KLONDIKE GOLD RUSH NATIONAL HISTORICAL PARK

NATURAL RESOURCES MANAGEMENT PROGRAM

LICHEN-AIR QUALITY PILOT STUDY

FOR

KLONDIKE GOLD RUSH NATIONAL HISTORICAL PARK

AND

THE CITY OF SKAGWAY, ALASKA

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TABLE OF CONTENTS

EXECUTIVE SUMMARY

The concentrations of chemical elements in lichen tissues from the Klondike Park - city of Skagway area were used to assess local air quality. Two tube lichens (*Hypogymnia enteromorpha* and *H. inactiva*) and rag lichen (*Platismatia glauca*) from the Klondike-Skagway area showed signs of air pollution. The Klondike-Skagway lichens had higher levels of heavy metals and sulfur in lichen tissues than baseline values for unpolluted areas of Southeast Alaska. The Klondike-Skagway area exceeded air pollution indication thresholds for the USDA-Forest Service Pacific Northwest and Alaska Regions for heavy metals, sulfur and other elements. All of this study's sites, two in the Skagway valley and two in the Taiya valley, showed signs of air pollution, but the site closest to the town hub of Skagway had the highest occurrence and highest levels of pollutants in lichen tissues. These results are discussed and options for continued monitoring are presented.

PURPOSE

Klondike Gold Rush National Historical Park (Klondike Park) and the city of Skagway, Alaska, are located at the terminus of Southeast Alaska's famous inside passage. Klondike Park and Skagway receive about 750,000 visitors (tourists and tourism support staff) each summer **(43)**. During the winter, Skagway is a city of about 700 year-round residents **(43)**. The facilities and services associated with tourism, transportation, and the town produce compounds which are released into the air, and which have an undetermined impact upon local air quality.

Klondike Park commissioned an ecological reconnaissance study from the U.S. Forest Service in the early 1990s. The Forest Service report, "Ecological Inventory of Klondike Gold Rush National Historical Park and Adjacent National Forest Lands" **(38)**, recommended that Klondike Park consider using lichens as bioindicators in an air quality biomonitoring program.

This pilot study is intended to provide Klondike Park and the city of Skagway with some preliminary information about air quality, current air quality impacts on lichens, and the feasibility of using lichens as air quality indicators. Klondike Park and the community of Skagway can use this information to further discussion of air quality issues and to consider if additional studies or monitoring are warranted.

OBJECTIVES

Determining the actual levels of pollutants in the air requires expensive equipment and laboratory analyses. An indirect method for gathering information about air pollutants examines the concentrations of air pollutants that are absorbed by lichens. This indirect method does not produce the rigorous level of information that direct measurements provide. But it is relatively inexpensive and has the advantage that bioindicators give a summary picture of air quality over time, rather than at a particular moment. This pilot study was intended to provide "orientation" level information – information that gives an outline of the air quality situation.

The objectives of this study are:

1) Determine the concentrations of selected chemical elements in lichen tissues from sites in the Klondike-Skagway area. *What are the chemical concentrations in lichen tissues?*

2) Estimate the difference in element concentrations, if any, between a site near the Skagway town hub and a similar site in the Taiya valley. *Is there a difference between the Skagway town hub (more exposed to sources of air pollution) and the Taiya valley (less exposed)?*

3) Compare this study's results to information from the greater Southeast Alaska region. *Does the Klondike-Skagway area have higher or lower levels than baseline levels for the rest of Southeast Alaska?*

4) Interpret the concentration levels found in this study in relation to the greater Pacific Northwest (including Southeast Alaska). *Does the Klondike-Skagway area have levels that are above air pollution thresholds developed for the Pacific Northwest?*

BACKGROUND

LICHEN BIOLOGY AND LICHEN-AIR QUALITY STUDIES

Lichens are unusual organisms because they are composites of two or more distinct organisms: a fungus and a photosynthetic partner, either a green alga or blue-green bacterium. The fungus provides structure and protection for itself and the photopartner; while the photopartner converts sunlight into food for itself and the fungus. These two separate life forms create a synergistic organism, the lichen, in which both partners benefit from association with the other. Lichens can be found in many habitats, growing on trees, on the surface of the ground, and even on bare rock.

Lichens absorb nutrients directly from their surroundings. Because of this, they are more susceptible to air pollutants than plants and animals that have better protective coverings and selectively obtain their nutrients from the soil or from eating other organisms. Some lichens are particularly sensitive to certain air pollutants, and they decline or die when exposed to high levels of those pollutants. The presence or absence of these lichens in an area can be used as an indication of air pollution. One type of lichen-air quality study examines the distribution of lichens in areas exposed to different levels of air pollution **(48)**.

Lichens that grow on trees get most of their nutrients from the air or from rainfall. Many chemical elements in the air and rainfall are easily absorbed by the lichens. Some elements are quickly absorbed and quickly leach out of the lichens again. Other elements can become concentrated, or bioaccumulate, in lichen tissues. These altered concentrations of chemicals may affect the lichen, leading to deformity, decline or death, or may simply bioaccumulate without harming the lichen. Studies that examine the concentrations of chemicals in lichen tissues may reveal signs of air pollution before more overt signs, such as lichen death and changes in the species composition of lichens in an area, become apparent **(40, 48)**.

This pilot study uses the second method, examination of chemical concentrations in lichen tissues, to collect information on air quality in the Klondike Park - city of Skagway area.

CHEMICAL ELEMENTS USED IN LICHEN-AIR QUALITY STUDIES

Most chemical elements can be harmful to organisms in extremely high concentrations. However, organisms also require some elements, called nutrients, in order to carry out the chemical reactions involved with life (metabolism). The elements commonly used in lichen tissue analysis have characteristics that help investigators piece together the air quality situation in their study area.

Nitrogen, Sulfur

These non-metals are major plant nutrients, and form compounds in the air which are mjor contributors to acid rain and visibility degradation. These compounds are quickly absorbed by lichens, but also quickly leach out of lichens if air quality improves. High nitrogen and sulfur concentrations in lichens are strong indicators of air pollution. **(18, 35, 41)**

Calcium, Magnesium and Sodium

Calcium and magnesium are major plant nutrients. Acid rain and air pollution tend to depress calcium and magnesium levels in lichens. In general, higher levels of calcium indicate healthy lichens. High levels of all three can indicate an ocean effect (exposure to marine water aerosols) or a dry, limestone-based environment. **(10, 21, 41)**

Aluminum, Iron

Aluminum and iron are primary constituents of rock and soils minerals. Higher levels of these elements usually indicate exposure to lots of wind-blown mineral dust, which may be naturally occuring or may indicate pollution exposure. Acid rain can increase concentrations of aluminum and iron. Iron is a minor plant nutrient. **(2, 27, 41)**

Phosphorus, Potassium

These elements are major plant nutrients. Potassium and phosphorus levels have not been strongly linked to air pollution, but some higher concentrations have been recorded near pollution sources. **(2, 12, 19, 20, 22, 41)**

Boron, Manganese

These elements are minor plant nutrients. Concentrations of these have not been strongly linked to air pollution, but unusually high levels may indicate pollution. Boron levels can also be generally elevated in lichens near marine environments. **(20, 41)**

Cadmium, Chromium, Copper, Lead, Nickel and Zinc

High levels of these heavy metals are rarely found naturally, and are usually strong indicators of human caused air pollution. Copper and zinc are minor plant nutrients, but many lichens are particularly sensitive to elevated copper concentrations which causes mortality in susceptible species. Cadmium levels can also be generally elevated in lichens near marine environments. Metals may bioaccumulate in lichens without causing any apparent harm, or they may cause deformity and death at high concentrations. **(4, 5, 6, 34, 41)**

THE KLONDIKE-SKAGWAY SETTING

The town proper of Skagway occupies a small river delta at the confluence of Skagway River and Lynn Canal (a saltwater fjord). Dyea, about 3 miles northwest of Skagway, lies at the end of the Taiya River where it meets Lynn Canal. Both areas are bound by steep, post-glacial valley walls (see map on page 5).

Skagway is known as the "windy city". Strong southerly winds in the Skagway area are usually caused by low pressure systems moving inland from the Gulf of Alaska. High pressure systems moving south from the continental interior bring associated north winds. Strong winds disperse any stagnant air pollution, but contribute to particulate air pollution during dry periods by stirring up mineral dusts.

Despite it's windy reputation, temperature inversions are not uncommon in the Skagway area. By confining a layer of cool air beneath a layer of warm air, temperature inversions trap air pollutants in the immediate vicinity of their source. The confined air layer develops into visible smog. Under certain conditions, smog plumes from temperature inversions over Skagway can move slowly, over the course of a day, south along Lynn Canal or west into the Taiya valley.

The Skagway area has unusually low precipitation for Southeast Alaska. The average precipitation for Skagway is only 26.44 inches per year, calculated from 1965-2000 **(36)**. Other Southeast Alaska towns typically average 50 to 150 inches of precipitation per year. Vegetation indicates that the Taiya River valley may experience slightly more precipitation than the Skagway River valley, but weather data are not available to confirm this proposition. Low precipitation in the Skagway area allows the ground surface to periodically dry out, which contributes to particulate air pollution when winds pick up and redistribute dust.

METHODS

The methods for this study were adapted from methodology of "Air Quality Monitoring on the Tongass National Forest, Methods and Baselines Using Lichens" **(20)**.

SAMPLE SITES AND MAP

Four sites were identified for this study in 1998: Dewey, Chilkoot, Sturgills and Dyea. The Dewey and Chilkoot sites were selected to encompass the range of supposed exposures to local sources of air pollution. The assumption was that the greatest exposure would be near the town proper of Skagway, and the least exposure would be near the beginning of the Chilkoot Trail. The two sites were positioned to be as similar as possible in other ways: similar terrain, vegetative cover, slope, aspect and elevation. But they are not identical - the Chilkoot site is farther from marine waters than the Dewey site (see map on next page).

The Sturgills and Dyea sites were selected to increase the sample size of local data so that the Klondike-Skagway data set could be compared to other data sets from Southeast Alaska and the Pacific Northwest. Sturgill's is near Dewey but on the other side of the Dewey Lake ridge, facing away from town. Dyea is an historic townsite and cultural attraction. These sites have differing topography and vegetative cover compared to the Dewey and Chilkoot sites.

Dewey (most exposed) - This site was about 4.4 hectares (10.9 acres) in size. It is situated on a low bench along the lower edge of the 1500 meter high ridge that is the east wall of the Skagway River valley, overlooking the Skagway small boat harbor. The plot elevation ranges from about 50 meters to about 175 meters. The plot slope ranges from about 10 degrees to about 45 degrees, facing west northwest (295 degrees).

Vegetative cover is a western hemlock - lodgepole pine - Sitka spruce - paper birch woodland in mid-seral stage (pole timber stage). Burn scars remain from a fire 50+ years ago. Understory is sparse, composed of rusty menziesie, feather and other mosses, and foliose and fruticose lichens.

Chilkoot (least exposed) – This site was about 4.9 hectares (12.1 acres) in size. It sits on a small hill known locally as "Saintly Hill". Saintly Hill is a low section of the AB Mountain ridge that forms the east wall of the Taiya River valley. The plot elevation ranges from 85 to 110 meters. The plot slopes to the west northwest (280 degrees) at 20 to 40 degrees.

Vegetative cover is a western hemlock - lodgepole pine - Sitka spruce - paper birch woodland in mid-seral stage. Burn scars remain from a fire 10+ years ago. Understory is sparse, composed of rusty menziesie, shag, feather and other mosses, and foliose and fruticose lichens.

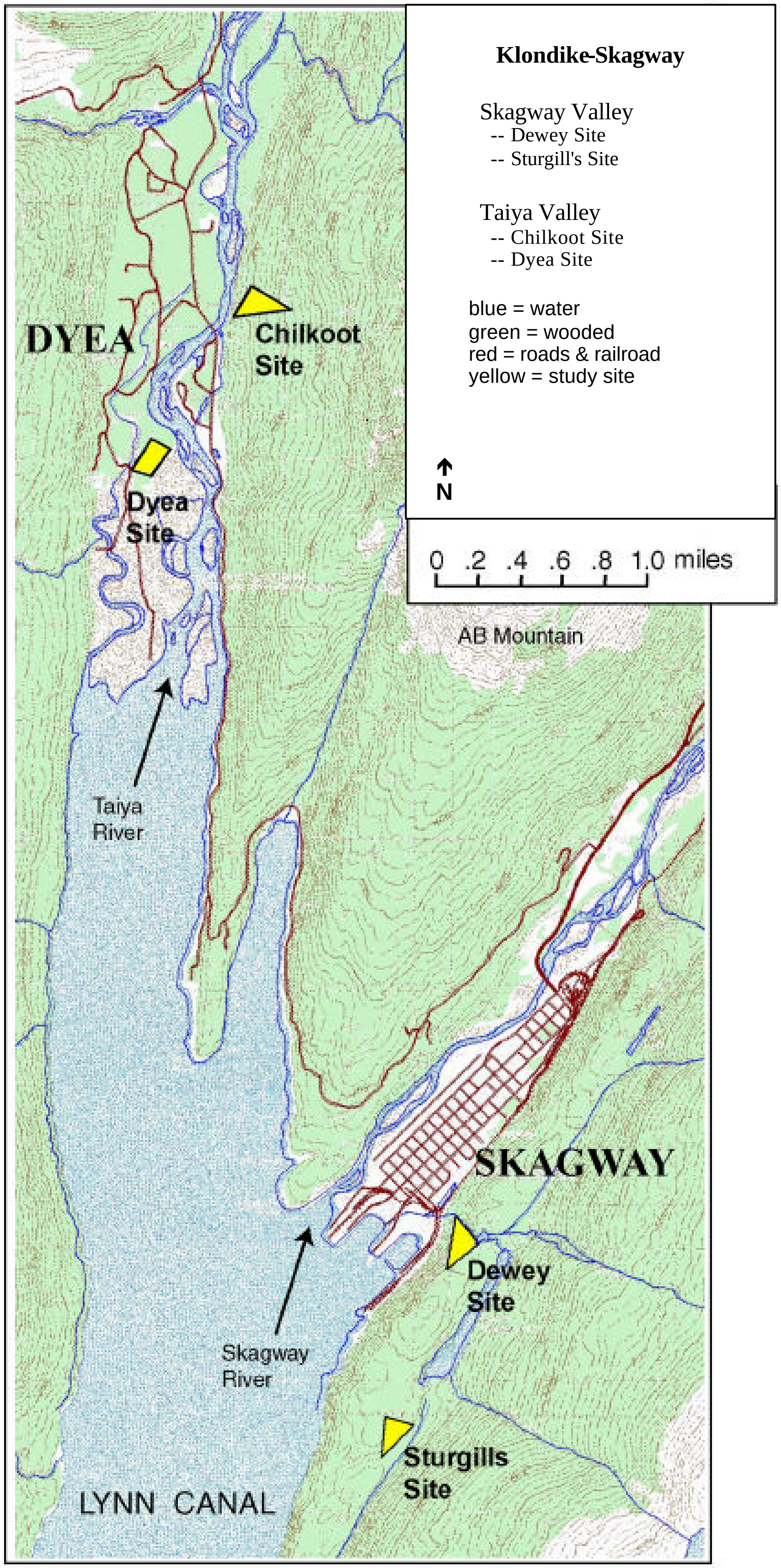
Sturgills - This site was about 4.0 hectares (8.6 acres) in size. It sits on a 150 meter high bench at the base of a 1500 meter ridge that is the east wall of the Skagway River valley, approximately 1 kilometer south of the Dewey site. The Sturgill site is on the southeast side of a low ridge, and on the south side of the depression that forms Dewey Lake. Elevation is 150 to 175 meters, with a gentle slope (4-15 degrees) facing south southeast (140 degrees).

Vegetative cover is a western hemlock - lodgepole pine - Sitka spruce - paper birch woodland in mid-seral stage. Understory is sparse, composed of rusty menziesie, feather and other mosses, and foliose and fruticose lichens.

Dyea – This site was about 4.2 hectares (10.3 acres) in size. It is located on the terminal delta of the Taiya River floodplain. Elevation is 3-18 meters, with near level slope. The site is located on a low bench above tidal grass/sedge meadows. Site of the historic 1989 gold rush town of Dyea, the area was cleared for agriculture during the decades after the gold rush. Soils are very sandy and well drained.

Vegetative cover is coastal Sitka spruce - black cottonwood - western hemlock in mid-seral stage. Trees are 20-30 meters tall. Cottonwood and Sitka spruce dominate, with some paper birch, lodgepole pine, Scoulers willow and unusually large Sitka willows. The pines were open grown and many of the dead, lower limbs are covered with lush foliose lichens, such as *Hypogymnia inactiva*. Undisturbed ground is covered with a deep bed of mosses and, in season, mushrooms.

FIGURE 1. MAP OF STUDY SITES



LICHENS

Three lichen species were used in this study: *Hypogymnia enteromorpha*, *Hypogymnia inactiva*, and *Platismatia glauca*. These three species were selected as the most locally abundant species from a list of 10 lichen species that had been used previously for air quality monitoring in Southeast Alaska or the Pacific Northwest.

Hypogymnia enteromorpha

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Hypogymnia inactiva

Platismatia glauca

FIELD DATA COLLECTION

Lichens were collected from the field plots during the Fall of 1998 and 1999. The target collection scheme during 1998 was three replicate samples per species per plot. Irregular sample sets were obtained during the first year due to logistic and set-up problems, including reduced sample sets due to concerns about overharvest of some lichen species. During the second year, two species at two plots were collected in order to check annual variability and to enlarge the data set.

Table 1. Field data collection schedule.

lichen species	Sample Site *				total number of samples
	Chilkoot	Dewey	Sturgills	Dyea	
year **1998**					
H. enteromorpha	Sept 17 (2)	Sept 16 (3)	Nov 4 (2)		7
H. inactiva	Sept 17 (4)	Sept 16 (3)	Nov 4 (2)	Oct 6 (2)	11
P. glauca		Dec 23 (2)	Nov 4 (2)	Oct 6 (3)	7
year **1999**					
H. enteromorpha	Oct 8, 9, 11, 13 (3)	Nov 11 (3)			6
P. glauca	Oct 8, 11 (3)	Nov 11 (3)			6
* Date of sample collection (number of samples)					37

Lichens were removed from the trunks and inner, lower limbs of trees, primarily conifers, from about 0.5 to 2.0 meters above ground. Lichens were collected by non-smoking individuals (smoking residues on the hands and clothes of cigarette smokers could contaminate samples), with either latex-gloved or recently cleaned hands. A sample consisted of about 20 grams clean, dry weight of lichens. Twenty to sixty trees were needed to complete a sample. Since lichens were collected when damp or wet, sometimes additional field collection trips were needed to complete samples that were found to be too small after they were dried and cleaned. Dry, cleaned lichens collected in 1999 weighed only 15 to 40% of the moist-wet lichen weights in the field.

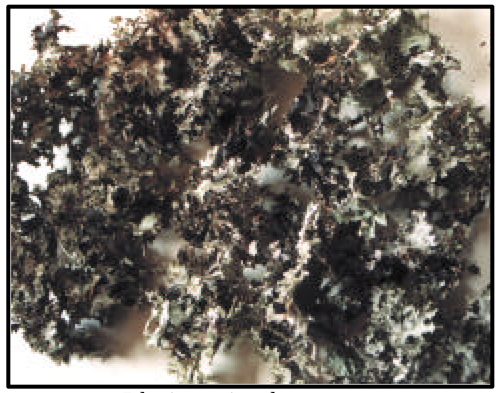
Species identification was accomplished based on morphological descriptions and reference to the Klondike Park herbarium. Samples were retained and photographs were taken, which were later used to confirm and document species identifications.

Lichens collected in the field were sealed in airtight, metalized polyester sample bags (Kapak Corp., Minneapolis, MN). Kapak bags are lined with a polymer, with a metal coating on the exterior to prevent gas exchange. The bags have been previously tested for possible metal contamination of contents (using blank filter papers as samples), and no detectable metals were found in those samples **(25)**.

