AIR QUALITY BIO-MONITORING WITH LICHENS
THE TONGASS NATIONAL FOREST

Epiphytic lichens used in air quality monitoring from Kah Shakes Cove, Misty Fiords

Karen L. Dillman*, Linda H. Geiser ** and Gregory Brenner***

USDA Forest Service, Tongass National Forest, PO Box 309, Petersburg Alaska 99833
USDA Forest Service, Suislaw National Forest, PO Box 1148, Corvallis, Oregon 97339
Pacific Analytics LLC, PO Box 1064, Corvallis, Oregon 97339

December 2007

I. TABLE OF CONTENTS

I. Table of Contents ....

II. Executive Summary and Acknowledgements i

III. Introduction 3

IV. Methods 8

V. Summary of Percent Sulfur Analysis 16

VI. Summary of Percent Nitrogen Analysis 30

VII. Summary of Al Analysis Results 40

VIII. Summary of B Analysis Results 52

IX. Summary of Ba Analysis Results 64

X. Summary of Be Analysis Results 75

XI. Summary of Ca Analysis Results 76

XII. Summary of Cd Analysis Results 87

XIII. Summary of Co Analysis Results 100

XIV. Summary of Cr Analysis Results 111

XV. Summary of Cu Analysis Results 123

XVI. Summary of Fe Analysis Results 135

XVII. Summary of K Analysis Results 147

XVIII. Summary of Li Analysis Results 159

XIX. Summary of Mg Analysis Results 170

Table of Contents

XX. Summary of Mn Analysis Results 181
XXI. Summary of Mo Analysis Results 194
XXII. Summary of Na Analysis Results 205
XXIII. Summary of Ni Analysis Results 217
XXIV. Summary of P Analysis Results 229
XXV. Summary of Pb Analysis Results 241
XXVI. Summary of Rb Analysis Results 253
XXVII. Summary of Si Analysis Results 254
XXVIII. Summary of Sr Analysis Results 265
XXIX. Summary of Ti Analysis Results 276
XXX. Summary of V Analysis Results 287
XXXI. Summary of Zn Analysis Results 298
XXXII. Thresholds 310
XXXIII. Conclusions 311
XXXIV. Literature Cited 320

EXECUTIVE SUMMARY

Air quality on the Tongass National Forest and in Southeast Alaska is very good. The prevailing winds off the Pacific Ocean, the relatively small amount of industrial development and population centers, and the general lack of smoke from wildland fire all contribute to maintaining clean air in the region. However, localized air pollution from sources such as mining operations, marine vessels and cruise ships, wood-burning stoves, vehicle exhaust, diesel power and asphalt plants, incinerators, and unpaved roads all contribute to the deterioration of air quality that can impact resources on the Tongass National Forest. Additionally, trans-Pacific pollutants such as nitrogen are a growing concern for all of western North America. .

Federal land managers, including the Forest Service, are required to protect, manage and improve (where appropriate) air quality on National Forest Lands by; 1) the Clean Air Act of 1970 (CCA) and its amendments (Sec 165 (d) (2) (B), 2) the Forest and Rangeland Renewable Resource Planning Act of 1974 as amended by the National Forest Management Act (NFMA) (16 U.S.C. 1602), and 3) the Federal Land Management Policy Act of 1976 (43 U.S.C. 1701 et seq.). Forest Service managers are also directed to monitor the effects of air pollution and atmospheric deposition on forest resources (FSM 2580.44). Furthermore, the Chief’s 10-Year Wilderness Stewardship Challenge (10YWSC) identifies air as one of the ten most critical challenge elements for wilderness stewardship. Several tasks for wilderness managers concerning air are to determine if air quality in wilderness is changing, and to develop strategies for improvement. These wilderness stewardship goals and other directives can only be accomplished through establishing a baseline for air quality values and monitoring of air quality.

Since 1989, air quality biomonitoring has been an integral part of natural resource management on the Tongass National Forest. Lichens are well known sensitive receptors for air pollution and are used as biomonitors of air quality worldwide. Some species of lichens are very tolerant of containments; others are very intolerant and can succumb due to high levels of contaminants over time. The most immediate benefit of biomonitoring is the ability to map conditions at a sampling intensity (spatial and temporal) which is prohibitively expensive using instrument monitors. Lichens are intimately tied to local conditions. Along with moisture from the surrounding environment, airborne contaminants are absorbed easily into the lichen thalli and become concentrated in the lichen tissues. Through lichen biomonitoring, areas needing additional instrument monitoring for human health concerns can also be identified. Elemental concentration of contaminants in lichens varies by lichen species, the amount of precipitation , and the exposure time to wet and dry deposition. Worldwide ranges are used for certain contaminants expected at both polluted and clean environments (i.e. natural background levels) to help determine if enhancements are anthropogenic or natural.

Results of the most recent biomonitoring initiative using lichens are reported here, its objectives were to: 1) Establish monitoring sites in wilderness areas that were not part of the baseline monitoring study of 1989-1994 (10YWSC, FSM 2580.44), 2) Perform elemental analysis of lichens from wilderness areas that were part of the initial baseline monitoring study to detect possible changes in concentrations of plant nutrients and metal-containing contaminants over time (10YWSC, FSM 2580.44), 3) Determine whether relationships exist between element concentrations in lichens and several physiographic site characteristics, 4) Establish Forest-wide provisional threshold levels for four lichen species and 27 elements (NFMA, FSM 2850.44), 5) Identify areas on the Forest where element concentrations in lichens are elevated above threshold (NFMA), 6) At locations where thresholds are exceeded, determine whether enhancement is due to anthropogenic or natural sources (10YWSC, NFMA, FSM 2580.44), and 7) Determine patterns of contaminant accumulation in lichens near downtown Juneau on Mt Roberts and at Greens Creek mining facility on Admiralty Island (FSM 2580.44). Monitoring locations outside wilderness near known polluted areas will be used in future modeling of air pollution gradients in the Alaska Region.

Elements analyzed simultaneously in lichens at the University of Minnesota Soil Laboratory with the inductively coupled plasma atomic emission spectrophotometry (ICP_AES) method were: Al, B, Ba, Be, Ca, Cd, Co, Cr, Cu, Fe, K, Li, Mg, Mn, Mo, Na, Ni, P, Pb, Rb, Si, Sr, Ti, V and Zn (expressed in ppm). Total sulfur and nitrogen were analyzed separately with a slightly different method. Provisional threshold levels for all elements were estimated for four lichen species through the use of; 1) ICP-AES contaminant concentrations measured in Tongass National Forest lichens from 1989 to 2005, and 2) the 97.5% quantiles for contaminant concentrations in lichens from sites that are relatively free from human disturbance and pollution effects. Provisional thresholds are the upper most limits for element concentrations expected in target lichen species from background (clean) sites. Concentrations above threshold can be considered elevated due to enhancement from natural or anthropogenic sources. Of the 127 monitoring sites with elemental data, 88 were used to calculate thresholds.

Except the Maurelle Islands wilderness, all wilderness areas on the Tongass National Forest contain; 1) at least two lichen biomonitoring plots, 2) lichen tissue analyzed for elemental content and 3) epiphytic lichen community presence/absence and abundance data available for future analysis. There were no significant differences in the elemental content from five wilderness areas and one Research Natural Area (RNA) near a wilderness that had repeated tissue data (Kootznoowoo, Misty Fiords, Tebenkof, Pleasant Island, and Karta Lake wilderness areas and Pikes Lake RNA). No significant relationships were found between elemental content in lichens and physiographic characteristics such as latitude, longitude, precipitation and elevation across the Tongass.

Of the 127 monitoring sites, 58 contained at least one lichen species that was at or above the threshold for one or more elements. Twenty of the 58 are in wilderness areas. Most of the elevated concentrations of certain elements in lichens from wilderness areas were likely due to natural variation, possibly enhanced by salt spray in exposed locations (e.g. Ca, Mg, K, S, and Mn), local geology or windblown soils (e.g. Al, Ba, Li, Si, Ni, Ti). Additionally, some lichens from wilderness monitoring sites at beach locations were above threshold for elements such as sulfur and nitrogen (i.e. Coronation, Warren and Tebenkof). Although ocean spray is likely the source for these elements, the bays in these wildernesses are also popular marine vessel anchorages where fossil fuel combustion releases nitrogen and sulfur containing emissions.

In areas near human activities outside wilderness, lichens found to be enhanced with contaminants may be due to unpaved road dust, vehicle exhaust, power plants and other small industries, and past mining activities. The lichens analyzed near the Sitka pulp mill from the early 1990's were above threshold in many contaminants including S and heavy metals. Future work will focus on going back to Sitka to determine if levels have dropped due to the closure of the mill. The ICP-AES analysis does not differentiate as to the source or type of compounds analyzed (such as the many compounds containing S both from anthropogenic and natural sources). Therefore, knowledge of the area and historic and current human uses are used to infer the sources of the elevated elements.

Lichens from the Greens Creek Mine vicinity contained more elements above threshold than any other monitoring site on the Tongass National Forest. From a site in the vicinity of the tailings pile, 19 elements were above threshold, including S, N, Cd, Cr, Cu, Fe, Pb, and Zn. Two locations near the mine portal were sampled; lichens from approximately 250 ft away from the portal had fewer elements above threshold than the lichens near the entrance to the portal (7 compared to 12). Contaminant levels of certain heavy metals in some lichen species were within the worldwide ranges considered enhanced due to mining and smelter activities. Future establishment of monitoring sites in a gradient of distances away from the mining activities may help determine at what distance contaminant levels in lichens drop below threshold.

Lichens from Mt Roberts were above thresholds in many elements; 13 elements at the 175 ft elevation (including S, N, Cu, Fe, Cr, P, K and Ni), five elements at the 600 ft elevation (S, K,P, V and Ni), four elements at the 910 ft elevation (K S, Zn, P), two elements at the 1241 ft elevation (K and P) and three elements at the 1750 ft elevation (Zn, K, P). The contaminent levels in lichens from Mt Roberts were enhanced by several sources including vehicle exhaust, diesel generators, wood stoves, past mining, and cruise ship emissions. The main source of sulfur and nitrogen found in lichens from Mt Roberts may be due to burning of fossil fuels by the cruise ships and other vehicles in downtown Juneau. To address human and ecosystem health concerns, a gradient of monitoring sites should be established in the area to determine how far the impacts from burning of fossil fuels in downtown Juneau are detected in lichens.

Elevated contaminants in lichens were more indicative of localized emission and dusts rather than poor regional air quality. Enhanced concentrations of certain elements in lichens are evidence that human activities near and on the Forest generate air pollution and the associated airborne contaminants are being introduced into the ecosystem. However, natural sources of some elements can also be high in lichens. Lichens from polluted and clean areas exist in dynamic equilibrium with the environmental conditions in which they are growing. Certain containments can affect photosynthesis and other metabolic processes in lichens more readily than others, such as sulfur, nitrogen, and some heavy metals. Additional work is needed to combine elemental analysis with the diversity and abundance of expected lichen species. A community analysis of epiphytic lichens would provide a sensitive tool for land managers to detect status and trends in air quality on the Forest in general and around local or stationary sources

ACKNOWLEDGEMENTS

The recent biomonitoring program with lichens was prompted through the keen interest of the Tongass National Forest wilderness managers. In their desire to attain Tongass wilderness areas to national standards of wilderness management for air quality they were instrumental in having lichen plots established in most wilderness areas. Rich Fisher and the USDA Forest Service Air Program provided financial support during the initiation of this recent program. Alaska Region Air Program and resource managers Ann Puffer and Dave Mott, and Tongass National Forest Wilderness Program manager Bill Tremblay provided additional support to complete this work. Region 6 Air Program and the Siuslaw National Forest provided technical support, interpretation of the results, and data base management of the elemental and community data. Much appreciation is owed to Anne Ingersoll from Region 6, and Jim Riley who carefully entered the lichen data into the R6 database. Gina Siroy, (GIS Tongass) assisted in creating the GIS map of plot locations. Many thanks to the people who have helped establish biomonitoring sites: Albert Faure and Carolyn Morehouse **(**State of Alaska Department of Environmental Conservation Commercial Passenger Vessel Compliance Program) Steve Hohensee (Minerals Specialist USFS), Kerry Lear (Greens Creek), Chiska Derr (Army Corps of Engineers-Juneau), Brad Kreickhause (Botanist USFS), Steve Trimble (Ecologist, USFS), Patti Krosse (Ecologist, USFS), Rick L Turner (Ecologist USFS), Barb Schrader (Regional Ecologist USFS), Mary Clemens (Recreation Forester USFS), Kevin Hood (Wilderness Ranger USFS), Tim Lydon (Lead Wilderness Ranger USFS), John Neary (Wilderness Field Manager USFS), Stephanie Clemens (Botanist USFS), Joni Johnson (Ecologist USFS), Kyle Kinsman (Biological Technician USFS), Mary Beth Nelson (Recreation Planner USFS), Mary Emerick (Wilderness Manager USFS), (Brad Hunter (Wilderness Manager USFS), Carin Christensen (Wilderness Ranger USFS), Chris Prew (Wilderness Manager USFS), and Dave Rak (Wilderness Manager USFS).

III. INTRODUCTION

III.I History of air quality biomonitoring with lichens on National Forests in Alaska

The United States Congress enacted the Clean Air Act (CAA) in 1970 and its amendments in 1977 and 1990 in response to an increased awareness of the nationwide consequences of air pollution and environmental degradation. Under the CAA the Federal Land Manager has the responsibility, specifically the Regional Forester for Alaskan national forests, to monitor air pollution and to protect this resource. Other national air mandates followed include: 1) The Forest and Rangeland Renewable Resource Planning Act of 1974 as amended by the National Forest Management Act (16 U.S.C. 1602), 2) The Federal Land Management Policy Act of 1976 (43 U.S.C. 1701 et seq.) 3) Forest Service Manual 2580.44, and 4) Chief's 10 year Wilderness Stewardship Challenge.

In response to the national mandates, the Tongass National Forest and the Alaska Regional Soil, Water, and Air Program of the Forest Service initiated the use of lichens as biomonitors of air pollution on the Tongass National Forest (Geiser et al. 1994). Seventy-three permanent monitoring sites were established between 1989 and 1992 (Geiser et al 1994). Lichen samples were collected and analyzed for baseline pollutant concentrations (Geiser et al. 1994). In this document, the 1989-1992 baseline monitoring period will henceforth be referred to as baseline monitoring.

Aside from sites close to industries and major population centers, the baseline monitoring data indicated that air quality on the Tongass was relatively good. A similar baseline monitoring pilot study was initiated on the Chugach National Forest (Derr 1997).

Lichens are considered one of the most pollution sensitive components of the vegetation within a given ecosystem and can have predictive value in assessing future effects on vascular plants (Nash & Gries 1991) Lichens are composite organisms formed by a fungus and a green alga and/or blue-green bacterium. They lack the mechanism utilized by higher plants for water uptake (e.g. roots, conducting tissue) and regulation of gas exchange (e.g. stomata, waxy cuticle). The elemental content of lichens is strongly affected by atmospheric influences: gases, particulate matter and precipitation. Studies have shown the usefulness of lichens to monitor air pollutants by translating pollutant concentration numbers to tangible effects on biological systems (Herzig et al 1989, Sigal & Nash 1983, Farmer et. al. 1991). Biomonitoring can provide a sensitive overview of air quality and detect fairly small changes in air quality geographically or over time (Boonpragob & Nash 1990, Richardson 1988, Garty 1988, USFS 2006).

Lichens are found in nearly all terrestrial ecosystems on the Tongass National Forest. An inventory listed over 500 lichens and allied fungi from 112 genera within the Tongass National Forest (Geiser et al. 1998).

III.II Tongass Lichen Biomonitoring Program 2003-2005

In 2003, the Tongass initiated the recent phase of biomonitoring with lichens. In this report, the 2003-2005 monitoring period will henceforth be referred to as the second monitoring period.

To date, 127 locations contain lichen tissue chemistry data from the Tongass National Forest and nearby environs (Figure III-1, see Conclusions Table XXXIII-1). Of the 127 locations, 52 are within a wilderness boundary. Of the 52, 13 were revisited during the second monitoring period (Table III-1). Except for the Maurelle Islands, all wilderness areas on the Tongass contain permanent air quality biomonitoring plots.

In 2005, the Alaska Department of Environmental Conservation, Division of Water, Commercial Passenger Vessel Environmental Compliance Program Manager recommended that lichens be collected along an elevational gradient on the trail to Mt.

Roberts in Juneau as part of the Tongass biomonitoring program. The results would help determine the locations of future instrumental air monitor installations for detecting pollution in downtown Juneau. Plots were also established at the Greens Creek Mine on Admiralty Island (Figure III-1). All lichen samples were evaluated for their chemical composition with the Soil Analytical Laboratory of the University of Minnesota. The data were submitted to Pacific Analytics for statistical analysis.

In summary, the objectives of the second biomonitoring period were to:

1) Establish monitoring sites in wilderness areas that were not part of the baseline monitoring study of 1989-1994
2) Perform elemental analysis of lichens from wilderness areas that were part of the initial baseline monitoring study to detect possible changes in concentrations of plant nutrients and metal-containing contaminants over time
3) Determine whether relationships exist between element concentrations in lichens and several physiographic site characteristics
4) Establish Forest-wide provisional threshold levels for four lichen species and 27 elements
5) Identify areas on the Forest where element concentrations in lichens are elevated above threshold
6) At locations where thresholds are exceeded, determine whether enhancement is due to anthropogenic or natural sources
7) Determine patterns of contaminant accumulation in lichens near downtown Juneau on Mt Roberts and at Greens Creek mining facility on Admiralty Island

Table III-1. Summary of lichen biomonitoring plots in wilderness and others on the Tongass National Forest visited between 2003 and 2005. Site names in bold were first established between 2003 and 2005.

Site Name	Plot numbers	Plots from 1989-91 with tissue data that were revisited	Date
Coronation Island	**513, 514**	NA	July 14-15, 2005
Chuck River	**491, 492, 493**	NA	July 19- 20, 2003
Endicott River	**506, 507, 508**	NA	July 27-28, 2005
Greens Creek Mine	**511, 512**	NA	July 26, 2005
Karta River	159	159	August 5, 2004
Kootznoowoo	189, 190	189, 190	June 7, 2005
Kuiu	**498, 499**	NA	August 23, 2004
Misty Fjords	86, 88	86, 88	May 19, 2005
Mt. Roberts-Juneau	**1000, 1001, 1002,1003,1004**	NA	July 29, 2005
Petersburg Creek/Duncan Salt Chuck	116, 57	116	August 26, 2004
Pleasant Island	145, 146	145, 146	July 28, 2004
Russell Fjords and Pikes Lake RNA	62, 69	69 (Pikes Lake) 62 (Harlequin Lk)	July 4-5, 2005
South Baranof	**487, 488, 489, 490**	NA	May 17, 2004
South Etolin	**496, 497**	NA	August 18, 2004
South Prince of Wales	**515, 516**	NA	June 15, 2005
Stikine-LeConte	30, 31, 195, 494, 495,503	30, 31	August 16-17 and 25, 2004
Tebenkof	33, 500	33	August 24, 2004
Tracy Arm/Fords Terror	**504, 505**	NA	September 15, 2003
Warren Island	**509, 510**	NA	July 13, 2005
West Chichagof-Yakobi	98, 99, 100, 101,	101	May 18, 2004

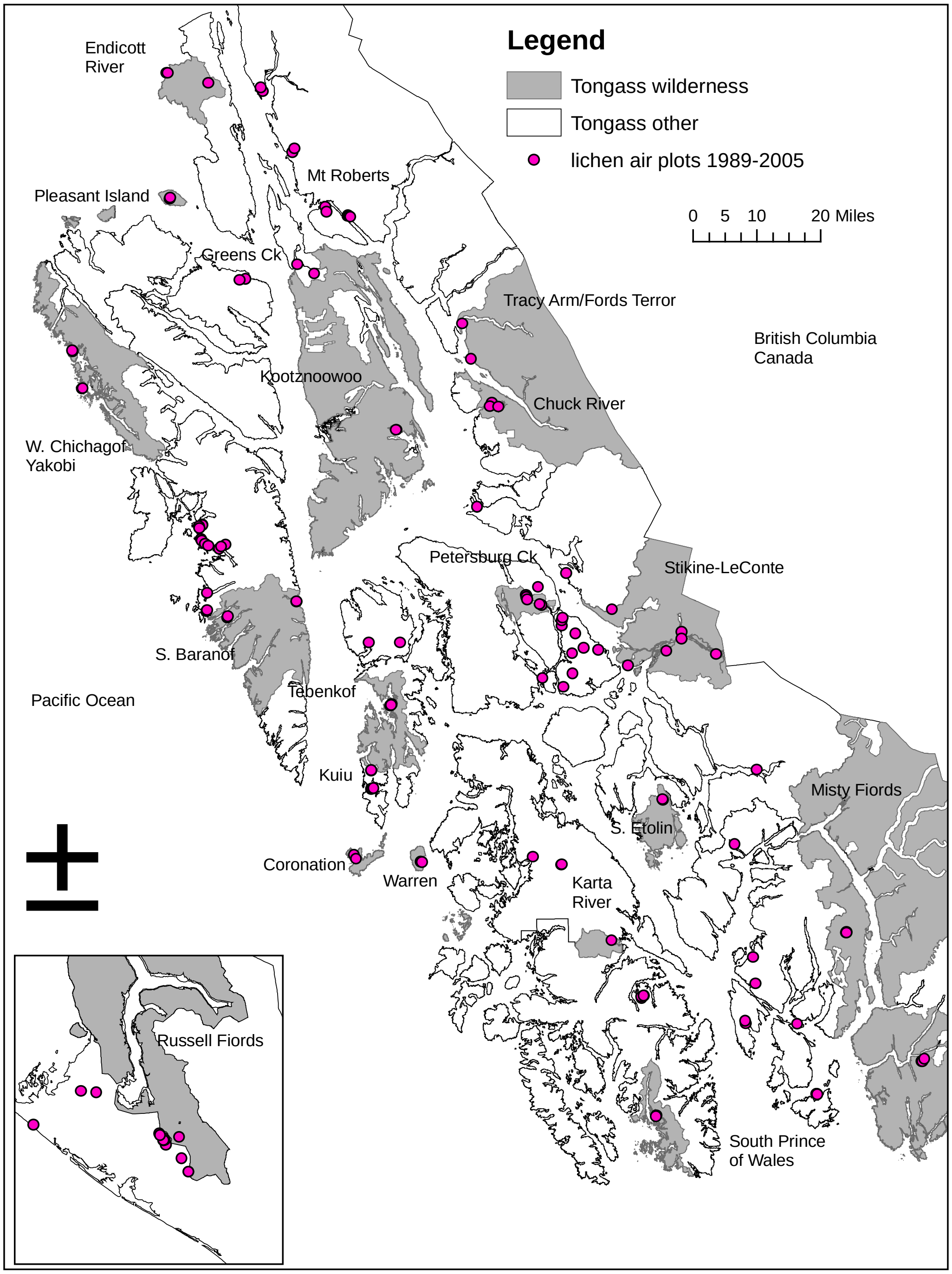

Figure III-1. Lichen biomonitoring plots on the Tongass National Forest that contain elemental data.

IV. Methods

Plots, tissue collection and abundance estimates

For the second monitoring period, lichens were collected during the summers of 2003, 2004, and 2005. Protocol for permanent plot establishment followed Geiser et. al (1994) and Geiser (2004). General plot locations in each new wilderness visited were determined by the accessibility to an area and the cost of the transportation methods. Plots were established in mature and old-growth forest habitats at the beach fringe, subalpine, and in *Pinus contorta* peatlands. Except for the presence of abundant material of the target lichen species for chemical analysis, plot centers were arbitrarily selected without a preconceived bias. All plots, except for those along the Mt Robert trail, have a narrow, one -meter aluminum or PCV plastic pole marking plot center for relocation purposes. Mt Roberts Trail is not on National Forest lands.

Tissue collection and sample treatment followed Geiser (2004). Voucher lichens from each plot were first identified and given an abundance rating by the lichenologist working in the field. Later, the identifications were verified and databased by contract lichenologists and the Region 6 database technician in Corvallis Oregon.

Abundance estimates for each macrolichen species per plot followed Derr (1994) and Geiser et al (1994). Abundance ratings used are similar to FIA (Forest Inventory Analysis) (Geiser 2004). Abundance ratings used in Derr (1994) were developed before FIA had formal ratings established for lichens. Therefore to remain consistent, the second monitoring period continued to use ratings from Derr (1994) and Geiser et al (1994) baseline monitoring. If necessary, abundance ratings from this study can be transformed into FIA ratings.

All Tongass air quality plot information, elemental values, and lichen community and abundance data are found in the www.nacse.org/lichenair website.

Mt Roberts and Greens Creek Mine

Collection sites on Mt Roberts were established at five elevations that were determined after the first tissues were collected at 1745 ft above sea level.   Samples were collected at; 1745, 1241, 910, 600 and 175 ft above sea level (plot numbers 1004, 1003, 1002, 1001, and 1000 respectively). Elevations were determined using a Garmin Vista GPS altimeter with less than 20 ft accuracy where possible.

Plots at Greens Creek were intentionally located near suspected pollution sources; about 250 ft upstream from the mine portal (Plot 511a), just across the bridge from the portal on the road (Plot 511b) and near the ore tailings pile (Plot 512). Samples collected at 511b were not collected from an established plot, but from trees scattered along the edge of the road leading into the mine that receive road dust and other airborne elements related to the mine portal. The other two locations (511a, and 512) have permanent plot markers.

Samples for Elemental Analysis

The lichens collected for elemental analysis are*: Alectoria sarmentosa* (Witch's Hair lichen), *Hypogymnia enteromorpha*, *H. appinata*, *H. inactiva (* Tube lichens*)*, *Lobaria oregana* (Lettuce lichen), and *Platismatia glauca* (Varied Rag lichen). Depending on the dominant species of *Hypogymnia* in the plot area, a single species of *Hypogymnia* was collected at a given plot for elemental analysis. However, for the data analysis the elemental data for all *Hypogymnia* species were combined because little difference in pollution tolerance or accumulation rates exists among the species in this genus. The lichen *P. glauca* was not targeted for elemental analysis during the baseline monitoring period. Therefore, the second monitoring period contains baseline values of *P. glauca* for the Tongass.

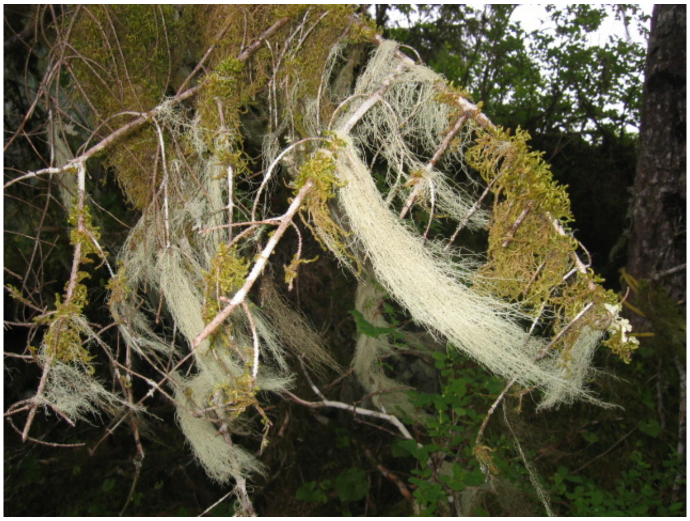

Figure IV-1 *Alectoria sarmentosa* (Witche's Hair) at Hugh Smith Lake, Misty Fiords. Photo by Karen L. Dillman

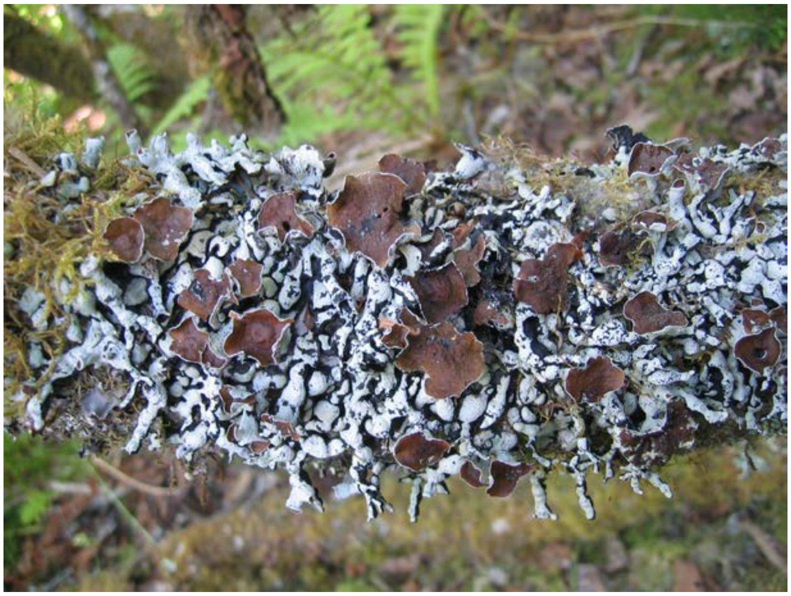

Figure IV-2. *Hypogymnia apinnata* (Tube lichen) is one of several species in the genus *Hypogymnia* collected for air quality biomonitoring. Photo by Karen L. Dillman

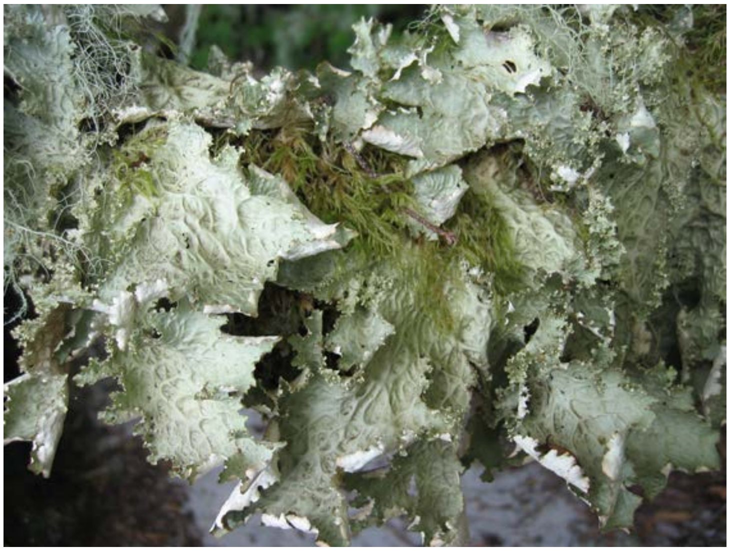

Figure IV-3 *Lobaria oregana* (Lung lichen) from Tebenkof wilderness. Photo by Karen L. Dillman

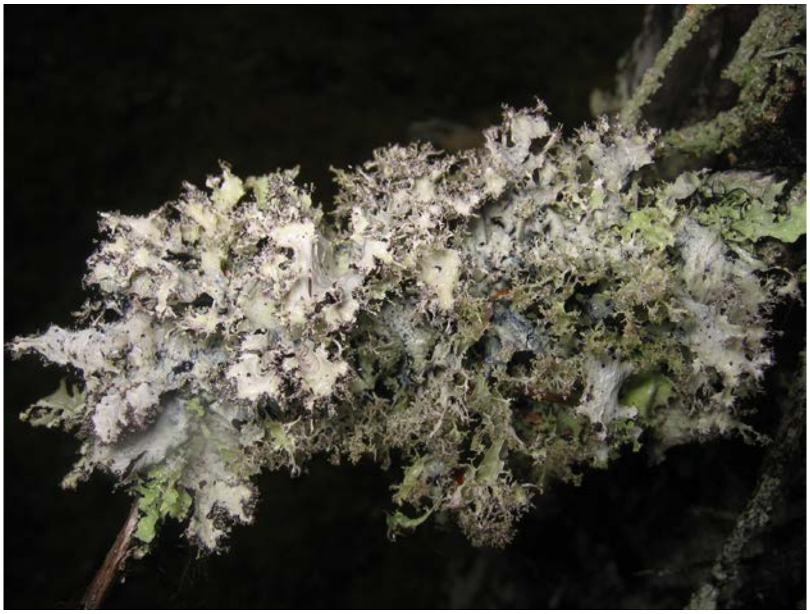

Figure IV-4. *Platismatia glauca* (Rag lichen) from Endicott River wilderness. Photo by Karen L. Dillman

Laboratory analysis

Lichens were prepared and sent to the University of Minnesota’s Soil Analytical Laboratory at the end of each field season. This laboratory also analyzed the lichen tissue from the baseline monitoring. Protocols for sample preparation for the inductively coupled plasma atomic emission spectrophotometry (ICP_AES) analysis are found in

Geiser et al. (1994). Standards were the same as those from the baseline monitoring period (Geiser et al 1994). No analytical splits were run with the samples. Duplicates from the tissue sample were run at the same time as the rest of the samples. Duplicate means were used in the statistical analysis for lichen species per element.

Nitrogen and sulfur are anlysed in lichens separately (see below). The elements determined simultaneously in ICP are: calcium (Ca), magnesium (Mg), sodium (Na), potassium (K), iron (Fe), manganese (Mn), aluminum (Al), copper (Cu), zinc (Zn), cadmium (Cd), chromium (Cr), nickel (Ni), lead (Pb), beryllium (Be), barium (Ba), boron (B), vanadium (V), molybdenum (Mo), rubidium (Rb), lithium (Li), strontium (Sr), silicon (Si) and tititanium (Ti). The values for beryllium, molybdenum, and rubidium were below the detection limits of the ICP machine and will not be described in detail in this report. Baseline monitoring did not report data for beryllium, barium, vanadium, lithium, strontium, silicon, and titanium. Therefore, the second monitoring period also contains baseline data for these seven elements.

