30.48	0.99	4.37	1.08	0.24	0.33	0.06	220
47	22.37	0.92	2.11	1.08	0.27	0.35	0.06	220
47	18.91	0.80	17.31	1.09	0.27	0.36	0.08	240
47	19.66	2.28	2.16	1.01	0.36	0.38	0.08	220
48	23.55	0.93	2.33	3.45	0.45	0.76	0.12	240
48	15.40	0.95	1.82	1.44	0.43	0.74	0.08	280
48	21.91	1.03	2.03	3.44	0.46	0.68	0.13	310
49	29.26	1.03	1.23	2.34	0.32	0.39	0.33	250
49	43.05	1.17	2.34	2.11	0.44	0.42	0.44	290
49	45.98	1.07	1.45	1.47	0.32	0.41	0.30	270
50	24.24	1.30	2.99	4.43	0.44	0.62	0.21	280
50	27.97	1.36	1.44	93.96	0.50	0.64	0.76	260
50	37.87	1.77	4.68	6.04	0.65	0.80	0.83	260

Appendix E Principal Components Analysis (PCA) scores of coordinates of 43 plots along three synthetic gradients of elemental content in <u>Alectoria sarmentosa</u>

PLOTS	AXIS 1	AXIS 2	AXIS 3
PLOT #1	-0.1501	0.2662	0.1360
PLOT #2	-0.6537	-0.0520	0.4019
PLOT #3	0.2972	0.5350	0.2601
PLOT #4	0.0905	-0.0185	0.4023
PLOT #5	0.6550	0.4699	0.1027
PLOT #8	-0.1614	0.5032	0.0470
PLOT #9	-0.1087	0.2721	-0.6639
PLOT #10	-0.0584	0.5573	0.3091
PLOT #11	-0.0890	0.3109	0.0752
PLOT #12	0.1341	0.3267	0.0473
PLOT #13	-0.0166	-0.2312	0.2531
PLOT #14	-0.2200	0.1580	-0.2898
PLOT #15	0.1356	-0.0268	-0.0658
PLOT #16	0.0458	-0.1326	-0.0203
PLOT #17	-0.0002	0.2617	0.1019
PLOT #18	-0.1845	0.4680	-0.1738
PLOT #19	0.1161	-0.1717	0.0147
PLOT #21	0.0757	0.0798	0.3740
PLOT #22	0.4122	-0.3364	-0.1413
PLOT #23	0.4014	-0.2403	0.0833
PLOT #25	0.1261	-0.1076	-0.1543
PLOT #26	0.2330	-0.1650	-0.0483
PLOT #28	-0.2924	-0.2654	-0.2645
PLOT #29	-0.4173	-0.3293	-0.0533
PLOT #30	-0.2863	0.0342	-0.0171
PLOT #31	-0.4042	-0.2407	0.0779
PLOT #32	0.1403	0.0935	0.1032
PLOT #33	0.2115	-0.4383	-0.0775
PLOT #34	0.2629	0.0548	0.0884
PLOT #35	0.2763	-0.0692	0.0818
PLOT #36	-0.0924	0.1102	-0.4118
PLOT #38	0.3708	-0.4004	0.0437
PLOT #39	0.2205	-0.2442	-0.0318
PLOT #40	0.1283	-0.0914	-0.1024
PLOT #41	0.3376	-0.0082	-0.2018
PLOT #42	-0.3261	0.0089	-0.1349
PLOT #43	-0.0427	-0.2259	-0.0900
PLOT #45	-0.0066	-0.0263	-0.2735
PLOT #46	0.0304	-0.2617	-0.2396
PLOT #47	-0.2522	0.2834	-0.3439
PLOT #48	-0.6489	-0.1299	0.0893
PLOT #49	-0.0250	-0.2530	0.1363
PLOT #50	-0.2646	-0.3276	0.5703

Appendix F Principal Components Analysis (PCA) eigenvector scores for 16 elements in *Alectoria sarmentosa*

Element	Vector 1	Vector 2	Vector 3
P	-0.0962	-0.3580	-0.2641
K	-0.0379	-0.4632	-0.0117
CA	0.1724	-0.2418	0.3342
MG	-0.1855	-0.2893	-0.1108
NA	-0.2495	-0.1591	-0.2724
AL	-0.4406	0.0524	0.1580
FE	-0.5012	-0.0834	0.0593
MN	0.0976	-0.3281	0.2666
ZN	0.1866	-0.3410	0.1026
CU	-0.2181	-0.2269	0.2759
B	-0.1971	-0.2007	-0.1200
PB	0.0635	0.0229	0.4592
NI	-0.2132	0.3075	0.3094
CR	-0.3897	-0.0512	0.2793
CD	0.1770	-0.0832	0.3826
S	-0.2328	0.2444	0.0146