Lichens were transported back to Klondike Park offices in Skagway. There, they were immediately set out to air-dry in a work area in a no-smoking building, on clean 100% acid-free herbarium sheets. The lichens were dried and cleaned in a protected, but not sterile, work area. Normal office cleaning and traffic were suspended during lichen processing to minimize contamination. Samples were cleaned by removing insects, spiders, loose leaves and any twigs or bark adhering to the lichen tissue. During 1998, the lichens were dried overnight, repackaged in Kapak bags, and shipped for laboratory analysis. During 1999, the lichens were dried until weight no longer changed, repackaged in Kapak bags, then shipped. Kapak bag openings were triple folded and completely sealed with tape to prevent contamination in transit.

Examples of lichens during the drying and cleaning process, 1999.

Hypogymnia enteromorpha



Platismatia glauca

LABORATORY ANALYSES

Laboratory analyses were performed by the University of Minnesota, Soil Science Department, Research Analytical Laboratory. The laboratory analysis determined dry weight concentrations of 17 elements and ash (the remains after combustion) for each sample:

Aluminum (AL)	Iron (FE)	Phosphorus (P)
Boron (B)	Lead (PB)	Potassium (K)
Cadmium (CD)	Magnesium (MG)	Sodium (NA)
Calcium (CA)	Manganese (MN)	Sulfur (S)
Chromium (CR)	Nickel (NI)	Zinc (Z)
Copper (CU)	Nitrogen (N)	--ASH--

Details of the laboratory methods can be found at the University of Minnesota web site (http://ral.coafes.umn.edu). Briefly, samples were ground and stored, then oven dried to 65°C prior to analysis. Percent total sulfur was determined by infrared absorption of sulfur dioxide following combustion. Percent total nitrogen was determined using the micro-Keldahl method using a one hour, high temperature acid/selenium digestion. All other elements were simultaneously determined as micrograms per gram of sample (ug/g or ppm) by inductively coupled plasma atomic emission spectrophotometry (Applied Research Laboratories 3560) following crucible ashing and 1/2 hour acid digestion with acid reflux after 3 hour settling period. One aliquot from each sample was measured three times to produce each datum.

Laboratory methods included several levels of quality assurance. Laboratory equipment was calibrated before and during sample analyses with NIST (National Institute of Standards and Technology) reference standards derived from pine needles, orchard, or peach leaves. Additional laboratory checks included inhouse laboratory standard solutions, acid blanks, and a special US Forest Service lichen-air quality check developed in 1993 using the lichen *Alectoria sarmentosa* from the Mt. Hood National Forest in Oregon. Finally, every tenth sample was measured twice to check laboratory precision within a batch.

DATA ANALYSES

Laboratory results were entered into computer spreadsheets, then triple checked for accuracy. Data examination and statistics were performed using SYSTAT **(55)**.

STUDY COSTS AND LABOR

Study design and preparation were done by Klondike Park's 1998 Biological Technician (hours not available, estimated at 120 hours) in consultation with a US Forest Service Lichen Monitoring Specialist. Data collection and processing work was accomplished by Klondike Park staff and volunteers. During 1999, this amounted to 44 hours of volunteer time, and 80 hours of staff time (for 2 lichen species at 2 field plots). Labor hours are not available for 1998, but were estimated at 180 hours (for 2-3 lichen species at 4 field plots). Materials and equipment costs were roughly $400 (field scale, sample bags, lab scale, herbarium sheets, shipping).

Laboratory analysis costs came to $1,165 for 1998, and $600 for 1999. Data entry and quality checks were done by a Klondike Park volunteer and Clerk (about 36 hours). Some literature research was performed by a Klondike Park Biological Technician (about 24 hours). Data analysis, literature research, and report writing were done by Klondike Park's Natural Resource Specialist and a consulting US Forest Service Lichen Monitoring Specialist, for a total of approximately 320 hours (9 work weeks at 40 hours/week).

Total non-labor costs: approximately $2,165
Total labor hours: approximately 844 hours

RESULTS

OBJECTIVE 1 - DETERMINE THE CONCENTRATIONS OF SELECTED CHEMICAL ELEMENTS IN LICHEN TISSUES FROM SITES IN THE KLONDIKE PARK - CITY OF SKAGWAY AREA.

What are the chemical concentrations in lichen tissues?

The concentrations of 17 elements in 3 different species of lichens, from 4 sites in the Klondike Park - city of Skagway area, during fall of 1998 and 1999 are given in Appendix A. Data from each site, for each lichen species, and for each year included 2, 3 or 4 replicate samples. Laboratory quality control/quality assurance checks are also included in Appendix A.

OBJECTIVE 2 - ESTIMATE THE DIFFERENCE, IF ANY, BETWEEN A SITE NEAR THE SKAGWAY TOWN HUB AND A SIMILAR SITE IN THE TAIYA VALLEY.

Is there a difference between the Skagway town hub (more exposed to sources of air pollution) and the Taiya valley (less exposed)?

The Dewey site was located near the Skagway town hub, an area presumed to be more exposed to air pollution, while the Chilkoot site was located in the Taiya valley, an area with less exposure. The two plots were carefully placed to be as similar as possible in other characteristics: terrain, plant community, slope, aspect and elevation. However, the Chilkoot site is located about 2 miles from Lynn Canal, whereas the Dewey site is located at the end of the fjord. Proximity to marine waters can elevate concentrations of some elements.

Different lichen species absorb and retain chemicals differently, therefore the data for the three lichen species used in this study must be examined separately. Collection year was also separated due to the low sample size and detailed level of this comparison. Four subsets of data resulted from these requirements:

1998 - *Hypogymnia enteromorpha* 1999 - *Hypogymnia enteromorpha*
1998 - *Hypogymnia inactiva* 1999 - *Platismatia glauca*

When the data were broken down into these sets, each data set contained only 2-4 values per site. These low sample sizes make statistical analyses problematic. Therefore, the data sets were graphed and examined for gross differences. The results are summarized below and presented in detail in Appendix B. The elements that showed consistent differences between Dewey and Chilkoot sites are highlighted.

Table 2. Comparison of Dewey and Chilkoot sites.

element	Dewey	Chilkoot	meaning
Aluminum (AL)	higher or same	lower or same	higher indicates more wind-blown mineral dust
Boron (B)	ambiguous	ambiguous	nutrient, from natural and human sources
Cadmium (CD)	**HIGHER**	**lower**	**higher may indicate air pollution, can be elevated by marine aerosols**
Calcium (CA)	**lower**	**HIGHER**	**nutrient, often elevated by marine aerosols, higher usually indicates healthy lichens**
Chromium (CR)	usually higher	usually lower	higher may indicate air pollution
Copper (CU)	**HIGHER**	**lower**	**higher may indicate air pollution**
Iron (FE)	**HIGHER**	**lower**	**nutrient, higher indicates more wind-blown mineral dust or may indicate air pollution**
Lead (PB)	**HIGHER**	**lower**	**higher may indicate air pollution, usually from human sources**
Magnesium (MG)	**lower**	**HIGHER**	**nutrient, often elevated by marine aerosols**
Manganese (MN)	**lower**	**HIGHER**	**nutrient, higher may indicate air pollution**
Nickel (NI)	**HIGHER**	**lower**	**higher may indicate air pollution**
Nitrogen (N)	ambiguous	ambiguous	nutrient and highly mobile pollutant (quickly absorbed, quickly leached out), from natural and human sources, high levels may indicate recent air pollution
Phosphorus (P)	lower or same	higher or same	nutrient, from natural and human sources
Potassium (K)	higher or same	lower or same	nutrient, from natural and human sources
Sodium (NA)	higher or same	lower or same	nutrient, often elevated by marine aerosols
Sulfur (S)	higher or same	lower or same	nutrient and highly mobile pollutant (quickly absorbed, quickly leached out), from natural and human sources, high levels may indicate recent air pollution
Zinc (ZN)	**HIGHER**	**lower**	**nutrient, higher may indicate air pollution**
Ash	ambiguous	ambiguous	ash levels usually indicate exposure to wind-blown mineral dust

Five elements that are usually associated with air pollution were higher at the Dewey site (CD, CU, PB, NI, ZN). Only one element that may indicate air pollution was higher at the Chilkoot site (MN). Calcium the indicator of healthy lichens, was lower at the Dewey site. Although the Dewey site is closer to marine waters, the concentrations of CA, MG and NA (indicators of a strong marine influence) were either lower or the same at the Dewey site.

These results suggest that there is a difference between the Dewey site and the Chilkoot site - with the Dewey site generally showing more indications of exposure to air pollution, and lower levels of calcium, the nutrient associated with healthy lichens. However, low sample size prevents statistical analysis and the determination of a confidence level associated with the observed differences between the two sites.

OBJECTIVE 3 - COMPARE THIS STUDY'S RESULTS TO INFORMATION FROM THE GREATER SOUTHEAST ALASKA REGION.

Does the Klondike-Skagway area have higher or lower levels than baseline levels for the rest of Southeast Alaska?

Baseline levels of element concentrations from 1989 and 1990 are available for 4 lichen species from the Tongass National Forest **(20)**. One of these species, *H. enteromorpha*, was also used in our pilot study. In the Tongass study, *H. enteromorpha* was collected from sites located throughout Southeast Alaska, including multiple sites along Lynn Canal but not in the immediate vicinity of Skagway. The Tongass data set also includes the Stikine River valley, another wind funnelling, high dust river system, though wetter (higher annual precipitation). The baseline data set excluded areas subject to obvious human inputs of air pollutants (at least 15 miles from known pollutant sources or urban areas). Baseline calculations included means and standard errors across sites, rather than a range of acceptable values.

In our study, *H. enteromorpha* was collected from the Dewey, Chilkoot and Sturgills sites in 1998 and 1999. These data were pooled to allow statistical testing for differences with the Tongass baseline data set.

The Tongass study used a slightly different laboratory procedure (a post-ash acid boil treatment was not used) which can affect the lab results for some elements. This effect was determined by examining lab results from an Oregon/Washington data set from 1993 to 1998 - the boil treatment was used in 1993, but not during 1994-1998. Aluminum, iron, manganese, sodium and zinc were found to have higher recovery (higher values) when the boil treatment was used, and correction factors were calculated. Also, the Oregon/Washington data set was examined to determine any changes in the laboratory's effectiveness at recovering elements over time. The recovery of copper and nickel was found to be slightly improved over the years, and correction factors were calculated for these elements. Therefore, Klondike values were adjusted, for the purposes of this objective only, by the following factors:

AL 0.654	CU 0.770	FE 0.629	MN 0.936
NA 0.887	NI 0.435	ZN 0.941	

Parametric and non-parametric statistical tests were used to look for differences between the Klondike-Skagway data and the Tongass data. The parametric test used was the t-test for difference in means, and the non-parametric test was the Mann-Whitney test for difference in ranked means.

Parametric statistical tests are sensitive (they will detect differences that might not show up in other kinds of tests) as long as the data sets have certain characteristics. Non-parametric statistical tests are not as sensitive, but they are "safer" - they have fewer requirements that the data sets contain particular characteristics. The Klondike-Skagway and Tongass data sets did not fully meet all parametric test requirements, but they were not so incompatible as to invalidate the tests. The results of the non-parametric tests reinforced the parametric results with only two exceptions: calcium and sodium. These statistical analyses can be strengthened and ambiguities can be clarified by increasing sample sizes.

See Appendix C for detailed graphs and tables of the statistical tests. The results are summarized below, elements that show a statistically significant difference are highlighted:

Table 3. Results of statistical tests for difference between Klondike-Skagway and Tongass baseline.

element	Klondike-Skagway data significantly different than Tongass baseline?	direction of difference
Aluminum (AL)	**YES**	**Klondike-Skagway higher than Tongass baseline**
Boron (B)	NO	
Cadmium (CD)	**YES**	**Klondike-Skagway higher than Tongass baseline**
Calcium (CA)	UNCLEAR	
Chromium (CR)	**YES**	**Klondike-Skagway higher than Tongass baseline**
Copper (CU)	**YES**	**Klondike-Skagway higher than Tongass baseline**
Iron (FE)	**YES**	**Klondike-Skagway higher than Tongass baseline**
Lead (PB)	**YES**	**Klondike-Skagway higher than Tongass baseline**
Magnesium (MG)	NO	
Manganese (MN)	NO	
Nickel (NI)	**YES**	**Klondike-Skagway higher than Tongass baseline**
Nitrogen (N)	(data not available from Tongass for *H. enteromorpha*)	
Phosphorus (P)	**YES**	**Klondike-Skagway higher than Tongass baseline**
Potassium (K)	**YES**	**Klondike-Skagway higher than Tongass baseline**
Sodium (NA)	UNCLEAR	
Sulfur (S)	**YES**	**Klondike-Skagway higher than Tongass baseline**
Zinc (ZN)	**YES**	**Klondike-Skagway higher than Tongass baseline**

The Klondike-Skagway area had numerous element concentrations that were significantly different than the Tongass baseline. AL and FE were higher than the baseline, indicating that the Klondike-Skagway area probably experiences more wind-blown dust than the rest of Southeast Alaska. CA, MG and NA were not higher than the baseline, indicating that the marine influence is not appreciably different in the Klondike-Skagway area compared to the rest of Southeast Alaska.

The Klondike-Skagway area was found to have significantly higher levels of the heavy metals CD, CR, CU, PB, NI and ZN. Sulfur, a strong indicator of pollution, was significantly higher in the Klondike-Skagway area. Phosphorus and potassium were found to be higher in the Klondike-Skagway area, but it is unclear how these elements are linked to air pollution. Iron levels were higher for Klondike-Skagway, these levels might be linked to naturally occurring wind-blown dust, but also might indicate pollution.

These statistical analyses can be strengthened and ambiguities can be clarified by increasing sample sizes.

OBJECTIVE 4 - INTERPRET THE CONCENTRATION LEVELS FOUND IN THIS STUDY IN RELATION TO THE GREATER PACIFIC NORTHWEST (INCLUDING SOUTHEAST ALASKA).

Does the Klondike-Skagway area have levels that are above air pollution thresholds developed for the Pacific Northwest?

While it is useful to compare different areas and establish if levels of chemicals are higher or lower between those areas, these types of comparisons may not help investigators determine whether certain areas are impacted by air pollution. Concentrations of elements at one site may be higher than another site, but both sites may be above or below levels that signal air pollution problems. To address this situation, a large data set from the greater Pacific Northwest region was used to develop thresholds, or air pollution indication levels, for a suite of chemicals and lichens **(51)**.

The Pacific Northwest data set, which includes Southeast Alaska, has been assembled for a number of lichen species from 1989 to the present. Encompassing a wide variety of natural conditions across 1200 sites in 11 National Forests, this data set should safely include the normal variation of chemical levels that are due to natural sources. Thus, conservative air pollution indication thresholds can be developed from this data set by calculating the 97.5 quantile levels for each chemical per lichen species. The 97.5 quantile level is the point below which 97.5% of the data set values are found. This means that values above the 97.5 quantile threshold concentrations are very unusual values. In other words, only 2.5% of values in the baseline data set exceed the threshold concentration levels, which indicates normal circumstances.

The data from our study were tested by site and lichen species against the 97.5 quantile threshold concentration levels for the Pacific Northwest. Graphs of the tests are given in Appendix D, and are summarized below:

Table 4. Klondike-Skagway elements that exceed Pacific Northwest 97.5 quantile threshold concentrations.

	DEWEY			CHILKOOT			STURGILLS			DYEA		Number and percentage of samples exceeding threshold concentration levels
	HYP ENT	HYP INA	PLA GLA	HYP ENT	HYP INA	PLA GLA	HYP ENT	HYP INA	PLA GLA	HYP INA	PLA GLA	
number of samples (37 total per row)	6	3	5	5	4	3	2	2	2	2	3	
Aluminum (AL)	0	0	0	0	0	0	0	0	0	0	0	0
Boron (B)	0	0	0	0	0	0	0	0	0	0	1	1 (2.7%)
Cadmium (CD)	5	3	5	0	4	0	0	0	0	2	0	19 (51.4%)
Calcium (CA)	0	0	0	0	0	0	0	0	0	0	3	3 (81.1%)
Chromium (CR)	1	0	2	0	0	3	0	0	0	0	0	6 (16.2%)
Copper (CU)	6	3	3	0	0	0	0	0	0	0	1	13 (35.1%)
Iron (FE)	4	3	2	0	0	0	0	0	0	0	1	10 (27.0%)
Lead (PB)	6	3	5	0	0	0	2	2	2	0	0	20 (54.0%)
Magnesium (MG)	0	0	0	0	0	0	0	0	2	2	3	7 (18.9%)
Manganese (MN)	0	0	0	0	0	0	0	0	0	0	0	0
Nickel (NI)	6	3	5	0	0	0	0	0	0	0	2	16 (43.2%)
Nitrogen (N)	0	0	0	0	0	0	0	0	0	0	0	0
Phosphorus (P)	0	0	1	0	0	2	0	0	0	0	3	6 (16.2%)
Potassium (K)	0	0	5	0	0	3	0	0	0	0	3	11 (29.7%)
Sodium (NA)	0	0	1	0	0	0	0	0	0	0	0	1 (2.7%)
Sulfur (S)	6	3	4	4	0	2	2	0	1	0	3	25 (67.6%)
Zinc (ZN)	6	3	5	5	2	3	2	2	0	2	3	33 (89.2%)

shaded box = one or more Klondike-Skagway samples exceed the 97.5 quantile threshold concentration.
HYP ENT = *Hypogymnia enteromorpha*, HYP INA = *Hypogymnia inactiva*, PLA GLA = *Platismatia glauca*

All Klondike-Skagway sites exceed some Pacific Northwest 97.5 quantile threshold concentrations. The Dewey site shows the highest number of exceedences. The heavy metals of particular concern as pollutants, CD, CR, CU, PB, NI and ZN, and the strong air pollution indicator, S, all exceeded Pacific Northwest thresholds repeatedly across the Klondike-Skagway sites. In addition, FE, P and K showed exceedences, which may also point to air pollution. The Dewey site had the most cases of exceedence, and a similar suite of elements exceeded the threshold concentrations in three lichen lichen species.

SUMMARY AND DISCUSSION

Lichens in the Klondike-Skagway area show signs of air pollution. The Klondike-Skagway area has higher levels of heavy metals and sulfur in lichen tissues than baseline values for unpolluted areas of Southeast Alaska. The Klondike-Skagway area exceeds air pollution indication thresholds for the USDA-Forest Service Pacific Northwest and Alaska Regions for heavy metals, sulfur and other elements. All sites included in this study, two in the Skagway valley and two in the Taiya valley, showed signs of air pollution, but the site closest to the town hub of Skagway had the highest occurrence and highest levels of pollutants in lichen tissues.

SOURCES OF POLLUTION

The Klondike-Skagway area is exposed to a number of common air pollution sources. Homes and businesses expel exhausts into the air from heating, cooking, cleaning and business operations. Residential and commercial open-air burning occurs in backyards and business lots. The city began operating an incinerator for trash disposal in 1999 (after initial data collection for this study had begun). Road transportation includes cars, buses, shuttles and large trucks. Ferries, barges and small boats operate year-round. Air traffic consists of small planes and helicopters. All of these sources increase dramatically during the summer tourist season.

The Klondike-Skagway area has also been exposed to uncommon air pollution sources. Local or regional forest fires are an infrequent but occasional source of smoke. Cruise ships dock at Skagway from May to September each summer. Larger cruise ships carry approximately 3,000 people (passengers and crew). With the support facilities of a small town, cruise ship operations produce exhausts that are usually visible to the naked eye as stack emissions. When three or more cruise ships dock at the same time, their sheer physical volume dwarfs the town of Skagway.

Tourist train excursions, mainly diesel train engines, operate during the summer. Before tourism became the focus of Skagway's economy, trains operated primarily for other purposes. Prior to 1982, when the railroad shut down for 6 years, trains were used to move passengers and freight between the port of Skagway and the interior **(54)**. During World War II, the U.S. Army made Skagway a supply center, using trains to transport materials to the Alaska Highway project in the Yukon. Between 1902 and 1982, but primarily from the 1960s to 1982, trains were used to transport mineral ores from the Yukon to the waterfront **(13)**.