All elements, except nitrogen (N) and sulfur (S) are reported in ppm (parts per million). For example, 2,500 mg of Calcium (Ca) per 1,000,000 mg of plant material is expressed on a dry weight basis of plant material (ppm). Nitrogen and sulfur are presented in percent (%) of dry weight. Nitrogen and sulfur are traditionally expressed in percent rather than ppm due to the generally higher levels of N and S found in plant material as compared to other elements. Percent can easily be converted to ppm by moving the decimal of the value over four places to the right. For example, if percent N is 1.25 then this is equivalent to 12,500 ppm.

During the second monitoring period, 241 individual samples were analyzed for all elements, with 76 percent of the samples analyzed for nitrogen and 83 percent of the samples analyzed for sulfur (Table IV. 1).

Table IV-1 Summary for lichen samples analyzed for all elements, nitrogen, and sulfur for 2003-2005.

Year	**All elements**	**Nitrogen**	**Sulfur**
2003	11	11	0
2004	121	101	118
2005	82	71	82
Totals	241	183	200

Nitrogen and Sulfur

A small portion of each ground sample was analyzed for total sulfur and total nitrogen following the procedures described in Geiser et al. (1994). For total N, a small portion of each ground sample (except samples of *Lobaria oregana*), were analyzed for total N. *Lobaria oregana* is a nitrogen-fixing lichen containing cyanobacteria that fix atmospheric N into a usable form for plants. Therefore, it is not a good indicator of elevated levels of N in lichens.

Baseline monitoring contained N values only for a small subset of *Alectoria sarmentosa* collected at the end of the monitoring period (Geiser et. al 1994; Derr 1994). The second monitoring period analyzed all *Alectoria sarmentosa* for N. The second monitoring period also contains baseline N values for *Platismatia glauca* and the combined *Hypogymnia* species.

Paired t-tests

Thirteen of the baseline monitoring plots were revisited during the second monitoring period (Table IV-2). Paired t-tests were used to determine if element content in lichens changed in pre-2000 and post-2000 samples. Paired t-tests are used where the entities measured in each sample are pairwise dependent. The goal is to test whether the mean difference between paired values is significantly different from zero (Ramsey and Schafer 1997).

Table IV-1. Revisited sites from which data were used for paired t-tests. Sites in bold are those where elemental analysis was repeated for nitrogen in *Alectoria sarmentosa* .

Plot Number	Location	Plot Number	Location
TNF 30	Stikine-LeConte	**TNF 145, 146**	**Pleasant Island**
TNF 31	Stikine-LeConte	**TNF 159**	**Karta River**
TNF033	Tebenkof	**TNF 189, 190**	**Kootznoowoo**
TNF069	**Pikes Lake**	**TNF 86, 88**	**Misty Fiords**
TNF101	Yakobi		
TNF116	Petersburg Ck		

Trends in Relation to Physiographic Features

Data were analyzed by regression to detect possible trends in lichen accumulation of elements in relation to year, latitude, longitude, precipitation, and elevation. Average precipitation was determined by using data for the nearest station at www.ncdc.noaa.gov/oa/climate/stationlocator

Provisional Thresholds

Provisional element analysis thresholds are levels of elements in certain lichen species that above which can be considered elevated. For this study, threshold is based on lichen species and background levels of air pollutants found in southeast Alaska. Thresholds were estimated for each element and lichen species by using the non-parametric 97.5% quartile in the data recorded from sites that are considered relatively free of human disturbance and pollution effects. Thresholds were calculated from 88 of the 127 plots that contain elemental tissue data collected between 1989 and 2005. Fifty-one of the 52 wilderness plots were considered pristine, even though some mining has occurred in the past in some wilderness areas. Fishing vessels also anchor off shore of many wilderness areas. Russell Fiords plot 62, which is within a mile of an existing road was excluded as a pristine area and is shown in the graphs as a non-wilderness plot. Some of the non-wilderness plots considered pristine are from Pikes Lake Research Natural Area (RNA), Old Toms Creek RNA, Dog Island, Kell Bay, Cape Fanshaw RNA, and Crystal Mountain on Mitkof Island. Thresholds are displayed as a solid line for each element and lichen species in the graphed figures for elemental content by year. A summary of the thresholds by element is found in Chapter XXXII.

To provide a broader picture of the elemental content of lichens from the Tongass, threshold levels are cursorily compared to published background levels from the Pacific Northwest. The term “background level” refers to the normal elemental content in a species in environments without enrichment of elements from natural or anthropogenic sources (USDA 1999). The term “baseline level” refers to the elemental content in collections from a given area that is recorded as historical points of reference (USDA 1999). Tongass baseline levels for three of the four lichen species analyzed in this report are found in Geiser et al. (1994). Tongass threshold levels are generally higher than background and baseline levels due to the natural enhancement of some elements from the hypermaritime environment and active geologic processes of the region.

Software used for all statistical analyses was S-Plus 2000 (MathSoft 1988-1999).

V. Summary of results for percent Sulfur (% S) from all species on the Tongass National Forest

Sulfur dioxide (SO_2) is a by-product of coal or fuel-oil combustion, ore reduction, paper manufacturing or other industrial processes, and vehicle exhaust. It is considered to be the primary factor causing lichen mortality in most urban and industrial areas, with fruticose or hair- like lichens being more susceptible to SO_2 than many foliose or crustose lichens (Seaward 1974). The first indications of SO_2 damage in lichens are the inhibition of nitrogen fixation in lichens that contain cyanobacteria, increased electrolyte leakage, and decreased photosynthesis and respiration followed by discoloration and death of the algae (Fields 1988).

The ICP analysis used in biomonitoring cannot distinguish between different forms of sulfur in a lichen sample. The two forms that are generally considered are inorganic sulfur (sulfates) and organic sulfur (sulfur in combination with organic molecules of the plant). The ICP method converts both forms into SO_2 gas and then measures the SO_2 by infra-red detection. This is the total sulfur reported (% S). Natural sources of sulfur can come from seawater and can be deposited on vegetation from ocean spray. Industrial pollution is also caused by sulfates (SO_2 gas from smokestakes that has combined with water in the atmosphere to form sulfates). Although many lichens are very sensitive to sulfur pollution, the lichens used in biomonitoring studies are relatively tolerant to elevated sulfur levels. Deposition must be high to have potentially toxic effects to sulfur tolerant lichens.

The lichens in wilderness areas on the Tongass are not expected to be high in sulfur due to considerable distances from anthropogenic sources in the region. Threshold values for % S in lichens are the following: *Alectoria sarmentosa* (Alesar) (.06 %), *Hypogymnia* species (.09%), *Lobaria oregana* (Lobore)(.13%) and *Platismatia glauca* (Plagla) (.08%).

Elemental plot means for % S in wilderness for each lichen species per year are at or below the % S threshold levels reported above (Figure V-1). Exceptions are plots 33 and 510 for Alesar (Figure V-4 for Tebenkof and Warren Island respectively) and plots, 500 and 516 for Lobore (Figure V-8 for Tebenkof and South POW respectively), which report plot means slightly above the % S threshold. Plot mean for % S in Plagla and *Hypogymnia* in some non-wilderness plots (Greens Creek mine and Mt Roberts) also report above threshold (see: Figure V-2 for plot means in non-wilderness per year ((blue diamonds and pink squares for 2005)), Figure V-4 for Alesar (plots 1000, 512), Figure V-6 for *Hypogymnia* (plots 512, 511b), and Figure V-10 for Plagla (plots 511a, 511b, 512).

SUMMARY OF PERCENT SULFUR DATA ANALYSIS

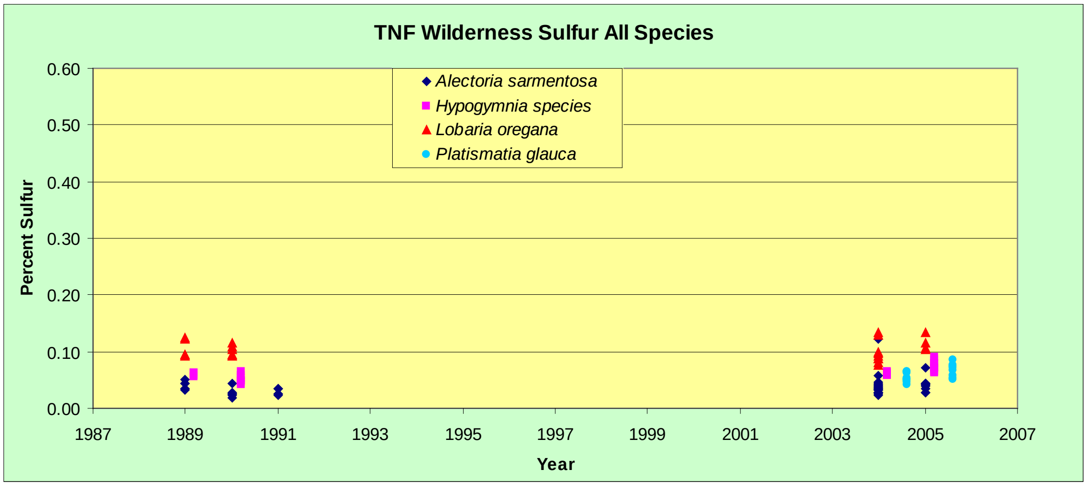

Figure V-1. Wilderness plot means of Percent Sulfur in *All Species* per year.

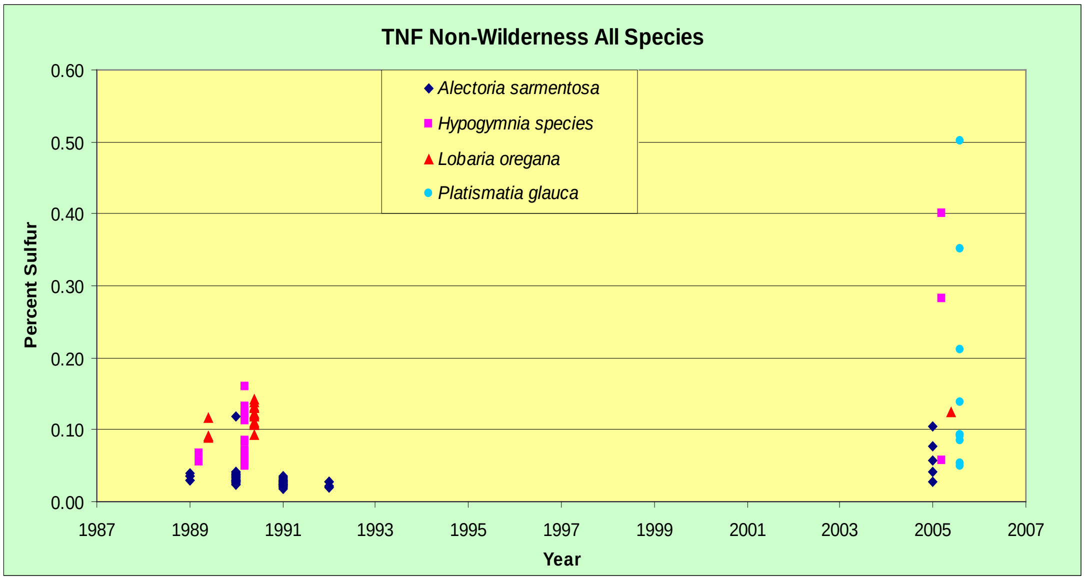

Figure V-2. Non-Wilderness plot means of Percent Sulfur in *All Species* per year.

Alectoria sarmentosa

Table V-2. Wilderness and Non-Wilderness Means, Standard Errors, and 95% Confidence Intervals for the Percent Sulfur content of *Alectoria sarmentosa* per year.

Percent Sulfur				**95% CI**	
Year	**Plot Type**	**Mean**	**Std. Error**	**Lower**	**Upper**
1989	Non-Wilderness	0.0344	0.0019	0.0292	0.0395
1989	Wilderness	0.0402	0.0030	0.0326	0.0478
1990	Non-Wilderness	0.0352	0.0033	0.0283	0.0420
1990	Wilderness	0.0264	0.0030	0.0190	0.0338
1991	Non-Wilderness	0.0259	0.0011	0.0236	0.0281
1991	Wilderness	0.0287	0.0027	0.0213	0.0361
1992	Non-Wilderness	0.0236	0.0011	0.0210	0.0262
2004	Wilderness	0.0386	0.0039	0.0304	0.0467
2005	Non-Wilderness	0.0592	0.0113	0.0302	0.0883
2005	Wilderness	0.0418	0.0039	0.0329	0.0506

Summary of Statistical Tests:

t = -1.6884, df = 8, p-value = 0.1298

There is no evidence of a difference in mean % S content in *Alectoria sarmentosa* from pre-2000 and post-2000(p-value = 0.1298). This analysis was for ten plots that had repeated values for % sulfur in *Alectoria sarmentosa*: Karta River (#159), Pleasant Island (#145, 146), Pikes Lake RNA (# 69), Kootznoowoo (# 189, 190), Petersburg Creek (#116), Stikine-LeConte (#30, 31), Yakobi (#101), Tebenkof (#33) and Misty Fiords (#85, 86).

Relationships are not strong in the % S content in *Alectoria sarmentosa* after accounting for latitude, longitude, elevation, year (Figures V-3, V-4 for year) and precipitation (see Brenner, 2006 for all graphed results).

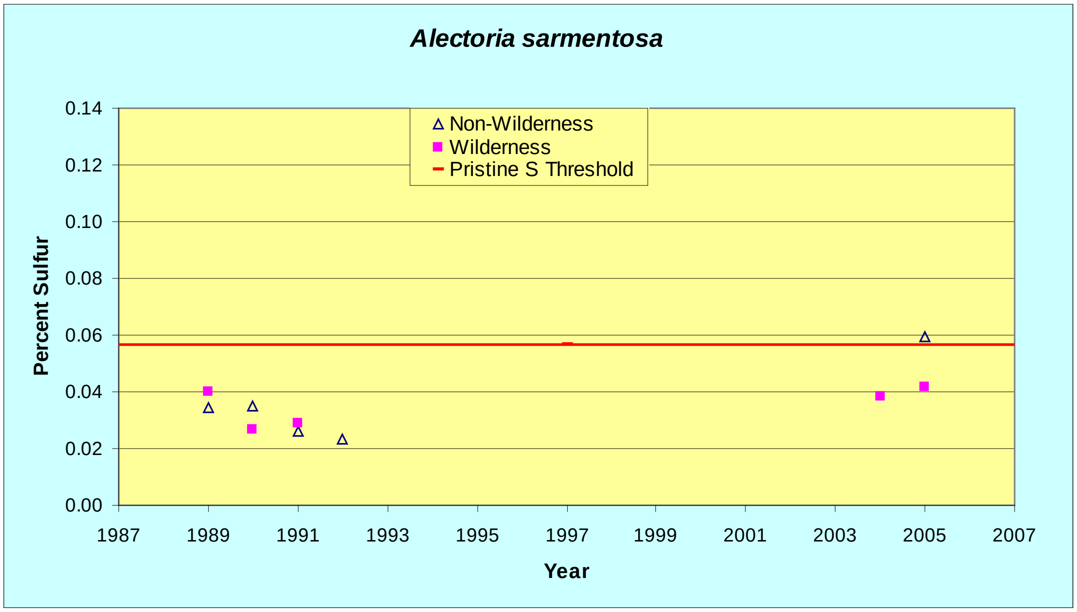

Figure V-3. Wilderness and Non-Wilderness yearly means of Percent Sulfur in *Alectoria sarmentosa* per year.

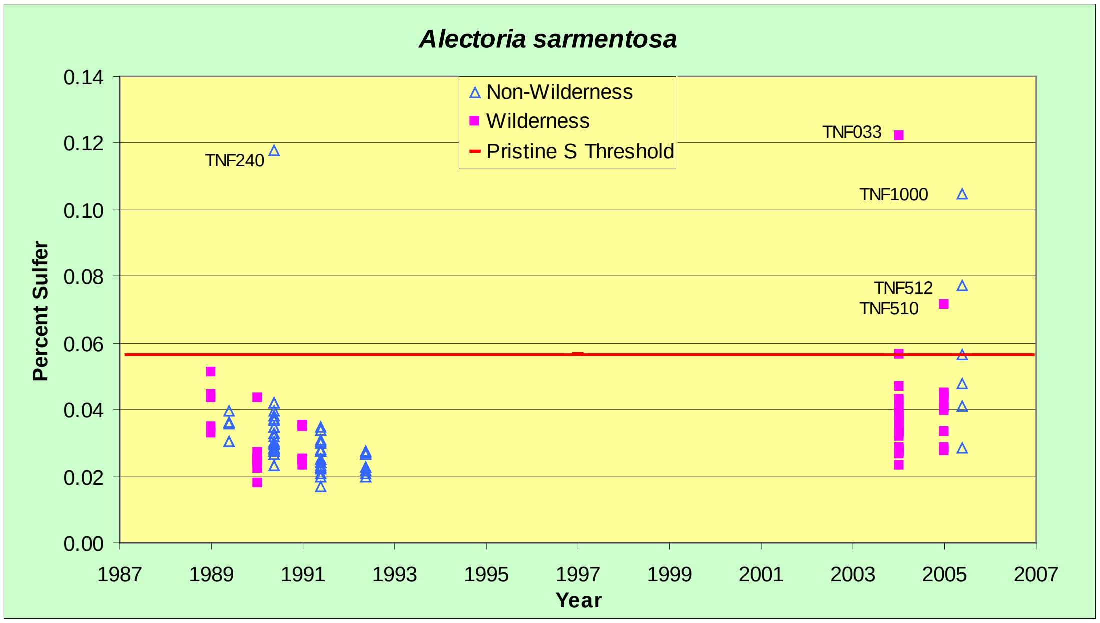

Figure V-4. Wilderness and Non-Wilderness plot means of Percent Sulfur in *Alectoria sarmentosa* per year.

Hypogymnia species

In this series, all of the *Hypogymnia* species were included as a group.

Table V-3. Wilderness and Non-Wilderness Means, Standard Errors, and 95% Confidence Intervals for the Percent Sulfur content of *Hypogymnia species* per year.

Percent Sulfur				95% CI	
Year	**Plot Type**	**Mean**	**Std. Error**	**Lower**	**Upper**
1989	Non-Wilderness	0.0620	0.0060	0.0142	0.1382
1989	Wilderness	0.0599	0.0014	0.0560	0.0637
1990	Non-Wilderness	0.0821	0.0078	0.0656	0.0986
1990	Wilderness	0.0511	0.0030	0.0438	0.0585
2004	Wilderness	0.0603	0.0012	0.0572	0.0634
2005	Non-Wilderness	0.2466	0.1004	0.1854	0.6786
2005	Wilderness	0.0746	0.0032	0.0673	0.0820

No t-tests were preformed for *Hypogymnia* due to any repeated samples.

Relationships are not strong in the % S content in *Hypogymnia* after accounting for latitude, longitude, elevation, year (see V-5 and V-6) and precipitation (see Brenner, 2006 for all graphed results).

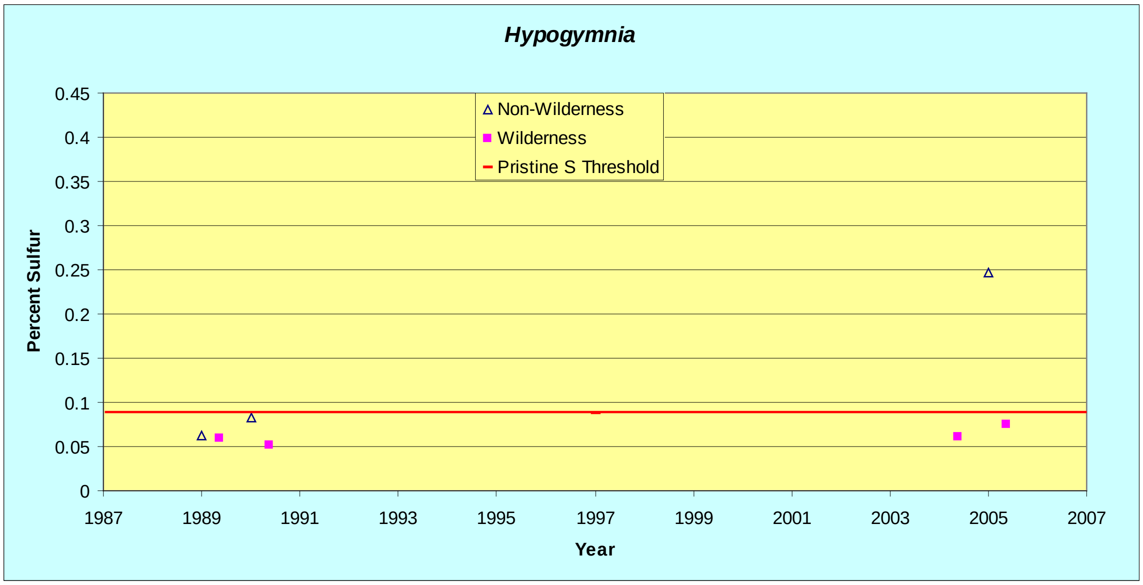

Figure V-5. Wilderness and Non-Wilderness yearly means of Percent Sulfur in *Hypogymnia species* per year.

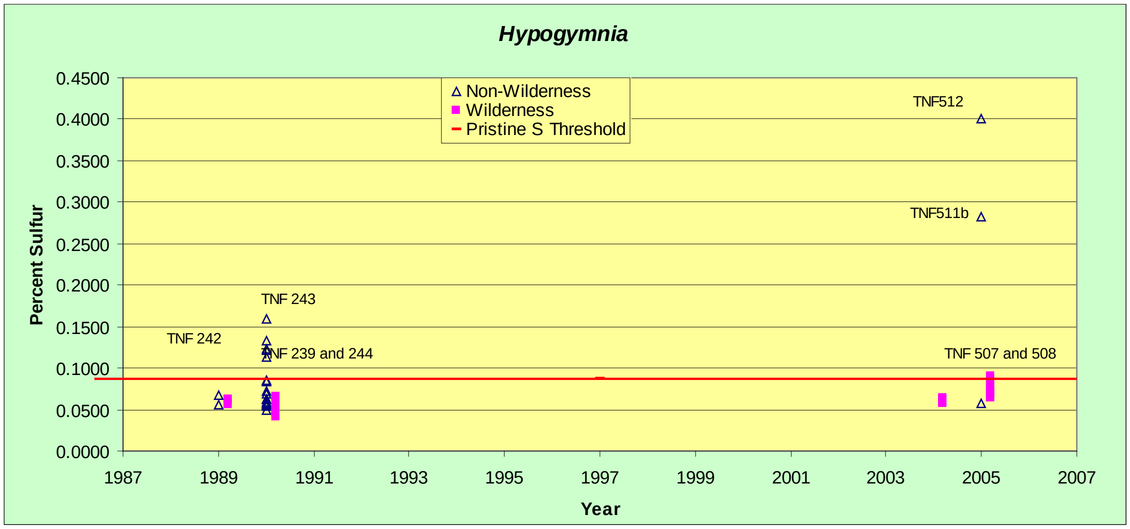

Figure V-6. Wilderness and Non-Wilderness plot means of Percent Sulfur in *Hypogymnia species* per year.

Lobaria oregana

Table V-4. Wilderness and Non-Wilderness Means, Standard Errors, and 95% Confidence Intervals for the Percent Sulfur content of *Lobaria oregana* per year.

Percent Sulfur				95% CI	
Year	**Plot Type**	**Mean**	**Std. Error**	**Lower**	**Upper**
1989	Non-Wilderness	0.0966	0.0065	0.0760	0.1172
1989	Wilderness	0.1055	0.0073	0.0851	0.1259
1990	Non-Wilderness	0.1203	0.0038	0.1122	0.1285
1990	Wilderness	0.1016	0.0036	0.0922	0.1109
2004	Wilderness	0.0980	0.0067	0.0824	0.1136
2005	Non-Wilderness	0.1242	NA	NA	NA
2005	Wilderness	0.1147	0.0067	0.0932	0.1361

Summary of Statistical Tests:

t = -0.1448, df = 4, p-value = 0.8884

There is no evidence of a difference in mean % S content in *Lobaria oregana* from pre-2000 and post 2000 samples (p-value = 0.8884). This analysis was for five plots that had repeated values for % S in *Lobaria oregana*, Stikine-LeConte (#30, 31), Tebenkof (#33) and Misty Fiords (# 86, 88).

Relationships are not strong in the % S content in *Lobaria oregana* after accounting for latitude, longitude, elevation, year (see Figures V-7 and V-8 for year) and precipitation (see Brenner, 2006 for all graphed results).

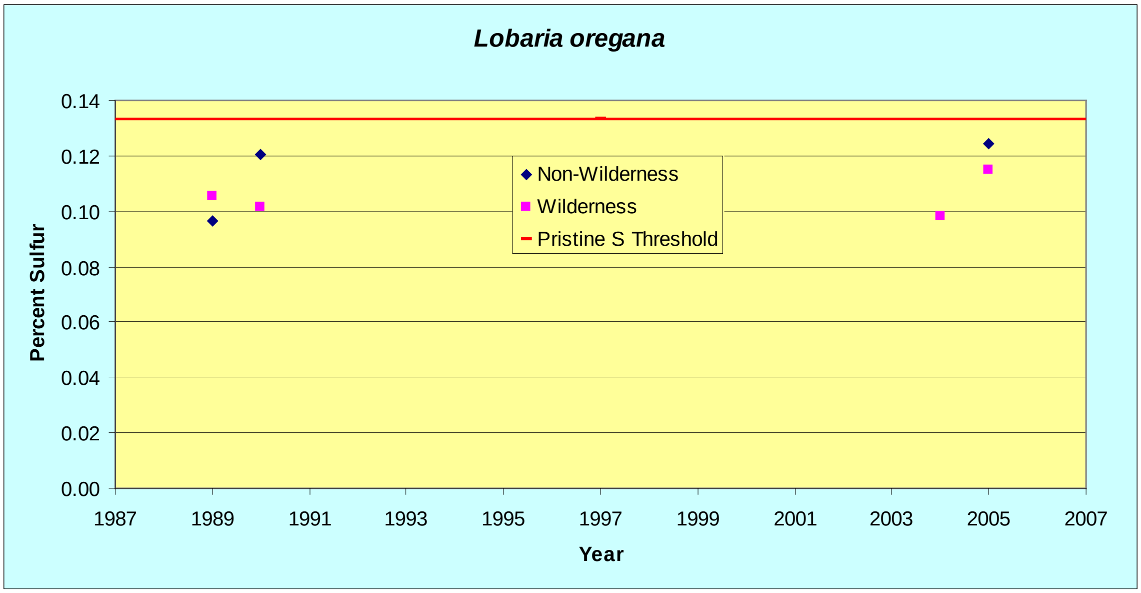

Figure V-7. Wilderness and Non-Wilderness yearly means of Percent Sulfur in *Lobaria oregana* per year.

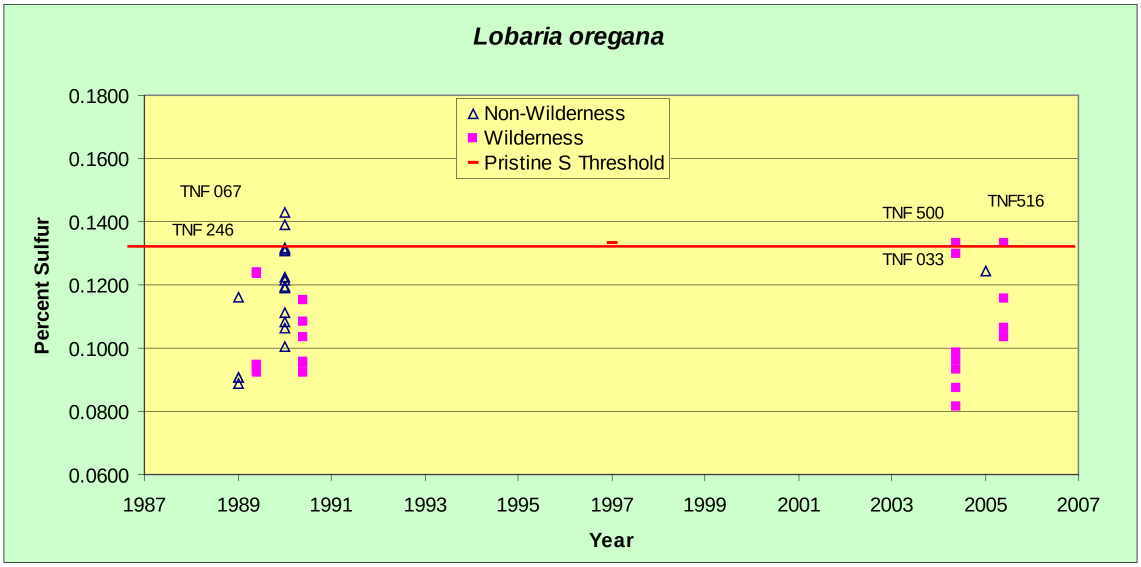

Figure V-8. Wilderness and Non-Wilderness plot means of Percent Sulfur in *Lobaria oregana* per year.

Platismatia glauca

Table V-5. Wilderness and Non-Wilderness Means, Standard Errors, and 95% Confidence Intervals for the Percent Sulfur content of *Platismatia glauca* per year.

Percent Sulfur				**95% CI**	
Year	**Plot Type**	**Mean**	**Std. Error**	**Lower**	**Upper**
2004	Wilderness	0.053483	0.002511	0.047802	0.059164
2005	Non-Wilderness	0.166472	0.046996	0.06016	0.272784
2005	Wilderness	0.066829	0.004328	0.056595	0.077063

No t-test was done due to lack of repeat samples. The values for % S are baseline for *Platismatia glauca*.

Relationships are not strong in the % S content in *Platismatia glauca* after accounting for latitude, longitude, elevation, year (see Figures V-9 and V-10 for year) and precipitation (see Brenner, 2006 for all graphed results).

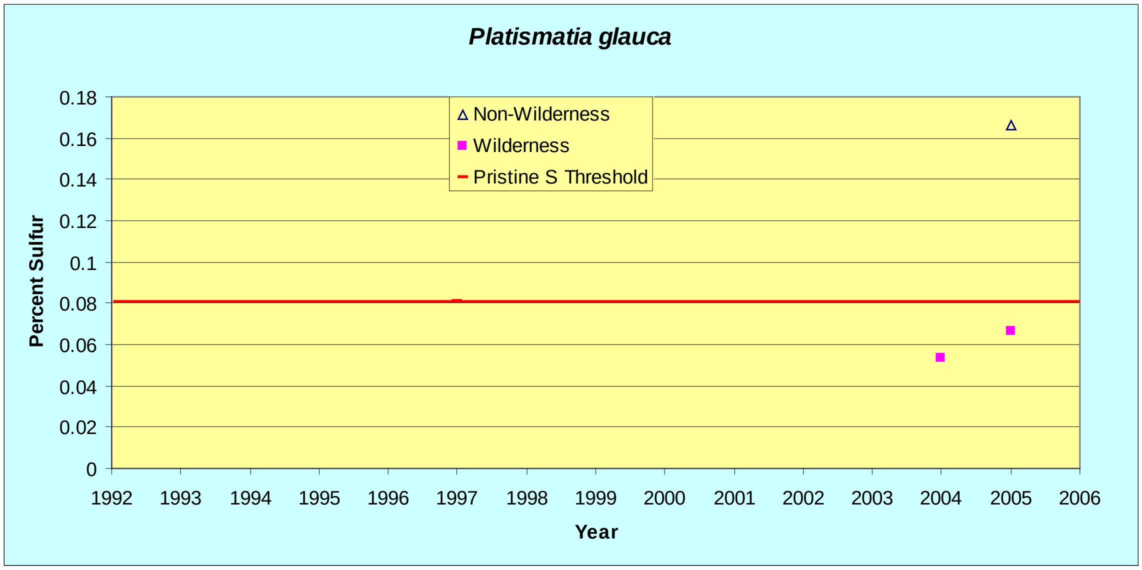

Figure V-9. Wilderness and Non-Wilderness yearly means of Percent Sulfur in *Platismatia glauca* per year.

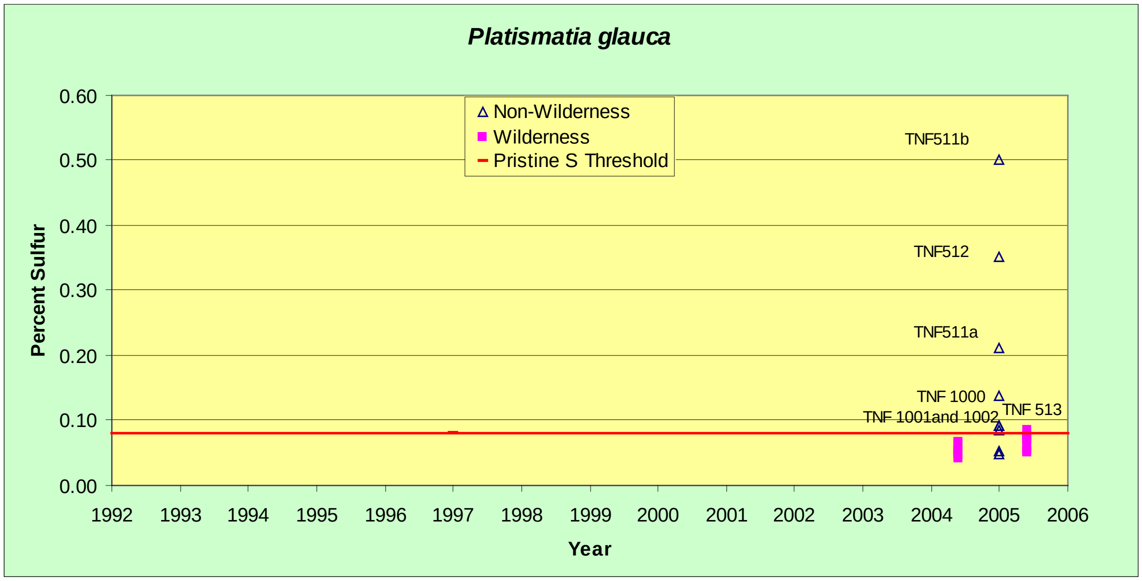

Figure V-10. Wilderness and Non-Wilderness plot means of Percent Sulfur in *Platismatia glauca* per year.

Conclusions*:* Percent Sulfur (% S) and all lichen species

General lichen enhancement levels for S due to urban or industrial sources are between .20 and 1.3 % S (USDA 1999). All thresholds of S for all lichen species are below .20 ppm. However, mean S in some lichens are above threshold and therefore within the range of the enhanced levels. Some of the enhanced lichens are in urban areas, but others are in wilderness. Since the ICP analysis does not differentiate between the sulfur types, it is difficult to determine if the wilderness lichens are elevated in sulfur due to their proximity to the ocean and in the variation in precipitation that washes pollutants out over time. It is most likely that the lichens with enhanced % S in urban and industrial areas are due to anthropogenic sources, as the lichens are not growing in exposed maritime beach locations in these urban or industrial areas. The difficulty lies in determining if the enhanced values in some of the wilderness lichens are due to the close proximity to the marine environment or to popular marine vessel anchorages and/or passageways in some. Trends in sulfur content can only be detected through repeated monitoring efforts to elucidate patterns of accumulation that may exist in these areas of elevated sulfur. Therefore, more sampling at regular intervals (every five years) is needed to determine the extent of the % S accumulation in the areas with values above threshold.

*Alectoria sarmentosa (*Alesar*)*

The estimated background for S in Alesar in the Pacific Northwest is 350 ppm (or .035 % S) (USDA 1999). Threshold for % S from Alesar in Southeast Alaska (.060 %) is elevated above the background .035 % due to the hypermaritime environment in this region. Yet, Alesar accumulates less and has a lower % S threshold compared to other lichens (Fig V-1 and V-2). Plot means of % S are above threshold in Alesar from plots 240, 33, 1000, 512, and 510 (Figure V-4). Plot 240, established in 1990, was within 3 km of the Sitka pulp mill which emitted sulfur dioxide in the paper bleaching process. This plot was not revisited during the second monitoring phase. The elevated % S in plots 33 and 510 could be due to close proximity to the open ocean and influence from extreme salt spray conditions in Tebenkof Bay and Warren Island. The waters adjacent to the plots in these wilderness areas are also used as anchorages for marine vessels. The other lichens analyzed from plot 33; the % S in *Lobaria oregana* and *Platismatia glauca* were just below threshold (see discussion below and Figures V-8 and V-10 respectively). There are no known industrial point sources near either wilderness. Plot 1000 is 175 ft. in elevation above sea level and is in the vicinity of the cruise ship docking area in downtown Juneau. Mean % S in plot 512 is probably enhanced due to the close proximity to the tailings pile and associated road machinery and power source at the Greens Creek mine in Admiralty Island.

Hypogymnia

Lichens analyzed in the genus *Hypogymnia* include *H. enteromorpha*, *H. duplicata*, *H inactiva*, and *H. appinata*. These lichens accumulate at similar rates and the results are combined for calculating the % S threshold for the genus *Hypogymnia* (.09%). The estimated background for % S in *Hypogymnia enteromorpha* is .075% in the Pacific Northwest (USDA 1999). The species *H. enteromorpha* was one of the four species with data that was combined in this study as little variation exists in elemental uptake in the genus *Hypogymnia* (USDA 1999). Elevated levels of % S in plots 511b (on road at mine portal) and 512 (area close to tailings pile) from Greens Creek are probably due to close proximity to industrial activities. Plot mean for % S in the wilderness plots 507 and 508 from Endicott River are just at threshold. It is difficult to determine if these levels are natural background due to oceanic influence or resulting from marine traffic along Lynn Canal or in Glacier Bay. Plots along the Sitka road system and near the pulp mill (plots 243, 242, 239 and 244) are above threshold from the baseline monitoring period in the 1990's. These areas should be revisited to determine if the lichens are now lower in S since the mill has since closed.

***Lobaria oregana* (Lobore)**

Most plots containing Lobore report at or below threshold for % S (see Figures V-7 and V-8 above). The general background level for % S in Lobore is .12% in the P acific Northwest (USDA 1999). As shown with the other lichens in this study, threshold for Lobore are slightly higher (.13%) than the background in the Pacific Northwest. The wilderness plots from South POW and Tebenkof that are slightly above the threshold for mean % S in Lobore are located in the beach fringe in exposed beach locations. The few plot means that report above threshold are from Sitka when the pulp mill was operating in 1990 (Figure V-8). Although considered a fair accumulator, Lobore was not collected at each plot. It is not analyzed for nitrogen due to this species nitrogen fixing physiology.

Platismatia glauca (Plagla)

Platismatia glauca (Plagla) was not used during baseline biomonitoring. Therefore, this report contains baseline for % S and Plagla (Table V.5). Background for % S in the Pacific Northwest for Plagla is .06% (USDA 1999), which is slightly lower than the threshold .08% on the Tongass. The wilderness plot from Egg Harbor on Coronation Island reported mean % S at the.08% threshold. Sulfur enhancement in the lichens could be due to the marine influence in this exposed location or due to it being an anchorage for fishing vessels. There was also mining at Egg Harbor during the turn of the 20th century. The non-wilderness plots that report above threshold are from Greens Creek mine, both near the portal (511a and 511b) and the tailings pile (512) (Figure V-10). It is noteworthy to mention that the tissue collected at the mine portal (511b) appears higher in mean sulfur than at the plot 250 feet away from the road (511a). The other non-wilderness plots 1000, 1001 and 1002 are elevated above threshold from the 175, 600, and 910 ft elevations respectively on Mt Roberts (Figure V-10). Elevated S is most likely due to industrial sources in this area of Juneau.

Plagla was also collected in Tebenkof and Warren Island, but both do not report elevated levels of % S as are reported in Alesar for these wildernesses (Figure V-4). *Platismatia glauca* is faster growing lichen and perhaps the tissue collected of this species was younger than the Alesar collected at the same sites.

VI. Summary of results for % Nitrogen (N) from all species on the Tongass National Forest

Nitrogen (NO_2) is a critical nutrient for many metabolic processes in plants and is often found in limited quantities in the environment. Nitrogen becomes a pollutant when more reactive N is released into the environment than can be assimilated without degradating air, land and water resources. Some of the largest sources of reactive N are airborne emissions (from the combustion of fossil fuels) and the production and use of nitrogen fertilizers. Besides being emitted in differing quantities from some areas within Alaska, nitrogen pollutants can also be transported across the Pacific Ocean from Asia. Long-term deposition of N compounds in elevated levels may affect resistance to insects and pathogens, soil microbiological processes, winter injury in conifers, and foliar leaching. Potential effects of long term N deposition are also changes in ecosystem structure and diversity, such as the replacement of some plants in nitrogen-poor systems with plants having higher N tolerances (Miller et. al. 1978).

Total N represents contributions from ammoniacal and oxidized forms of N and wet and dry deposition. Because this region has high precipitation, tissue analysis cannot differentiate wet from dry deposition, and is difficult to distinguish different forms of N (e.g. nitrate vs. ammoniacal forms of N). The lichens in wilderness areas on the Tongass are not generally expected to be high in N due to distances from point source pollutions in the region. Threshold (in percent) for % N in lichens from pristine areas are the following: *Alectoria sarmentosa* (.56%), *Hypogymnia* species (.88%), and *Platismatia glauca* (.80%). Plot means per year in wilderness and non-wilderness areas for each lichen species are all below the % N threshold (Figures VI-1 and VI-2.). However, some individual plot means are above threshold (Figures VI-4, VI-6, and VI-8). Additionally, plot means in % N in lichens collected from 1989 to 2005 appear to show an increase over time. (Figures V-1, V-2, V-4, V-6 and V-10)

VI. SUMMARY OF PERCENT NITROGEN DATA ANALYSIS

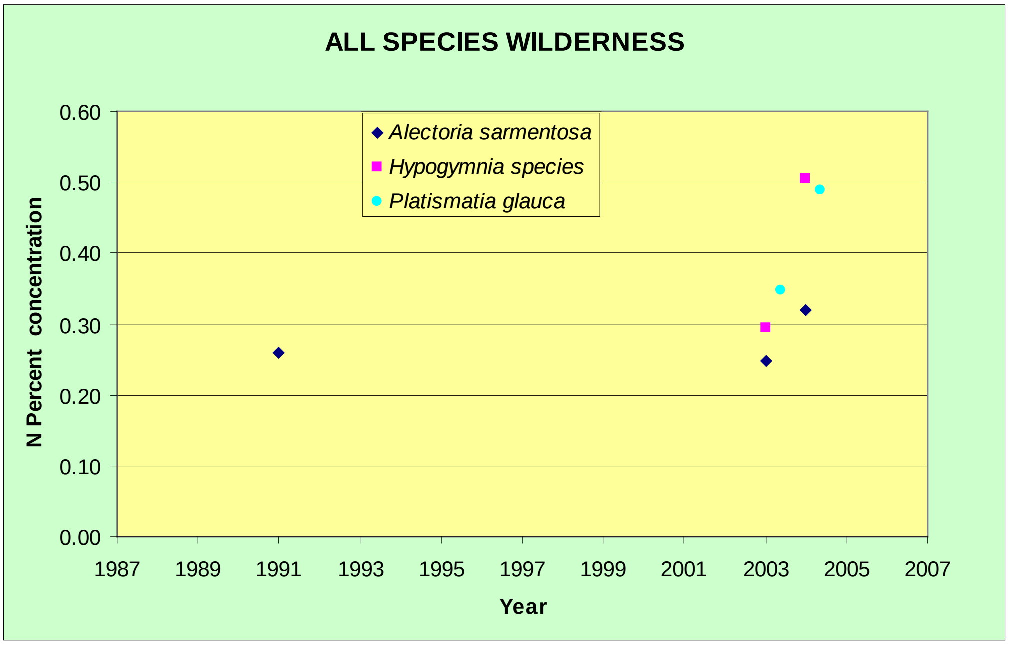

Figure VI-1. Wilderness plot means of Percent Nitrogen in *All Species* per year.

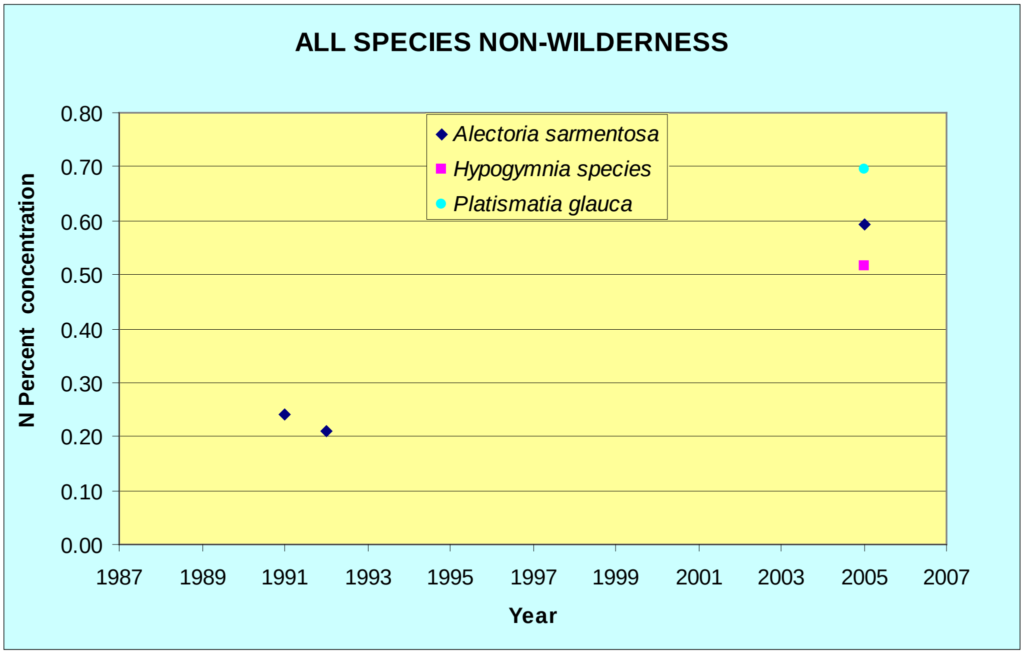

Figure VI-2. Non-Wilderness plot means of Percent Nitrogen in *All Species* per year.

Alectoria sarmentosa

Table VI-2. Wilderness and Non-Wilderness Means, Standard Errors, and 95% Confidence Intervals for the Percent Nitrogen content of *Alectoria sarmentosa* per year.

Percent Nitrogen				**95% CI**	
Year	**Plot Type**	**Mean**	**Std. Error**	**Lower**	**Upper**
1991	Non-Wilderness	0.24	0.0082	0.2236	0.2578
1991	Wilderness	0.26	0.0184	0.2089	0.3111
1992	Non-Wilderness	0.24	0.0082	0.2236	0.2578
2003	Wilderness	0.25	0.0724	-0.6719	1.1684
2004	Wilderness	0.32	0.0084	0.3031	0.3378
2005	Wilderness	0.46	0.0503	0.3453	0.5730
2005	Non-Wilderness	0.59	0.1142	0.2996	0.8865

Summary of Statistical Tests:

t = -0.9604, df = 4, p-value = 0.3912

There is no evidence of a difference in mean % N content in *Alectoria sarmentosa* from pre-2000 and post 2000 samples (p-value = 0.3912). Wilderness areas and plots close to wilderness that were compared for differences in % N from Alesar were: Pikes Lake RNA (69), Pleasant Island,(145, 146) Karta River (159) and Kootznoowoo (189, 190).

Relationships are not strong in the % N content in *Alectoria sarmentosa* after accounting for latitude, longitude, elevation, year (Figures VI-3, VI-4 for year) and precipitation (see Brenner, 2006 for all graphed results).

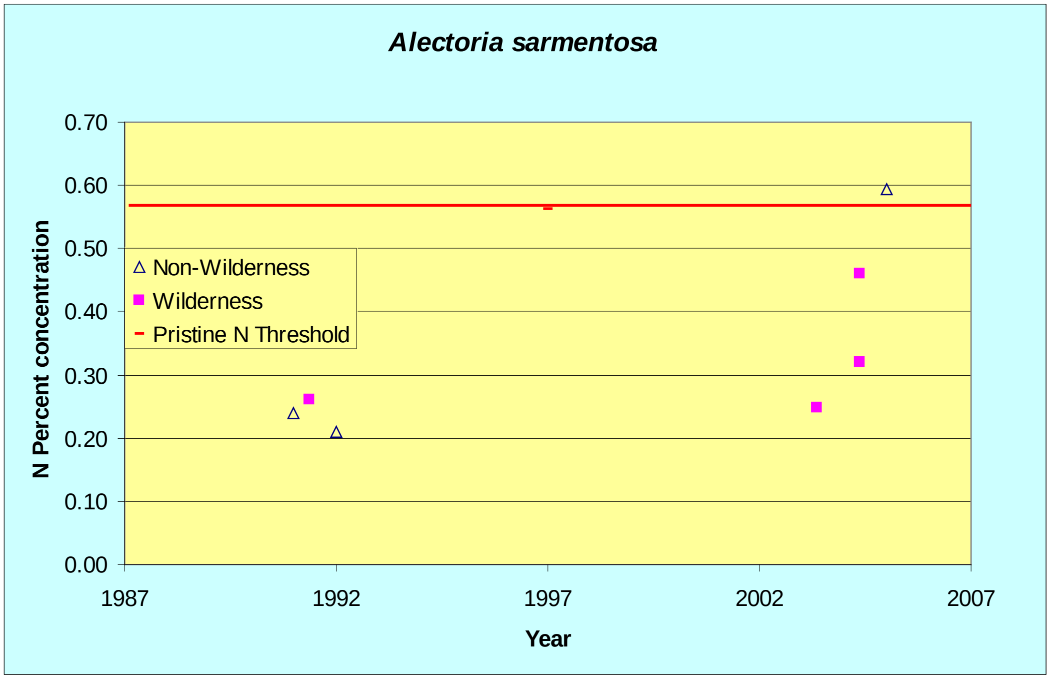

Figure VI-3. Wilderness and Non-Wilderness yearly means of Percent Nitrogen in *Alectoria sarmentosa* per year.

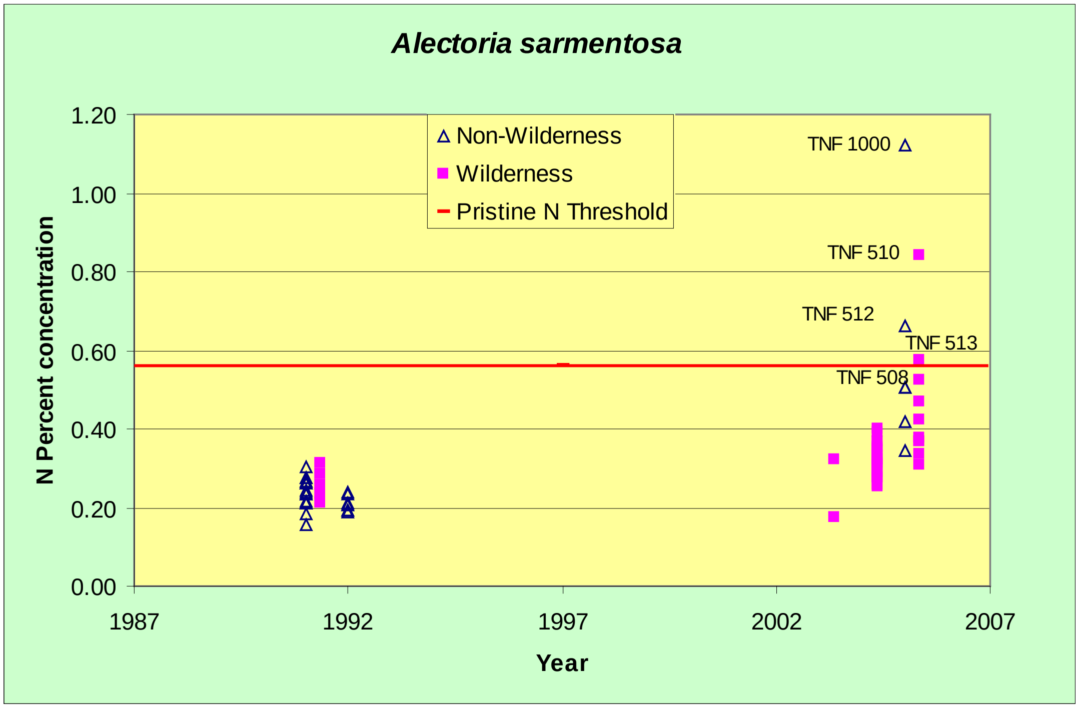

Figure VI-4. Wilderness and Non-Wilderness plot means of Percent Nitrogen in *Alectoria sarmentosa* per year.

Hypogymnia species

In this series, all of the *Hypogymnia* species were included as a group.

Table VI-3. Wilderness and Non-Wilderness Means, Standard Errors, and 95% Confidence Intervals for the Percent Nitrogen content of *Hypogymnia species* per year.

Percent Nitrogen				95% CI	
Year	**Plot Type**	**Mean**	**Std. Error**	**Lower**	**Upper**
2003	Wilderness	0.29	NA	NA	NA
2004	Wilderness	0.50	0.0144	0.4670	0.5409
2005	Wilderness	0.65	0.0495	0.5393	0.7676
2005	Non-Wilderness	0.71	0.0465	0.5067	0.9069

No t-test was done for *Hypogymnia* due to any repeated samples.

Relationships are not strong in the % N content in *Hypogymnia* species after accounting for latitude, longitude, elevation, year (Figures VI-5, VI-6 for year) and precipitation (see Brenner, 2006 for all graphed results).

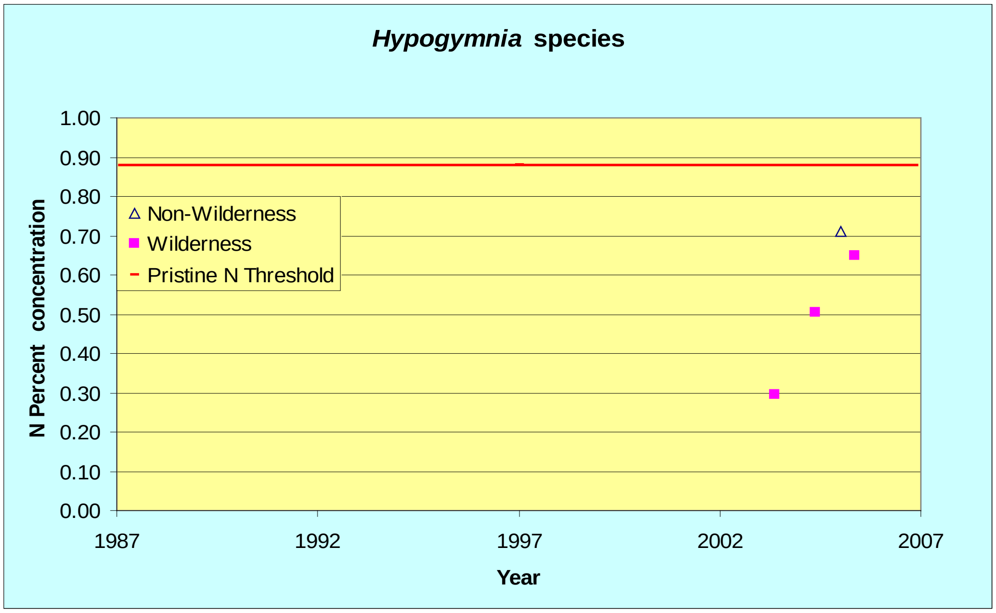

Figure VI-5. Wilderness and Non-Wilderness yearly means of Percent Nitrogen in *Hypogymnia species* per year.

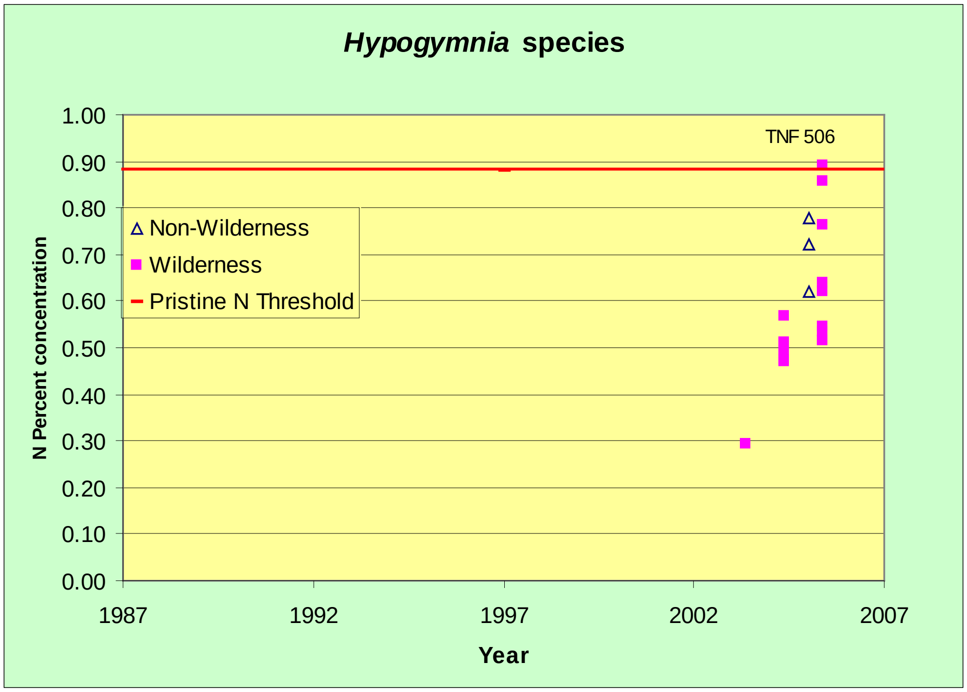

Figure VI-6. Wilderness and Non-Wilderness plot means of Percent Nitrogen in *Hypogymnia species* per year.

Platismatia glauca

Table VI-4. Wilderness and Non-Wilderness Means, Standard Errors, and 95% Confidence Intervals for the Percent Nitrogen content of *Platismatia glauca* per year.

Percent Nitrogen				**95% CI**	
Year	**Plot Type**	**Mean**	**Std. Error**	**Lower**	**Upper**
2003	Wilderness	0.35	NA	NA	NA
2004	Wilderness	0.49	0.0192	0.4435	0.5321
2005	Wilderness	0.64	0.0379	0.5529	0.7321
2005	Non-Wilderness	0.73	0.0520	0.6118	0.8472

No t-test was done for *Platismatia glauca* due to lack of repeat samples. The values for N are baseline for *Platismatia glauca* on the Tongass.

Relationships are not strong in the % N content in *Platismatia glauca* after accounting for latitude, longitude, elevation, year (Figures VI-5, VI-6 for year) and precipitation (see Brenner, 2006 for all graphed results).

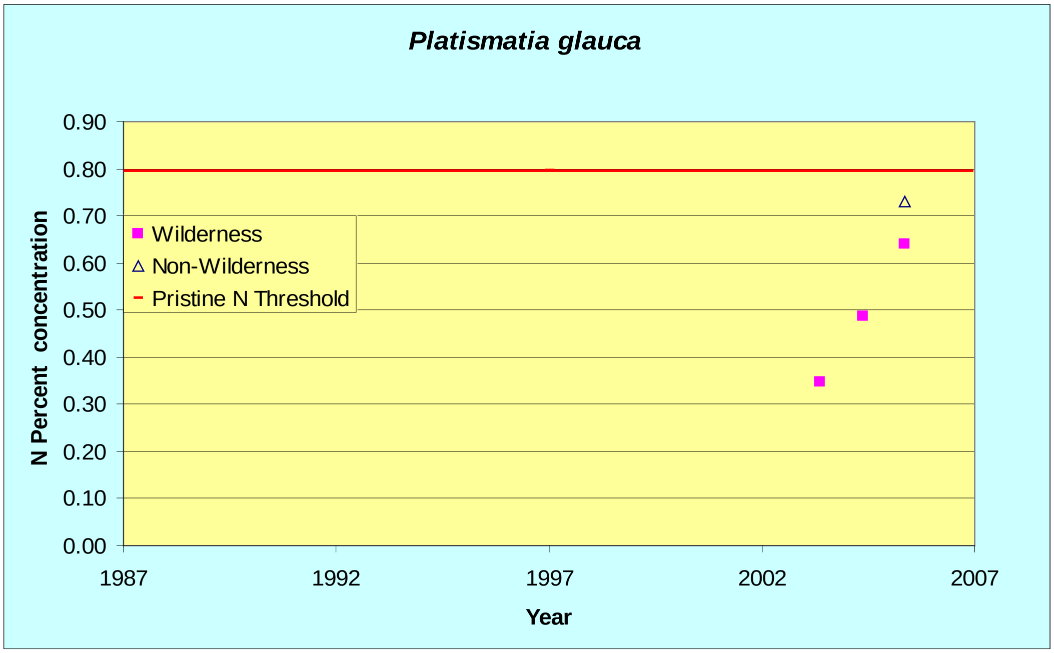

Figure VI-7. Wilderness and Non-Wilderness yearly means of Percent Nitrogen in *Platismatia glauca* per year.

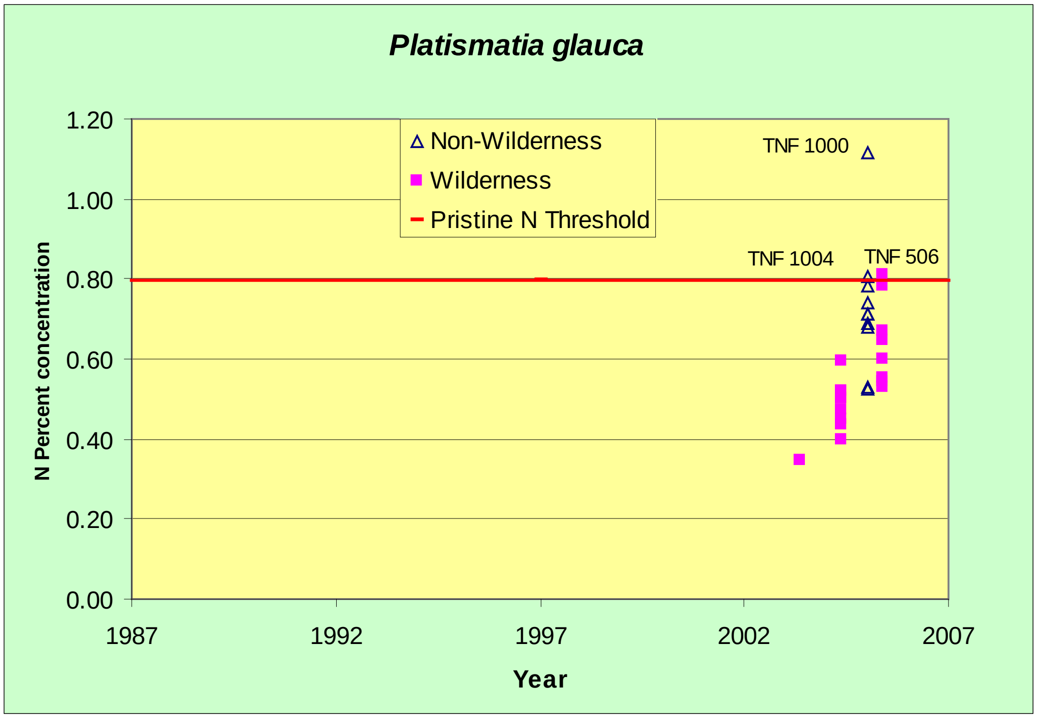

Figure VI-8. Wilderness and Non-Wilderness plot means of Percent Nitrogen in *Platismatia glauca* per year.

Conclusions: Percent Nitrogen (% N) and all lichens species

In *Alectoria sarmentosa,* the mean % N appears to increase over time from the early 1990's to 2005(Figure VI-2). Nitrogen levels in lichens collected from the 2003 to 2005 also show an apparent increase in mean nitrogen over time. However, the sample size is not large enough to determine if levels are statistically different across years. More regular sampling is needed to get trend information for N deposition. Steady rise in N deposition on the Tongass could be due to transpacific sources, as most of the plots in this recent study are from wilderness areas that are generally far from pollution point sources. Background values for % N from the Pacific Northwest are not available.

Alectoria sarmentosa (Alesar)

Alesar accumulates less and therefore has a lower % N threshold (.56%) compared to other lichens (Fig VI-1). Plot means of % N are above threshold in Alesar from plots 1000, 510, 512, and 513 (Figure VI-4). Plot 1000 is 175 ft. above the cruise ship docking area in downtown Juneau. The % N in Alesar could be elevated due to proximity to this industry and other urban sources. Plot 510 from Warren Island wilderness has no known industrial sources. However, the nearby Warren Cove is an anchorage for marine fishing vessels in transit. Plot 512 is from Greens Creek near the tailings pile and associated pollution from the mine. Plot 513 from Egg Harbor on Coronation is also an anchoring location, and elevated % N could be due to this influence.

Hypogymnia

Plot means for % N were not elevated above threshold in the samples of *Hypogymnia* collected (Figures VI-5 and VI-6). The Endicott River plot 506 is just at threshold for % N. It is mentioned here because Plagla from plot 506 is also right at threshold. It is unclear weather this is natural background for this area or due to marine vessel traffic on Lynn Canal and Glacier Bay. *Hypogymnia* was not collected for N analysis in the first monitoring period.

Platismatia glauca (Plagla)

The plot mean for % N in Plagla is elevated above threshold in plot 1000, which is 175 ft above the cruise ship docking area in Juneau (Figure VI-8). Plot means of % N in Plagla for plot 1004 (Mt Roberts at 1700 ft) and 506 (Endicott River wilderness) were at threshold. All other plot means were below the % N threshold for Plagla (Figure VI-8). Again, plot means by year show an increase in nitrogen from 2003, 2004 and 2005 in Plagla as in *Hypogymnia* and *Alectoria*. More sampling is needed in the Juneau area around the downtown cruise ship docking area to determine the extent of the nitrogen deposition from cruise ship emissions and other industrial sources in the downtown area.

VII. Summary of results for Aluminum (Al) from all lichen species on the Tongass National Forest

Aluminum (Al) is mineralogically abundant on earth. Elevated levels in lichens are usually associated with road dust.

Provisional thresholds for Al on the Tongass are the following in ppm: *Alectoria sarmentosa* (56.78 ppm), *Hypogymnia* (1126.44 ppm), *Lobaria oregana* (580.03 ppm), and *Platismatia glauca* (1063.57ppm).