The transport of mineral ores through Skagway contributed to air pollution in ways beyond engine exhausts. Ore concentrates containing lead, zinc and other heavy metals **(13)** were moved from the Yukon to Skagway by train. At the Skagway waterfront, the ores were loaded onto barges using an open conveyor system. When the ore concentrates were exposed to the air, mineral particles could be lifted and blown away on the winds. Between 1986 and 1993, mining transport shifted to trucks using the new Klondike Highway **(11)**. A covered conveyor barge loading system was installed in 1988-89 **(23)**. No ore transport through Skagway has occurred between 1993 to 2000.

Concerns about exposure of Skagway residents to lead prompted the removal of contaminated soils in the town area in 1989-1990 by the Alaska Dept. of Environmental Conservation. **(23)** Although the original source of mineral dust air pollutants from ore transport no longer exists in Skagway today, particles that were released prior to 1993 may still be in the ecosystem and could be redistributed in the air during dry, windy periods.

TIME PERIOD

Some information about the time period that these results represent can also be gleaned from this study. The length of time that chemicals remain in lichen tissues, called retention time, varies according to the chemical. Sulfur and nitrogen have short retention times - they are quickly absorbed and quickly leach from lichen tissues. The estimated retention time for N and S is from several weeks to 3-5 years **(35)**. Heavy metals have longer retention times, and may bioaccumulate for the life of the lichen. Other elements such as phosphorus, potassium and magnesium may vary seasonally. The US Forest Service is working to establish the retention times for elements in lichen tissues in the Pacific Northwest, but results from those studies are not yet available. However, we can safely say that the high sulfur levels in our study indicate ongoing air pollution, while high heavy metal levels could indicate ongoing exposure or may result from exposure sometime during the time period from the present to the age of the lichens.

Lichens are slow-growing, long-lived organisms. The exact life spans of lichens are unknown, however, *Hypogymnia* and *Platismatia* are among the faster-growing lichens **(29, 33, 42)**. Being sessile organisms, lichens cannot be older than the substrate upon which they grow. The trees of all of the Klondike-Tongass sites are at mid-seral stage, meaning the succession of plant growth following a disturbance is midway between immediate disturbance recovery and climax characteristics that develop in the absence of disturbance. For these types of woodlands, mid-seral stage usually occurs from about 30 to 130 years after a major disturbance **(31)**. In addition to unrecorded natural disturbances, a human-caused fire swept through the Dewey site approximately 50 years ago. Agriculture and other human developments have affected the Skagway and Dyea areas since the gold rush 100 years ago. Considering tree development, disturbances, and lichen growth rate, a reasonable estimate for the age of lichens in this study is about 1-50 years. Adding information about mining ore transport (see previous section), heavy metals found in the Klondike-Skagway lichens probably accumulated sometime from 12-50 years ago to the present. However, this does not rule out the potential for particles containing heavy metals to still be moving in the ecosystem today or the possibility of recent inputs of heavy metals from non-ore sources.

HUMAN AND ENVIRONMENTAL HEALTH

There are no human health or national environmental protection standards relating to chemical concentrations in lichen tissues. The U.S. Environmental Protection Agency has set human health and environmental protection standards for some air pollutants as part of the National Ambient Air Quality Standards (NAAQS) program. These standards apply to the levels of these compounds in the air, or ambient air standards. There are NAAQS for carbon monoxide, nitrogen oxide, sulfur dioxide, ozone, lead and two levels of particulate matter (PM10 and PM2.5 ug). Two levels of standards have been developed: primary standards for human health protection, and secondary standards for human welfare and environmental protection. A variety of air pollutants with potential human health and/or environmental concerns, such as volatile organic compounds and flourides, are not part of the NAAQS program. **(14, 15)**

The effects of air pollution upon human health are primarily experienced by the young, old, or those with respiratory problems. Air pollution can affect the lungs of growing children, and exacerbate medical conditions in the elderly. People with asthma, heart or lung diseases are more susceptible to damage from air pollution. However, short-term and long-term effects can be felt throughout the population. Short-term effects include eye irritation, upper respiratory tract irritation, headaches, nausea, allergic reactions, and respiratory system infections (bronchitis, pneumonia). Long-term effects include chronic respiratory diseases, lung cancer, heart disease, and brain, nervous system, liver, or kidney damage. **(3, 17, 45)**

Environmental impacts include changes to the environment that affect human welfare, such as degradation of viewshed visibility or damage to structures. They also include changes to the ecological structure of the environment, such as replacement of pollution-sensitive species with pollution-tolerant species. Forest health and vigor can be degraded by air pollution. Plants and animals can be damaged directly by air pollution, but may also be affected by indirect impacts. Air pollution may cause changes to soils and aquatic chemistry. Nitrogen may act as an artifical fertilizer in some environments. Air pollutants include metals and other compounds that have the potential for harmful bioaccumulation effects. **(4, 30, 56)**

AIR QUALITY MONITORING OPTIONS FOR KLONDIKE-SKAGWAY

This pilot study has shown that lichens can be used to assess air quality and lichen health in the Klondike-Skagway area. However, a number of air quality questions remain.

Are the high levels of some heavy metals seen in this study soley due to past exposures, or are they currently in the air we breathe?

To answer this question immediately, direct measurements of ambient air quality would unambiguously determine the current levels in the air. This method requires sophisticated equipment and analyses. Also, ambient air quality monitoring typically does not include measurements of a broad suite of separate chemical elements, but concentrates on the National Ambient Air Quality Standards (NAAQS) set by the US Environmental Protection Agency. Lead is the only heavy metal specifically included in the NAAQS. Ambient air quality sampling in the Klondike-Skagway area could augment the NAAQS parameters with instruments or analyses to test for other heavy metals.

To answer this question quickly (within a few years) very young lichens could be examined, those lichens found growing on the tips of young branches, which will only have accumulated elements during the short time period that is the age of the branch. Problems with this approach include the difficulty of collecting these lichens, which will be located on the higher branches of trees, and some level of uncertainty as to the exact age of the lichens. Alternatively, lichen transplant studies examine changes in concentrations of elements after lichens are moved from a pristine area to the study area. The exact time period of exposure in the study area will be known, but other problems with this approach include the difficulty of keeping transplanted lichens alive (lichens are sensitive to changes in microclimate, which change drastically when they are transplanted).

To answer this question over a long period of time (several decades) concentrations of metals in lichen tissues from the Klondike-Skagway area could be determined every 5-10 years. If concentrations do not increase, additional inputs can be ruled out.

Which sources are most responsible for air pollution?

Most sources of air pollution have characteristic signatures, or certain levels and combinations of elements that usually result from that particular source. Levels of chemicals in lichens and/or ambient air measurements could be compared to these signatures to see which sources are more likely to be the major contributors to air quality degradation in Klondike-Skagway. Also, real-time air quality measurements from an ambient air quality monitoring program could be used to link poor air quality events with human activities occurring at the same time. Finally, a survey of local air pollution sources could describe the pollutants they produce and estimate the volume of pollutant output in the local area. Specific information on outputs should be available from permitted point sources, such as the Skagway incinerator.

Are current air pollutants at levels that have human health implications?

Human health standards have only been set for ambient air quality measurements. Ambient air quality monitoring is required to answer this question.

Are current air pollutants at levels that have environmental implications?

Visibility in the Skagway area can be noticably reduced by smog. Clear viewsheds can be an important part of human welfare and economy, especially as it relates to quality of life and to the Klondike-Skagway reputation as a tourist destination.

Forest health changes are complicated to describe and must be monitored over long time periods. Monitoring programs usually include descriptions of species compositions (especially plants and lichens, but could also include animals such as aquatic invertebrates), soil and water characteristics. These parameters are monitored over long periods of time to detect changes in the forest character. The US

Forest Service has developed Forest Health Monitoring methodologies which can be applied to the Klondike-Skagway area to help address this question. The Forest Health Monitoring program is a cooperative effort that includes 6 federal land management agencies, such as the Bureau of Land Management, and over 33 state agriculture or forest management agencies **(50)**.

What are the options for short-term and long-term air quality monitoring?

Short-term air quality information, such as day to day conditions, can be gathered through an ambient air quality monitoring program. Ambient air quality instruments measure sulfur dioxide, nitrogen oxide, ozone, lead, and particulate matters. Visibility monitoring can be accomplished with compartive photography, optical measurements, and/or particulate or aerosol monitoring. These methods produce short-term data that can identify specific episodes of degraded visibility, and can also be used for long-term monitoring. Monitoring of specific sources, such as cruise ship stack emmissions by trained observers, can provide immediate information on those sources.

Long term monitoring can include comparisons of data from short-term monitoring over long periods of time. Conversely, monitoring can be specifically designed to detect broad trends over time, to give a more comprehensive picture of the environmental effects of air pollution. Lichen biomonitoring methods (tissue analysis and species compositions) have the advantage of combining information about the input of air pollution chemicals and an indication of ecological change. Since lichen tissue analysis is destructive (the lichens are removed and destroyed in the process of obtaining the information), annual sampling is not recommended. In a small geographic area such as the Klondike-Skagway area used for this pilot study, annual sampling could affect the distribution and abundance of the lichens being collected. Tissue analysis every 5 or 10 years might help Klondike-Skagway track overall trends in air pollution input, especially with the heavy metals. Species composition studies are useful for tracking long-term ecological trends. Information on lichen species composition every 5-10 years would help describe the accumulated effects of air pollution on the forest ecosystem over a time span of decades.

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Appendix A. Klondike-Skagway Lichen Element Concentration Data and Laboratory Checks.

SAMPLE ID	YEAR	SITE	LICHEN	ALUMINUM	BORON	CADMIUM	CALCIUM	CHROMIUM	COPPER
KL 9801	1998	Dewey	H. enteromorpha	1119.0	3.16	1.14	5753.0	1.52	53.06
KL 9802	1998	Dewey	H. enteromorpha	1074.0	3.22	1.00	5753.0	1.48	53.48
KL 9803	1998	Dewey	H. enteromorpha	1323.0	3.70	1.16	5074.0	1.72	61.64
KL 9804	1998	Dewey	H. inactiva	1352.0	2.80	0.76	1637.0	2.28	73.08
KL 9805	1998	Dewey	H. inactiva	1351.0	2.76	0.82	1918.0	2.40	71.88
KL 9806	1998	Dewey	H. inactiva	1209.0	2.76	0.66	1254.0	2.00	79.48
KL 9824	1998	Dewey	P. glauca	834.6	2.20	0.52	1152.0	3.04	15.34
KL 9825	1998	Dewey	P. glauca	864.7	2.08	0.52	1129.0	3.48	15.44
KL 9807	1998	Chilkoot	H. enteromorpha	690.3	2.72	0.64	9572.0	0.82	38.30
KL 9808	1998	Chilkoot	H. enteromorpha	713.3	3.26	0.50	7513.0	0.92	28.76
KL 9809	1998	Chilkoot	H. inactiva	694.3	3.18	0.66	7805.0	0.88	36.96
KL 9810	1998	Chilkoot	H. inactiva	826.4	2.36	0.42	3005.0	0.94	32.46
KL 9811	1998	Chilkoot	H. inactiva	836.2	2.36	0.48	3255.0	0.98	32.58
KL 9812	1998	Chilkoot	H. inactiva	871.8	2.88	0.52	3158.0	1.06	36.18
KL 9818	1998	Sturgills	H. enteromorpha	582.2	3.32	0.48	7418.0	0.72	15.48
KL 9819	1998	Sturgills	H. enteromorpha	516.4	2.90	0.48	6697.0	0.72	14.64
KL 9820	1998	Sturgills	H. inactiva	644.4	2.30	0.36	2498.0	0.74	13.72
KL 9821	1998	Sturgills	H. inactiva	620.1	2.18	0.36	2718.0	0.64	14.04
KL 9822	1998	Sturgills	P. glauca	318.9	1.70	0.30	1835.0	0.74	7.58
KL 9823	1998	Sturgills	P. glauca	320.5	1.62	0.34	1640.0	0.76	9.58
KL 9813	1998	Dyea	H. inactiva	1354.0	4.22	0.46	4909.0	1.66	38.90
KL 9814	1998	Dyea	H. inactiva	1511.0	4.98	0.44	4866.0	1.84	41.82
KL 9815	1998	Dyea	P. glauca	1097.0	3.62	0.28	3939.0	1.84	32.04
KL 9816	1998	Dyea	P. glauca	837.3	2.80	0.18	3863.0	1.22	27.12
KL 9817	1998	Dyea	P. glauca	784.8	2.90	0.22	4105.0	1.14	20.62
KL9920	1999	Dewey	H. enteromorpha	983.4	2.40	0.98	5036.0	4.90	57.82
KL9921	1999	Dewey	H. enteromorpha	1061.0	2.82	1.00	3262.0	3.50	46.90
KL9923	1999	Dewey	H. enteromorpha	1178.0	2.66	0.78	2266.0	3.32	59.50
KL9922	1999	Dewey	P. glauca	619.0	1.56	0.64	927.0	2.16	31.16
KL9924	1999	Dewey	P. glauca	551.9	1.46	0.56	973.6	2.38	29.42
KL9925	1999	Dewey	P. glauca	711.3	1.70	0.68	833.3	2.32	39.30
KL9904	1999	Chilkoot	H. enteromorpha	700.6	3.14	0.38	9128.0	2.14	4.80
KL9905	1999	Chilkoot	H. enteromorpha	880.5	3.10	0.40	7234.0	2.76	5.00
KL9906	1999	Chilkoot	H. enteromorpha	1031.0	3.26	0.42	8172.0	2.86	5.08
KL9901	1999	Chilkoot	P. glauca	483.7	1.66	0.30	2680.0	3.64	2.86
KL9902	1999	Chilkoot	P. glauca	678.8	1.56	0.20	1963.0	3.22	3.78
KL9903	1999	Chilkoot	P. glauca	577.0	1.66	0.24	2568.0	3.34	2.84

all values are ug/g, except nitrogen (percent total nitrogen) and sulfur (percent total sulfur)

Appendix A. Klondike-Skagway Lichen Element Concentration Data and Laboratory Checks

SAMPLE ID	YEAR	SITE	LICHEN	IRON	LEAD	MAGNESIUM	MANGANESE	NICKEL	NITROGEN
KL 9801	1998	Dewey	H. enteromorpha	1800.0	181.00	775.0	97.22	11.16	57.0
KL 9802	1998	Dewey	H. enteromorpha	1704.0	173.80	836.7	93.70	10.66	62.5
KL 9803	1998	Dewey	H. enteromorpha	2090.0	193.20	765.7	85.22	11.00	69.9
KL 9804	1998	Dewey	H. inactiva	2782.0	324.40	686.6	67.40	13.96	59.5
KL 9805	1998	Dewey	H. inactiva	2721.0	312.00	733.0	82.32	13.64	54.5
KL 9806	1998	Dewey	H. inactiva	2463.0	305.40	638.3	58.50	12.38	59.4
KL 9824	1998	Dewey	P. glauca	1505.0	156.80	599.8	71.78	6.88	55.9
KL 9825	1998	Dewey	P. glauca	1563.0	153.20	629.8	85.36	7.34	57.2
KL 9807	1998	Chilkoot	H. enteromorpha	697.3	11.02	1120.0	308.00	3.48	53.7
KL 9808	1998	Chilkoot	H. enteromorpha	768.6	11.34	1100.0	310.20	2.86	65.7
KL 9809	1998	Chilkoot	H. inactiva	721.7	9.72	1096.0	309.40	2.94	52.2
KL 9810	1998	Chilkoot	H. inactiva	936.4	14.70	859.7	98.30	2.86	44.5
KL 9811	1998	Chilkoot	H. inactiva	959.6	14.02	881.6	118.20	2.60	40.2
KL 9812	1998	Chilkoot	H. inactiva	987.3	13.98	994.1	130.00	2.92	43.0
KL 9818	1998	Sturgills	H. enteromorpha	689.3	42.66	1284.0	178.70	2.74	63.9
KL 9819	1998	Sturgills	H. enteromorpha	696.3	44.78	1288.0	309.70	2.72	63.1
KL 9820	1998	Sturgills	H. inactiva	618.7	28.92	1060.0	136.60	2.36	48.4
KL 9821	1998	Sturgills	H. inactiva	603.2	31.08	1058.0	131.50	2.62	50.2
KL 9822	1998	Sturgills	P. glauca	433.4	23.74	869.3	155.40	1.82	44.8
KL 9823	1998	Sturgills	P. glauca	435.1	22.46	860.0	173.70	2.06	42.9
KL 9813	1998	Dyea	H. inactiva	1844.0	12.74	1372.0	140.30	5.20	45.3
KL 9814	1998	Dyea	H. inactiva	2130.0	13.98	1513.0	151.00	5.38	48.3
KL 9815	1998	Dyea	P. glauca	1547.0	9.84	1105.0	225.50	6.98	51.3
KL 9816	1998	Dyea	P. glauca	1133.0	6.40	920.2	209.30	5.36	49.8
KL 9817	1998	Dyea	P. glauca	1023.0	6.84	924.1	211.60	3.84	50.6
KL9920	1999	Dewey	H. enteromorpha	1606.0	149.60	729.7	62.20	13.40	70.0
KL9921	1999	Dewey	H. enteromorpha	1610.0	104.80	697.0	69.34	10.44	69.6
KL9923	1999	Dewey	H. enteromorpha	1912.0	200.80	722.4	66.82	11.36	63.5
KL9922	1999	Dewey	P. glauca	1015.0	72.78	542.3	43.66	7.02	52.5
KL9924	1999	Dewey	P. glauca	810.5	40.96	500.3	42.42	5.42	41.0
KL9925	1999	Dewey	P. glauca	1240.0	105.70	530.1	34.60	8.04	46.1
KL9904	1999	Chilkoot	H. enteromorpha	785.9	9.26	1147.0	340.20	1.90	70.0
KL9905	1999	Chilkoot	H. enteromorpha	932.0	10.74	1220.0	573.40	2.22	65.6
KL9906	1999	Chilkoot	H. enteromorpha	1158.0	10.16	1243.0	552.80	2.24	59.9
KL9901	1999	Chilkoot	P. glauca	480.9	5.24	767.6	345.70	2.54	52.8
KL9902	1999	Chilkoot	P. glauca	725.1	6.16	775.9	327.00	2.24	50.0
KL9903	1999	Chilkoot	P. glauca	628.2	6.38	717.1	326.60	2.26	57.7

all values are ug/g, except nitrogen (percent total nitrogen) and sulfur (percent total sulfur)

Appendix A. Klondike-Skagway Lichen Element Concentration Data and Laboratory Checks