Plot means for Al are above threshold in Alesar from Greens Creek tailings pile area (plot 512), area 175 ft above Juneau on Mt Roberts (plot 1000) the Sitka, Kuiu and Hoonah road systems (plots 108, 240, 219, and 143), Tebenkof Bay Wilderness (plot 33), and Endicott River Wilderness (plot 508) (Figure VII-4). Plots means for Al are above threshold in *Hypogymnia* for the Greens Creek mine tailing pile area (plot 512), Russell Fiords (plot 62), near the Shrine of St Therese off the Juneau road system (plot 43), and Mitkof Island near Petersburg (plot 44) (Figure VII-6). The Russell Fiord plot 62 is just inside the wilderness boundary and is not considered a pristine wilderness plot in this study due to the proximity to the Dangerous River Bridge, the airstrip, and the unpaved road system of Yakutat (shown as an open triangle indicating non-wilderness). Plot means for Al in Lobore are above threshold in Russell Fiords (plot 62) (Figure VII-8). Plot means for Al in Plagla are above threshold in three plots; Greens Creek tailing pile (512), Pikes Lake plot within 5 miles of the Yakutat road (69) and the Russell Fiord plot near the Dangerous River bridge (Figures VII-9 and VII-10).

VII. SUMMARY OF Al PPM DATA ANALYSIS

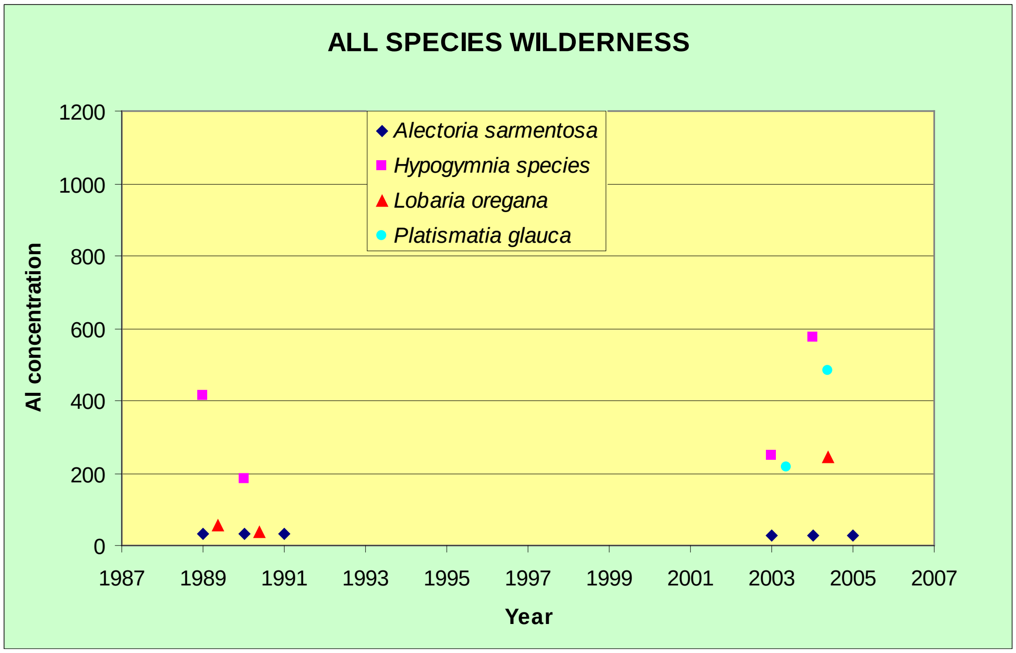

Figure VII-1. Wilderness plot means of Al ppm in *All Species* per year.

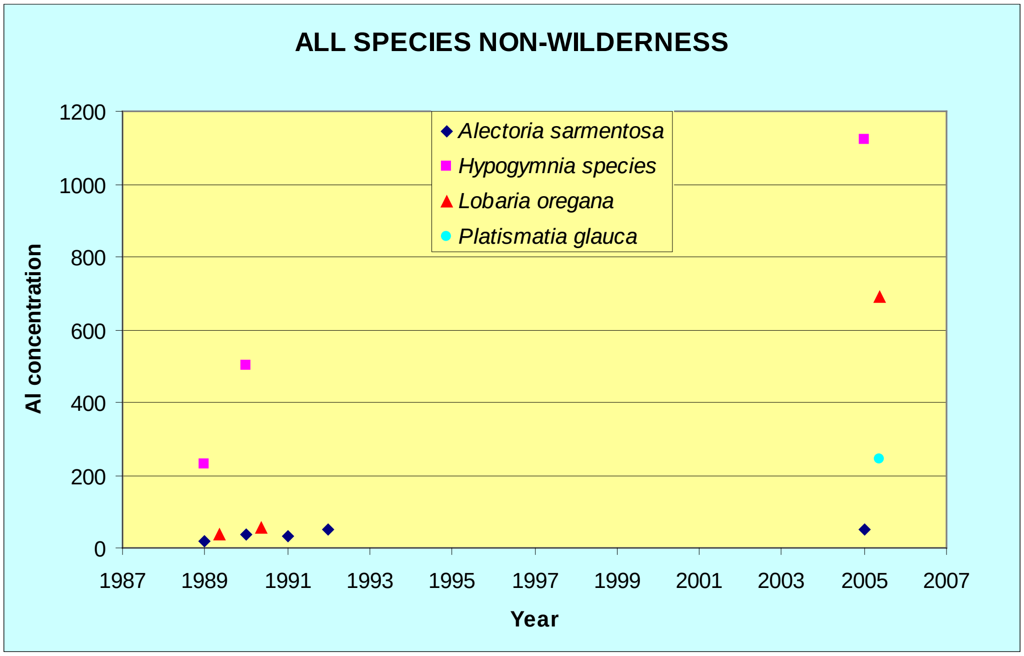

Figure VII-2. Non-Wilderness plot means of Al ppm in *All Species* per year.

Alectoria sarmentosa

Table VII-2. Wilderness and Non-Wilderness Means, Standard Errors, and 95% Confidence Intervals for the Al ppm content of *Alectoria sarmentosa* per year.

Al ppm				**95% CI**	
Year	**Plot Type**	**Mean**	**Std. Error**	**Lower**	**Upper**
1989	Non-Wilderness	20.44	3.8508	9.7485	31.13
1989	Wilderness	31.61	2.3594	25.5455	37.6768
1990	Non-Wilderness	39.00	3.8960	30.9901	47.0066
1990	Wilderness	30.64	4.2295	20.2942	40.9929
1991	Non-Wilderness	33.60	3.4532	26.3451	40.8549
1991	Wilderness	32.50	7.1454	12.6625	52.3401
1992	Non-Wilderness	52.0302	13.7371	19.5470	84.5133
2003	Wilderness	28.17	11.1950	0	170.4120
2004	Wilderness	27.10	2.2231	22.5006	31.6982
2005	Non-Wilderness	50.47	13.9491	14.6127	86.3273

Summary of Statistical Tests:

t = -0.2644, df = 8, p-value = 0.7981

There is no evidence of a difference in mean Al content in *Alectoria sarmentosa* from pre-2000 and post 2000 samples (p-value = 0.7981). This analysis was for six wildernesses or near wilderness plots that had repeated values for Al in *Alectoria sarmentosa*: Karta River (# 159), Pleasant Island (# 145, 146), Pikes Lake RNA (# 69), Kootznoowoo (#189, 190), Petersburg Creek (# 116), and Tebenkof (#33).

Relationships are not strong in the Al content in *Alectoria sarmentosa* after accounting for latitude, longitude, elevation, year (Figures VII-3, VII-4 for year) and precipitation (see Brenner, 2006 for all graphed results).

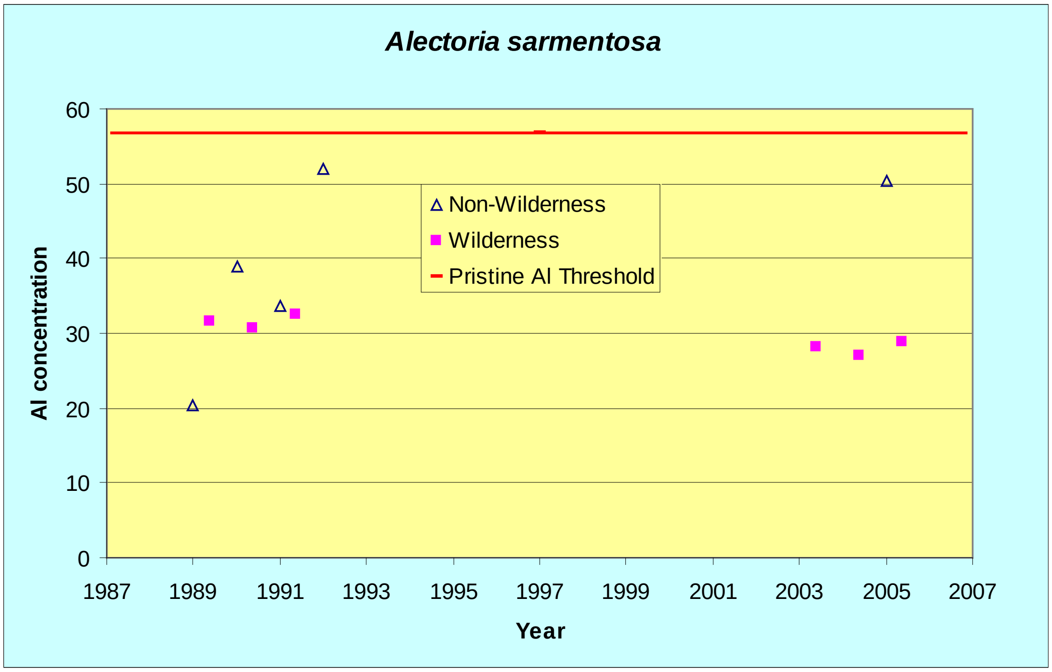

Figure VII-3. Wilderness and Non-Wilderness yearly means of Al ppm in *Alectoria sarmentosa* per year.

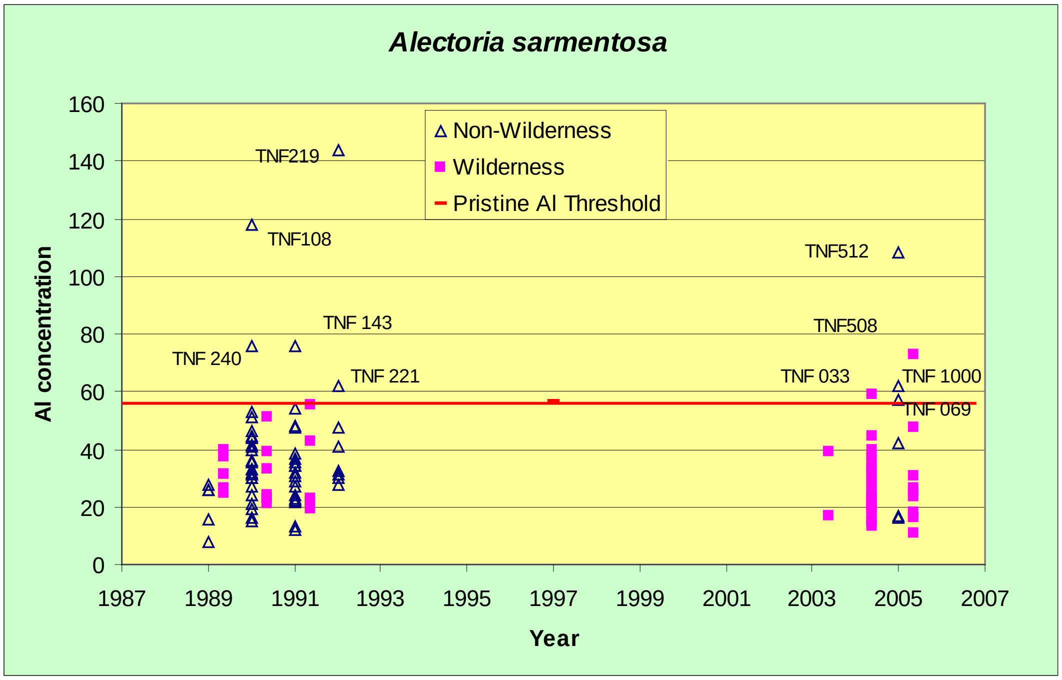

Figure VII-4. Wilderness and Non-Wilderness plot means of Al ppm in *Alectoria sarmentosa* per year.

Hypogymnia species

In this series, all of the *Hypogymnia* species were included as a group.

Table VII-3. Wilderness and Non-Wilderness Means, Standard Errors, and 95% Confidence Intervals for the Al ppm content of *Hypogymnia species* per year.

Al ppm				95% CI	
Year	Plot Type	Mean	Std. Error	Lower	Upper
1989	Non-Wilderness	229.50	205.5000	0	2840.6250
1989	Wilderness	411.83	142.6811	15.6871	807.9796
1990	Non-Wilderness	502.16	78.3077	337.6395	666.6763
1990	Wilderness	185.71	11.4701	157.6480	213.7806
2003	Wilderness	246.07	na	na	na
2004	Wilderness	572.74	104.7184	303.5572	841.9314
2005	Non-Wilderness	1,122.16	294.7619	0	2390.4146
2005	Wilderness	443.83	110.8418	188.2312	699.4344

No t-tests were preformed for *Hypogymnia* due to the lack of repeat samples.

Relationships are not strong in the Al content in *Hypogymnia* species after accounting for latitude, longitude, elevation, year (Figures VII-5, VII-6 for year) and precipitation (see Brenner, 2006 for all graphed results).

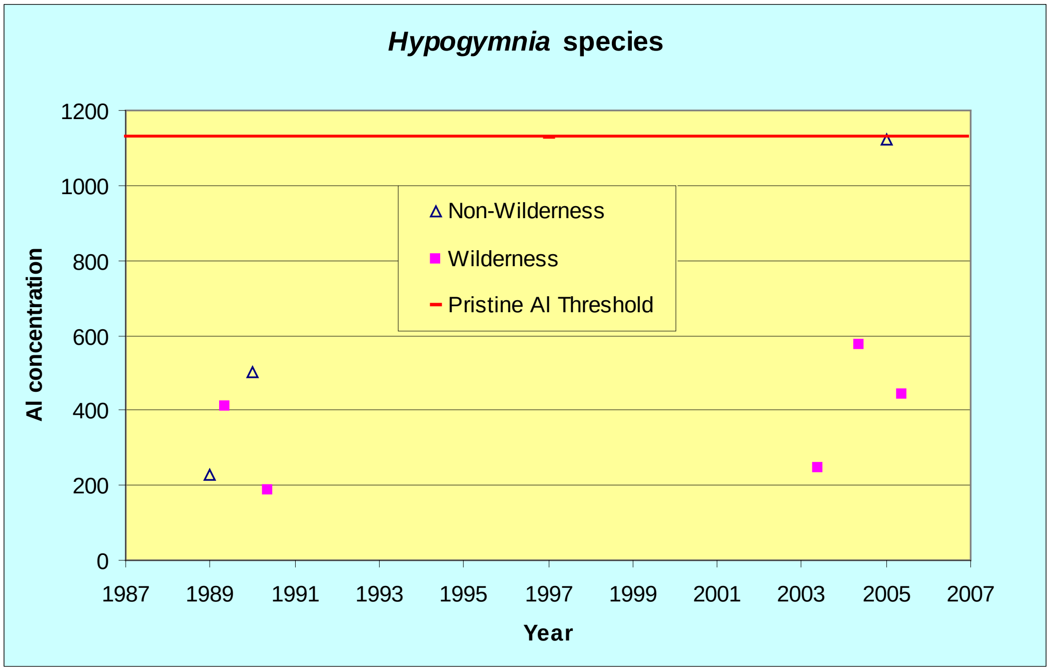

Figure VII-5. Wilderness and Non-Wilderness yearly means of Al ppm in *Hypogymnia species* per year.

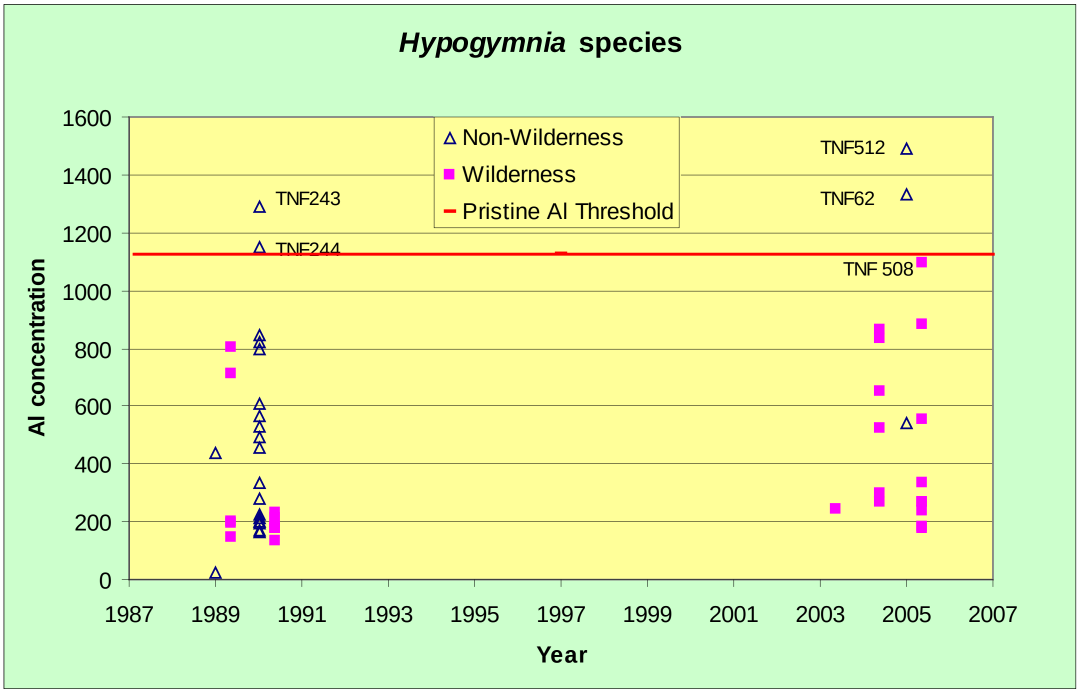

Figure VII-6. Wilderness and Non-Wilderness plot means of Al ppm in *Hypogymnia species* per year.

Lobaria oregana

Table VII-4. Wilderness and Non-Wilderness Means, Standard Errors, and 95% Confidence Intervals for the Al ppm content of *Lobaria oregana* per year.

Al ppm				95% CI	
Year	**Plot Type**	**Mean**	**Std. Error**	**Lower**	**Upper**
1989	Non-Wilderness	35.08	12.3516	0	74.3917
1989	Wilderness	57.15	15.2926	14.6874	99.6057
1990	Non-Wilderness	55.69	11.2639	31.1439	80.2279
1990	Wilderness	37.93	17.2154	0	82.1850
2004	Wilderness	242.58	72.9612	64.0497	421.1091
2005	Non-Wilderness	689.71	NA	NA	NA
2005	Wilderness	98.79	44.7471	0	241.1986

Summary of Statistical Tests:

t = -1.9293, df = 4, p-value = 0.1259

There is no evidence of a difference in mean Al content in *Lobaria oregana* from pre-2000 and post 2000 samples (p-value = 0.1259). This analysis was for three wildernesses areas that had repeated values for Al in *Lobaria oregana*: Stikine-LeConte (# 30, 31), Tebenkof (#33), and Misty Fiords (#86, 88).

Relationships are not strong in the Al content in *Lobaria oregana* after accounting for latitude, longitude, elevation, year (Figures VII-7, VII-8 for year) and precipitation (see Brenner, 2006 for all graphed results).

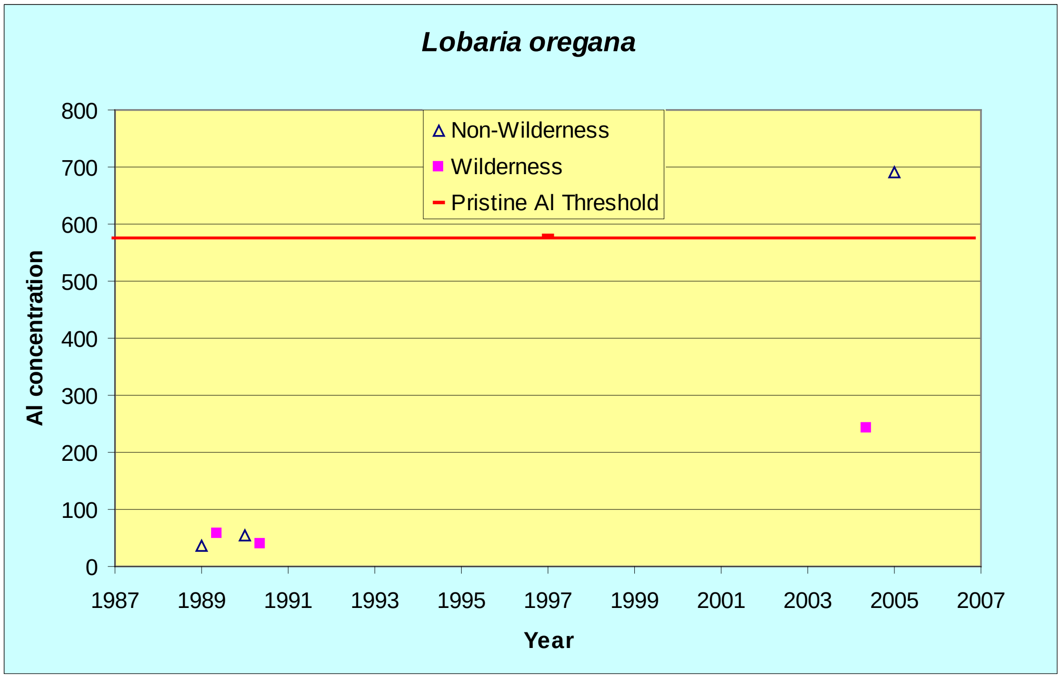

Figure VII-7. Wilderness and Non-Wilderness yearly means of Al ppm in *Lobaria oregana* per year.

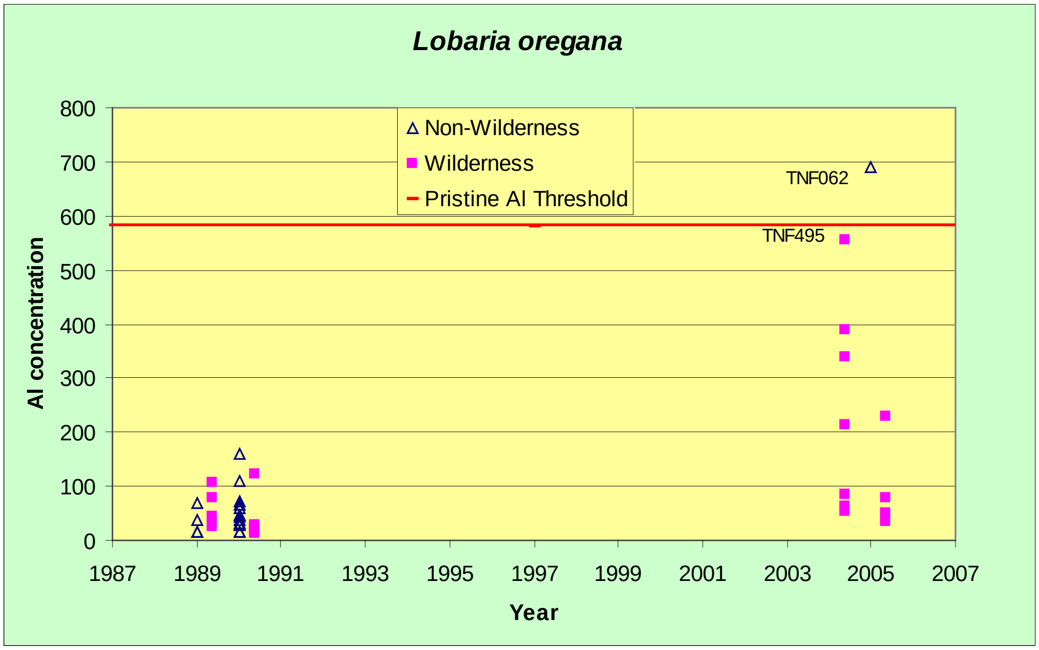

Figure VII-8. Wilderness and Non-Wilderness plot means of Al ppm in *Lobaria oregana* per year.

Platismatia glauca

Table VII-4. Wilderness and Non-Wilderness Means, Standard Errors, and 95% Confidence Intervals for the Al ppm content of *Platismatia glauca* per year.

Al ppm				95% CI	
Year	**Plot Type**	**Mean**	**Std. Error**	**Lower**	**Upper**
2003	Wilderness	213.86	na	na	na
2004	Wilderness	483.88	88.8447	282.8962	684.8574
2005	Non-Wilderness	781.3696	97.6291	560.5172	1002.2219

No t-test was done for *Platismatia glauca* due to the lack of repeat samples. Values are baseline for Al and Plagla.

Relationships are not strong in the Al content in *Platismatia glauca* after accounting for latitude, longitude, elevation, year (Figures VII-9, VII-10 for year) and precipitation (see Brenner, 2006 for all graphed results).

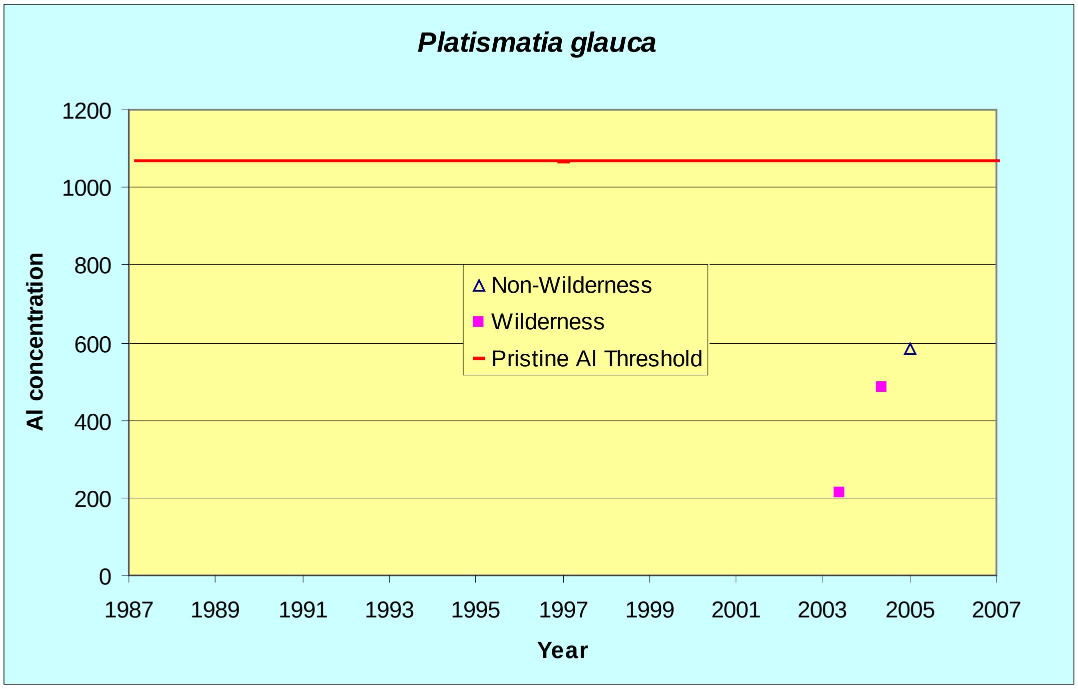

Figure VII-9. Wilderness and Non-Wilderness yearly means of Al ppm in *Platismatia glauca* per year.

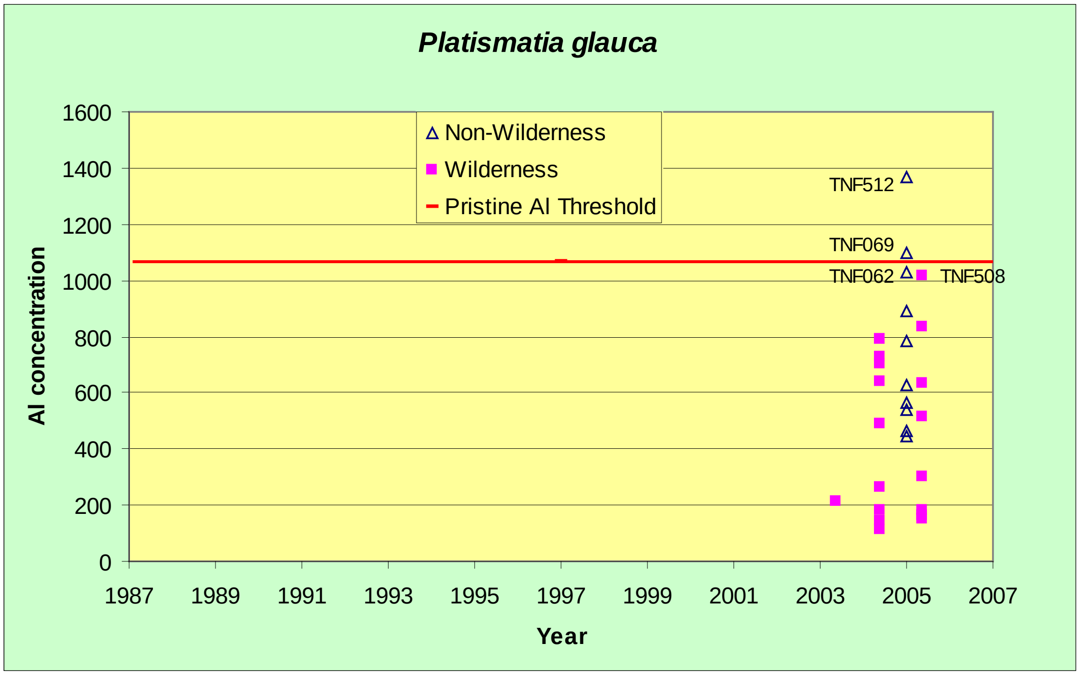

Figure VII-10. Wilderness and Non-Wilderness plot means of Al ppm in *Platismatia glauca* per year.

Conclusions: Aluminum (Al) and all lichen species

The provisional threshold for Al in lichens on the Tongass is slightly higher than the estimated background and enhanced cutoff values from the Pacific Northwest (USDA 1999). This could be due to the geology and the large amount of exposed rock from retreating glaciers and other geomorphic features that occur in southeast Alaska.

***Alectoria sarmentosa* (Alesar)**

The background value for Al in the Pacific Northwest is 50 ppm, which is almost equal to the threshold of 56.78 ppm (USDA 1999). The proximity to unpaved roads may explain the elevated values of Al in lichens from the Greens Creek plot near the tailings pile, and other plots near road systems (plot 219 from Kuiu,108 and 240 from Sitka, 221 from Douglas, and 143 from Whitestone area near Hoonah) (Figure VII-4). Plot 33 from Tebenkof is also slightly above threshold. It is unclear why Al would be elevated in this maritime location. Plot 508 from Endicott River could be elevated due to the close proximity to Glacier Bay and glacial dust.

Hypogymnia

The general background values for Al in *Hypogymnia* are between 500 and 700 ppm, which is lower than the Tongass threshold of 1126 ppm (USDA 1999). The plot means for Al in *Hypogymnia* are elevated above threshold from plot 512 (Greens Creek Tailings pile), plot 62 (Russell Fiord near Harlequin Lake), and plots 243 and 244 (Sitka road system) (Figure VII-6). Elevated levels can be attributed to the close proximity to unpaved roads. The Harlequin Lake plot is also within a half mile of an unpaved airstrip which may induce more windblown dust to the area. Natural erosion and windblown soils from the Yukon during high pressure conditions can bring massive sand clouds over the region as well (James per comm. 2007). Mean Al from plot 508 in the Endicott River wilderness is just below the threshold. All other plot means are at or below the Al threshold for *Hypogymnia* (Figure VII-5 and VII-6).

***Lobaria oregana* (Lobore)**

The background value for Al in Lobore is 200 ppm, which is lower than the Tongass threshold of 580 ppm (USDA 1999). The plot means for Al in Lobore are elevated above threshold from plot 62 (Russell Fiords) (Figure VII-8). The elevated level is possibly due to the reasons stated above under *Hypogymnia*.

Platismatia glauca

Background for Al for the Pacific Northwest in Plagla is 500 ppm and the threshold value for the Tongass is 1063 ppm (USDA 1999). The plot means for Al in Plagla are elevated above threshold from plot 69 (Pike Lake) and plot 512 (Greens Creek tailings pile area) (Figure VII-10). Again, the elevated levels in Plagla are probably due to the close proximity to unpaved roads. Plot 69 near Pike Lake may also be enhanced by windblown soils from the Yukon as described above under *Hypogymnia* for the Harlequin Lake plot as the Pike Lakes area is within a few miles of Harlequin Lake. Plot 508 from Endicott has levels of Al just below threshold. This plot shows elevated levels of Al in Alesar, Hypo and Plagla. It is unclear why this area is elevated, but it could be due to windblown dusts from Glacier Bay and the Chilkat Peninsula.

VIII. Summary of results for Boron (B) from all species on the Tongass National Forest

Boron is a naturally occurring element. Borates are boron combined with oxygen and other elements in compounds. Boron (B) enters the environment mainly from weathering of boron-containing rocks, from seawater in the form of boric acid vapor, and from volcanic and other geothermal activities. Although to a lesser extent, boron is also released from human activities. These include the use of borate-containing fertilizers and herbicides, and the burning of plant-based products such as wood, coal, or oil (IPCS 1998). Boron also enters into the environment from the use of borates and perborates in the home and industry, through leaching from treated wood or paper and from sewage and sewage sludge disposal. Plants and lichens can accumulate boron, but it does not accumulate to a greater extent along the food chain when animals consume plants. Boron is an essential nutrient for plants, but in some plants there is only a narrow margin between deficiency and toxicity.

Provisional thresholds for B on the Tongass are the following: *Alectoria sarmentosa* (9.33 ppm), *Hypogymnia* (9.47 ppm), *Lobaria oregana* (4.06 ppm), and *Platismatia glauca* (6.05 ppm).

Mean boron is elevated above threshold from various locations and in all lichen species. The Stikine-LeConte plot 195 is slightly elevated in Plagla from the recent monitoring period (Figure VIII-10). Samples from the Sitka road system when the pulp mill was operating are above thresholds (in Alesar plot 108, 208, 209, and 246 in Figure VIII-4; in Hypo plots 243 245, 246, 108 and 113 in Figure VIII-6; in Lobore plot 246, Figure VIII-8).

VIII. SUMMARY OF B PPM DATA ANALYSIS

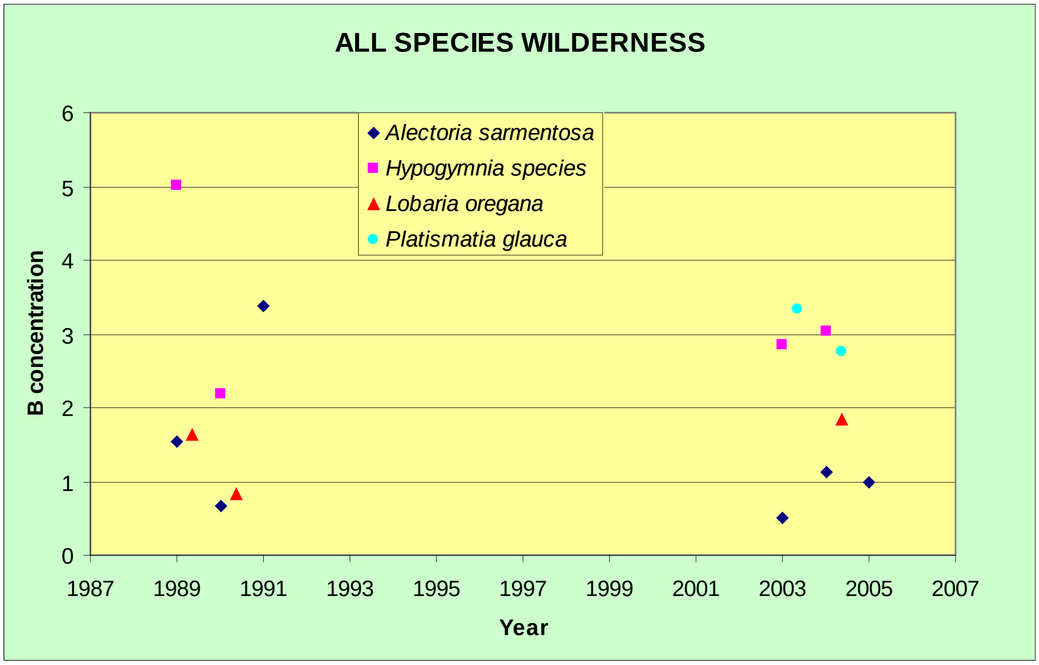

Figure VIII-1. Wilderness plot means of B ppm in *All Species* per year.

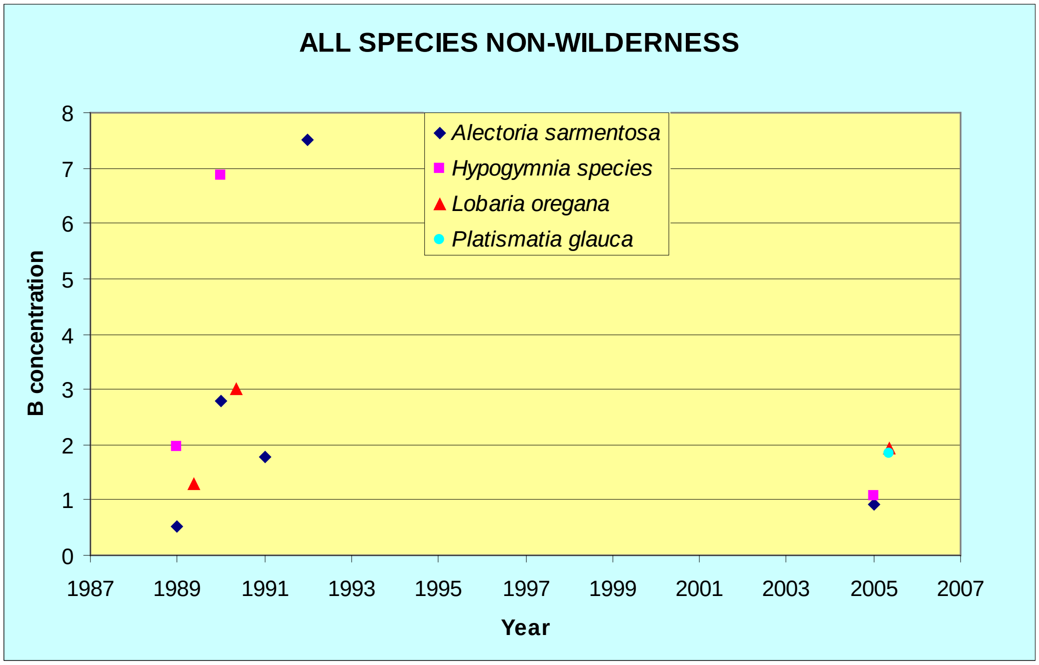

Figure VIII-2. Non-Wilderness plot means of B ppm in *All Species* per year.

Alectoria sarmentosa

Table VIII-2. Wilderness and Non-Wilderness Means, Standard Errors, and 95% Confidence Intervals for the B ppm content of *Alectoria sarmentosa* per year.

B ppm				**95% CI**	
Year	**Plot Type**	**Mean**	**Std. Error**	**Lower**	**Upper**
1989	Non-Wilderness	0.53	0.0586	0.3626	0.6878
1989	Wilderness	1.54	0.5888	0.0263	3.0535
1990	Non-Wilderness	2.78	0.7734	1.1994	4.3790
1990	Wilderness	0.66	0.1238	0.3587	0.9646
1991	Non-Wilderness	1.77	0.1778	1.3973	2.1443
1991	Wilderness	3.37	1.5110	0	7.5697
1992	Non-Wilderness	7.50	1.9605	2.8674	12.1389
2003	Wilderness	0.50	0.0362	0.0366	0.9557
2004	Wilderness	1.22	0.1280	0.8574	1.3870
2005	Non-Wilderness	0.92	0.0905	0.6893	1.1545
2005	Wilderness	0.99	0.1800	0.5786	1.3929

Summary of Statistical Tests:

t = 1.2005, df = 8, p-value = 0.2643

There is no evidence of a difference in mean B content in *Alectoria sarmentosa* from pre-2000 and post 2000 samples (p-value = 0.2643). This analysis was for ten plots with repeated values for B in Alesar from: Karta River (# 159), Pleasant Island (#145, 146), Pikes Lake RNA (# 69), Kootznoowoo (#189, 190), Petersburg Creek (#116), and Tebenkof (#33).

Relationships are not strong in B content for Alesar after accounting for latitude, longitude, elevation, year (see Figures VIII-3, VIII-4 for year) and precipitation (see Brenner, 2006 for all graphed results).

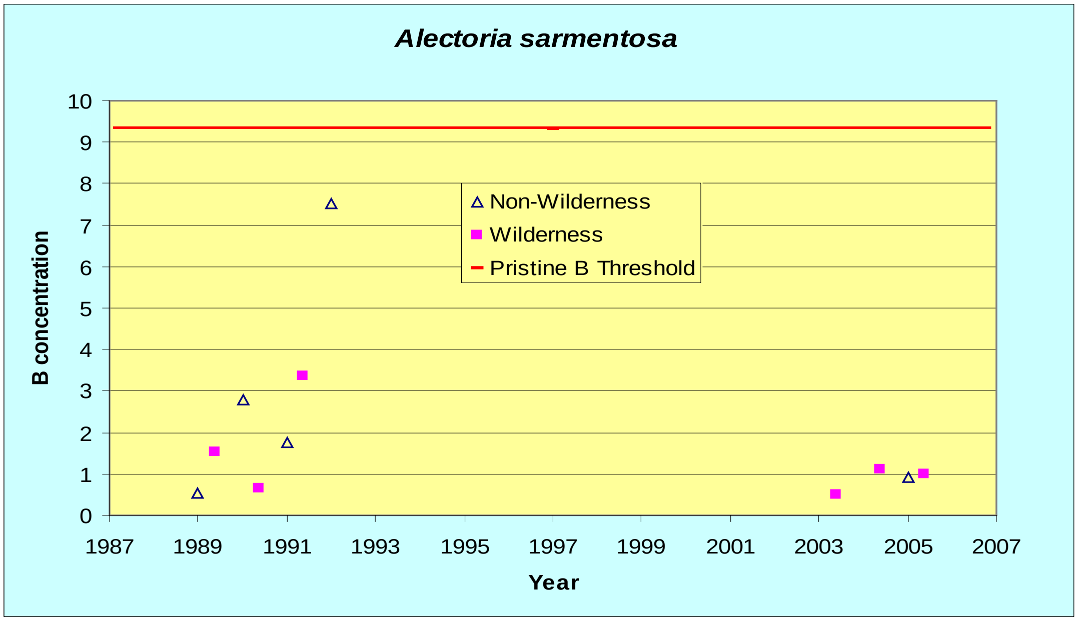

Figure VIII-3. Wilderness and Non-Wilderness yearly means of B ppm in *Alectoria sarmentosa* per year.

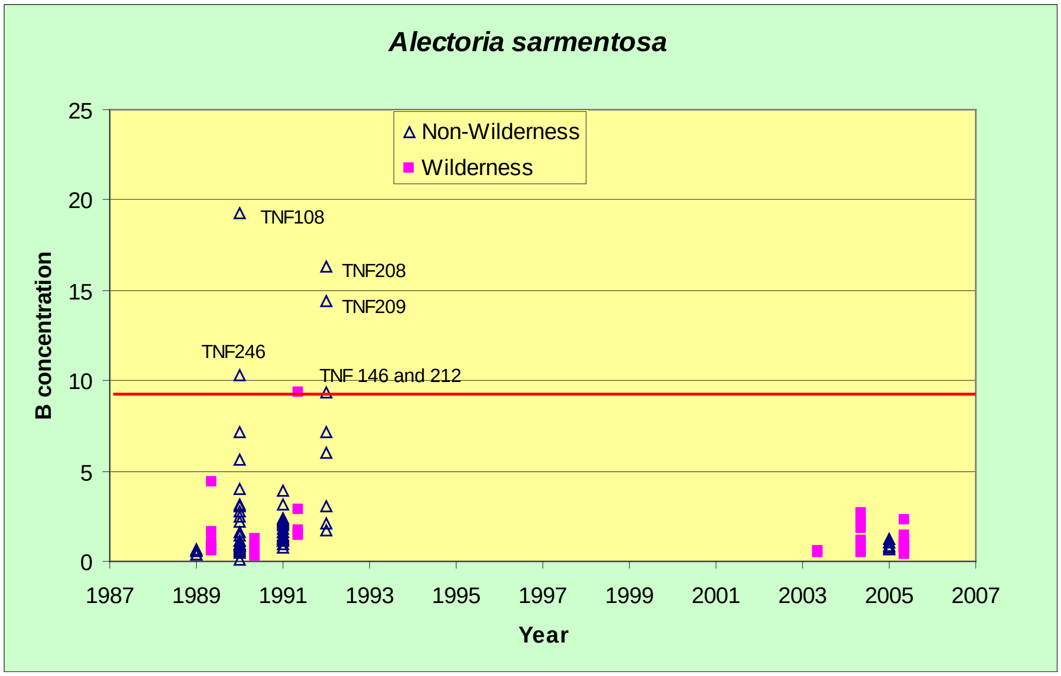

Figure VIII-4. Wilderness and Non-Wilderness plot means of B ppm in *Alectoria sarmentosa* per year.

Hypogymnia species

In this series, all of the *Hypogymnia* species were included as a group.

Table VIII-3. Wilderness and Non-Wilderness Means, Standard Errors, and 95% Confidence Intervals for the B ppm content of *Hypogymnia species* per year.

B ppm				95% CI	
Year	**Plot Type**	**Mean**	**Std. Error**	**Lower**	**Upper**
1989	Non-Wilderness	1.97	1.56	0	21.7917
1989	Wilderness	5.01	1.1197	1.9060	8.1236
1990	Non-Wilderness	6.87	0.8718	5.0392	8.7024
1990	Wilderness	2.18	0.4829	0.9978	3.3612
2003	Wilderness	2.86	na	na	na
2004	Wilderness	3.04	0.3202	2.2151	3.8615
2005	Non-Wilderness	1.08	0.5080	0	3.2650
2005	Wilderness	2.87	0.4287	1.8815	3.8586

T-tests were not performed on *Hypogymnia* data due to lack of repeat samples.

Relationships are not strong in B content for *Hypogymnia* after accounting for latitude, longitude, elevation, year (Figures VIII-5, VIII-6 for year) and precipitation (see Brenner, 2006 for all graphed results).

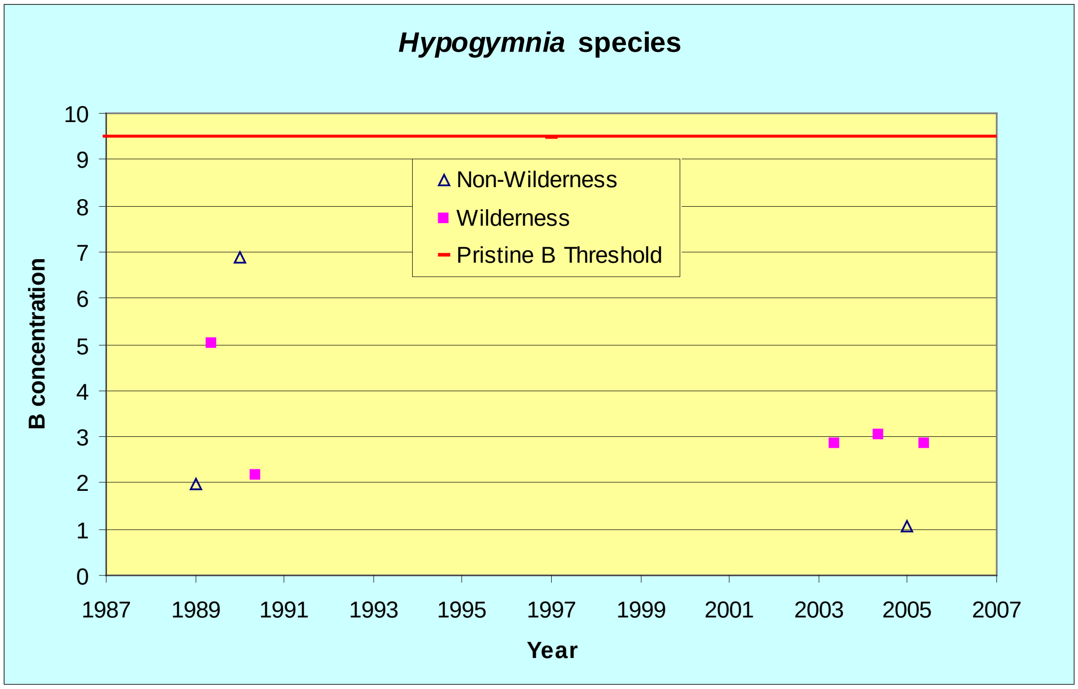

Figure VIII-5. Wilderness and Non-Wilderness yearly means of B ppm in *Hypogymnia species* per year.

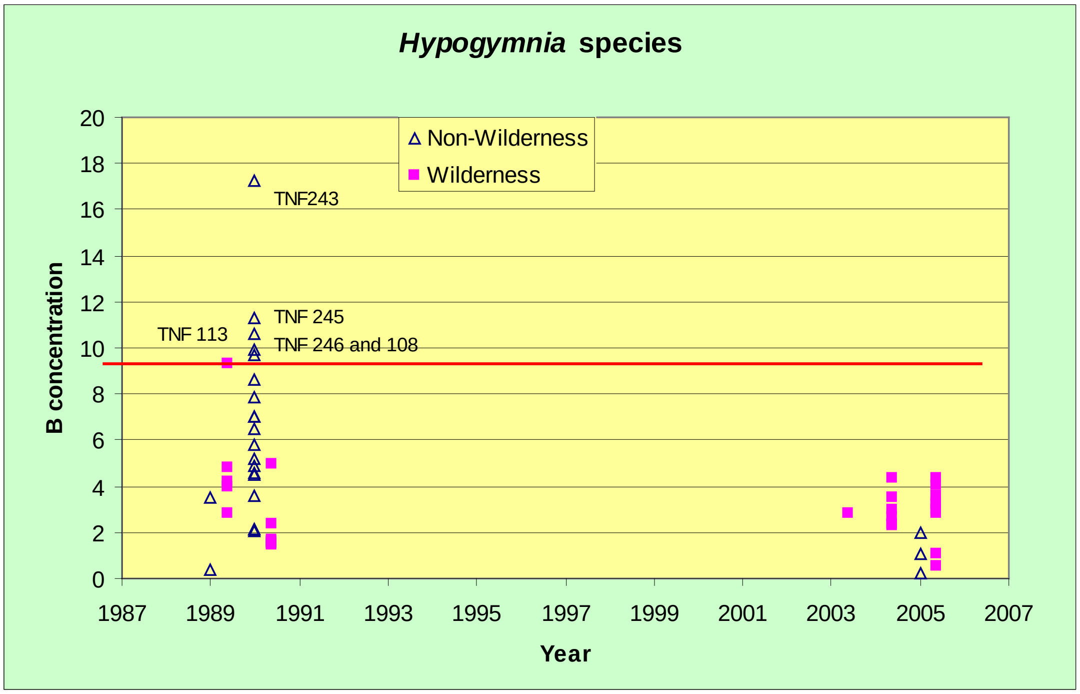

Figure VIII-6. Wilderness and Non-Wilderness plot means of B ppm in *Hypogymnia species* per year.

Lobaria oregana

Table VIII-4. Wilderness and Non-Wilderness Means, Standard Errors, and 95% Confidence Intervals for the B ppm content of *Lobaria oregana* per year.

B ppm				95% CI	
Year	**Plot Type**	**Mean**	**Std. Error**	**Lower**	**Upper**
1989	Non-Wilderness	1.27	0.0419	1.1408	1.4075
1989	Wilderness	1.63	0.2415	0.9576	2.2988
1990	Non-Wilderness	3.00	0.7282	1.4169	4.5900
1990	Wilderness	0.84	0.1442	0.4670	1.2083
2004	Wilderness	1.84	0.4057	0.8450	2.8304
2005	Non-Wilderness	1.93	na	na	na
2005	Wilderness	1.59	0.3193	0.5711	2.6036

Summary of Statistical Tests:

t = -1.4197, df = 4, p-value = 0.2287

There is no evidence of a difference in B content in *Lobaria oregana* from pre-2000 and post 2000 samples (p-value = 0.2287). This analysis was for three wildernesses areas that had repeated values for B in *Lobaria oregana*: Tebenkof (#33), Misty Fiords (# 86, 88), and Stikine-LeConte (# 30, 31).

Relationships are not strong in B content for Lobore after accounting for latitude, longitude, elevation, year (Figures VIII-7, VIII-8 for year) and precipitation (see Brenner, 2006 for all graphed results).

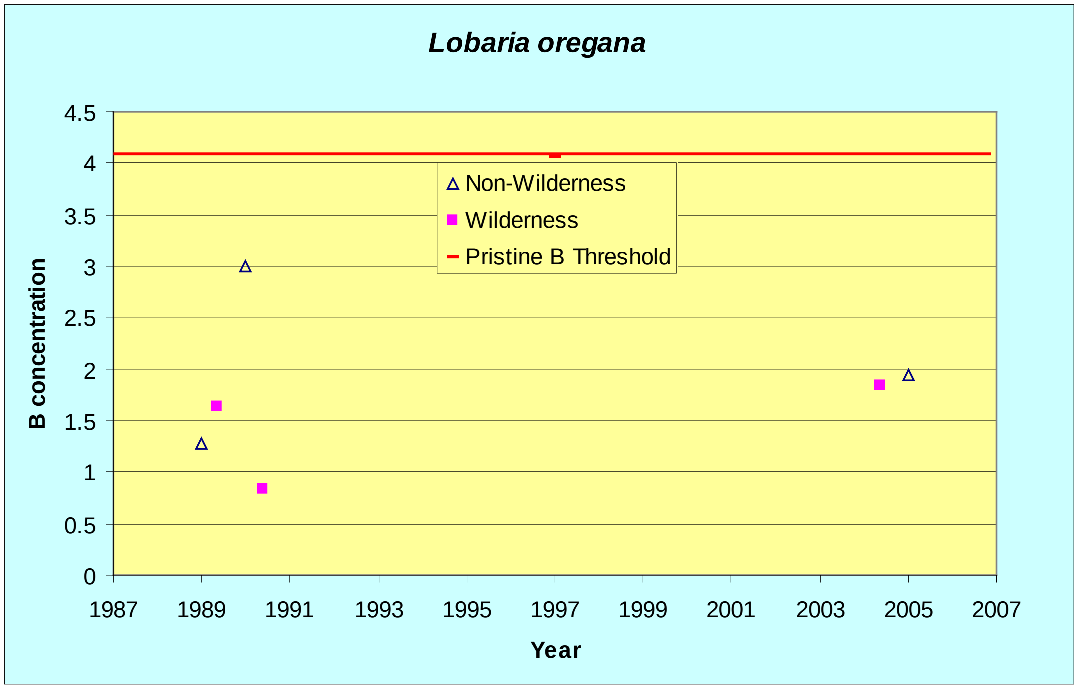

Figure VIII-7. Wilderness and Non-Wilderness yearly means of B ppm in *Lobaria oregana* per year.

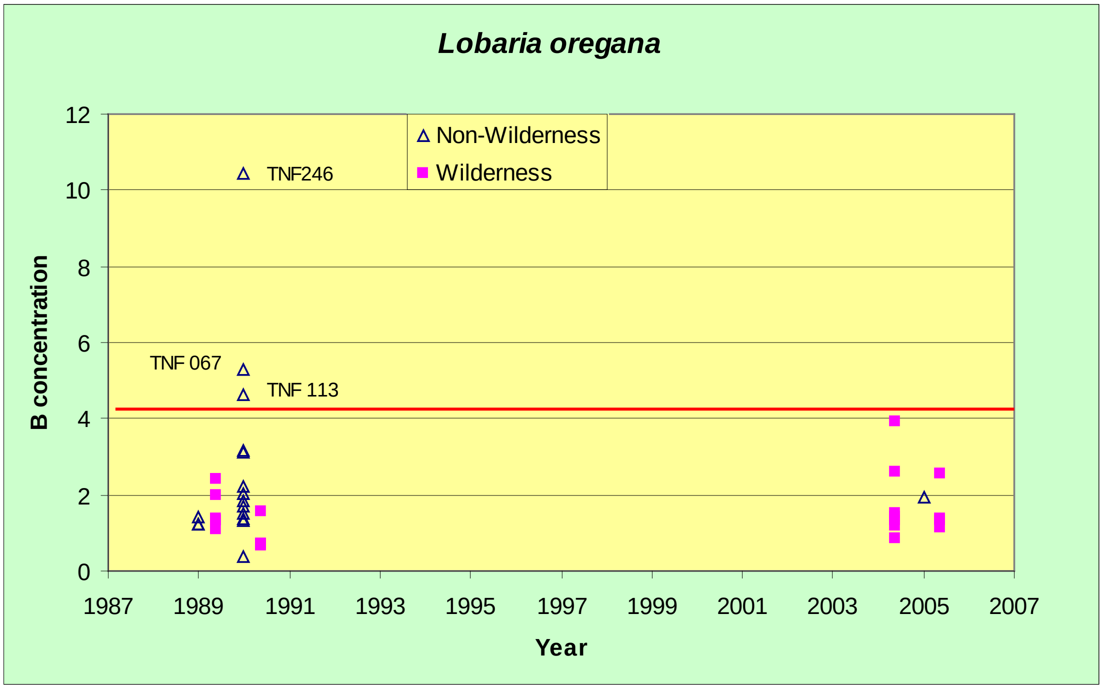

Figure VIII-8. Wilderness and Non-Wilderness plot means of B ppm in *Lobaria oregana* per year.

Platismatia glauca

Table VIII-4. Wilderness and Non-Wilderness Means, Standard Errors, and 95% Confidence Intervals for the B ppm content of *Platismatia glauca* per year.

B ppm				**95% CI**	
Year	**Plot Type**	**Mean**	**Std. Error**	**Lower**	**Upper**
2003	Wilderness	3.33	na	na	na
2004	Wilderness	2.75	0.5855	1.4256	4.0747
2005	Non-Wilderness	1.73	0.3344	0.9751	2.4879
2005	Wilderness	2.77	0.6650	1.1995	4.3447

No t-tests were performed on the data for *Platismatia glauca* due to lack of repeat samples. Values are baseline for B in *Platismatia glauca*.

Relationships are not strong in B content for Plagla after accounting for latitude, longitude, elevation, year (Figures VIII-9, VIII-10 for year) and precipitation (see Brenner, 2006 for all graphed results).

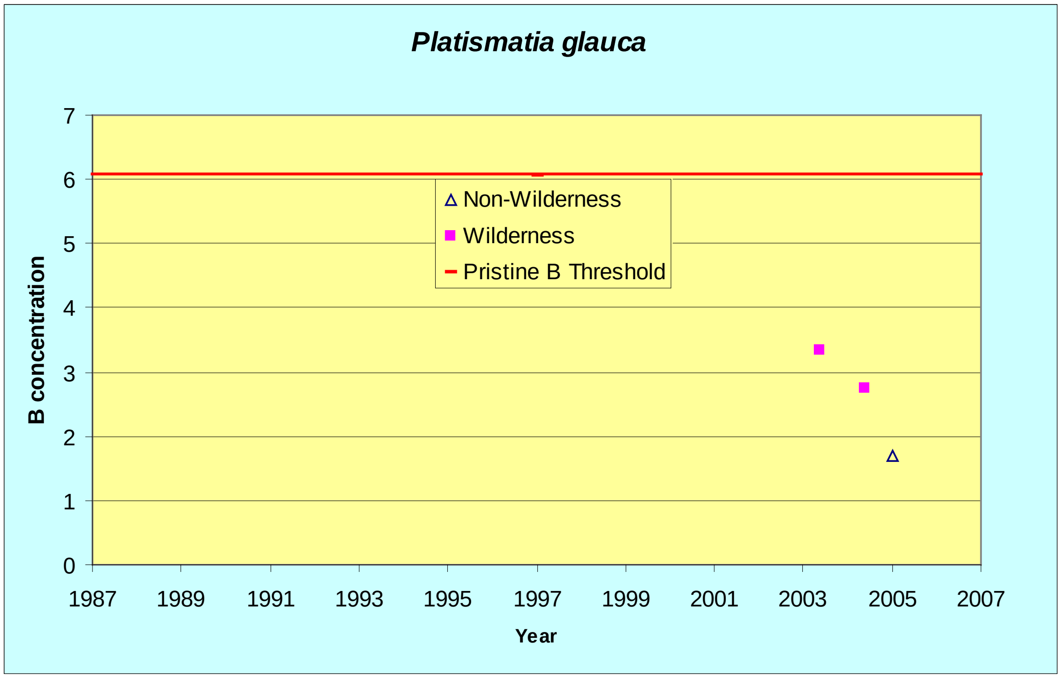

Figure VIII-9. Wilderness and Non-Wilderness yearly means of B ppm in *Platismatia glauca* per year.

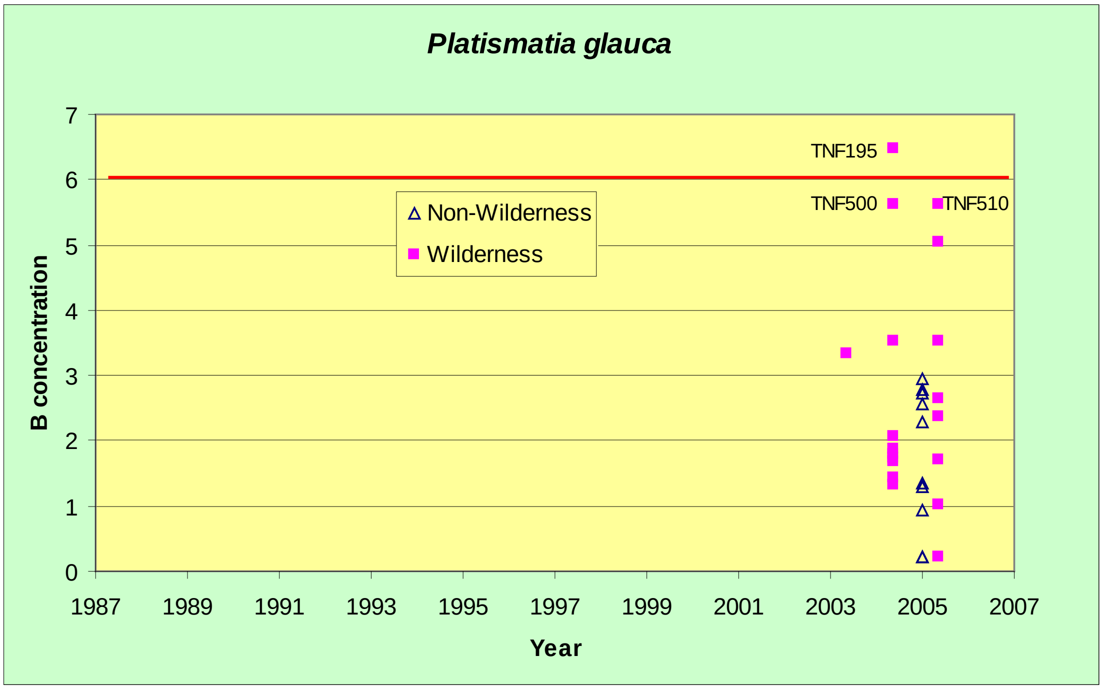

Figure VIII-10. Wilderness and Non-Wilderness plot means of B ppm in Platismatia glauca per year.

Conclusions: for Boron (B) and all lichen species

Background levels of boron in the Pacific Northwest are lower than the threshold levels on the Tongass (between 2.0 and 4.0 ppm and 4.0 to 9.47 ppm respectively). Higher threshold values may be due to the hypermaritime environment, where boron is released from the ocean in the form of boric acid vapor across the region. It may also be due to the region's relatively close proximity to recent volcanic activity.

***Alectoria sarmentosa* (Alesar)**

Tongass threshold level for boron in Alesar is higher than the background value for boron in the Pacific Northwest (9.33 ppm and approximately 2.0 ppm respectively) (USDA 1999). None of the plot means for B in Alesar are above threshold in the recent monitoring period, but are elevated from the past monitoring period in plots 108 and 246 (Figure VIII-2) on the Sitka road system near the pulp mill. Pike Lakes RNA has two plots elevated (208 and 209) and one that is on the threshold line (plot 212) (Figure VIII-2). This may be due to the proximity to the glaciated areas around Yakutat. One plot from Pleasant Island wilderness is also at threshold for B from the first monitoring period (Plot 146) (Figure VIII-4). This island is located near the entrance to Glacier Bay in Icy Strait. Re-sampling of this plot in 2004 did not detect a statistically significant change in B for Alesar (Table VIII-2). Pleasant Island consists of volcanic rock.

Hypogymnia

Background value for B in *Hypogymnia* from the Pacific Northwest is lower than on the Tongass (approximately 2.0 to 3.0 ppm and 9.47 ppm respectively) (USDA 1999). All plot means of B are below threshold for the genus *Hypogymnia*, except for plots 243, 245 and 246 on the Sitka road system, and plot 113 from Berners Bay near Cove Point (Figure VIII-5). Elevated levels may be due to the close proximity to Lynn Canal and wind blown glacial dust.

***Lobaria oregana* (Lobore)**

Background value for B for Lobore in the Pacific Northwest is lower than on the Tongass (approximately 2.0 ppm and 4.06 ppm respectively). Plot means for B in Lobore are below threshold except for plot 246 on the Sitka road system, plot 67 from the Yakutat road system and 113 from Berners Bay (Figure VIII-8). All elevated lichens are from plots from the baseline monitoring period and were not revisited. These areas may be elevated due to their proximity to industry (Sitka) and to wind blown glacial dusts.

***Platismatia glauca* (Plagla)**

Background for B in Plagla from the Pacific Northwest is 4.0 ppm (USDA 1999) and threshold is 6.0 ppm from the Tongass. Plot means for B in Plagla are above the threshold in Stikine-LeConte wilderness on Gut Island (Figure VIII-10). Elevated B could be due to natural sources of boron in saltwater and windblown soils (i.e. from loess on the Stikine Delta).