SAMPLE ID	YEAR	SITE	LICHEN	PHOSPHORUS	POTASSIUM	SODIUM	SULFUR	ZINC	ASH
KL 9801	1998	Dewey	H. enteromorpha	1118.0	2573	141.9	12.7	163.60	5.96
KL 9802	1998	Dewey	H. enteromorpha	1219.0	2842	152.1	13.2	154.00	5.32
KL 9803	1998	Dewey	H. enteromorpha	1228.0	2792	195.0	14.3	167.60	6.10
KL 9804	1998	Dewey	H. inactiva	1091.0	2980	185.6	14.9	156.50	4.60
KL 9805	1998	Dewey	H. inactiva	998.7	2620	151.4	12.4	163.90	4.88
KL 9806	1998	Dewey	H. inactiva	1192.0	3083	169.7	13.9	151.50	4.52
KL 9824	1998	Dewey	P. glauca	1057.0	2882	194.1	10.7	99.12	3.60
KL 9825	1998	Dewey	P. glauca	1129.0	3015	199.8	10.2	106.00	3.66
KL 9807	1998	Chilkoot	H. enteromorpha	1154.0	2406	125.0	8.2	93.32	3.78
KL 9808	1998	Chilkoot	H. enteromorpha	1286.0	2580	151.3	9.0	81.68	4.70
KL 9809	1998	Chilkoot	H. inactiva	1351.0	2668	149.6	8.6	86.50	4.48
KL 9810	1998	Chilkoot	H. inactiva	832.3	1998	161.8	7.2	62.44	2.74
KL 9811	1998	Chilkoot	H. inactiva	828.9	2024	144.9	6.2	65.54	2.94
KL 9812	1998	Chilkoot	H. inactiva	891.2	2013	188.1	8.5	67.30	3.18
KL 9818	1998	Sturgills	H. enteromorpha	1314.0	2646	375.7	10.2	92.10	3.90
KL 9819	1998	Sturgills	H. enteromorpha	1304.0	2621	327.5	10.5	109.30	3.86
KL 9820	1998	Sturgills	H. inactiva	1114.0	2543	326.0	9.2	69.46	2.36
KL 9821	1998	Sturgills	H. inactiva	1077.0	2529	328.4	9.2	68.74	2.48
KL 9822	1998	Sturgills	P. glauca	1137.0	2439	222.6	7.6	68.96	1.94
KL 9823	1998	Sturgills	P. glauca	1091.0	2395	243.8	6.9	67.82	1.70
KL 9813	1998	Dyea	H. inactiva	1262.0	3010	233.3	10.0	73.98	5.72
KL 9814	1998	Dyea	H. inactiva	1353.0	3281	285.7	9.5	74.06	6.44
KL 9815	1998	Dyea	P. glauca	1554.0	3295	164.9	8.7	74.60	5.86
KL 9816	1998	Dyea	P. glauca	1472.0	3179	144.7	8.9	74.04	5.38
KL 9817	1998	Dyea	P. glauca	1500.0	3182	138.9	9.4	73.56	4.96
KL9920	1999	Dewey	H. enteromorpha	1256.0	3286	369.5	11.6	129.50	4.86
KL9921	1999	Dewey	H. enteromorpha	1296.0	3201	313.9	11.8	140.80	4.66
KL9923	1999	Dewey	H. enteromorpha	1273.0	3137	373.1	11.7	126.50	4.72
KL9922	1999	Dewey	P. glauca	1192.0	3282	248.9	8.4	93.92	2.66
KL9924	1999	Dewey	P. glauca	970.6	3000	230.1	7.2	94.86	2.30
KL9925	1999	Dewey	P. glauca	994.2	3202	296.7	8.6	95.14	2.90
KL9904	1999	Chilkoot	H. enteromorpha	1650.0	3254	190.1	9.8	72.50	5.10
KL9905	1999	Chilkoot	H. enteromorpha	1570.0	3150	203.6	10.1	77.38	5.32
KL9906	1999	Chilkoot	H. enteromorpha	1626.0	3146	187.9	10.3	74.62	6.16
KL9901	1999	Chilkoot	P. glauca	1241.0	2641	92.3	7.4	55.10	2.68
KL9902	1999	Chilkoot	P. glauca	1321.0	2932	130.6	7.1	64.36	2.94
KL9903	1999	Chilkoot	P. glauca	1114.0	2512	117.0	7.8	54.48	2.78

all values are ug/g, except nitrogen (percent total nitrogen) and sulfur (percent total sulfur)

Appendix A. Klondike-Skagway Lichen Element Concentration Data and Laboratory Checks

Laboratory checks		ALUMINUM	BORON	CADMIUM	CALCIUM	CHROMIUM	COPPER	IRON	LEAD	MAGNESIUM
Alec Ck	1998	87.28	1.34	0.12	3313.00	0.42	1.32	73.20	308.70	5.32
Alec Ck %	1998	99.10	191.60	0.00	107.40	106.10	115.30	101.10	104.60	97.37
NBS-P Ck2	1998	471.70	17.96	0.28	4565.00	2.00	4.76	188.60	1201.00	12.48
NBS-P Ck%	1998	102.30	104.50	109.40	106.10	80.26	159.20	109.60	104.50	112.00
BL	1998	3.58	0.46	0.12	7.42	0.44	0.52	6.16	3.80	1.68
BL Avg	1998				4.82	0.44		3.72		
BL rd%	1998				107.90	36.36		131.20		
BL2	1998	3.58	0.46	0.12	2.22	0.28	0.52	1.28	3.80	1.68
KL 9801 Avg	1998	1153.00	3.24	1.16	5748.00	1.55	53.38	1852.00	781.90	183.40
KL 9801 rd%	1998	5.80	4.94	3.45	0.17	3.87	1.20	5.56	1.78	2.59
KL 9801 Dup	1998	1186.00	3.32	1.18	5743.00	1.58	53.70	1903.00	788.90	185.70
KL 9810 Avg	1998	787.40	2.36	0.43	2905.00	0.91	31.12	891.60	835.40	14.29
KL 9810 rd%	1998	9.90	0.00	4.65	6.86	6.59	8.61	10.03	5.82	5.74
KL 9810 Dup	1998	748.40	2.36	0.44	2806.00	0.88	29.78	846.90	811.10	13.88
KL 9820 Avg	1998	662.30	2.34	0.36	2511.00	0.75	13.72	639.40	1077.00	29.80
KL 9820 rd%	1998	5.41	3.42	0.00	1.04	2.67	0.00	6.50	3.26	5.91
KL 9820 Dup	1998	680.20	2.38	0.36	2524.00	0.76	13.72	660.20	1095.00	30.68
Alec Ck	1999	86.96	0.62	0.12	3091.00	1.34	1.24	80.54	296.10	4.92
Blank	1999	3.58	0.46	0.12	3.42	1.36	0.52	9.12	3.80	1.68
CRM482 Ck2	1999	772.10	2.76	0.60	2444.00	4.34	7.10	809.70	531.40	38.68
SRM1547 Ck3	1999	228.20	28.08	0.14	16240.00	1.50	4.48	208.30	4312.00	2.72
KL9901 Dup	1999	492.00	1.82	0.32	2713.00	2.38	2.90	482.00	774.30	5.54

all values are ug/g, except nitrogen (percent total nitrogen) and sulfur (percent total sulfur)

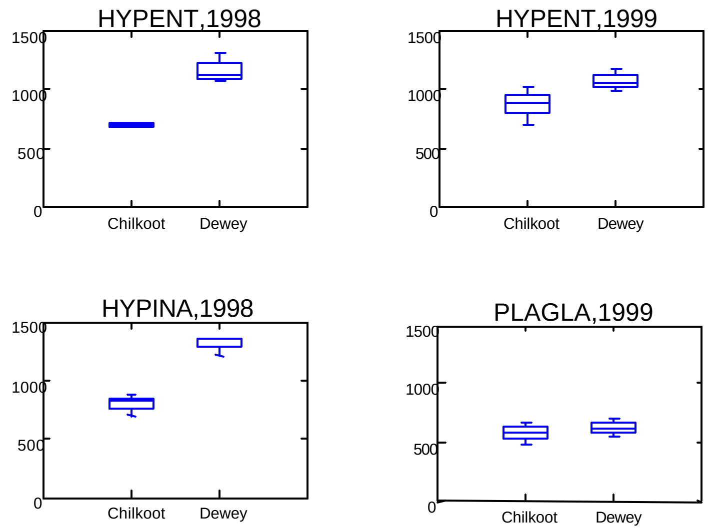
Appendix A. Klondike-Skagway Lichen Element Concentration Data and Laboratory Checks

Laboratory checks		MANGANESE	NICKEL	NITROGEN	PHOSPHORUS	POTASSIUM	SODIUM	SULFUR	ZINC	ASH
Alec Ck	1998	99.36	0.58	39.20	451.90	1604.00	54.42	4.10	1.12	22.58
Alec Ck %	1998	103.50	172.00		103.50	104.10	103.00			107.30
NBS-P Ck2	1998	711.70	3.30	125.40	1237.00	3704.00	25.38	19.80	2.34	67.22
NBS-P Ck%	1998	102.40	156.50		102.00	102.40	142.00			91.27
BL	1998	0.24	0.50		0.70	14.14	3.96			7.12
BL Avg	1998	0.24	0.50				3.96			3.75
BL rd%	1998	75.00	12.00				9.09			179.70
BL2	1998	0.06	0.44		0.70	14.14	3.60			0.38
KL 9801 Avg	1998	97.86	11.30		1125.00	2602.00	143.60			164.70
KL 9801 rd%	1998	1.31	2.48		1.32	2.25	2.38			1.41
KL 9801 Dup	1998	98.50	11.44	61.20	1132.00	2632.00	145.40	13.40	6.12	165.90
KL 9810 Avg	1998	96.09	2.84		824.00	1985.00	154.80			60.50
KL 9810 rd%	1998	4.60	1.41		2.02	1.25	9.06			6.41
KL 9810 Dup	1998	93.88	2.82	40.70	815.70	1973.00	147.80	7.60	2.74	58.56
KL 9820 Avg	1998	139.10	2.36		1113.00	2537.00	330.70			69.78
KL 9820 rd%	1998	3.55	0.00		0.13	0.47	2.84			0.92
KL 9820 Dup	1998	141.50	2.36	42.90	1112.00	2531.00	335.40	9.20	2.56	70.10
Alec Ck	1999	95.88	1.06	35.20	438.50	1577.00	53.58	3.80	1.28	21.30
Blank	1999	0.20	0.86		0.70	14.14	3.60			0.44
CRM482 Ck2	1999	31.18	3.48		674.70	3624.00	52.00			102.80
SRM1547 Ck3	1999	96.28	1.22		1403.00	23980.00	26.58			18.40
KL9901 Dup	1999	350.00	1.86	52.80	1261.00	2665.00	93.00	7.80	2.64	55.26

all values are ug/g, except nitrogen (percent total nitrogen) and sulfur (percent total sulfur)

Appendix B. Comparison of Dewey and Chilkoot sites.

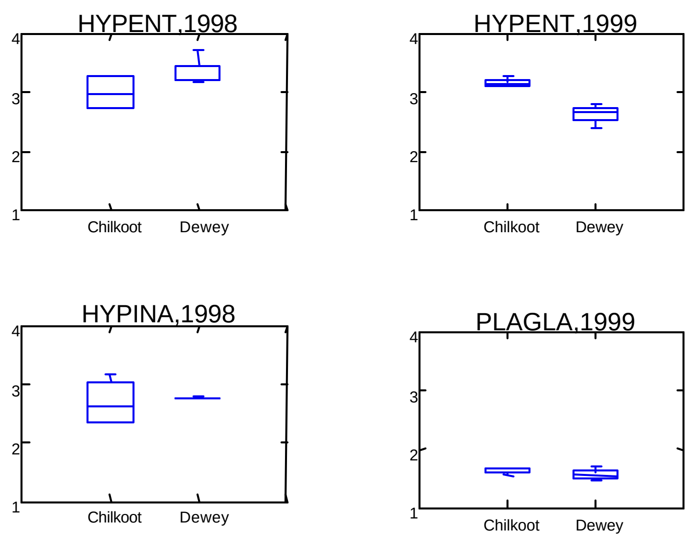
ALUMINUM (ug/g)



Aluminum levels are higher at the Dewey site in 1998, for both *H. enteromorpha* and *H. inactiva*. It is slightly higher at the Dewey plot in 1999 with *H. enteromorpha*, and there is no difference between Dewey and Chilkoot in 1999 with *P. glauca*.

High aluminum concentrations are usually an indication of wind-blown mineral dust. Aluminum levels can also be elevated by acid rain.

BORON (ug/g)



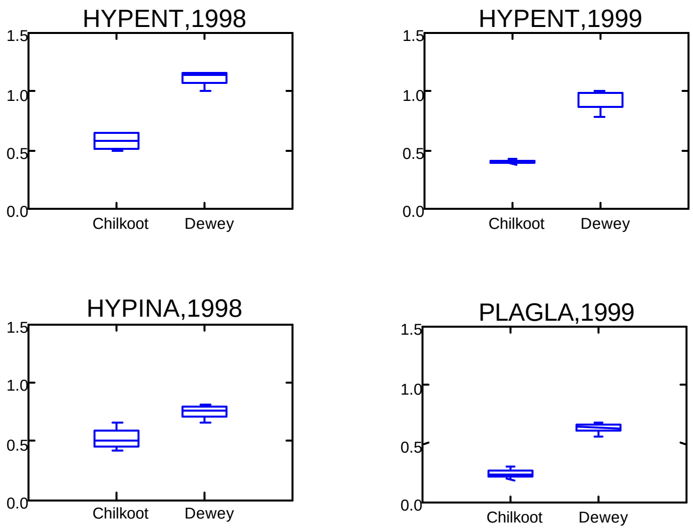
Boron concentrations in *H. enteromorpha* were slightly higher at Dewey in 1998, but were lower in 1999. No appreciable difference is seen in boron levels with *H. inactiva* in 1998 or *P. glauca* in 1999.

Boron is a minor nutrient. Boron levels can be elevated near marine waters.

How to read a box plot: the box area shows where the middle half of values occur, the line within the box gives the median value (median = middle value when all values are put in order from smallest to largest). The lines coming out from the boxes show the spread for 75% of the values. If there are no lines coming out from the box, then the box also includes 75% of the values. Stars beyond the box and lines indicate values that lie outside the 75% range. If two box areas overlap, there is probably no real difference between the data sets that the boxes represent.

HYPENT = *Hypogymnia enteromorpha* HYPINA = *Hypogymnia inactiva* PLAGLA = *Platismatia glauca*

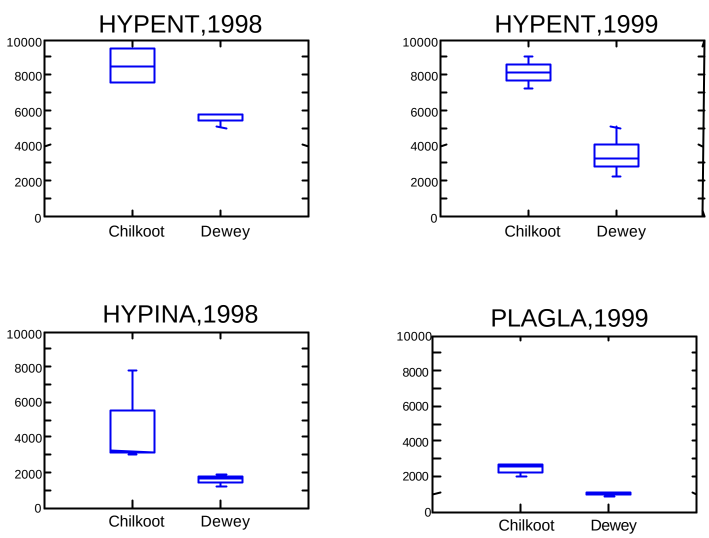
CADMIUM (ug/g)



Cadmium levels are consistently higher at the Dewey site than the Chilkoot site. This difference is seen for each lichen species, and during 1998 and 1999.

Cadmium is a strong indicator of air pollution, but cadmium levels may also be elevated near marine waters.

CALCIUM (ug/g)



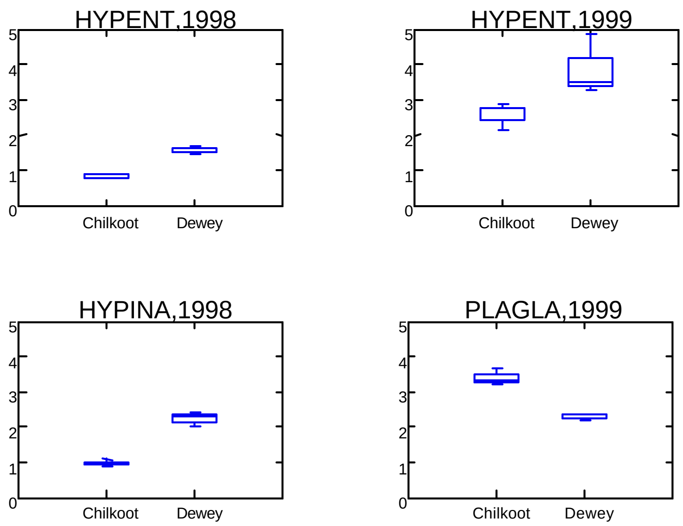
Calcium is consistently lower at the Dewey site compared to the Chilkoot site. The difference is seen with all 3 lichen species, and in 1998 and 1999.

Calcium is a major nutrient, high concentrations are usually associated with healthy lichens. Calcium is found in marine water aerosols, so sites near marine waters are expected to have higher concentrations of calcium. Calcium levels can be depressed by acid rain.

How to read a box plot: the box area shows where the middle half of values occur, the line within the box gives the median value (median = middle value when all values are put in order from smallest to largest). The lines coming out from the boxes show the spread for 75% of the values. If there are no lines coming out from the box, then the box also includes 75% of the values. Stars beyond the box and lines indicate values that lie outside the 75% range. If two box areas overlap, there is probably no real difference between the data sets that the boxes represent.

HYPENT = *Hypogymnia enteromorpha* HYPINA = *Hypogymnia inactiva* PLAGLA = *Platismatia glauca*

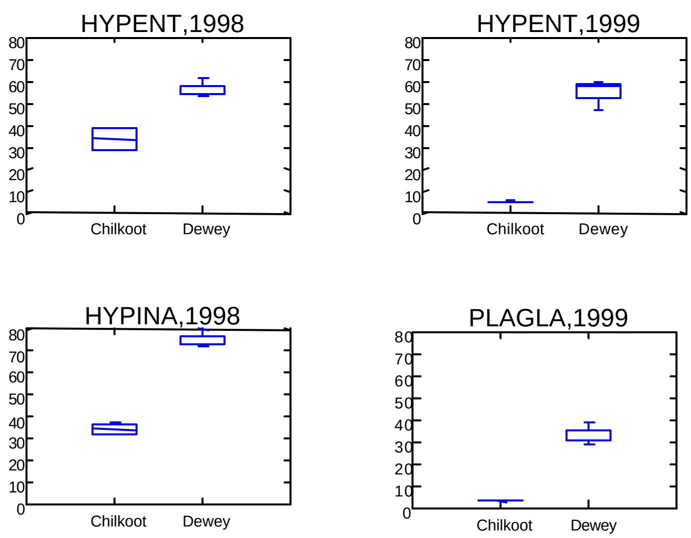
CHROMIUM (ug/g)



Chromium levels are usually higher at the Dewey site than at the Chilkoot site. Only *P. glauca* in 1999 shows a lower concentration at Dewey.

Chromium is a strong indicator of air pollution.

COPPER (ug/g)



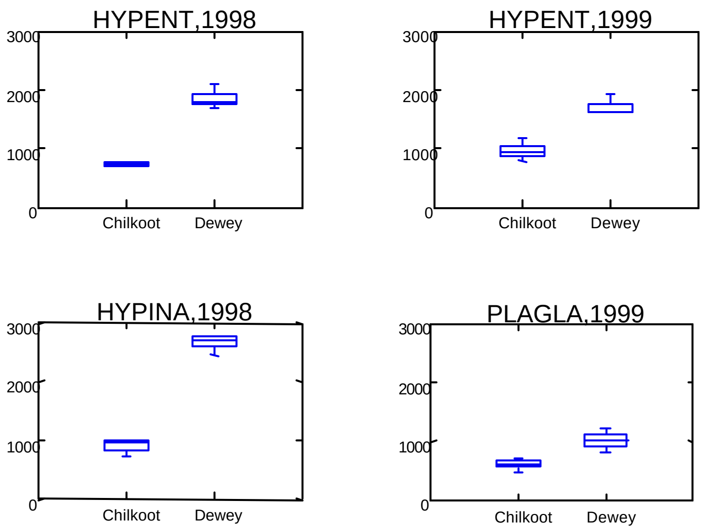
Copper levels are consistently higher at the Dewey site than the Chilkoot site. This difference is seen for each lichen species, and during 1998 and 1999.

Copper is a minor nutrient, but lichens are particularly sensitive to copper as a toxic element. Copper is a strong indicator of air pollution.

How to read a box plot: the box area shows where the middle half of values occur, the line within the box gives the median value (median = middle value when all values are put in order from smallest to largest). The lines coming out from the boxes show the spread for 75% of the values. If there are no lines coming out from the box, then the box also includes 75% of the values. Stars beyond the box and lines indicate values that lie outside the 75% range. If two box areas overlap, there is probably no real difference between the data sets that the boxes represent.