IX. Summary of results for Barium (Ba) from all species on the Tongass National Forest

Barium is an alkaline-earth metal found only in combination with other elements in nature (mainly combined with peroxide, chloride, sulfate, carbonate, nitrate and chlorate). Two forms of barium, barium sulfate and barium carbonate, are often found in nature as underground ore deposits (USPHS 1992). It is also found in small quantities in igneous rocks, feldspar and micas. Pure Ba oxidizes readily and reacts with water to emit hydrogen, which is similar to calcium (Weast et al 1987). Barium naturally occurs in most surface waters, and marine plants and invertebrates may accumulate Ba from sea water. General background of Ba is very low. However, the most likely source of elevated Ba is from industrial emissions (USPHS 1992). It is used by the oil and gas industries to make drilling muds which augment rock drilling. Barium sulfate is used to make paints, bricks, tiles, glass, and rubber. Due to its particulate form, it is expected to have a residence time of hundreds of years and is not expected to be very mobile in soils.

The laboratory analysis during the first monitoring period did not include Ba in the ICP analysis. During the second monitoring period, baseline elemental analyses of Ba and provisional thresholds have been established for the Tongass. Thresholds for target lichen species are the following: *Alectoria sarmentosa* (15.84 ppm), *Hypogymnia* (16.46 ppm), *Lobaria oregana* (76.62 ppm), and *Platismatia glauca* (53.80 ppm).

Plot means for Ba are above threshold in Alesar for the Greens Creek (plot 512) near the tailing pile and Endicott River wilderness (plot 508) (Figure IX-4). Plot 1000 near Juneau and Endicott River wilderness (plot 507) are at threshold in Alesar. Plot means for Endicott River wilderness plot 508 was above threshold for *Hypogymnia* (Figure IX-6). Plot means for Ba in the Stikine-LeConte wilderness plot 495 was slightly above threshold in Lobore (Figure IX-8). Plot means for Plagla at Greens Creek (plots 511a and 512) and Endicott River wilderness (plot 508) contain elevated Ba (Figures IX-10).

IX. SUMMARY OF Ba PPM DATA ANALYSIS

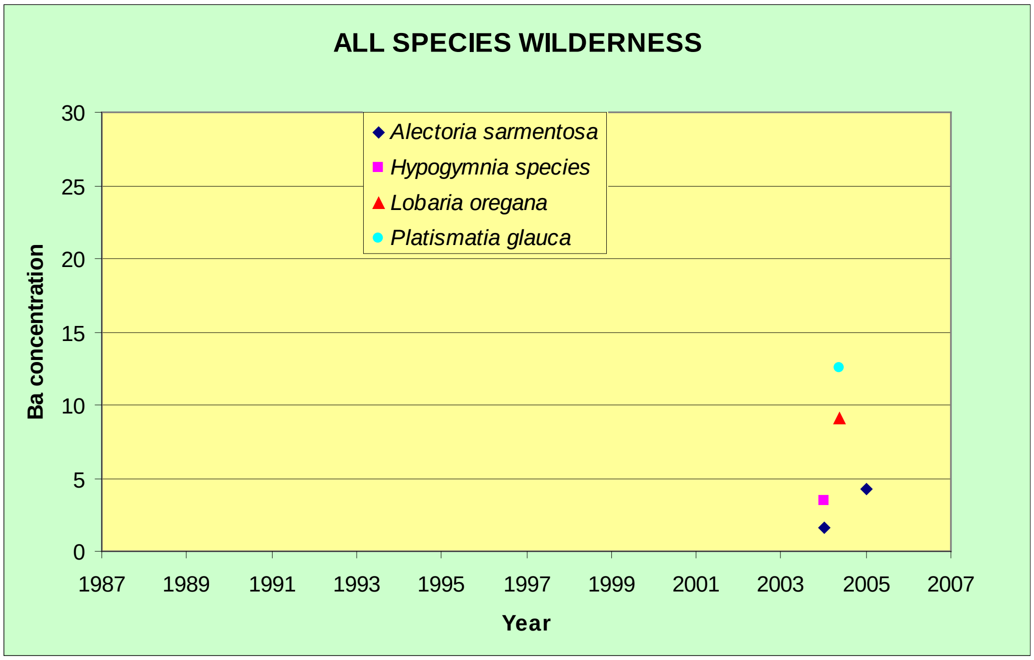

Figure IX-1. Wilderness plot means of Ba ppm in *All Species* per year.

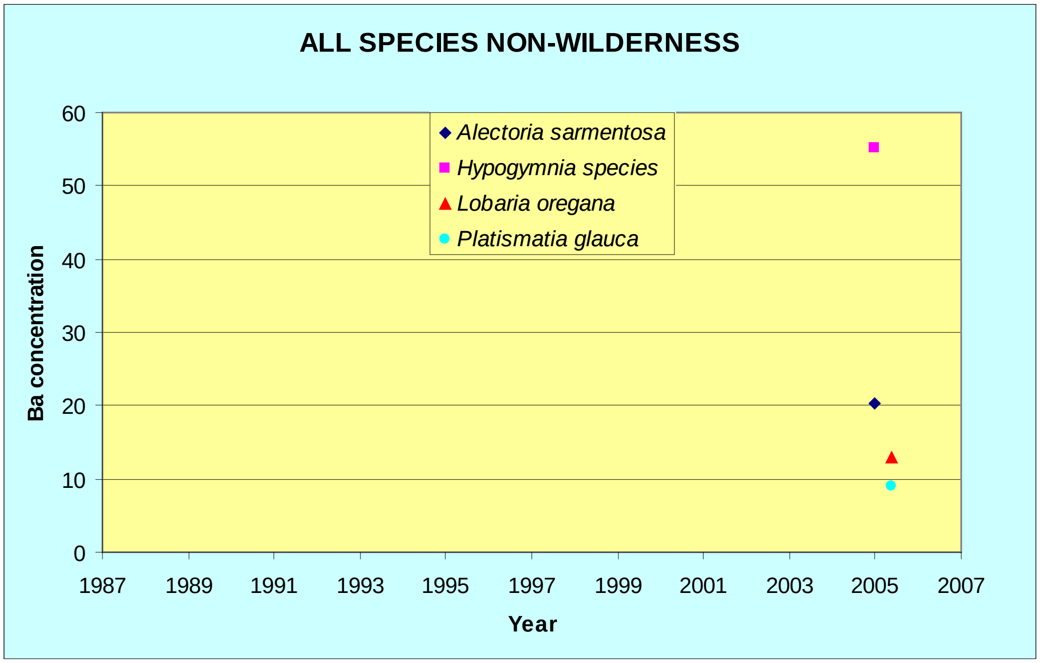

Figure IX-2. Non-Wilderness plot means of Ba ppm in *All Species* per year.

Alectoria sarmentosa

Table XI-1. Wilderness and Non-Wilderness Means, Standard Errors, and 95% Confidence Intervals for the Ba ppm content of *Alectoria sarmentosa* per year.

Ba ppm				**95% CI**	
Year	**Plot Type**	**Mean**	**Std. Error**	**Lower**	**Upper**
2004	Wilderness	1.65	0.5999	0.4113	2.8934
2005	Non-Wilderness	20.39	13.2402	0	54.4205
2005	Wilderness	4.28	2.1299	0	9.0980

No t-tests were performed on this data due to lack of repeated samples. The values for Ba are baseline in *Alectoria sarmentosa.*

Relationships are not strong in the Ba content in Alesar after accounting for latitude, longitude, elevation, year (Figures IX-3, IX-4 for year) and precipitation (see Brenner, 2006 for all graphed results).

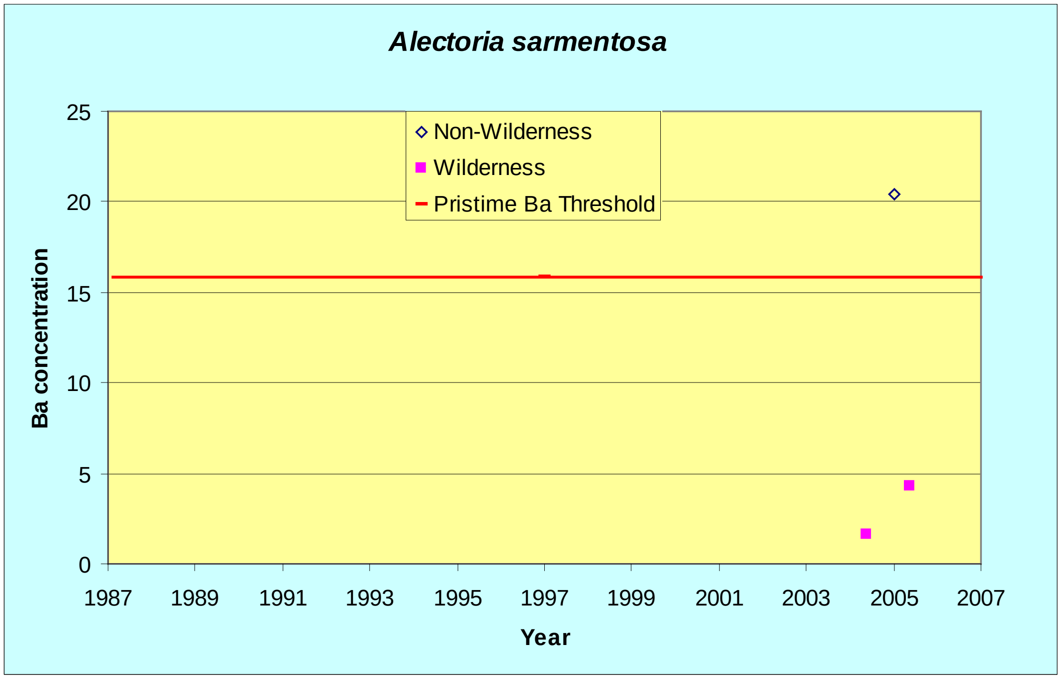

Figure IX-3. Wilderness and Non-Wilderness yearly means of Ba ppm in *Alectoria sarmentosa* per year.

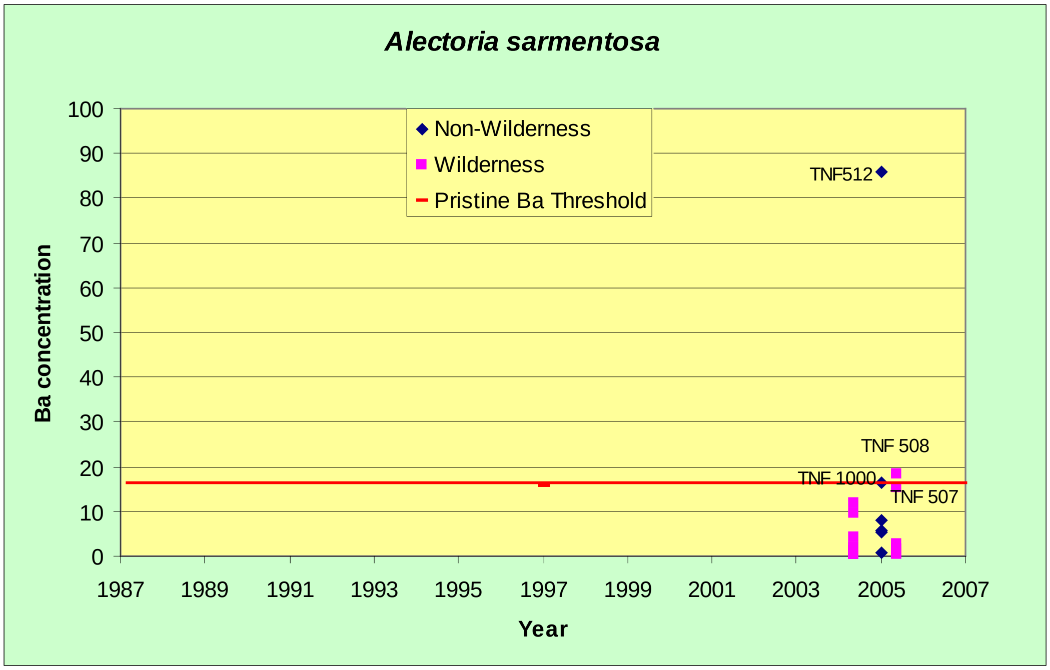

Figure IX-4. Wilderness and Non-Wilderness plot means of Ba ppm in *Alectoria sarmentosa* per year.

Hypogymnia species

In this series, all of the *Hypogymnia* species were included as a group.

Table XI-2. Wilderness and Non-Wilderness Means, Standard Errors, and 95% Confidence Intervals for the Ba ppm content of *Hypogymnia species* per year.

Percent Sulfur				95% CI	
Year	**Plot Type**	**Mean**	**Std. Error**	**Lower**	**Upper**
2004	Wilderness	3.50	0.6441	1.8491	5.1605
2005	Non-Wilderness	55.13	9.0562	16.1617	94.0930
2005	Wilderness	25.42	9.1365	4.3554	46.4929

No t-tests were performed on this data due to lack of repeat samples. The values for Ba are baseline for *Hypogymnia.*

Relationships are not strong in Ba content for *Hypogymnia* after accounting for latitude, longitude, elevation, year (Figures IX-5, IX-6 for year) and precipitation (see Brenner, 2006 for all graphed results).

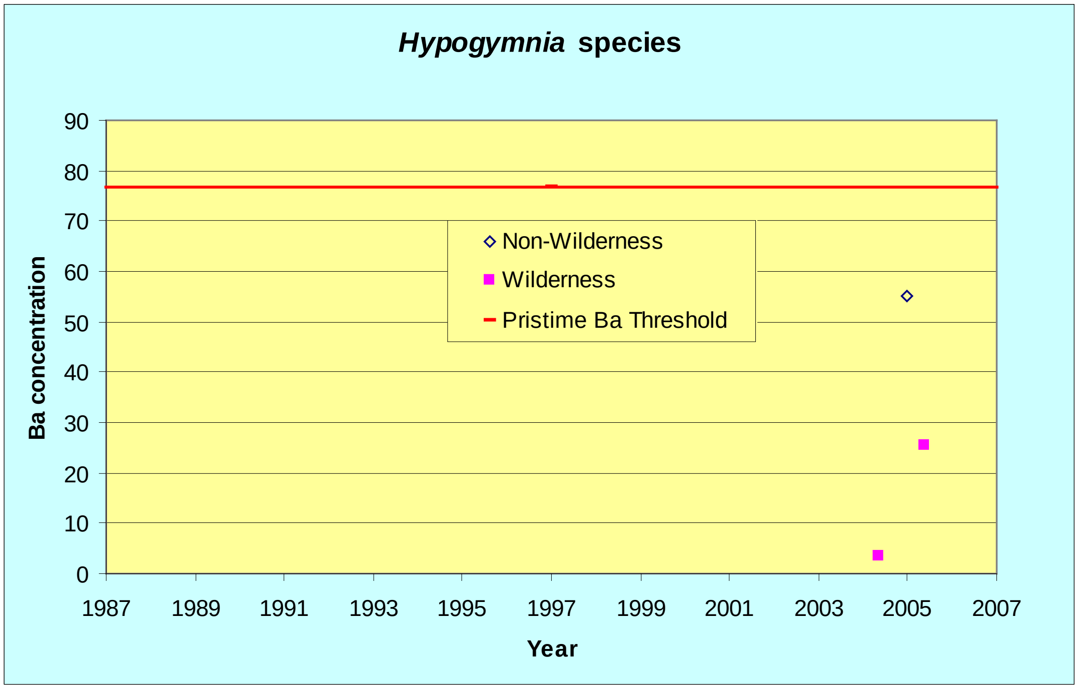

Figure IX-5. Wilderness and Non-Wilderness yearly means of Ba ppm in *Hypogymnia species* per year.

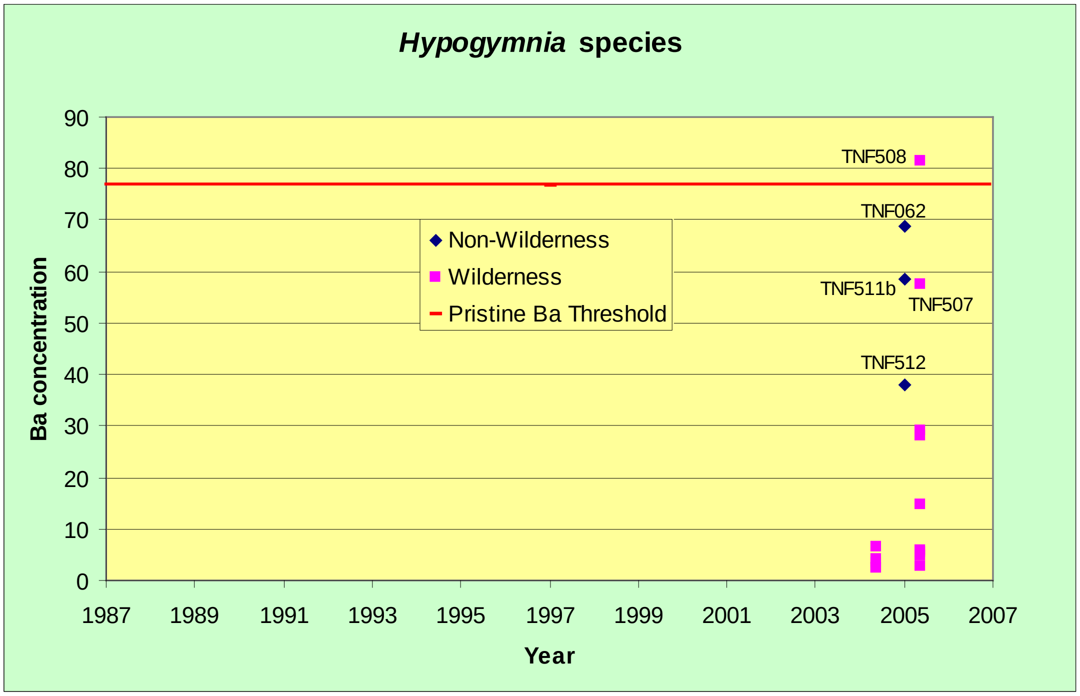

Figure IX-6. Wilderness and Non-Wilderness plot means of Ba ppm in *Hypogymnia species* per year.

Lobaria oregana

Table IX-3. Wilderness and Non-Wilderness Means, Standard Errors, and 95% Confidence Intervals for the Ba ppm content of *Lobaria oregana* per year.

Ba ppm				95% CI	
Year	**Plot Type**	**Mean**	**Std. Error**	**Lower**	**Upper**
2004	Wilderness	9.03	2.5273	2.8483	15.2166
2005	Non-Wilderness	12.98	NA	NA	NA
2005	Wilderness	4.13	3.1883	-6.0131	14.2803

No t-tests were performed on this data. The values for Ba are baseline for *Lobaria oregana.*

Relationships are not strong in Ba content for Lobore after accounting for latitude, longitude, elevation, year (Figures IX-6, IX-6 for year) and precipitation (see Brenner, 2006 for all graphed results).

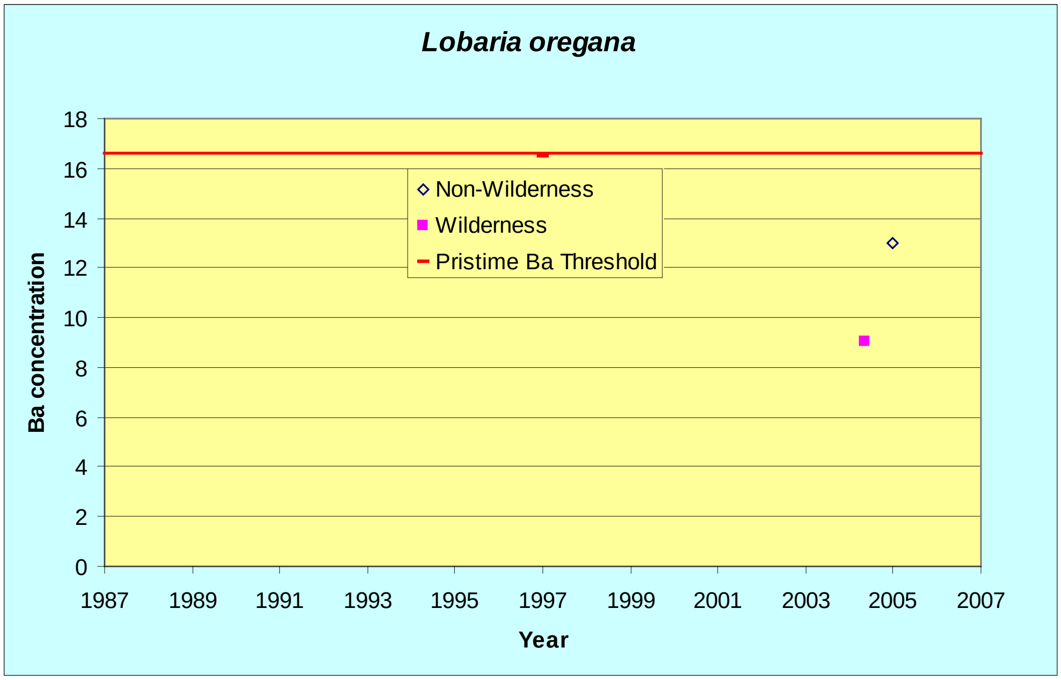

Figure IX-7. Wilderness and Non-Wilderness yearly means of Ba ppm in *Lobaria oregana* per year.

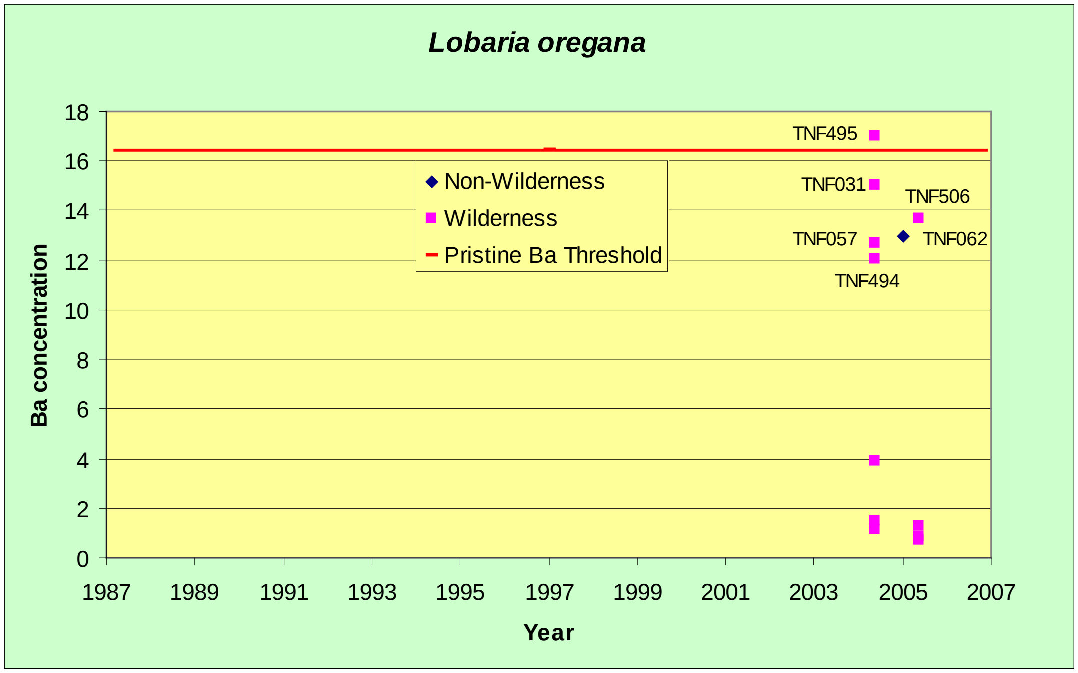

Figure IX-8. Wilderness and Non-Wilderness plot means of Ba ppm in *Lobaria oregana* per year.

Platismatia glauca

Table IX-4. Wilderness and Non-Wilderness Means, Standard Errors, and 95% Confidence Intervals for the Ba ppm content of *Platismatia glauca* per year.

Ba ppm				95% CI	
Year	**Plot Type**	**Mean**	**Std. Error**	**Lower**	**Upper**
2004	Wilderness	12.49	3.6615	4.2085	20.7742
2005	Non-Wilderness	38.39	5.3959	26.1874	50.6000
2005	Wilderness	23.15	7.3451	5.7827	40.5196

No t-tests were performed on this data. The values for Ba are baseline for *Platismatia glauca.*

Relationships are not strong in Ba content for Plagla after accounting for latitude, longitude, elevation, year (Figures IX-9, IX-10 for year) and precipitation (see Brenner, 2006 for all graphed results).

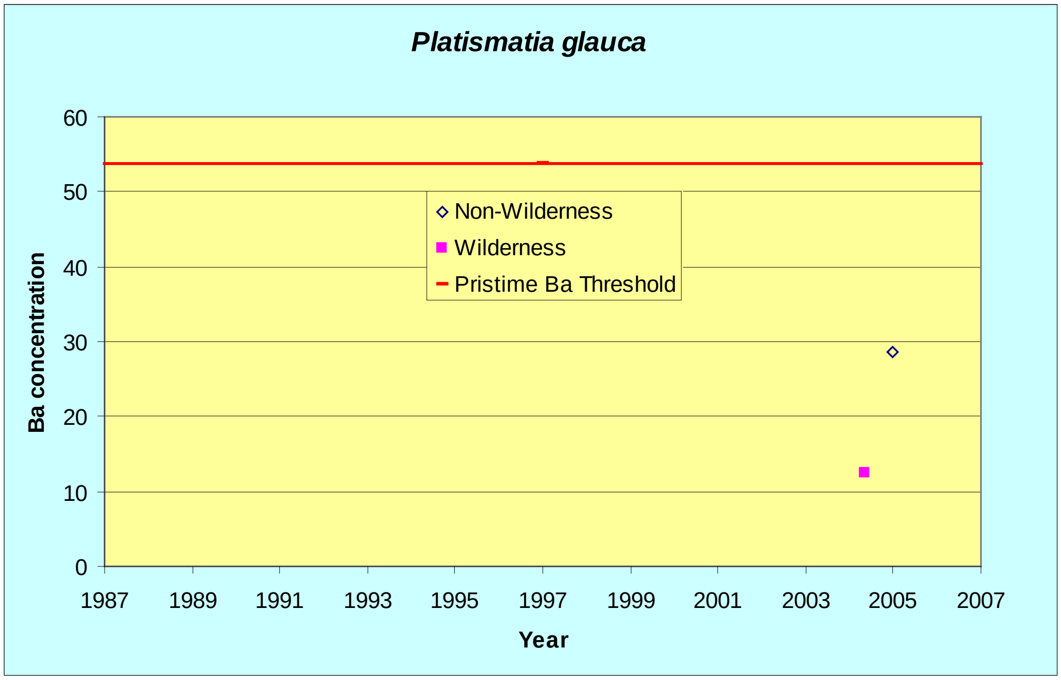

Figure IX-9. Wilderness and Non-Wilderness yearly means of Ba ppm in *Platismatia glauca* per year.

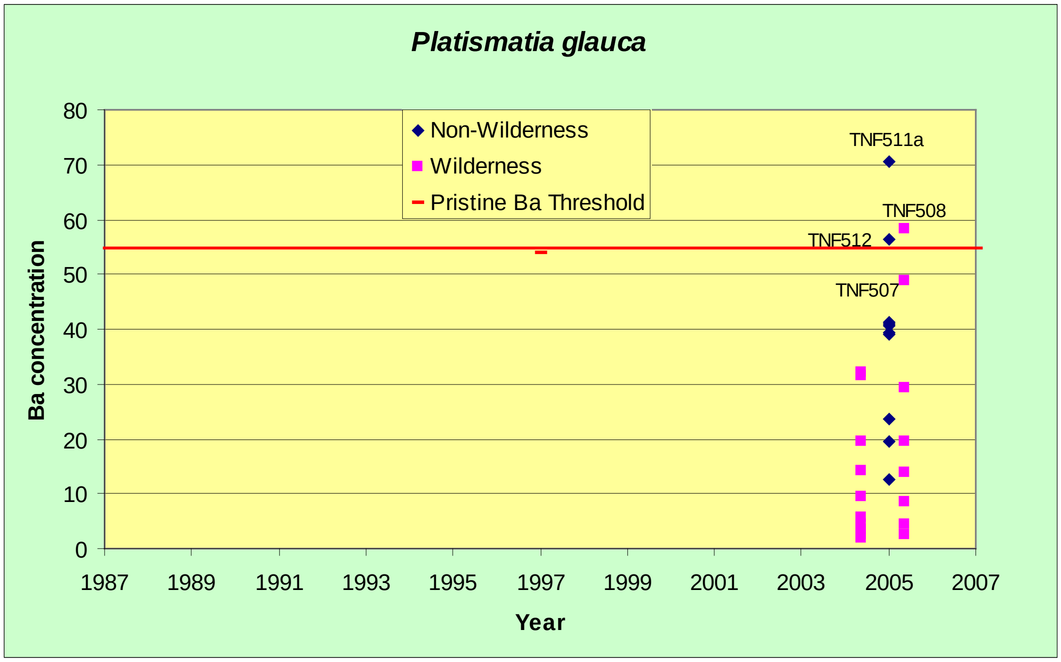

Figure IX-10. Wilderness and Non-Wilderness plot means of Ba ppm in *Platismatia glauca* per year.

IX. Conclusions for Barium and all lichen species.

Background levels for barium have not been compiled for the Pacific Northwest region (USDA 1999).

Alectoria sarmentosa (Alesar)

Plot mean for Ba is quite elevated above threshold for plot 512 (over 80 ppm in Figure IX-4) (Greens Creek tailings pile). The yearly means for Ba in all non- wilderness plots are elevated above threshold (over 20 ppm in Figure IX-5). Above threshold values in lichens are most likely due to the close proximity of the plots to the road system dusts and the tailings pile at Greens Creek. Plot 508 in Endicott Wilderness is slightly elevated above threshold, along with plots 507 (upper Endicott River) and 1000 (Mt Roberts) at threshold. Higher Ba from upper Endicott River plots could be due to the glacial influence and exposed geology in the area. The lower slope of Mt Roberts is also the home of a closed mine, near the cruise ship dock and downtown Juneau, all of which could account for the higher levels of Ba at 175 ft (compared to the Mt Roberts plots at higher elevations that are not elevated).

Hypogymnia

Plot mean for Ba is slightly elevated in the Endicott River wilderness plot 508. This plot is located upstream from the mouth of the river at least 10 miles and is not near a point pollution source. Source of barium is most likely attributed to natural airborne dusts from nearby Glacier Bay and exposed rocks.

Lobaria oregana (Lobore)

Mean Ba in Lobore from Plot 495 from Flemer Cabin on the Stikine River is elevated above threshold. This could be attributed to the proximity to the nearby glaciers up the river in British Columbia.

Platismatia glauca (Plagla)

Mean Ba in two places from Greens Creek have elevated levels in Plagla. Plot 511b is at the portal of the mine and plot 512 is near the tailing pile and elevated levels are likely due to this industry. The wilderness plot 508 from Endicott River is also elevated in Ba. This may be due to the proximity to windblown dust from Glacier Bay and Canada.

X. Summary of results for Beryllium (Be) from all species on the Tongass National Forest

Beryllium in almost all forms is known to have adverse effects upon human health. Beryllium extraction processes generate emissions that include beryllium salts, acids, beryllium oxide and other compounds in the form of dust, fume or mist.

Beryllium values are not discussed further in this report as the levels of Be in Tongass lichens were below the detection limits of .04 ppm in ICP machine.

XI. Summary of results for Calcium (Ca) from all species on the Tongass National Forest

Calcium is the fifth most abundant metallic element in the earth's crust. It is particulary abundant in sites that have limestone or carbonate geology. Areas that have exposed rocks will have Ca enrichment in lichens and levels will appear elevated (USDA 1999). This may be in areas near roads, glaciers, cliffs and other exposed rock areas. While Ca can be enhanced near urban/industrial areas, it is also found in lichens near the seashore as surface layers of the ocean are also sources for this element (Davidson et al. 1985; Neiboer et al 1978). Neiboer and Richardson (1981) define Ca background levels in lichens to be less than 1000 ppm in areas without marine or crustal influences.

Southeast Alaska is an area of strong marine influence. Many of the lichen biomonitoring plots are located within a few miles of saltwater, and some are on the beach fringe forest edge ecotone. Threshold for Ca in all lichens from the Tongass are above background (> 1000 ppm) for non-enriched areas: *Alectoria sarmentosa* (9689.25 ppm), *Hypogymnia* (24671.17ppm), *Lobaria oregana* (1158.10 ppm) and *Platismatia glauca* (4104.48 ppm).

Plot means for Ca in Alesar are elevated above threshold in a few maritime plots on Kuiu Island (#81) and on Revilla Island (#130) (Figure XI- 4). Plot means for *Hypogymnia* are at or above threshold for plot 506 (lower Endicott River) and plot 79 (Kell Bay, Kuiu) (Figure XI-6). Mean Ca in plot 506 on the Endicott River is above threshold in *Lobaria oregana* and *Platismatia glauca* (Figures XI-8 and XI-10 respectively).

XI. SUMMARY OF Ca PPM DATA ANALYSIS

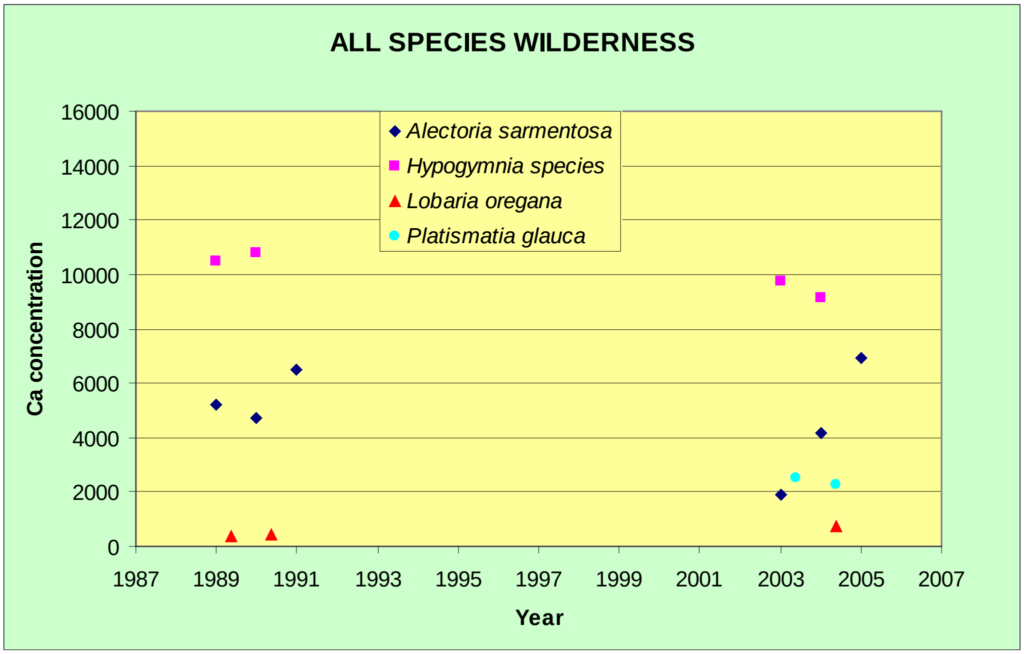

Figure XI-1. Wilderness plot means of Ca ppm in *All Species* per year.

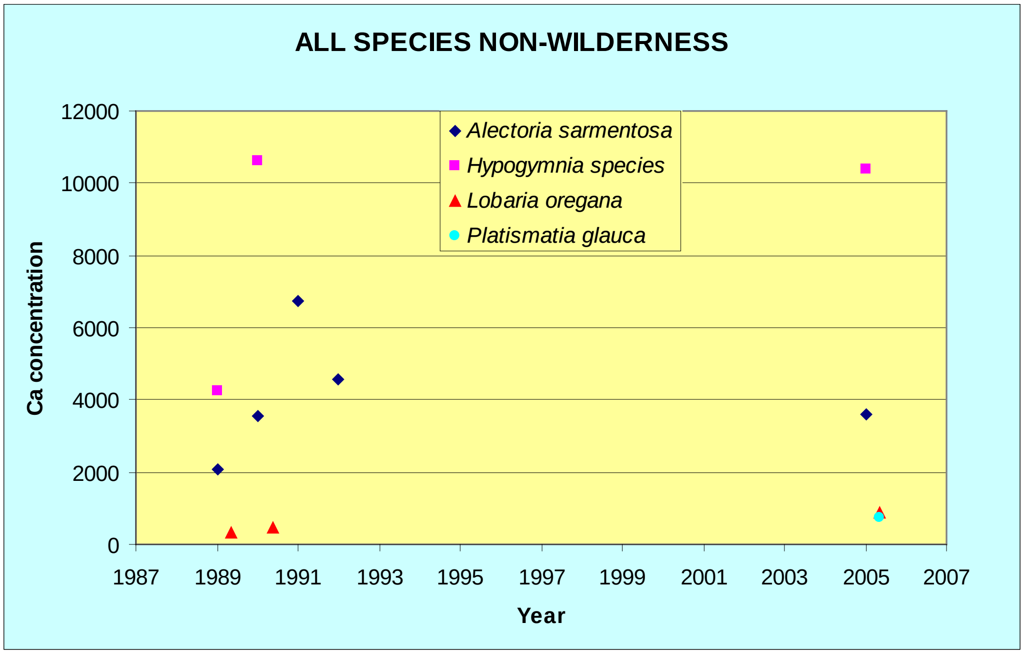

Figure XI-2. Non-Wilderness plot means of Ca ppm in *All Species* per year.

Alectoria sarmentosa

Table XI-2. Wilderness and Non-Wilderness Means, Standard Errors, and 95% Confidence Intervals for the Ca ppm content of *Alectoria sarmentosa* per year.

Ca ppm				**95% CI**	
Year	**Plot Type**	**Mean**	**Std. Error**	**Lower**	**Upper**
1989	Non-Wilderness	2081.72	529.9073	610.4615	3552.9785
1989	Wilderness	5234.99	954.3677	2781.7141	7688.2748
1990	Non-Wilderness	3567.36	560.4786	2415.2845	4719.4451
1990	Wilderness	4729.97	1012.8840	2251.5300	7208.4080
1991	Non-Wilderness	6727.52	1359.4200	3871.4850	9583.5570
1991	Wilderness	6504.13	1181.7710	3223.0110	9785.2540
1992	Non-Wilderness	4556.83	NA	2775.5152	6338.1427
2003	Wilderness	1889.64	776.6950	7979.2070	11758.4840
2004	Wilderness	4146.98	373.4374	3374.4615	4919.4896
2005	Non-Wilderness	3604.71	463.4197	2413.4502	4795.9665
2005	Wilderness	6938.53	604.0697	5572.0295	8305.0305

Summary of Statistical Tests:

t = 1.5029, df = 8, p-value = 0.1713

There is no evidence of a difference in Ca content in *Alectoria sarmentosa* from pre-2000 and post 2000 samples (p-value = 0.1713). Samples remeasured are from the wilderness areas of: Tebenkof Bay (#33), Pleasant Island (# 145, 146), Pikes Lake RNA (#69), Petersburg Creek (# 116), Kootznoowoo (# 189, 190), and Karta River (# 159).

Relationships are not strong in Ca content for Alesar after accounting for latitude, longitude, elevation, year (Figures XI-3, XI-4 for year) and precipitation (see Brenner, 2006 for all graphed results).

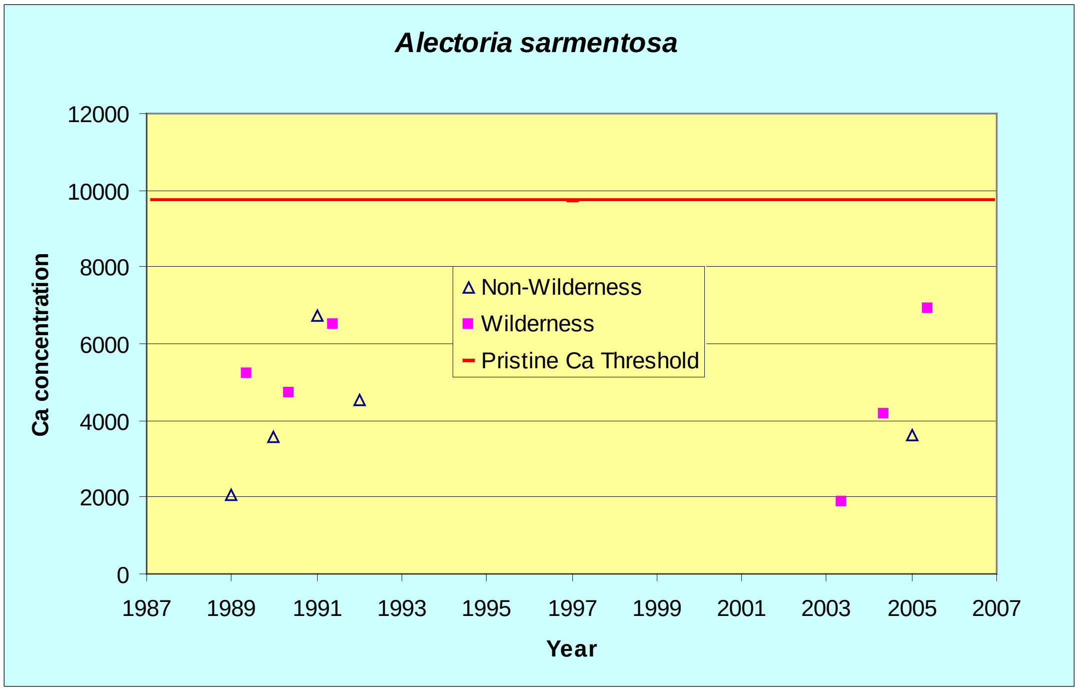

Figure XI-3. Wilderness and Non-Wilderness yearly means of Ca ppm in *Alectoria sarmentosa* per year.

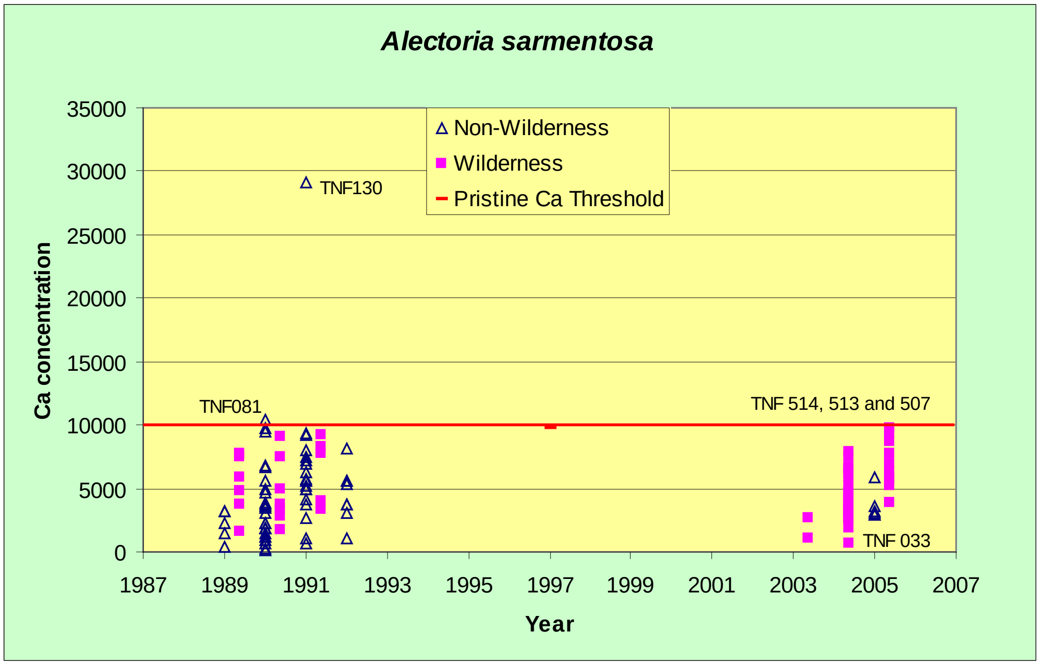

Figure XI-4. Wilderness and Non-Wilderness plot means of Ca ppm in *Alectoria sarmentosa* per year.

Hypogymnia species

In this series, all of the *Hypogymnia* species were included as a group.

Table XI-3. Wilderness and Non-Wilderness Means, Standard Errors, and 95% Confidence Intervals for the Ca ppm content of *Hypogymnia species* per year.

Ca ppm				95% CI	
Year	**Plot Type**	**Mean**	**Std. Error**	**Lower**	**Upper**
1989	Non-Wilderness	4245.50	1452.5000	14210.2600	22701.2600
1989	Wilderness	10509.67	2082.5800	4727.4980	16291.8350
1990	Non-Wilderness	10596.47	1541.7000	7357.4740	13835.4560
1990	Wilderness	10759.10	2303.8300	5121.8270	16396.3630
2003	Wilderness	9740.80	NA	NA	NA
2004	Wilderness	9139.63	1222.0490	5998.2480	12281.0040
2005	Non-Wilderness	10365.47	1652.7150	3254.4090	17476.5250
2005	Wilderness	14090.39	1292.1380	11110.7120	17070.0650

T-tests were not performed with *Hypogymnia* data due to no repeated samples.

Relationships are not strong in Ca content for *Hypogymnia* after accounting for latitude, longitude, elevation, year (Figures XI-5, XI-6 for year) and precipitation (see Brenner, 2006 for all graphed results).

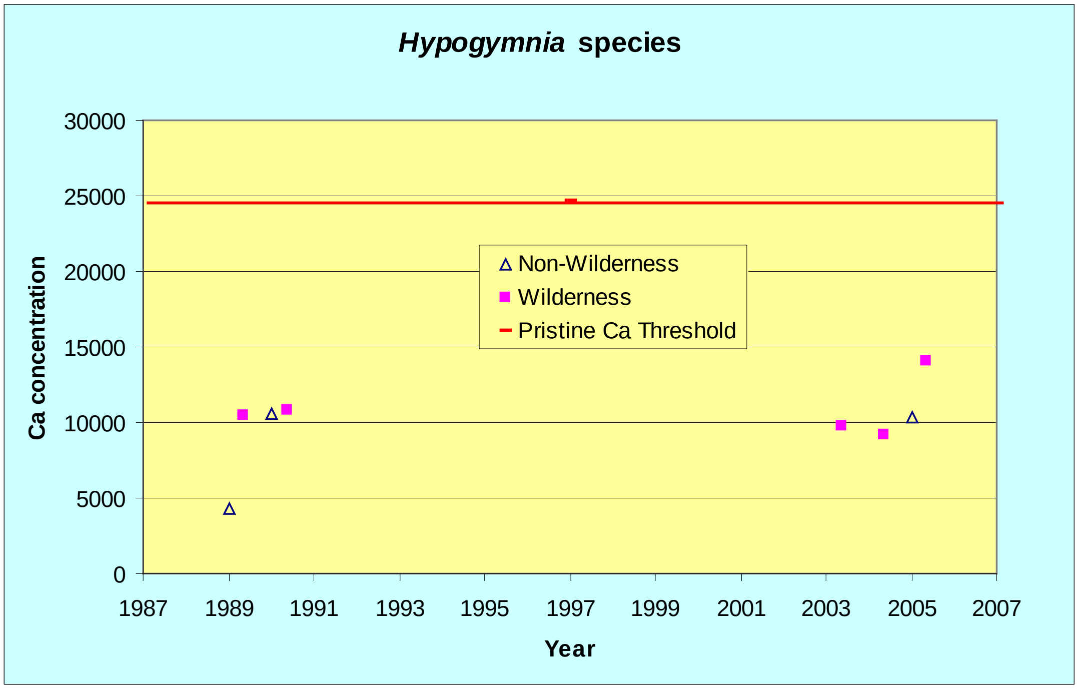

Figure XI-5. Wilderness and Non-Wilderness yearly means of Ca ppm in *Hypogymnia species* per year.

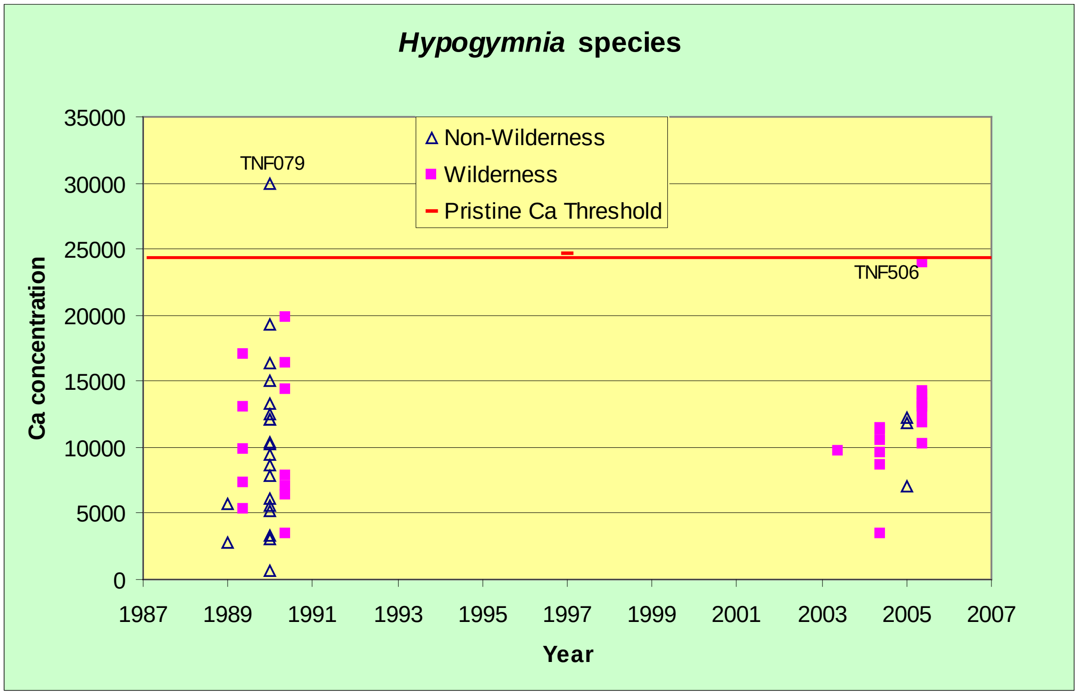

Figure XI-6. Wilderness and Non-Wilderness plot means of Ca ppm in *Hypogymnia species* per year.

Lobaria oregana

Table XI-4. Wilderness and Non-Wilderness Means, Standard Errors, and 95% Confidence Intervals for the Ca ppm content of *Lobaria oregana* per year.

Ca ppm				95% CI	
Year	**Plot Type**	**Mean**	**Std. Error**	**Lower**	**Upper**
1989	Non-Wilderness	334.17	19.7224	271.4013	396.9321
1989	Wilderness	390.24	35.9300	290.4857	490.0010
1990	Non-Wilderness	467.88	27.8034	407.3061	528.4631
1990	Wilderness	418.34	28.4251	345.2751	491.4133
2004	Wilderness	739.66	76.1875	553.2329	926.0812
2005	Non-Wilderness	877.24	NA	NA	NA
2005	Wilderness	698.11	262.3059	NA	1532.8808

Summary of Statistical Tests:

t = -1.4706, df = 4, p-value = 0.2153

There is no evidence of a difference in Ca content in *Lobaria oregana* from pre-2000 and post 2000 samples (p-value = 0.2153). Wilderness areas remeasured are Tebenkof (#33), Stikine-LeConte (#30, 31), and Misty Fiords (#86, 88).

Relationships are not strong in Ca content for Lobore after accounting for latitude, longitude, elevation, year (Figures XI-5, XI-6 for year) and precipitation (see Brenner, 2006 for all graphed results).

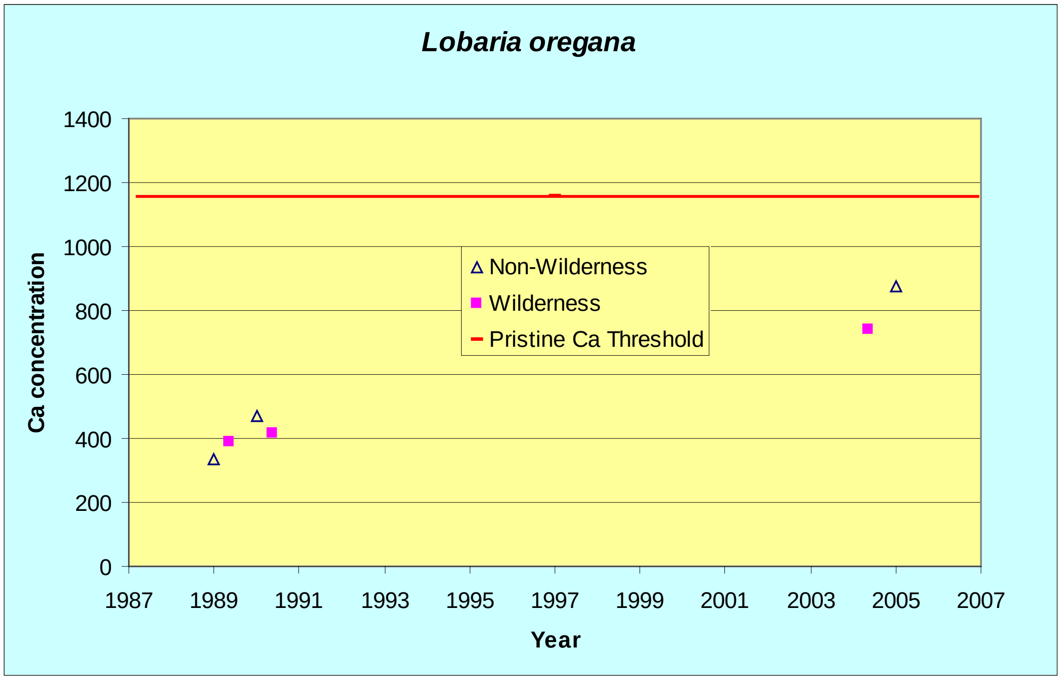

Figure XI-7. Wilderness and Non-Wilderness yearly means of Ca ppm in *Lobaria oregana* per year.

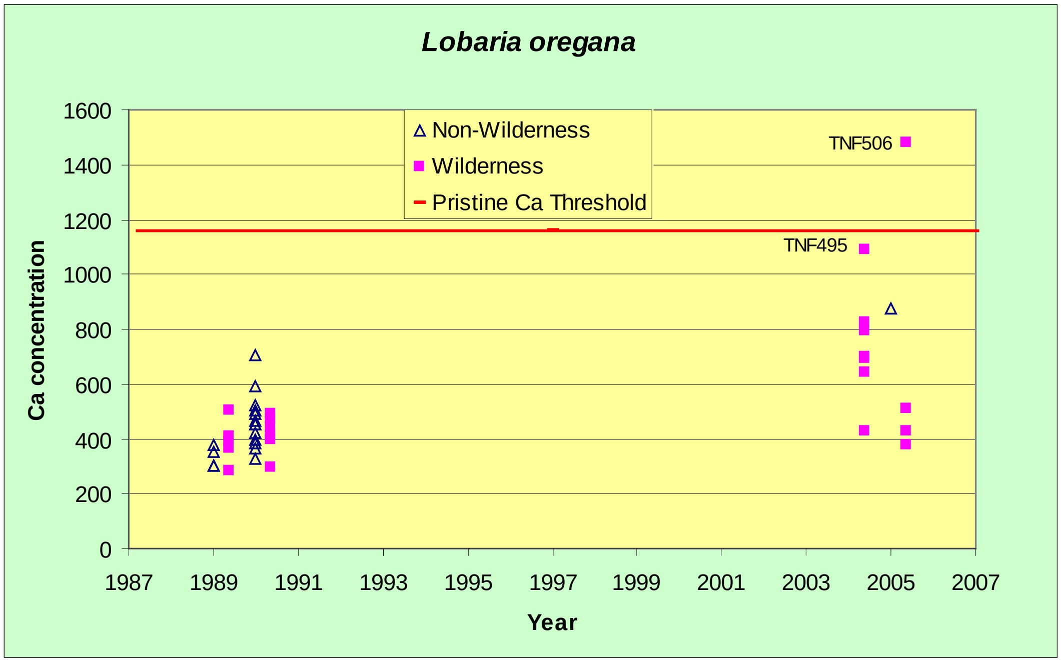

Figure XI-8. Wilderness and Non-Wilderness plot means of Ca ppm in *Lobaria oregana* per year.

Platismatia glauca

Table XI-4. Wilderness and Non-Wilderness Means, Standard Errors, and 95% Confidence Intervals for the Ca ppm content of *Platismatia glauca* per year.

Ca ppm				95% CI	
Year	**Plot Type**	**Mean**	**Std. Error**	**Lower**	**Upper**
2003	Wilderness	2505.97	NA	NA	NA
2004	Wilderness	2294.39	219.3717	1798.1345	2790.6412
2005	Non-Wilderness	2523.86	235.6644	1990.7517	3056.9716
2005	Wilderness	2860.64	380.3439	1961.2671	3760.0079

No t-tests were performed on this data. The mean values for Ca are baseline in *Platismatia glauca.*

Relationships are not strong in Ca content for Plagla after accounting for latitude, longitude, elevation, year (Figures XI-9, XI-10 for year) and precipitation (see Brenner, 2006 for all graphed results).

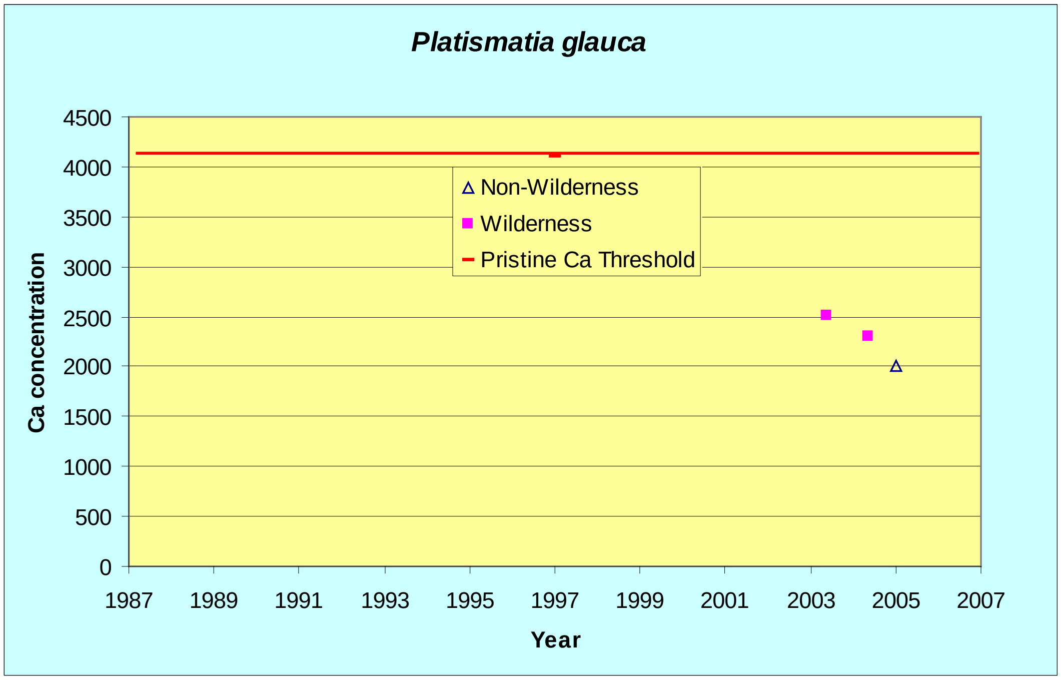

Figure XI-9. Wilderness and Non-Wilderness yearly means of Ca ppm in *Platismatia glauca* per year.

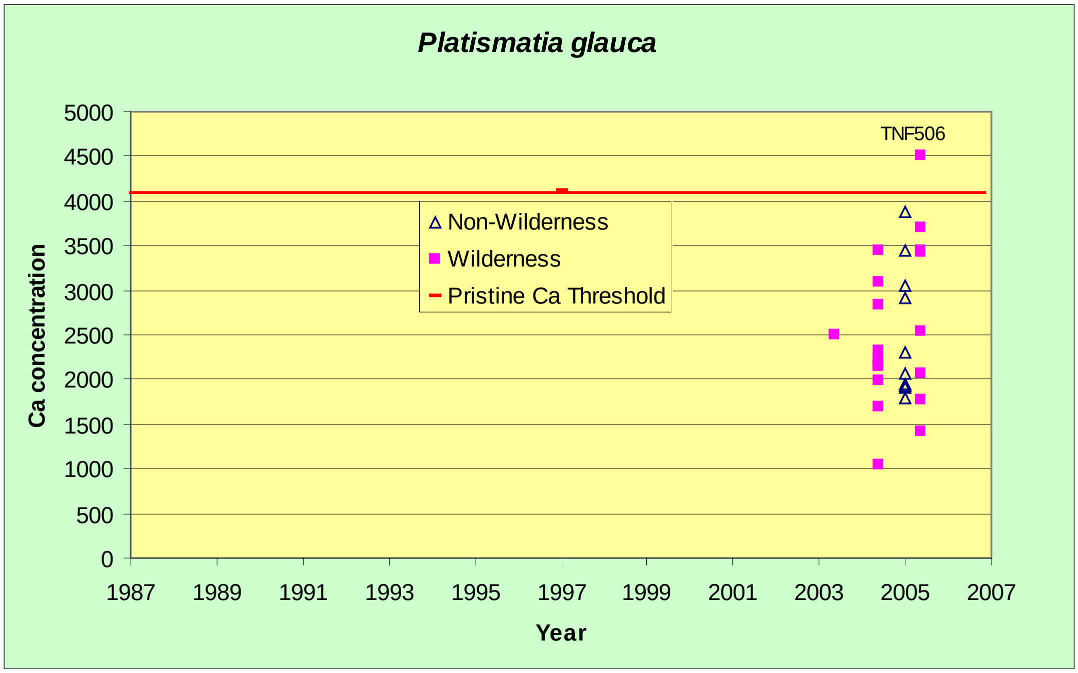

Figure XI-10. Wilderness and Non-Wilderness plot means of Ca ppm in *Platismatia glauca* per year.

Conclusions: For Calcium (Ca) and all lichen species

Background levels of Ca for seashore enhanced lichens vary among species and range between 40,000 and 50,000 ppm (USDA 1999). Tongass thresholds for Ca range between 1158 and 24,671 ppm which are well below the levels considered enhanced by the seashore environment. High precipitation on the Tongass eventually washes nutrients and other elements from the lichen thalli over time. However, the Ca in all lichen species analysed from the Tongass is higher than background levels (those that are not enhanced by the seashore) found in the Pacific Northwest (USDA 1999).

Alectoria sarmentosa

Calcium background level for Alesar in the Pacific Northwest is 2500 ppm, which is well below the 9689 ppm threshold for Ca on the Tongass (USDA 1999). Very few plots are above threshold for Ca in Alesar. Plots 130 (Settlers Cove on Revilla Island) and 81 (Kell Bay on Kuiu Island) from the baseline monitoring period are above threshold (Figure XI-4). Both of these plots are near marine beaches in exposed locations. Just at or below threshold are plots 514, 513 (Coronation) and 507 (Endicott River), all of which are located in areas with calcareous geology (Nowacki et al. 2001). Plot 33 from Tebenkof wilderness is particulary high in total sulfur (Figure V-4), and yet it was one of the lowest in Ca (Figure XI-4). In Geiser et al (1994) there were depressed levels of calcium near the pulp mill in Sitka, which was interpreted as damage from high sulfur from that industry.

Hypogymnia, Lobaria oregana (Lobore) and *Platismatia glauca* (Plagla)

Plot 506 from the lower Endicott River contains elevated levels for Ca in *Hypogymnia*, Lobore and Plagla that are probably related to the carbonate geology on the river and surrounding landscape (Nowacki et al 2001).

XII. Summary of results for Cadmium (Cd) from all species on the Tongass National Forest

Cadmium is an element that occurs naturally in the earths crust. In the pure form, it is a soft metal but it is not found in the environment as a metal. It is usually found combined with other elements such as oxygen (cadmium oxide) chlorine (cadmium chloride) or sulfur (cadmium sulfate or sulfide) (USPHS 1993). Cadmium can enter the air from the buring of coal and household waste, or in the metal mining and refining process. Attached to small particles in the air, Cd may get into the air and travel great distances before coming back to earth as dust or in rain and snow. Where it lands, it does not break down and is eventually taken up by fish, plants and animals (USPHS 1993).

As expected, thresholds for Cd in all lichens from the Tongass are below the mine and smelter enhanced levels (30 to 330 ppm). Threshold levels are the following: *Alectoria sarmentosa* (.40 ppm), *Hypogymnia* (.61ppm), *Lobaria oregana* (.55 ppm) and *Platismatia glauca* (.32 ppm).

Some areas contain elevated levels of mean Cd above threshold: plots 108, 107 (Sitka road system), 76 (Dog Island), 221 (Douglas Island), 512 (Greens Creek tailings pile), 189 (Kootznoowoo) and 118 (Mitkof Island) for Alesar (Figure XII-4). Mean levels are elevated in *Hypogymnia* for the plots 511b (Greens Creek mine portal) and plot 512 (Greens Creek tailing pile) (Figure XII-6). Plot 110 (Amalga Trail) is the only area with elevated levels in Lobore (Figure XII-8). Greens Creek mine contains elevated levels of Cd from three locations in Plagla (plot 511a, 511b and 512) (Figure XLL-10).

There is suggestive evidence that Cd levels have changed from the pre-2000 (baseline monitoring period) to the post 2000 (second monitoring period) for three wilderness areas in *Lobaria oregana* (Table XII-3).

XII. SUMMARY OF Cd PPM DATA ANALYSIS

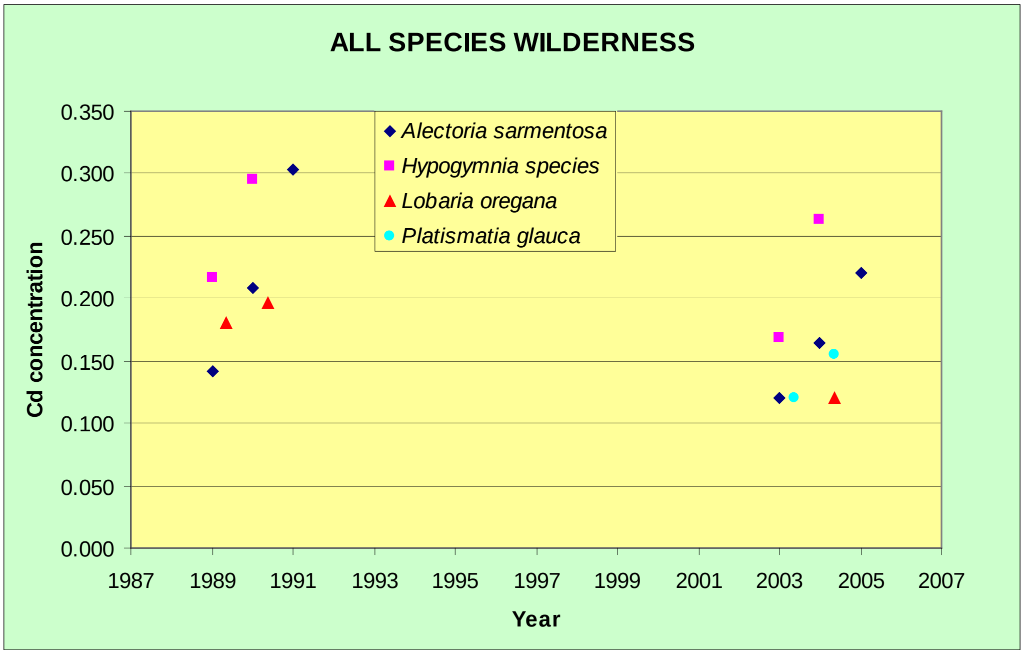

Figure XII-1. Wilderness plot means of Cd ppm in *All Species* per year.