HYPENT = *Hypogymnia enteromorpha* HYPINA = *Hypogymnia inactiva* PLAGLA = *Platismatia glauca*

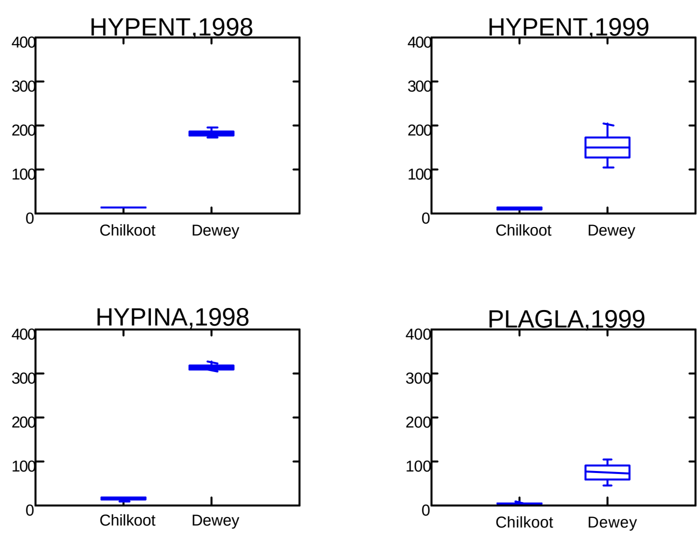
IRON (ug/g)



Iron is consistently higher at the Dewey site compared to the Chilkoot site. The difference is seen with all 3 lichen species, and in 1998 and 1999.

High iron concentrations can indicate wind-blown mineral dust, but also may indicate air pollution. Iron levels may also be elevated by acid rain. Iron is a minor nutrient.

LEAD(ug/g)



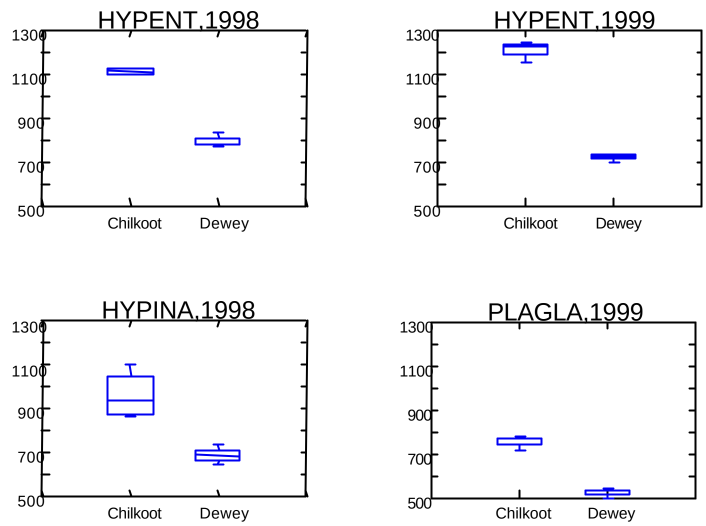
Lead levels are consistently higher at the Dewey site than the Chilkoot site. This difference is seen for each lichen species, and during 1998 and 1999.

Lead is a strong indicator of air pollution.

How to read a box plot: the box area shows where the middle half of values occur, the line within the box gives the median value (median = middle value when all values are put in order from smallest to largest). The lines coming out from the boxes show the spread for 75% of the values. If there are no lines coming out from the box, then the box also includes 75% of the values. Stars beyond the box and lines indicate values that lie outside the 75% range. If two box areas overlap, there is probably no real difference between the data sets that the boxes represent.

HYPENT = *Hypogymnia enteromorpha* HYPINA = *Hypogymnia inactiva* PLAGLA = *Platismatia glauca*

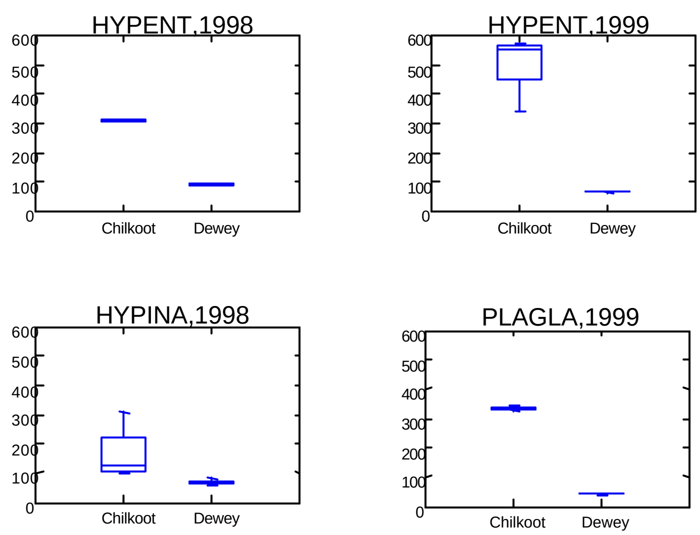
MAGNESIUM (ug/g)



Magnesium is consistently lower at the Dewey site compared to the Chilkoot site. The difference is seen with all 3 lichen species, and in 1998 and 1999.

Magnesium is a major nutrient. Magnesium is found in marine water aerosols, so sites near marine waters are expected to have higher concentrations of magnesium. Magnesium levels can be depressed by acid rain.

MANGANESE (ug/g)



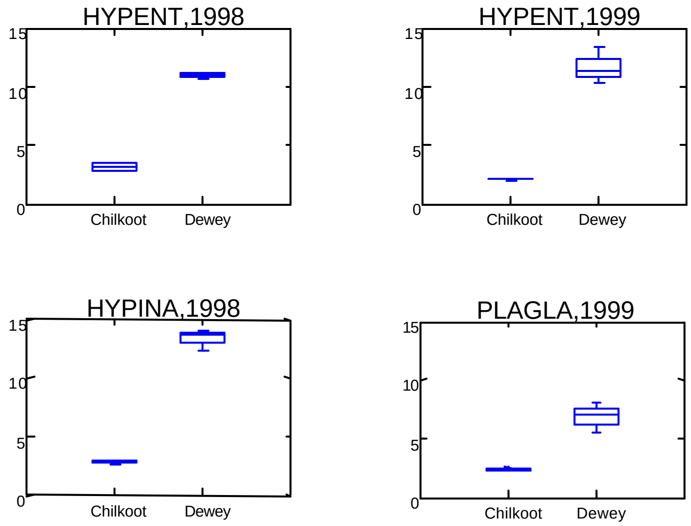
Manganese is consistently lower at the Dewey site compared to the Chilkoot site. The difference is seen with all 3 lichen species, and in 1998 and 1999.

Manganese is a minor nutrient. Manganese may be affected by acid rain.

How to read a box plot: the box area shows where the middle half of values occur, the line within the box gives the median value (median = middle value when all values are put in order from smallest to largest). The lines coming out from the boxes show the spread for 75% of the values. If there are no lines coming out from the box, then the box also includes 75% of the values. Stars beyond the box and lines indicate values that lie outside the 75% range. If two box areas overlap, there is probably no real difference between the data sets that the boxes represent.

HYPENT = *Hypogymnia enteromorpha*   HYPINA = *Hypogymnia inactiva*   PLAGLA = *Platismatia glauca*

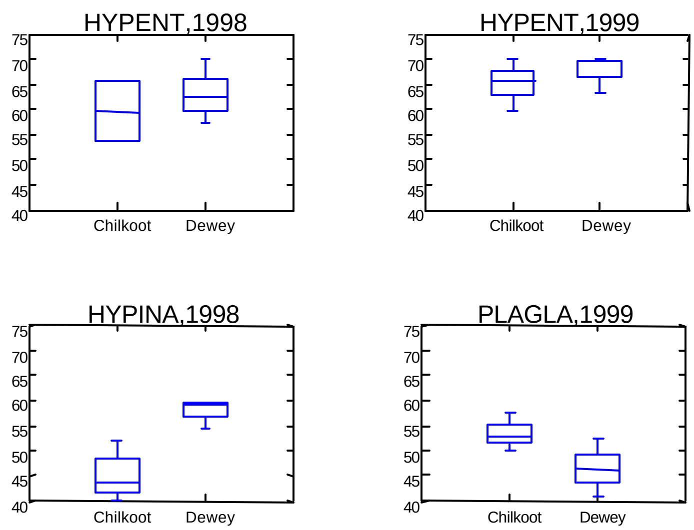
NICKEL (ug/g)



Nickel levels are consistently higher at the Dewey site than the Chilkoot site. This difference is seen for each lichen species, and during 1998 and 1999.

Nickel is an indicator of air pollution.

NITROGEN (%)



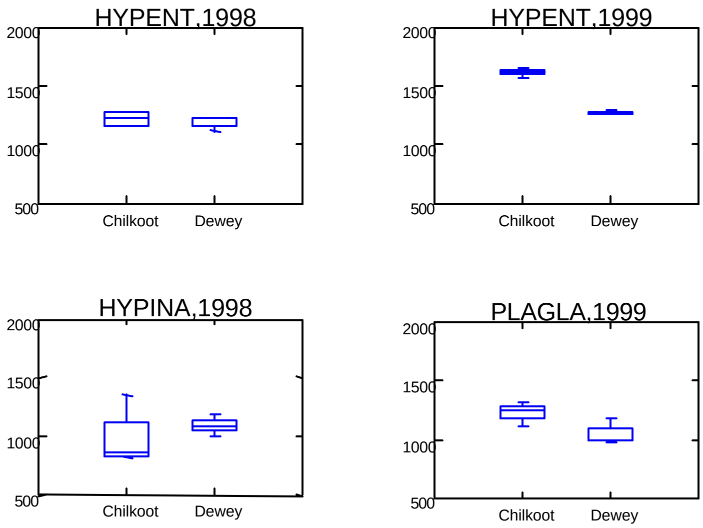
Nitrogen levels in *H. enteromorpha* are about the same between Dewey and Chilkoot sites in 1998 and 1999. The levels are higher for Dewey in 1998 with *H. inactiva*, and lower for Dewey in 1999 with *P. glauca*.

Nitrogen is a major nutrient and a strong indicator of air pollution. It is absorbed quickly and leaches quickly from lichen tissues.

How to read a box plot: the box area shows where the middle half of values occur, the line within the box gives the median value (median = middle value when all values are put in order from smallest to largest). The lines coming out from the boxes show the spread for 75% of the values. If there are no lines coming out from the box, then the box also includes 75% of the values. Stars beyond the box and lines indicate values that lie outside the 75% range. If two box areas overlap, there is probably no real difference between the data sets that the boxes represent.

HYPENT = *Hypogymnia enteromorpha* HYPINA = *Hypogymnia inactiva* PLAGLA = *Platismatia glauca*

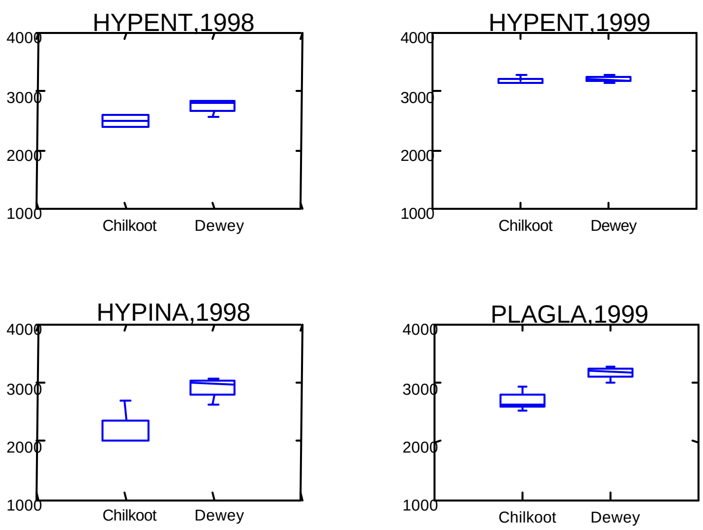
PHOSPHORUS (ug/g)



Phosphorus levels are roughly the same between Dewey and Chilkoot in 1998, with *H. enteromorpha* and *H. inactiva*. Phosphorus levels are lower at Dewey in 1999, with *H. enteromorpha* and *P. glauca*.

Phosphorus is a major nutrient. Phosphorus levels have been linked to air pollution.

POTASSIUM (ug/g)



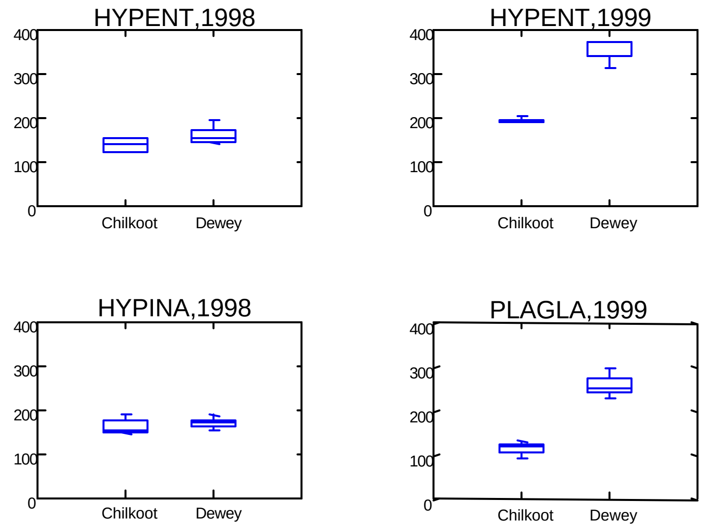
Potassium levels in are higher at the Dewey site for *H. enteromorpha* in 1998, *H. inactiva* in 1998, and *P. glauca* in 1999. There was no difference in potassium levels between Dewey and Chilkoot in 1999 with *H. enteromorpha*.

Potassium is a major nutrient.

How to read a box plot: the box area shows where the middle half of values occur, the line within the box gives the median value (median = middle value when all values are put in order from smallest to largest). The lines coming out from the boxes show the spread for 75% of the values. If there are no lines coming out from the box, then the box also includes 75% of the values. Stars beyond the box and lines indicate values that lie outside the 75% range. If two box areas overlap, there is probably no real difference between the data sets that the boxes represent.

HYPENT = *Hypogymnia enteromorpha* HYPINA = *Hypogymnia inactiva* PLAGLA = *Platismatia glauca*

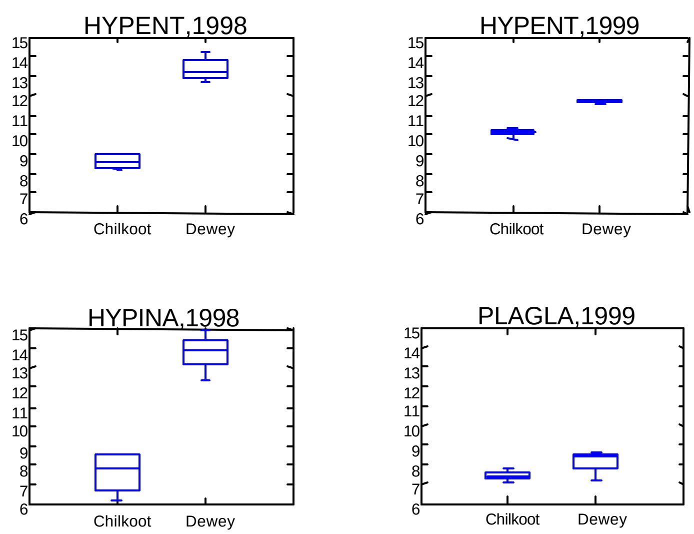
SODIUM (ug/g)



Sodium is the same or slightly higher at Dewey in 1998 with *H. enteromorpha* and *H. inactiva*. In 1999, it is substantially higher at Dewey for both *H. enteromorpha* and *P. glauca*.

Sodium is a major nutrient. Sodium is found in marine water aerosols, so sites near marine waters are expected to have higher concentrations of sodium.

SULFUR (%)



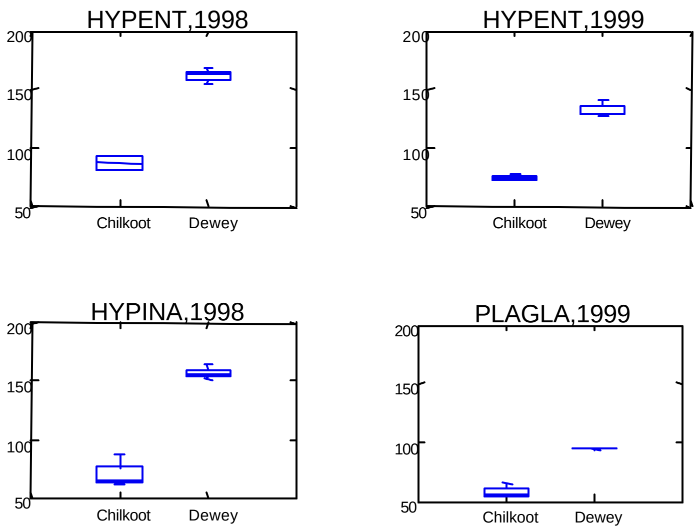
Sufur levels were higher at Dewey in 1998 for both lichen species, and in 1999 for in *H. enteromorpha*. No appreciable difference between sites is seen in sulfur levels of *P. glauca* in 1999.

Sulfur is a major nutrient and a strong indicator of air pollution. It is absorbed quickly and leaches quickly from lichen tissues.

How to read a box plot: the box area shows where the middle half of values occur, the line within the box gives the median value (median = middle value when all values are put in order from smallest to largest). The lines coming out from the boxes show the spread for 75% of the values. If there are no lines coming out from the box, then the box also includes 75% of the values. Stars beyond the box and lines indicate values that lie outside the 75% range. If two box areas overlap, there is probably no real difference between the data sets that the boxes represent.

HYPENT = *Hypogymnia enteromorpha* HYPINA = *Hypogymnia inactiva* PLAGLA = *Platismatia glauca*

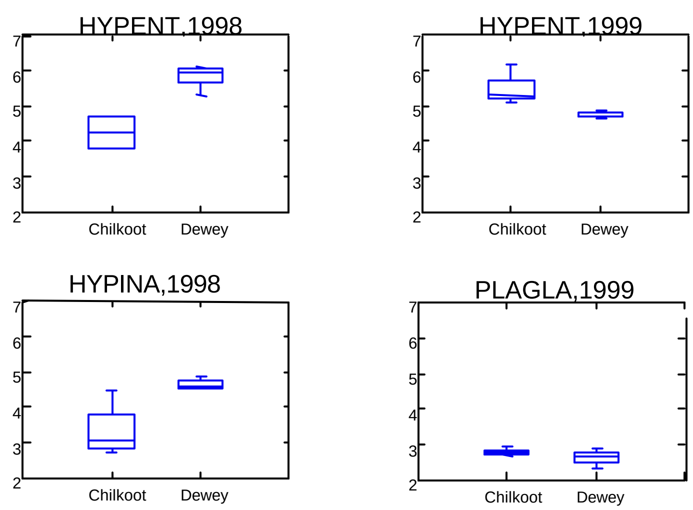
ZINC (ug/g)



Zinc levels are consistently higher at the Dewey site than the Chilkoot site. This difference is seen for each lichen species, during both 1998 and 1999.

Zinc is a minor nutrient, and a strong indicator of air pollution.

ASH (ug/g)



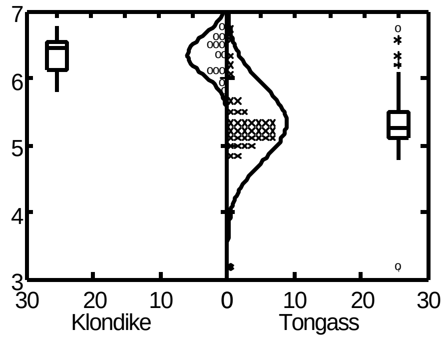
Ash levels are higher at the Dewey site in 1998, and lower or the same at the Dewey site in 1999.

Higher ash levels usually indicate more exposure to wind-blown mineral dust.

How to read a box plot: the box area shows where the middle half of values occur, the line within the box gives the median value (median = middle value when all values are put in order from smallest to largest). The lines coming out from the boxes show the spread for 75% of the values. If there are no lines coming out from the box, then the box also includes 75% of the values. Stars beyond the box and lines indicate values that lie outside the 75% range. If two box areas overlap, there is probably no real difference between the data sets that the boxes represent.

HYPENT = *Hypogymnia enteromorpha* HYPINA = *Hypogymnia inactiva* PLAGLA = *Platismatia glauca*

Appendix C. Statistical tests for difference between Klondike-Skagway and Tongass baseline.



ALUMINUM significantly different? YES

PARAMETRIC TEST *

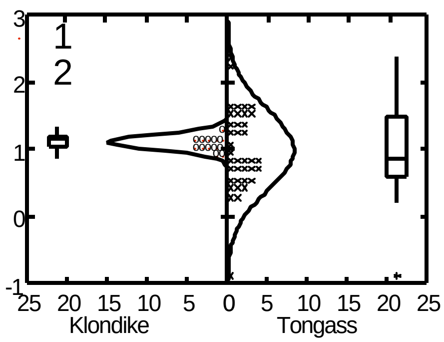
Group	N	Mean	SD
Klondike	13	6.353	0.293
Tongass	38	5.340	0.570

Pooled Variance t =6.109
Difference in Means = 1.013
99.00% CI = 0.680 to 1.346
df = 49 Prob =0.000

NON-PARAMETRIC TEST

Group	Count	Rank Sum
Klondike	13	574.000
Tongass	38	752.000

Mann-Whitney U test
statistic = 483.000
Chi-square approx. = 26.026
with 1 df Prob = 0.000



BORON significantly different? NO

PARAMETRIC TEST *

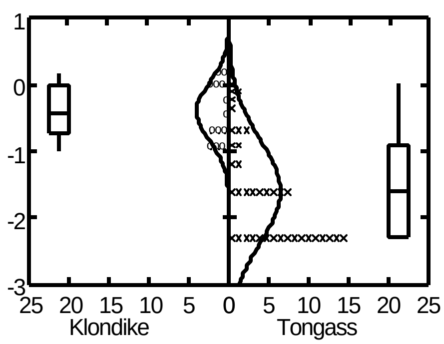
Group	N	Mean	SD
Klondike	13	1.109	0.114
Tongass	38	0.992	0.605

Separate Variance t =1.142
Difference in Means =0.118
99.00% CI = -0.160 to 0.395
df = 43.6 Prob =0.260

NON-PARAMETRIC TEST

Group	Count	Rank Sum
Klondike	13	376.000
Tongass	38	950.000

Mann-Whitney U test
statistic = 285.000
Chi-square approx. = 0.675
with 1 df Prob = 0.411



CADMIUM significantly different? YES

PARAMETRIC TEST *

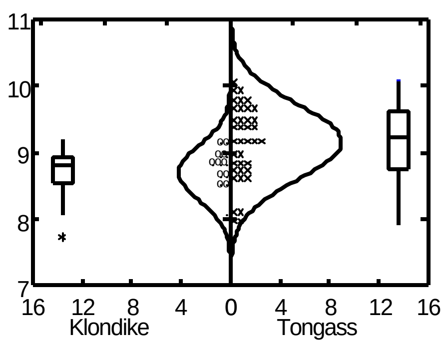
Group	N	Mean	SD
Klondike	13	-0.411	0.427
Tongass	38	-1.598	0.781

Separate Variance t = 6.845
Difference in Means = 1.187
99.00% CI = 0.717 to 1.657
df = 38.7 Prob = 0.000

NON-PARAMETRIC TEST

Group	Count	Rank Sum
Klondike	13	524.500
Tongass	38	801.500

Mann-Whitney U test
statistic = 433.500
Chi-square approx. = 16.984
with 1 df Prob = 0.000



CALCIUM significantly different? UNCLEAR

PARAMETRIC TEST *

Group	N	Mean	SD
Klondike	13	8.693	0.410
Tongass	38	9.157	0.563

Separate Variance t = -3.181
Difference in Means = -0.464
99.00% CI = -0.866 to -0.062
df =28.7 Prob = 0.004

NON-PARAMETRIC TEST

Group	Count	Rank Sum
Klondike	13	212.000
Tongass	38	1114.000

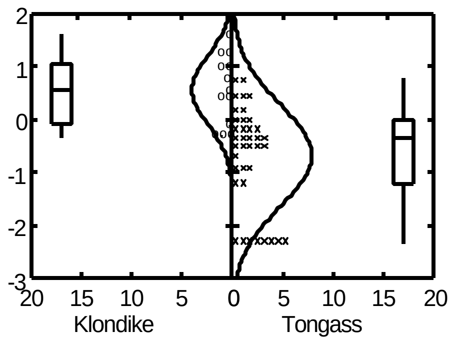
Mann-Whitney U test
statistic = 121.000
Chi-square approxi. = 7.417
with 1 df Prob = 0.006

How to read plots: the data are graphed in three ways - 1) counts of values extend out from the central axis, o = Klondike, x = Tongass; 2) normal approximation distribution curves overlay the values, the peak of the curve is the mean (average), the span of the bottom of the curve along the central axis is the variance (spread of the values), and 3) box plots are placed near the outside edges of the graphs (see Appendix B for box plot information). Graphs are % total for N and S, ug/g for all others, with log transformation if indicated.

Statistical tests: Hypothesis: no difference between means of Klondike and Tongass data. Probability set at 0.005 to minimize compounded Type 1 error from multiple t-tests (1 out of 200 tests likely to be incorrect). If "Prob" value is greater than 0.005, there is no significant difference between Klondike and Tongass data.

t-tests: * Data were log transformed to reduce heterogeneity of variance (substantial difference between the spread of values).

♦ Separate rather than pooled variance used when log transformation did not achieve homogeneous variances.



CHROMIUM signficantly different? YES

PARAMETRIC TEST * ¨

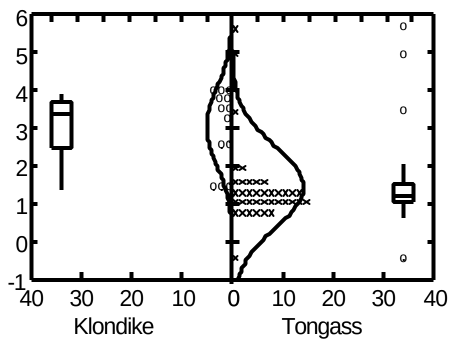
Group	N	Mean	SD
Klondike	13	0.560	0.649
Tongass	38	-0.680	0.965

Separate Variance t = 5.199
Difference in Means = 1.240
99.00% CI = 0.586 to 1.895
df = 31.2 Prob = 0.000

NON-PARAMETRIC TEST

Group	Count	Rank Sum
Klondike	13	524.000
Tongass	38	802.000

Mann-Whitney U test
statistic = 433.000
Chi-square approx. = 16.267
with 1 df Prob = 0.000



COPPER significantly different? YES

PARAMETRIC TEST * ¨

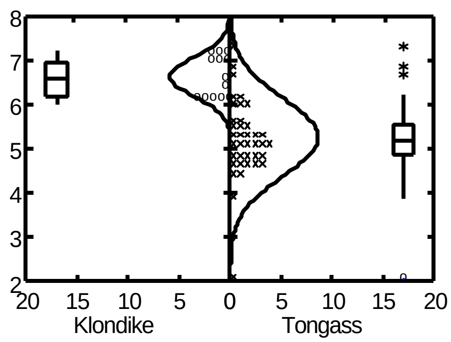
Group	N	Mean	SD
Klondike	13	2.915	1.015
Tongass	38	1.434	1.073

Separate Variance t = 4.477
Difference in Means = 1.482
99.00% CI = 0.795 to 2.168
df = 21.9 Prob = 0.000

NON-PARAMETRIC TEST

Group	Count	Rank Sum
Klondike	13	545.000
Tongass	38	781.000

Mann-Whitney U test
statistic = 454.000
Chi-square approx. = 20.018
with 1 df Prob = 0.000



IRON significantly different? YES

PARAMETRIC TEST * ¨

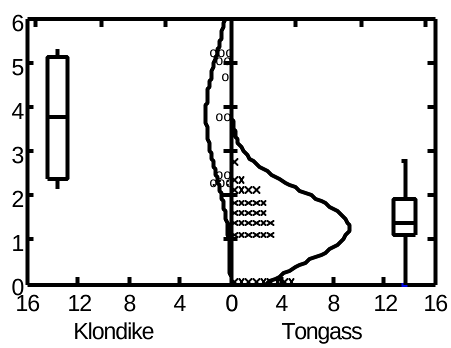
Group	N	Mean	SD
Klondike	13	6.539	0.439
Tongass	38	5.260	0.877

Separate Variance t = 7.119
Difference in Means = 1.333
99.00% CI = 0.955 to 1.711
df = 41.9 Prob = 0.000

NON-PARAMETRIC TEST

Group	Count	Rank Sum
Klondike	13	568.000
Tongass	38	758.000

Mann-Whitney U test
statistic = 477.000
Chi-square approx. = 24.713
with 1 df Prob = 0.000



LEAD significantly different? YES

PARAMETRIC TEST * ¨

Group	N	Mean	SD
Klondike	13	3.837	1.320
Tongass	38	1.275	0.819

Separate Variance t = 6.576
Difference in Means = 2.562
99.00% CI = 1.417 to 3.707
df = 15.3 Prob = 0.000

NON-PARAMETRIC TEST

Group	Count	Rank Sum
Klondike	13	576.000
Tongass	38	750.000

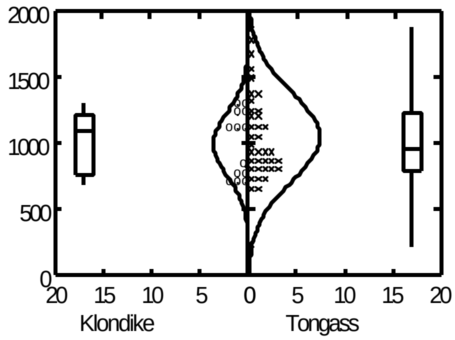
Mann-Whitney U test
statistic = 485.000
Chi-square approx. = 26.717
with 1 df Prob = 0.000

How to read plots: the data are graphed in three ways - 1) counts of values extend out from the central axis, o = Klondike, x = Tongass; 2) normal approximation distribution curves overlay the values, the peak of the curve is the mean (average), the span of the bottom of the curve along the central axis is the variance (spread of the values), and 3) box plots are placed near the outside edges of the graphs (see Appendix B for box plot information). Graphs are % total for N and S, ug/g for all others, with log transformation if indicated.

Statistical tests: Hypothesis: no difference between means of Klondike and Tongass data. Probability set at 0.005 to minimize compounded Type 1 error from multiple t-tests (1 out of 200 tests likely to be incorrect). If "Prob" value is greater than 0.005, there is no significant difference between Klondike and Tongass data.

t-tests: * Data were log transformed to reduce heterogeneity of variance (substantial difference between the spread of values).

♦ Separate rather than pooled variance used when log transformation did not achieve homogeneous variances.



MAGNESIUM significantly different? NO

PARAMETRIC TEST

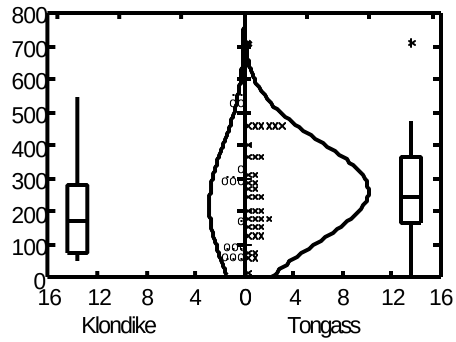
Group	N	Mean	SD
Klondike	13	994.500	239.928
Tongass	38	1050.611	339.990

Pooled Variance t = -0.548
Difference in Means = -56.111
99.00% CI = -330.286 to 218.065
df = 49 Prob = 0.586

NON-PARAMETRIC TEST

Group	Count	Rank Sum
Klondike	13	312.000
Tongass	38	1014.000

Mann-Whitney U test
statistic = 221.000
Chi-square approxi. = 0.316
with 1 df Prob = 0.574



MANGANESE significantly different? NO

PARAMETRIC TEST

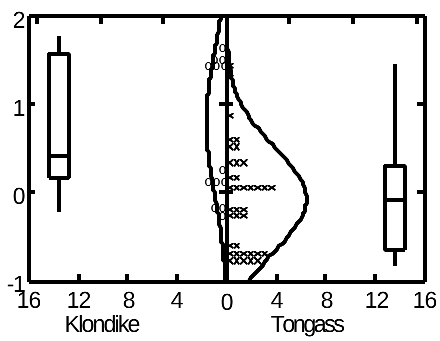
Group	N	Mean	SD
Klondike	13	219.420	169.448
Tongass	38	261.658	150.143

Pooled Variance t = -0.848
Difference in Means = -42.238
99.00% CI = -142.380 to 57.904
df = 49 Prob = 0.401

NON-PARAMETRIC TEST

Group	Count	Rank Sum
Klondike	13	306.000
Tongass	38	1020.000

Mann-Whitney U test
statistic = 215.000
Chi-square approx. = 0.478
with 1 df Prob = 0.489



NICKEL significantly different? YES

PARAMETRIC TEST *

Group	N	Mean	SD
Klondike	13	0.791	1.787
Tongass	38	-0.075	0.588

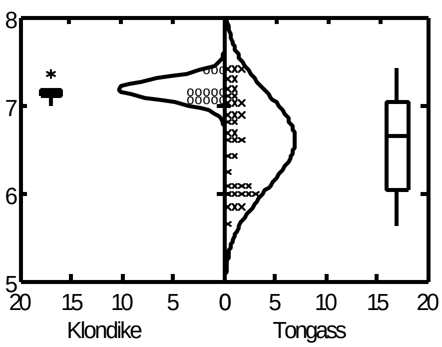
Pooled Variance t = 4.196
Difference in Means = 0.866
99.00% CI = 0.451 to 1.281
df = 49 Prob = 0.000

NON-PARAMETRIC TEST

Group	Count	Rank Sum
Klondike	13	568.000
Tongass	38	758.000

Mann-Whitney U test
statistic = 477.000
Chi-square approx. = 24.726
with 1 df Prob = 0.000

(Nitrogen not included, no Tongass data available)



PHOSPHORUS significantly different? YES

PARAMETRIC TEST * ♦

Group	N	Mean	SD
Klondike	13	7.186	0.124
Tongass	38	6.596	0.545

Separate Variance t = 6.219
Difference in Means = 0.590
99.00% CI = 0.335 to 0.845
df = 45.8 Prob = 0.000

NON-PARAMETRIC TEST

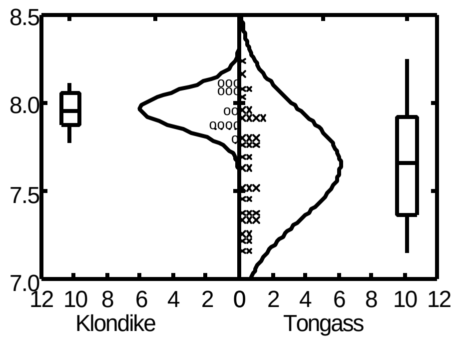
Group	Count	Rank Sum
Klondike	13	502.500
Tongass	38	823.500

Mann-Whitney U test
statistic = 411.500
Chi-square approx. = 12.642
with 1 df Prob = 0.000

How to read plots: the data are graphed in three ways - 1) counts of values extend out from the central axis, o = Klondike, x = Tongass; 2) normal approximation distribution curves overlay the values, the peak of the curve is the mean (average), the span of the bottom of the curve along the central axis is the variance (spread of the values), and 3) box plots are placed near the outside edges of the graphs (see Appendix B for box plot information). Graphs are % total for N and S, ug/g for all others, with log transformation if indicated.

Statistical tests: Hypothesis: no difference between means of Klondike and Tongass data. Probability set at 0.005 to minimize compounded Type 1 error from multiple t-tests (1 out of 200 tests likely to be incorrect). If "Prob" value is greater than 0.005, there is no significant difference between Klondike and Tongass data.

t-tests: * Data were log transformed to reduce heterogeneity of variance (substantial difference between the spread of values).
♦ Separate rather than pooled variance used when log transformation did not achieve homogeneous variances.



POTASSIUM significantly different? YES

PARAMETRIC TEST *

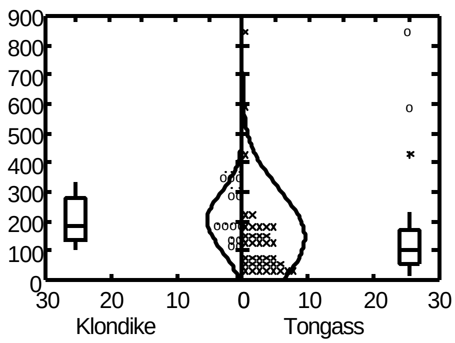
Group	N	Mean	SD
Klondike	13	2894.923	310.176
Tongass	38	2191.447	681.748

Separate Variance t = 5.021
Difference in Means = 703.476
99.00% CI = 326.546 to 1080.406
df = 44.8 Prob = 0.000

NON-PARAMETRIC TEST

Group	Count	Rank Sum
Klondike	13	490.000
Tongass	38	836.000

Mann-Whitney U test
statistic = 399.000
Chi-square approx. = 10.793
with 1 df Prob = 0.001



SODIUM significantly different? UNCLEAR

PARAMETRIC TEST

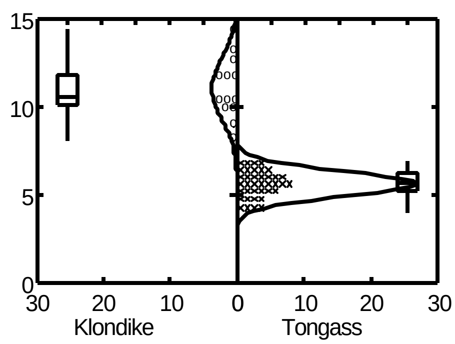
Group	N	Mean	SD
Klondike	13	211.966	86.074
Tongass	38	146.026	159.073

Pooled Variance t = 1.419
Difference in Means = 65.939
99.00% CI = -27.455 to 159.334
df = 49 Prob = 0.162

NON-PARAMETRIC TEST

Group	Count	Rank Sum
Klondike	13	492.000
Tongass	38	834.000

Mann-Whitney U test
statistic = 401.000
Chi-square approx. = 11.080
with 1 df Prob = 0.001



SULFUR significantly different? YES

PARAMETRIC TEST

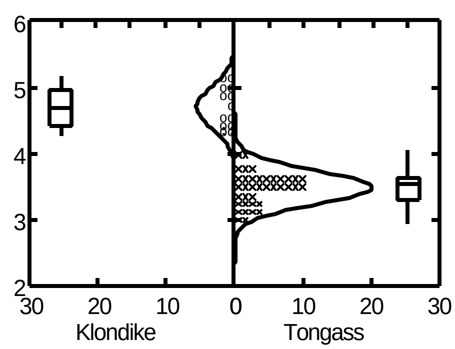
Group	N	Mean	SD
Klondike	13	11.031	1.722
Tongass	38	5.637	0.713

Pooled Variance t = 15.939
Difference in Means = 5.394
99.00% CI = 4.487 to 6.301
df = 49 Prob =0.000

NON-PARAMETRIC TEST

Group	Count	Rank Sum
Klondike	13	585.000
Tongass	38	741.000

Mann-Whitney U test
statistic = 494.000
Chi-square approx = 28.558
with 1 df Prob = 0.000



ZINC significantly different? YES

PARAMETRIC TEST *

Group	N	Mean	SD
Klondike	13	4.632	0.310
Tongass	38	3.483	0.250

Pooled Variance t = 13.445
Difference in Means = 1.149
99.00% CI = 0.978 to 1.321
df = 49 Prob = 0.000

NON-PARAMETRIC TEST

Group	Count	Rank Sum
Klondike	13	585.000
Tongass	38	741.000

Mann-Whitney U test
statistic = 494.000
Chi-square approx. = 28.505
with 1 df Prob = 0.000

How to read plots: the data are graphed in three ways - 1) counts of values extend out from the central axis, o = Klondike, x = Tongass; 2) normal approximation distribution curves overlay the values, the peak of the curve is the mean (average), the span of the bottom of the curve along the central axis is the variance (spread of the values), and 3) box plots are placed near the outside edges of the graphs (see Appendix B for box plot information). Graphs are % total for N and S, ug/g for all others, with log transformation if indicated.

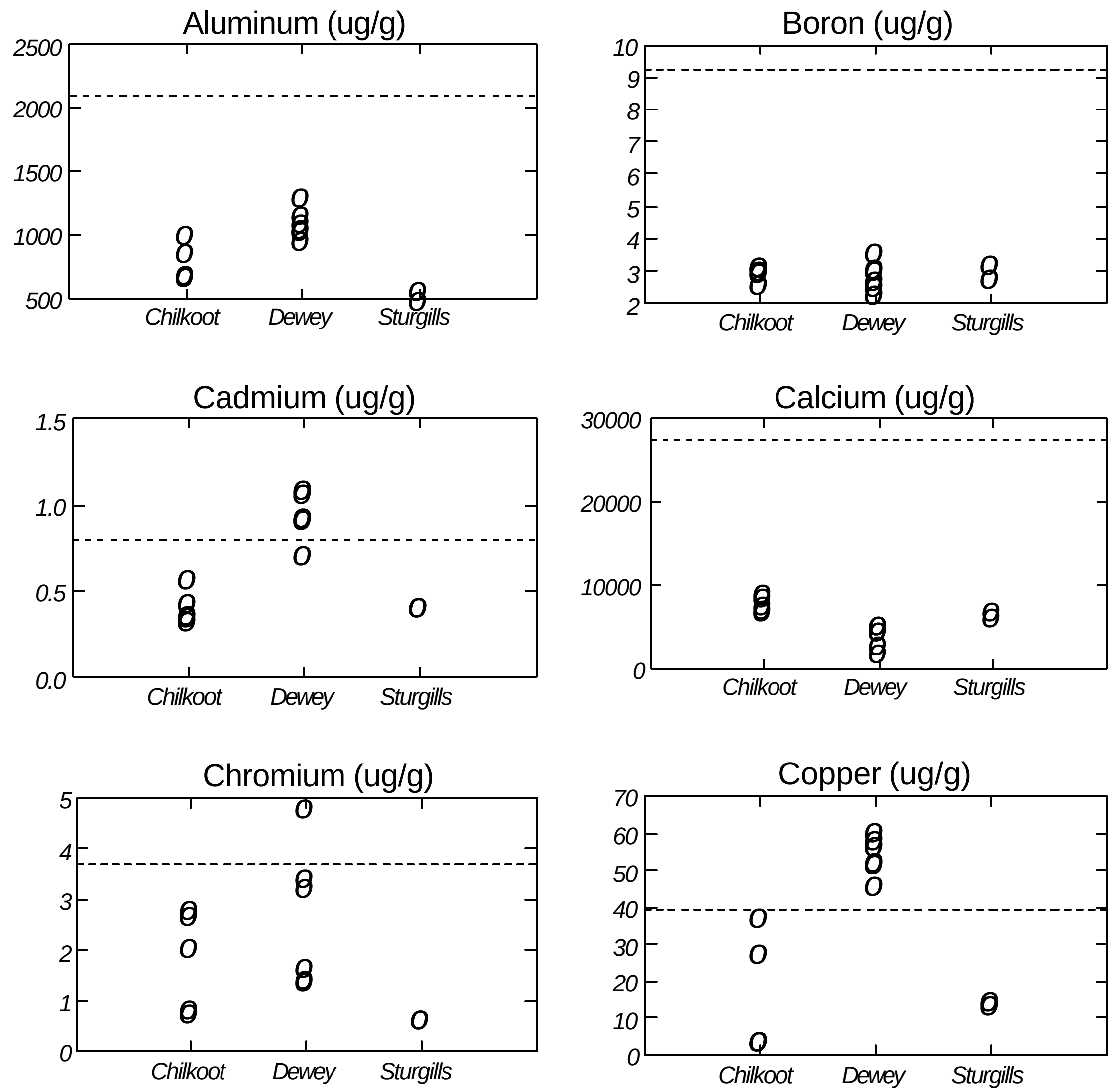
Statistical tests: Hypothesis: no difference between means of Klondike and Tongass data. Probability set at 0.005 to minimize compounded Type 1 error from multiple t-tests (1 out of 200 tests likely to be incorrect). If "Prob" value is greater than 0.005, there is no significant difference between Klondike and Tongass data.

t-tests: * Data were log transformed to reduce heterogeneity of variance (substantial difference between the spread of values).
♦ Separate rather than pooled variance used when log transformation did not achieve homogeneous variances.

Appendix D. Klondike-Skagway sites compared to 97.5 quantile threshold concentrations for Pacific Northwest.

Hypogymnia enteromorpha

Klondike-Skagway sites and Pacific Northwest 97.5 quantile cutoffs



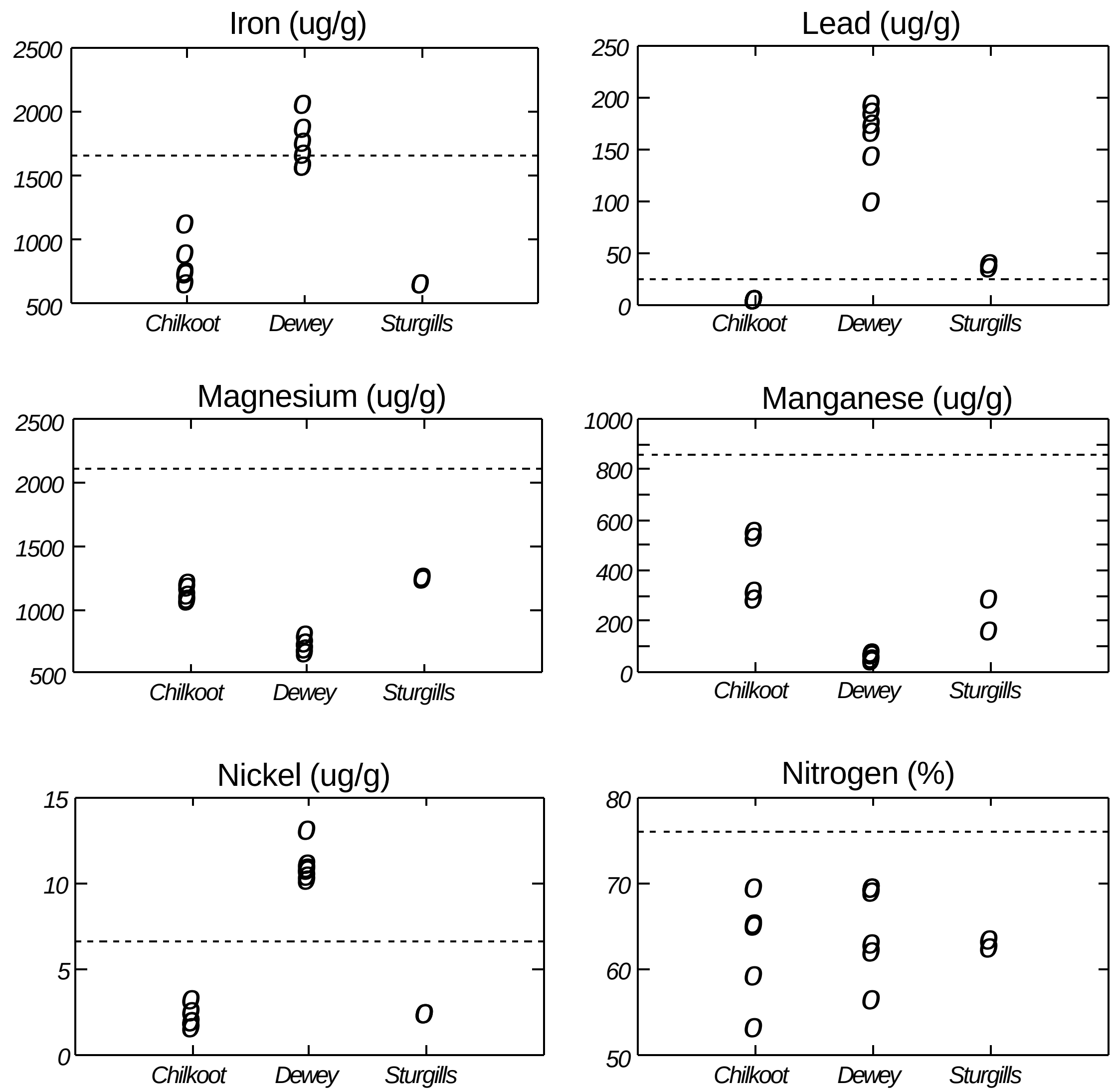
<u>Pacific Northwest 97.5 quantile threshold concentration values</u>

Aluminum	2101
Boron	9.2
Cadmium	0.8
Calcium	27,346
Chromium	3.7
Copper	39.1

Horizontal dashed lines on graphs are Pacific Northwest threshold concentration levels. Circles indicate samples (one circle = one sample). Klondike-Skagway values that lie above the threshold concentration levels indicate air pollution.

Hypogymnia enteromorpha

Klondike-Skagway sites and Pacific Northwest 97.5 quantile threshold concentrations



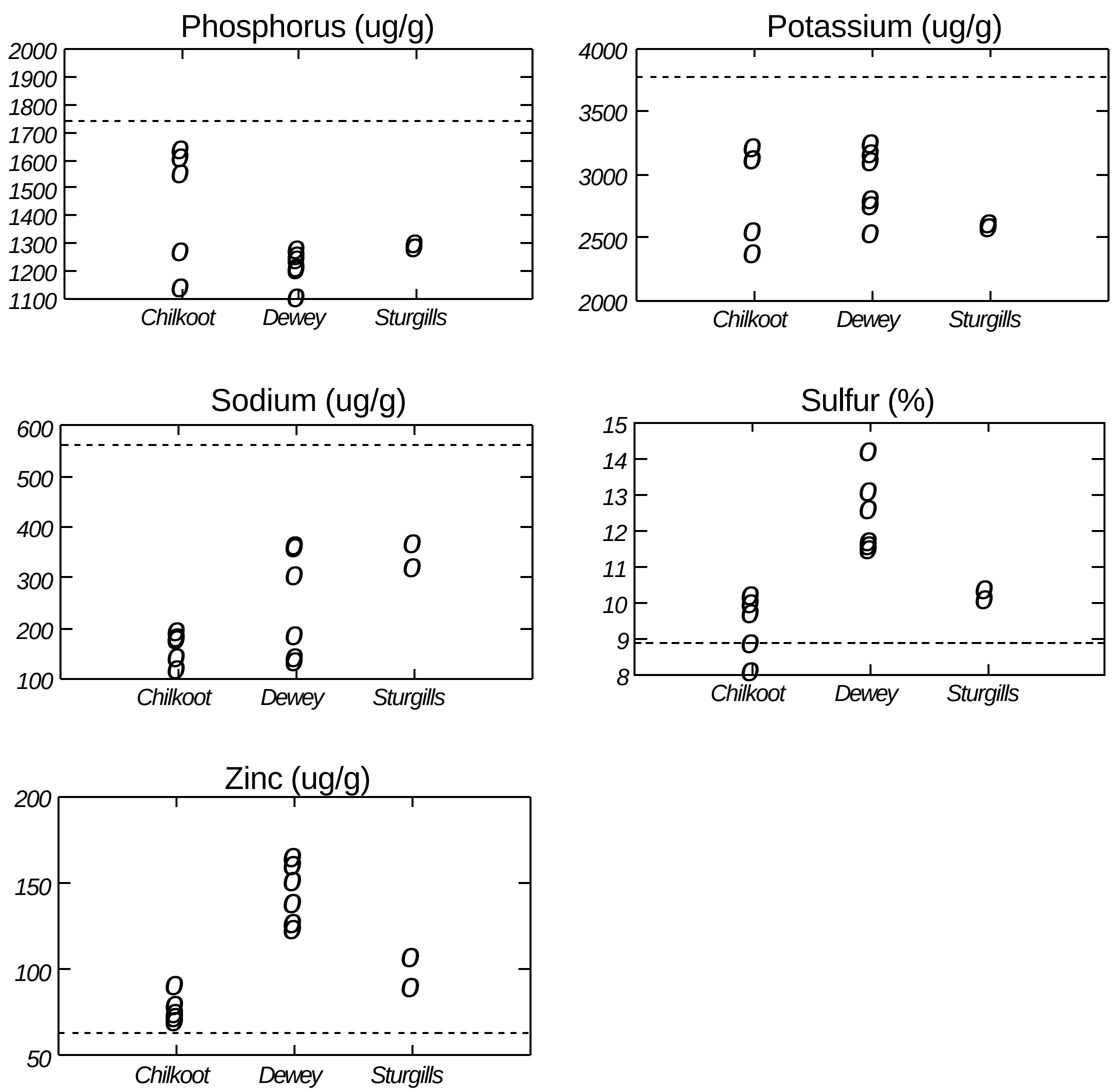
Pacific Northwest 97.5 quantile threshold concentration values

Iron	1655
Lead	23.8
Magnesium	2109
Manganese	858.5
Nickel	6.6
Nitrogen	76

Horizontal dashed lines on graphs are Pacific Northwest threshold concentration levels. Circles indicate samples (one circle = one sample). Klondike-Skagway values that lie above the threshold concentration levels indicate air pollution.

Hypogymnia enteromorpha

Klondike-Skagway sites and Pacific Northwest 97.5 quantile threshold concentrations



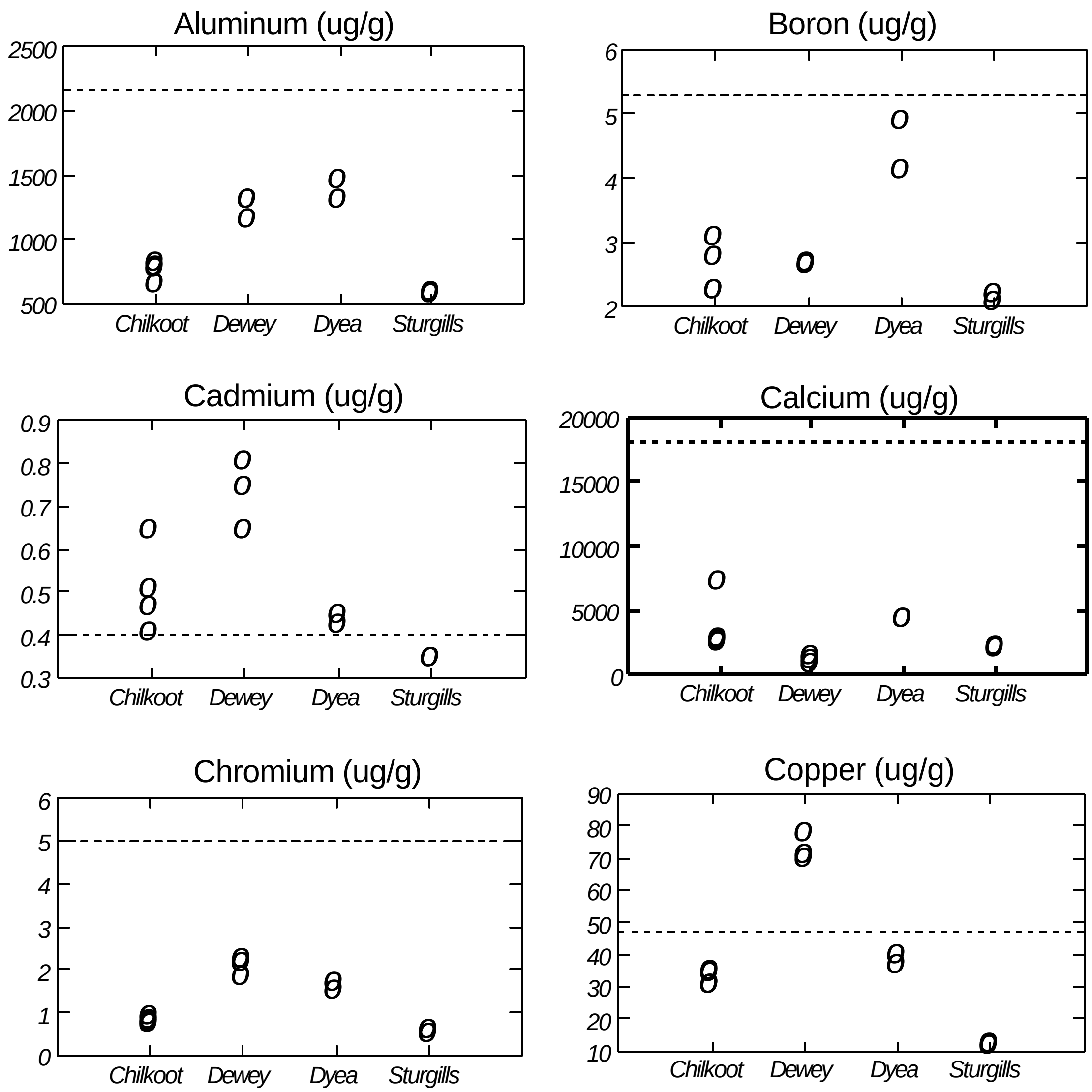
<u>Pacific Northwest 97.5 quantile threshold concentration values</u>

Phosphorus	1739
Potassium	3767
Sodium	561.6
Sulfur	8.9
Zinc	62.7

Horizontal dashed lines on graphs are Pacific Northwest threshold concentration levels. Circles indicate samples (one circle = one sample). Klondike-Skagway values that lie above the threshold concentration levels indicate air pollution.

Hypogymnia inactiva

Klondike-Skagway sites and Pacific Northwest 97.5 quantile threshold concentrations



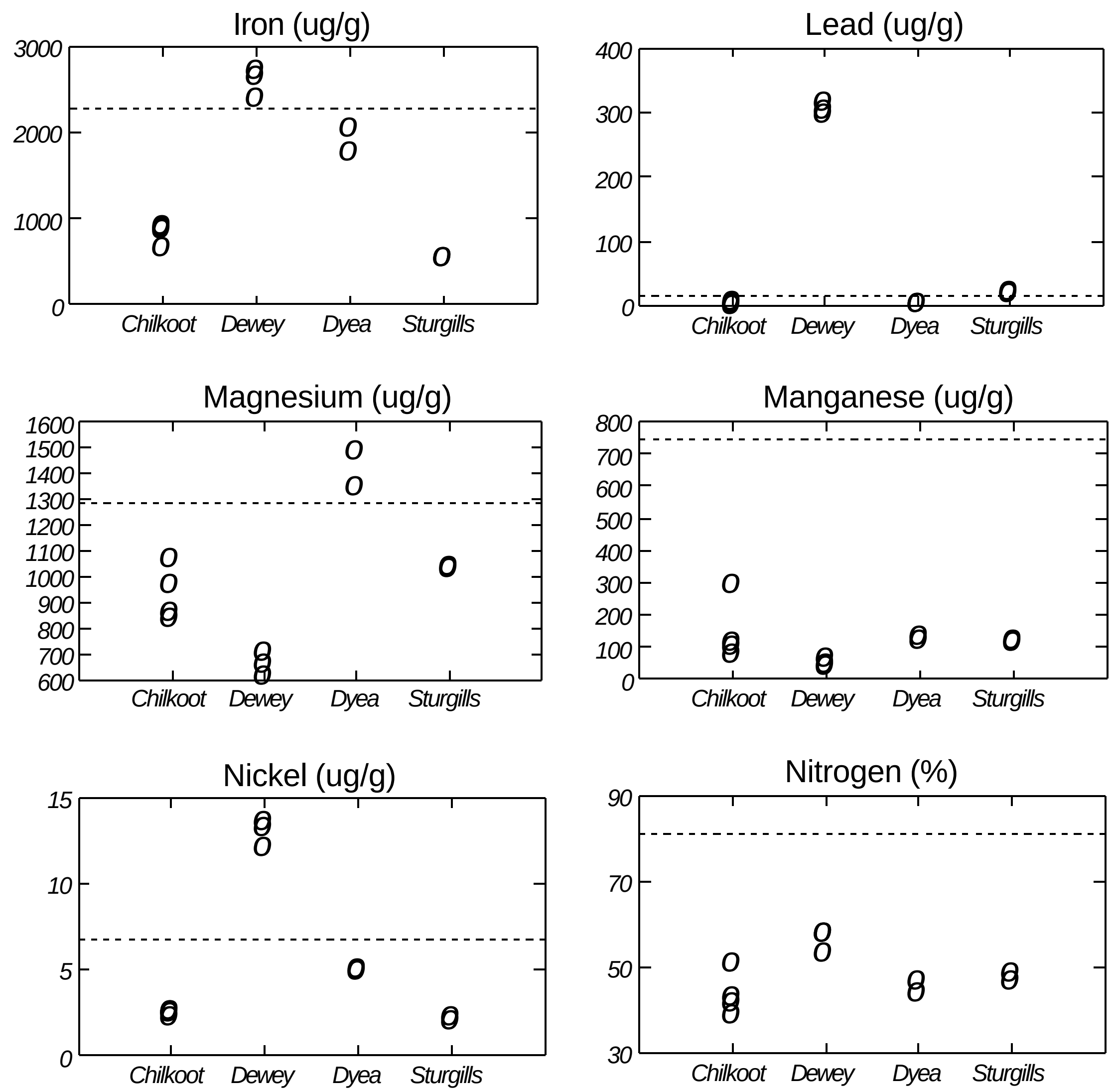
<u>Pacific Northwest 97.5 quantile threshold concentration values</u>

Aluminum	2166
Boron	5.3
Cadmium	0.4
Calcium	18,107
Chromium	5.0
Copper	47.2

Horizontal dashed lines on graphs are Pacific Northwest threshold concentration levels. Circles indicate samples (one circle = one sample). Klondike-Skagway values that lie above the threshold concentration levels indicate air pollution.

Hypogymnia inactiva

Klondike-Skagway sites and Pacific Northwest 97.5 quantile threshold concentrations



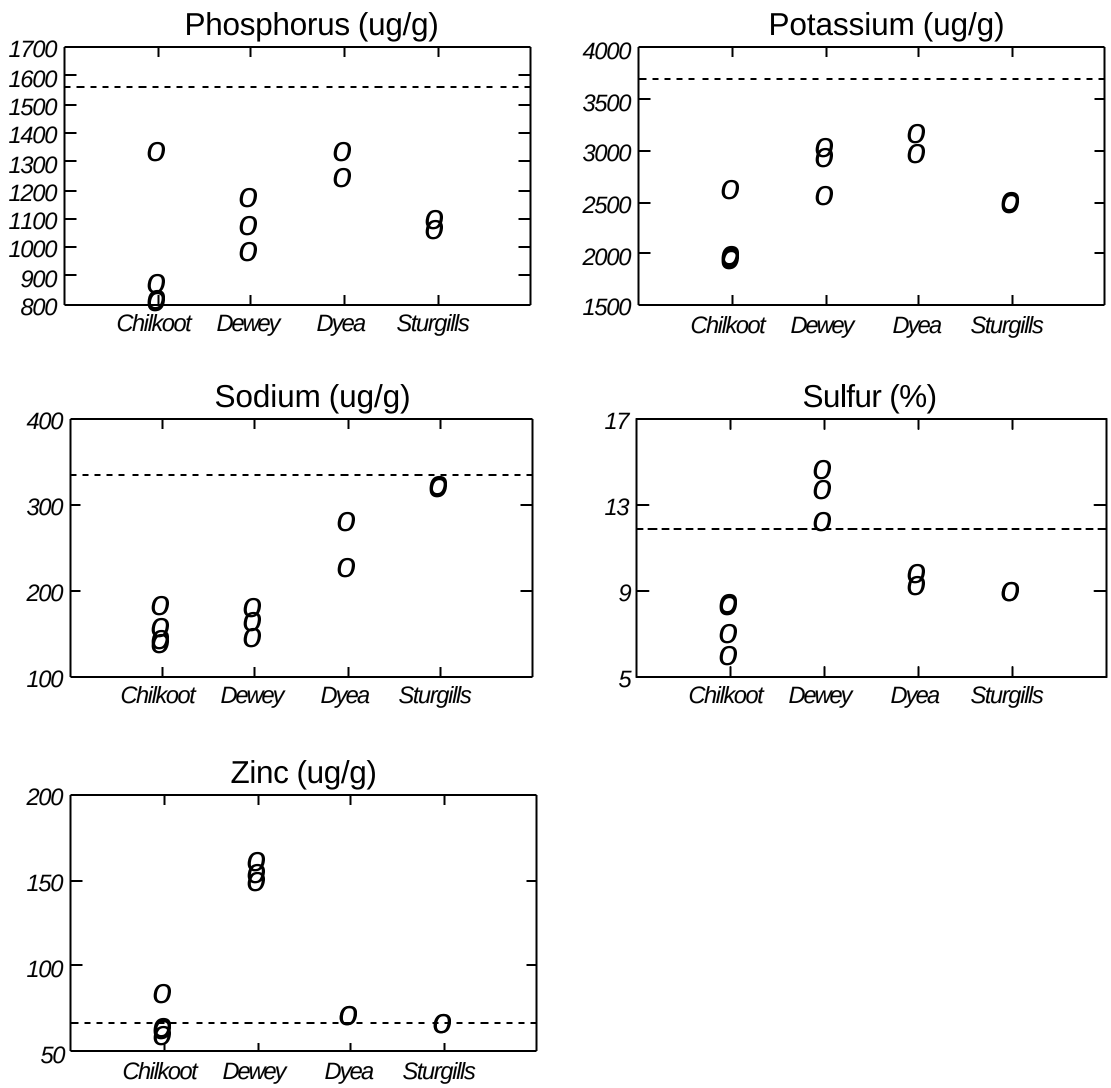
<u>Pacific Northwest 97.5 quantile threshold concentration values</u>

Iron	2286
Lead	16.6
Magnesium	1283
Manganese	745.9
Nickel	6.8
Nitrogen	76

Horizontal dashed lines on graphs are Pacific Northwest threshold concentration levels. Circles indicate samples (one circle = one sample). Klondike-Skagway values that lie above the threshold concentration levels indicate air pollution.

Hypogymnia inactiva

Klondike-Skagway sites and Pacific Northwest 97.5 quantile threshold concentrations



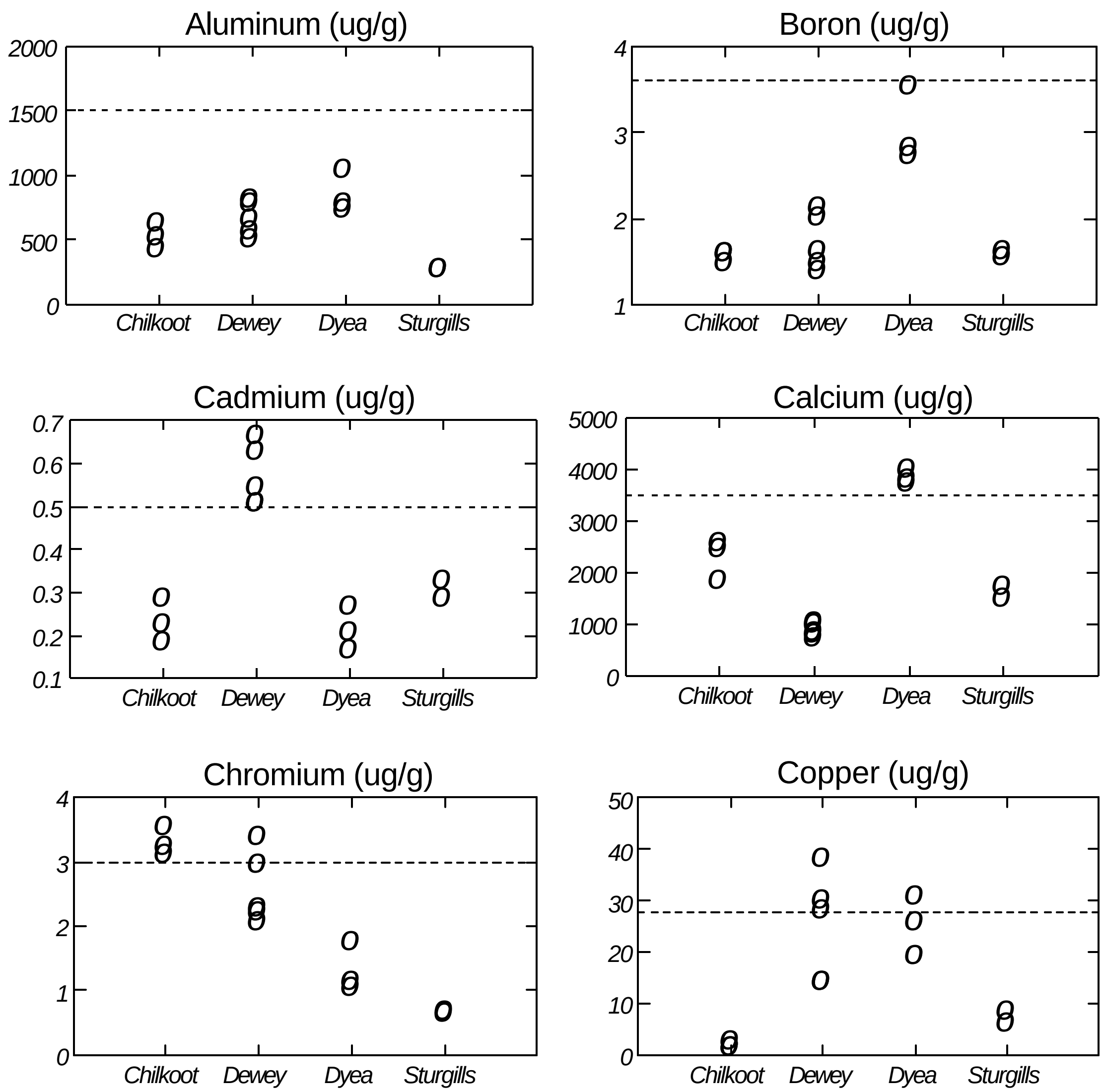
<u>Pacific Northwest 97.5 quantile threshold concentration values</u>

Phosphorus	1560
Potassium	3701
Sodium	334.2
Sulfur	11.9
Zinc	66.8

Horizontal dashed lines on graphs are Pacific Northwest threshold concentration levels. Circles indicate samples (one circle = one sample). Klondike-Skagway values that lie above the threshold concentration levels indicate air pollution.

Platismatia glauca

Klondike-Skagway sites and Pacific Northwest 97.5 quantile threshold concentrations



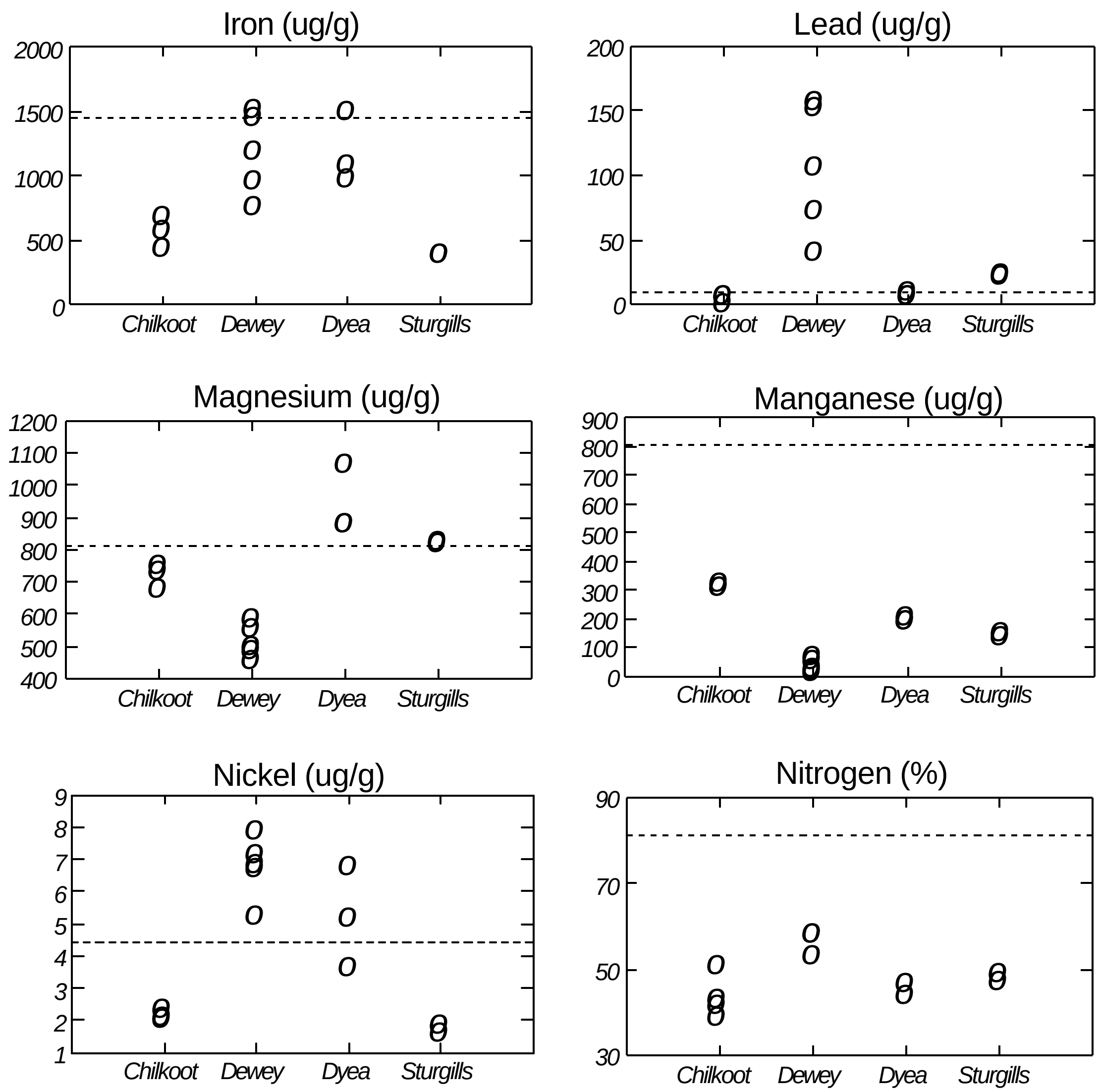
<u>Pacific Northwest 97.5 quantile threshold concentration values</u>

Aluminum	1514
Boron	3.6
Cadmium	0.5
Calcium	3507
Chromium	3.0
Copper	27.8

Horizontal dashed lines on graphs are Pacific Northwest threshold concentration levels. Circles indicate samples (one circle = one sample). Klondike-Skagway values that lie above the threshold concentration levels indicate air pollution.

Platismatia glauca

Klondike-Skagway sites and Pacific Northwest 97.5 quantile threshold concentrations



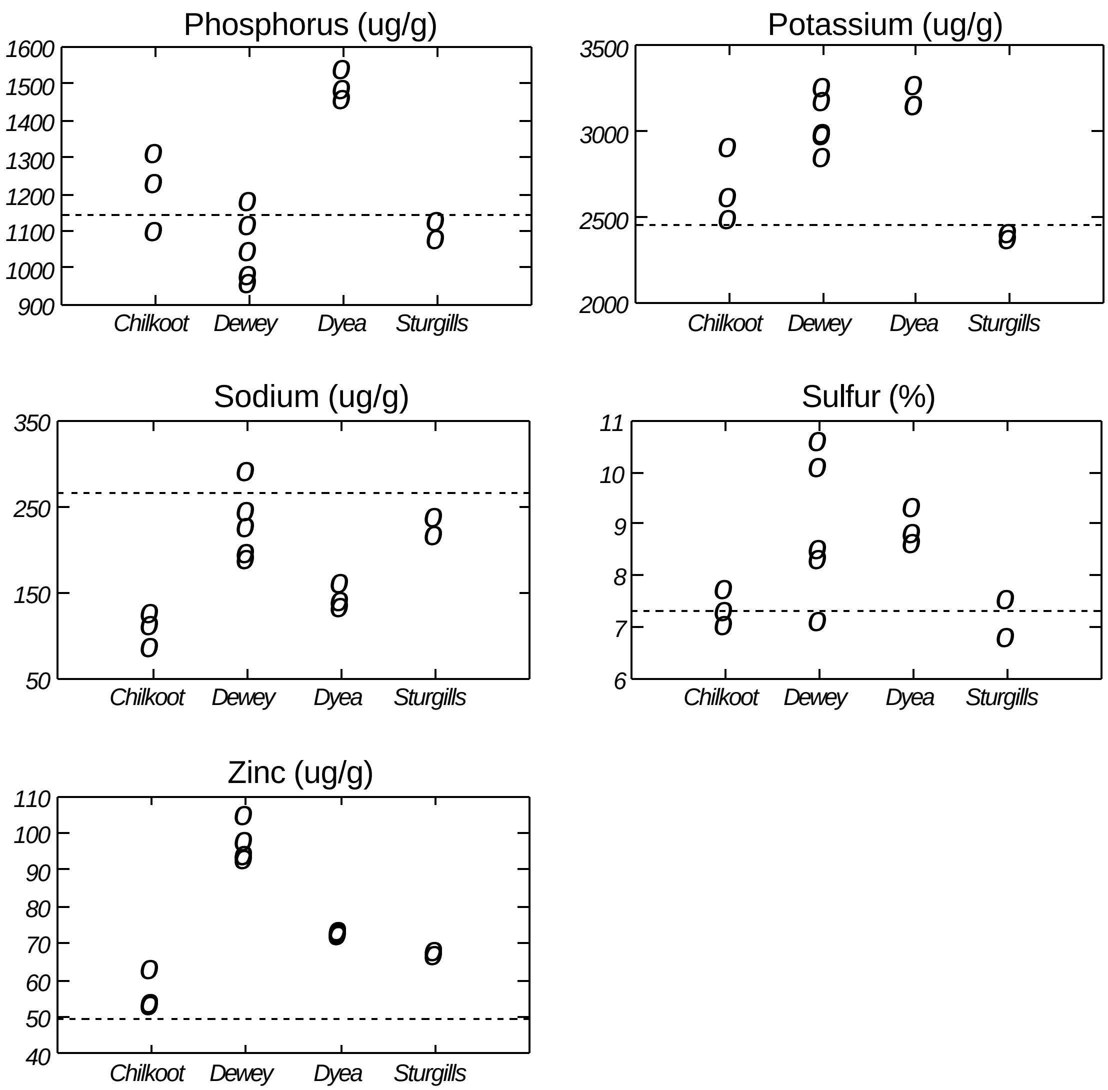
Pacific Northwest 97.5 quantile threshold concentration values

Iron	14598
Lead	10.0
Magnesium	813
Manganese	803.7
Nickel	4.4
Nitrogen	59

Horizontal dashed lines on graphs are Pacific Northwest threshold concentration levels. Circles indicate samples (one circle = one sample). Klondike-Skagway values that lie above the threshold concentration levels indicate air pollution.

Platismatia glauca

Klondike-Skagway sites and Pacific Northwest 97.5 quantile threshold concentrations



<u>Pacific Northwest 97.5 quantile threshold concentration values</u>

Phosphorus	1145
Potassium	2454
Sodium	266.2
Sulfur	7.3
Zinc	49.6

Horizontal dashed lines on graphs are Pacific Northwest threshold concentration levels. Circles indicate samples (one circle = one sample). Klondike-Skagway values that lie above the threshold concentration levels indicate air pollution.