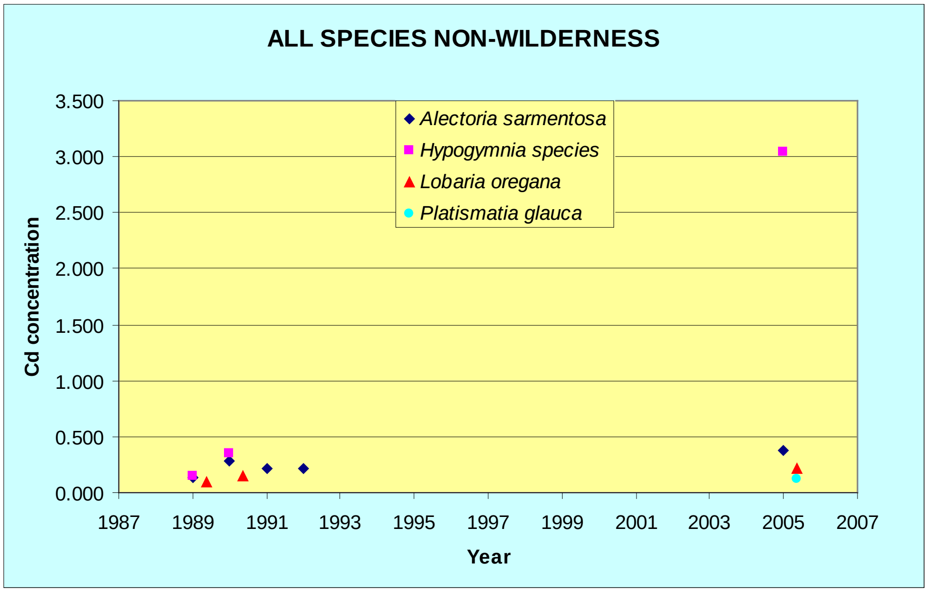

Figure XII-2. Non-Wilderness plot means of Cd ppm in *All Species* per year.

Alectoria sarmentosa

Table XII-2. Wilderness and Non-Wilderness Means, Standard Errors, and 95% Confidence Intervals for the Cd ppm content of *Alectoria sarmentosa* per year.

Cd ppm				95% CI	
Year	**Plot Type**	**Mean**	**Std. Error**	**Lower**	**Upper**
1989	Non-Wilderness	0.13	0.0087	0.1068	0.1552
1989	Wilderness	0.14	0.0327	0.0576	0.2257
1990	Non-Wilderness	0.29	0.0527	0.1768	0.3936
1990	Wilderness	0.21	0.0315	0.1320	0.2861
1991	Non-Wilderness	0.2189	0.0205	0.1757	0.2620
1991	Wilderness	0.30	0.0474	0.1722	0.4355
1992	Non-Wilderness	0.21	0.0657	0.0533	0.3642
2003	Wilderness	0.12	0.0000	0.1200	0.1200
2004	Wilderness	0.16	0.0125	0.1383	0.1902
2005	Non-Wilderness	0.37	0.1416	0.0072	0.7353
2005	Wilderness	0.22	0.0004	0.2197	0.2215

Summary of Statistical Tests:

t = 0.957, df = 8, p-value = 0.3666

There is no evidence of a difference in Cd content in *Alectoria sarmentosa* from pre-2000 and post 2000 samples (p-value = 0.3666). Plots with repeated samples for Cd in Alesar are: Karta River (#159), Pleasant Island (#145, 146), Pikes Lake RNA (# 69), Kootznoowoo (# 189, 190), Petersburg Creek (#116), Stikine-LeConte (#30, 31), Yakobi (#101), Tebenkof (#33) and Misty Fiords (#85, 86).

Relationships are not strong in the Cd content in *Alectoria sarmentosa* after accounting for latitude, longitude, elevation, year (Figures XII-3, XII-4 for year) and precipitation (see Brenner, 2006 for all graphed results).

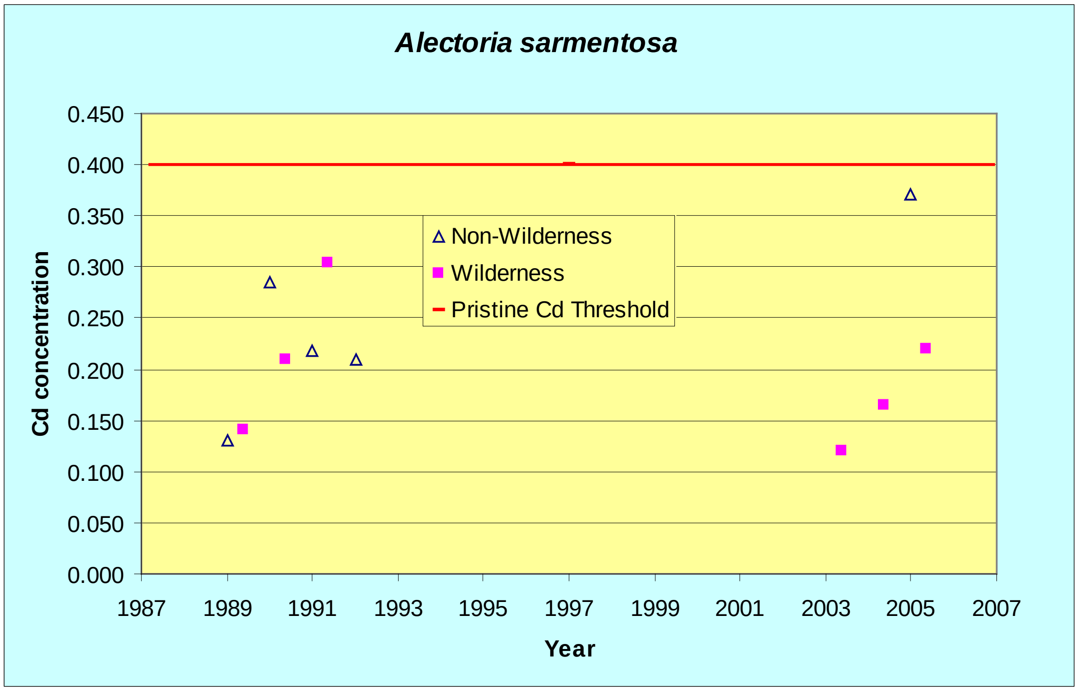

Figure XII-3. Wilderness and Non-Wilderness yearly means of Cd ppm in *Alectoria sarmentosa* per year.

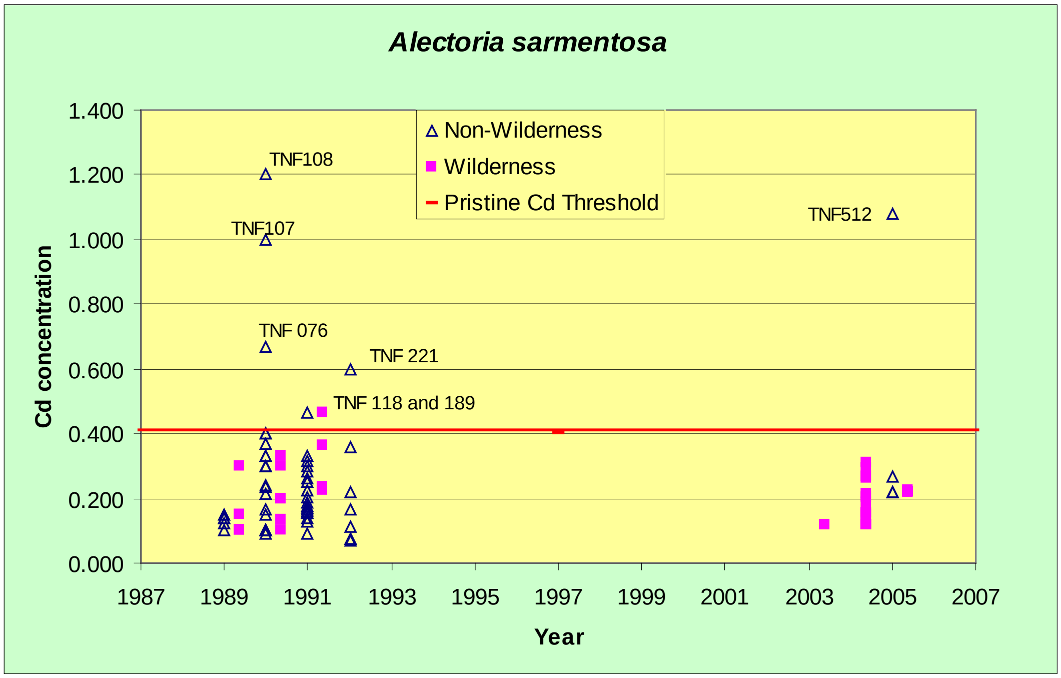

Figure XII-4. Wilderness and Non-Wilderness plot means of Cd ppm in *Alectoria sarmentosa* per year.

Hypogymnia species

In this series, all of the *Hypogymnia* species were included as a group.

Table XII-3. Wilderness and Non-Wilderness Means, Standard Errors, and 95% Confidence Intervals for the Cd ppm content of *Hypogymnia species* per year.

Cd ppm				95% CI	
Year	**Plot Type**	**Mean**	**Std. Error**	**Lower**	**Upper**
1989	Non-Wilderness	0.15	0.0500	0.4853	0.7853
1989	Wilderness	0.22	0.0726	0.0150	0.4184
1990	Non-Wilderness	0.35	0.0623	0.2235	0.4853
1990	Wilderness	0.30	0.0570	0.1557	0.4347
2003	Wilderness	0.17	NA	NA	NA
2004	Wilderness	0.26	0.0711	0.0809	0.4466
2005	Non-Wilderness	3.04	1.4535	3.2093	9.2986
2005	Wilderness	0.31	0.0576	0.1775	0.4432

No t-tests were performed on this data due to any repeated samples.

Relationships are not strong in Cd content for *Hypogymnia* after accounting for latitude, longitude, elevation, year (Figures XII-5, XII-6 for year) and precipitation (see Brenner, 2006 for all graphed results).

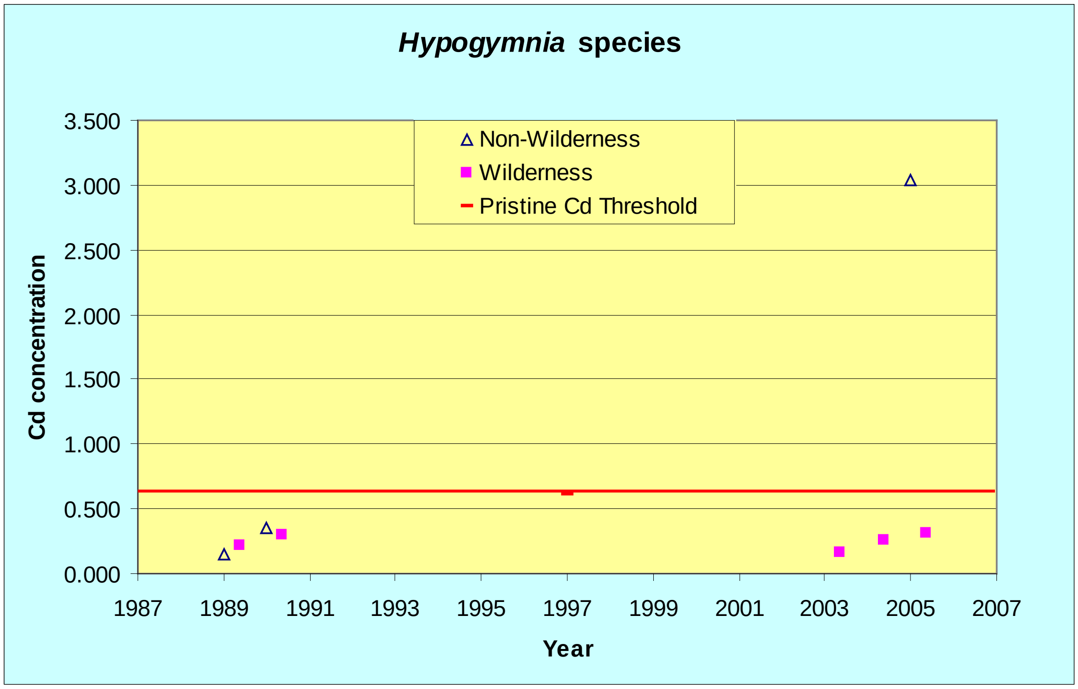

Figure XII-5. Wilderness and Non-Wilderness yearly means of Cd ppm in *Hypogymnia species* per year.

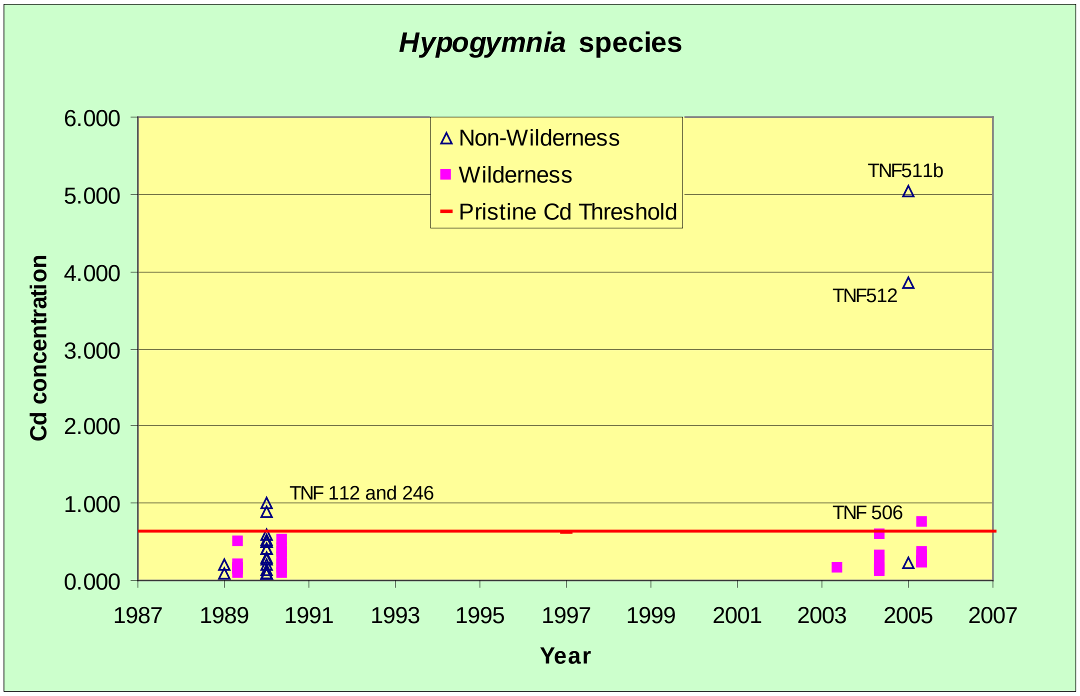

Figure XII-6. Wilderness and Non-Wilderness plot means of Cd ppm in *Hypogymnia species* per year.

Lobaria oregana

Table XII-4. Wilderness and Non-Wilderness Means, Standard Errors, and 95% Confidence Intervals for the Cd ppm content of *Lobaria oregana* per year.

Cd ppm				95% CI	
Year	**Plot Type**	**Mean**	**Std. Error**	**Lower**	**Upper**
1989	Non-Wilderness	0.10	0.0000	0.1000	0.1000
1989	Wilderness	0.18	0.0800	0.0421	0.4021
1990	Non-Wilderness	0.15	0.0519	0.0388	0.2651
1990	Wilderness	0.20	0.0664	0.0261	0.3673
2004	Wilderness	0.12	0.0000	0.1200	0.1200
2005	Non-Wilderness	0.22	NA	NA	NA
2005	Wilderness	0.22	0.0000	0.2200	0.2200

Summary of Statistical Tests:

t = -2.5145, df = 4, p-value = 0.0657

There is suggestive evidence of a slight difference in Cd content in *Lobaria oregana* from pre-2000 and post 2000 samples (p-value = 0.0657). This analysis was for three wilderness areas that had repeated values for Cd in *Lobaria oregana*, Stikine-LeConte (#30, 31), Tebenkof (#33) and Misty Fiords (# 86, 88).

Relationships are not strong in the Cd content in *Lobaria oregana* after accounting for latitude, longitude, elevation, year (Figures XII-7, XII-8 for year) and precipitation (see Brenner, 2006 for all graphed results).

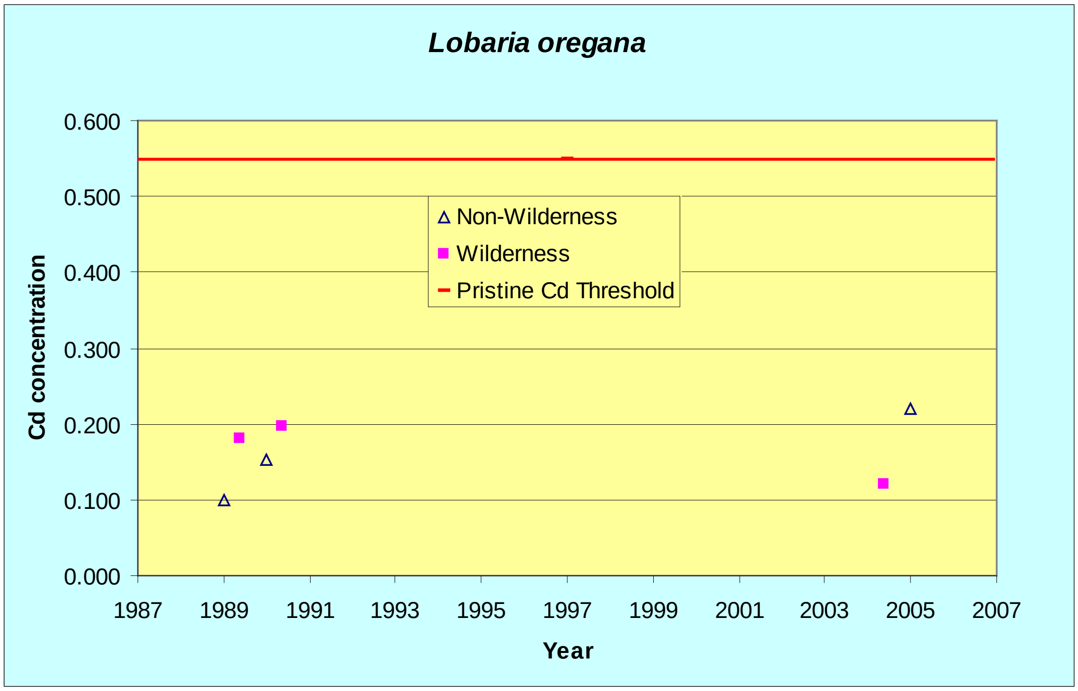

Figure XII-7. Wilderness and Non-Wilderness yearly means of Cd ppm in *Lobaria oregana* per year.

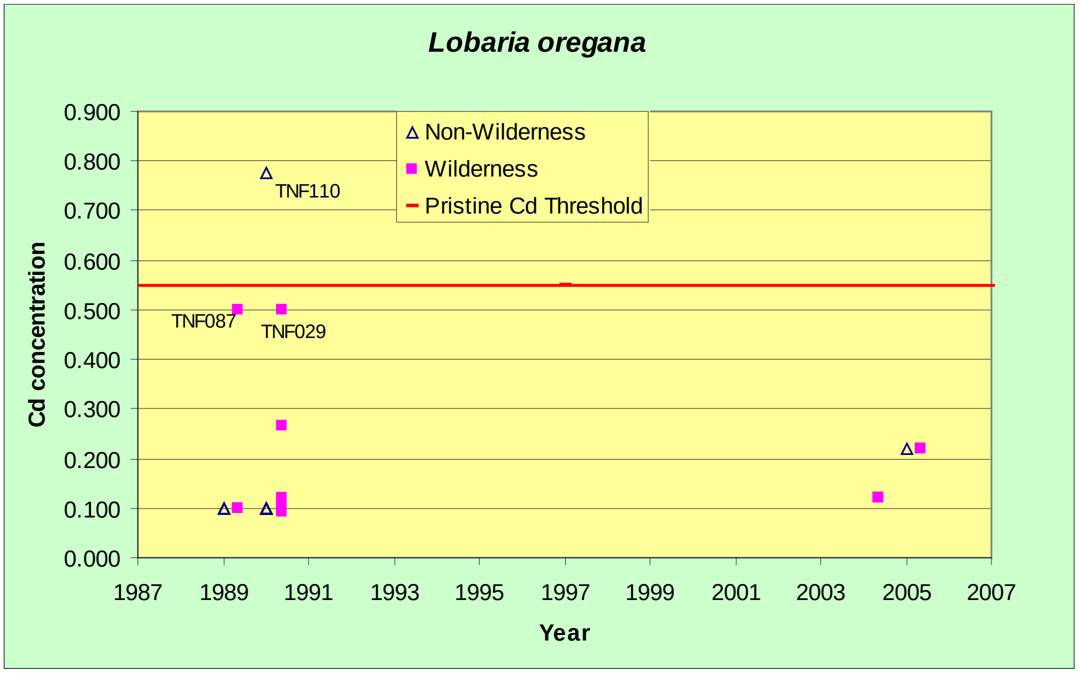

Figure XII-8. Wilderness and Non-Wilderness plot means of Cd ppm in *Lobaria oregana* per year.

Platismatia glauca

Table XII-4. Wilderness and Non-Wilderness Means, Standard Errors, and 95% Confidence Intervals for the Cd ppm content of *Platismatia glauca* per year.

Cd ppm				95% CI	
Year	**Plot Type**	**Mean**	**Std. Error**	**Lower**	**Upper**
2003	Wilderness	0.12	NA	NA	NA
2004	Wilderness	0.16	0.0298	0.0878	0.2227
2005	Non-Wilderness	1.71	0.9383	0.4089	3.8361
2005	Wilderness	0.22	0.0000	0.2200	0.2200

No t-tests were performed on these data. The mean values for Cd are baseline in *Platismatia glauca.*

Relationships are not strong in Cd content for Plagla after accounting for latitude, longitude, elevation, year (Figures XII-9, XII-10 for year) and precipitation (see Brenner, 2006 for all graphed results).

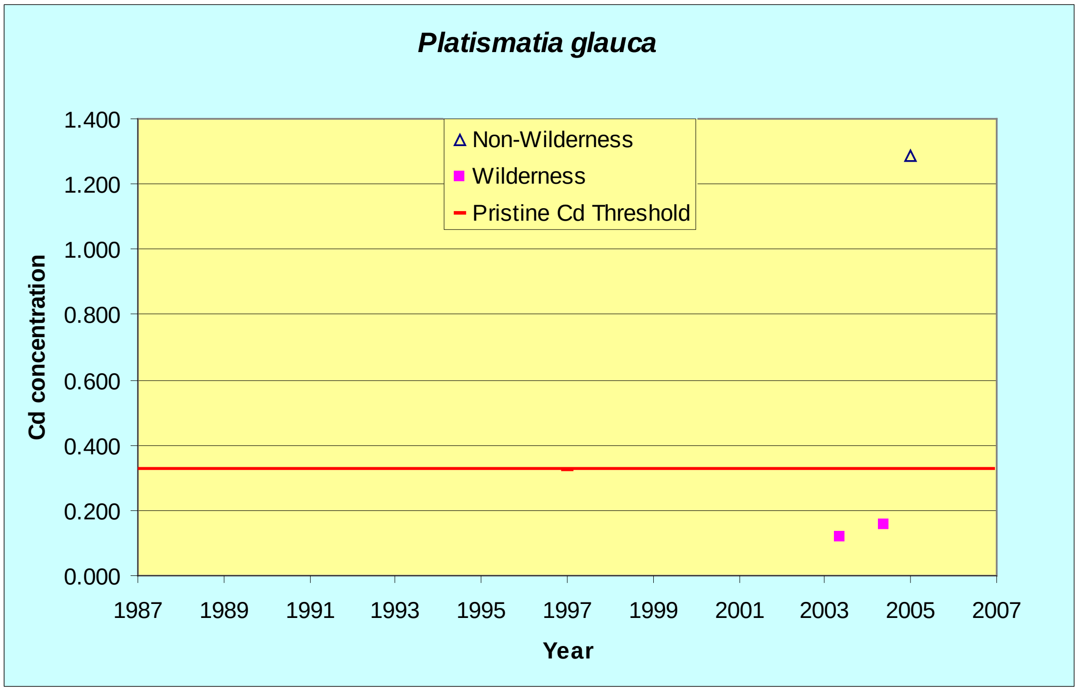

Figure XII-9. Wilderness and Non-Wilderness yearly means of Cd ppm in *Platismatia glauca* per year.

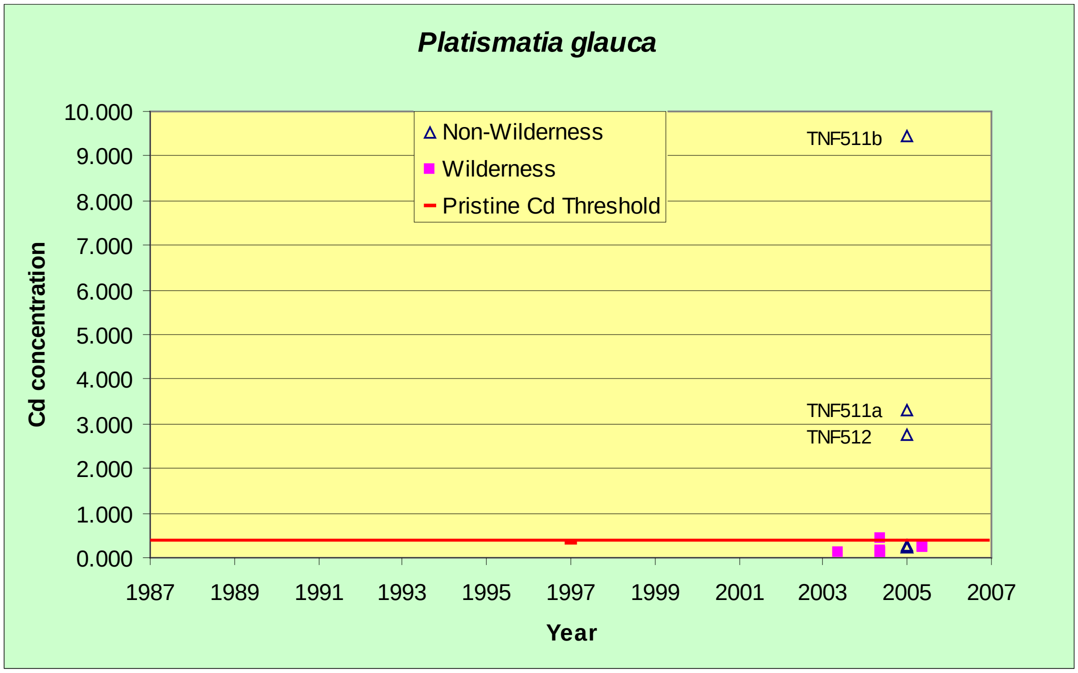

Figure XII-10. Wilderness and Non-Wilderness plot means of Cd ppm in *Platismatia glauca* per year.

Conclusions: for Cadmium (Cd) and all lichen species

Cadmium in lichens from enhanced areas due to mining and smelter activities range between 30 and 330 ppm, depending on the species (USDA 1999). The highest Cd levels in lichens on the Tongass are from near the tailings pile (between 1.0 and 4.0 ppm) and near the mine portal (between 5 ppm and 10ppm) at Greens Creek. The high rainfall in our region may flush the accumulation of Cd from lichens and other vegetation around the mining zone, but individual plot means near the mine are still higher than provisional threshold levels. Since the Cd levels are slightly higher in all species compared to the Pacific Northwest background levels, it may be that the lichens are universally enhanced in Cd due to the marine and crustal influence.

There is suggestive evidence that Cd levels have changed from the pre-2000 (baseline monitoring period) to the post 2000 (second monitoring period) for three wilderness areas: Stikine-LeConte, Tebenkof and Misty Fiords (Table XII-3). The slight change over time of Cd in *Lobaria oregana* cannot be explained except for the natural variation in Cd, as these areas are not near industry.

Alectoria sarmentosa (Alesar)

Threshold for Cd in Alesar on the Tongass is slightly higher than in the Pacific Northwest (.40 ppm compared to .20 ppm respectively) (USDA 1999). This may be attributed to the natural variation of Cd in lichens explained by environmental factors such as oceanic influence and the geology of the region. Some locations on the Tongass contain above threshold for Cd in Alesar such as on the Sitka road system near the pulp mill from the early 1990's (plots 107, 108), Greens Creek tailing pile area (plot 512), Dog Island (Plot 76), and Douglas Island near Eaglecrest (plot 221). Mitkof Island on Froot Road (plot 118) and Kootznoowoo wilderness in Gambier Bay (189) were slightly above threshold (Figure XII-4). Plot 189 on Admiralty Island was remeasured during the second monitoring period and Cd levels are not statistically different from the first monitoring period (Table XII-2). Douglas Island (plot 221) is about 1300 ft off the Eagle Creek

Road and elevated Cd levels could be attributed to the ski and housing developments, and automobile traffic in the area. It was not revisited in the second monitoring period. There is also mining history on Douglas Island. Dog Island (plot 76) is a small island off of Duke Island, and consists of gabbro, which is an igneous rock and can contain Cd as a mineral. The slightly elevated levels of Cd on Mitkof and Admiralty Islands must be part of the natural variation of Cd on the Tongass.

Hypogymnia

Background level for Cd in *Hypogymnia* in the Pacific Northwest is .25 ppm (USDA 1999), which is slightly lower than the Tongass threshold of .61 ppm. Plots from Greens Creek contain Cd levels nearly four times above threshold (Figure XII-6). Plots 511b (near the portal) and 512 (tailings pile) are near the industrial sections and road corridors of the mine, so it is likely these are the sources of the Cd in the lichens. Lichens at the tailing pile muskeg appeared healthy, but the lichens from the trees near the portal were covered in road dust and did not appear very robust. Douglas Island plot 112 near Eaglecrest also contains slightly elevated Cd, which could be attributed to close proximity to development in that area. Sitka road system plot 246 is elevated above threshold during the first monitoring period and was not revisited. Elevated levels are probably due to the proximity to the road and the pulp mill. Endicott River wilderness plot 506 has slightly elevated levels of Cd which is unexplained at this time except for natural variation and crustal sources.

Lobaria oregana (Lobore)

Plot 110 from the Amalga Trail area in Juneau is above threshold for Cd (Figure XII-8). This area is in the vicinity of a mine from the past century and could explain the elevated levels. Exposed rock can produce windblown dust in the area, as well as the surrounding glaciers. The suggestive evidence in the changes of mean Cd levels (Table XII-3) may be due to the natural variation and not human enhancement of Cd in the wilderness areas sampled (ie in Tebenkof).

Platismatia glauca (Plagla)

Pacific Northwest background for Cd in Plagla is .25 ppm, while the Tongass threshold is .32 ppm (USDA 1999). All three Greens Creek plots contain elevated levels of Cd, with the area closest to the portal at the bridge being the highest among all the plots analyzed on the Tongass (at over 9.0 ppm) (Figure XIV-10). While not as high as the 30 ppm that is considered the low end for mine enhanced levels (USDA 1999), it is high considering the amount of rainfall and leaching that occurs in this hyper maritime region.

XIII. Summary of results for Cobalt (Co) from all species on the Tongass National Forest

Cobolt is a compound that occurs in nature and in many different chemical forms. It is not currently mined in the United States. All cobalt used in industry is imported or obtained by recycling scrap metals. Cobalt is used to make alloys, colored pigments, and for enameled paints on appliances. It is part of vitamin B-12 that is essential for human health. Natural sources of cobalt are soils, dust and seawater. It is also released into the environment from burning oil and coal, and from automobile exhaust (USPHS 1992)

Cobalt detection levels in the ICP analysis varied between 2004 and 2005. In 2004, the Co detection in the ICP machine was .240 ppm. In 2005, the ICP utilized had a higher detection limit of .780 ppm. Samples of Alesar were below detection limit of .78 for Co. Provisional threshold of colbalt on the Tongass are: *Hypogymnia* (1.25 ppm), *Lobaria oregana* (.83 ppm) and *Platismatia glauca* (1.14 ppm). Cobalt was not analyzed in the first monitoring period, or in the 2003 samples. Therefore, threshold were established from 2004 and 2005 data.

Elevated levels of Co are reported for *Hypogymnia* from plot 512 (Greens Creek tailing pile), and 62 (Russell Fiord Harlequin Lake area) (Figure XIIV-6). For Lobore plot 62 (Russell Fiords) is just above threshold (Figure XIIV-8). For Plagla plot 512 (Greens Creek tailings) and 508 and 506 (Endicott River wilderness) are elevated above threshold (Figure XIIV-10).

XIII. SUMMARY OF Co PPM DATA ANALYSIS

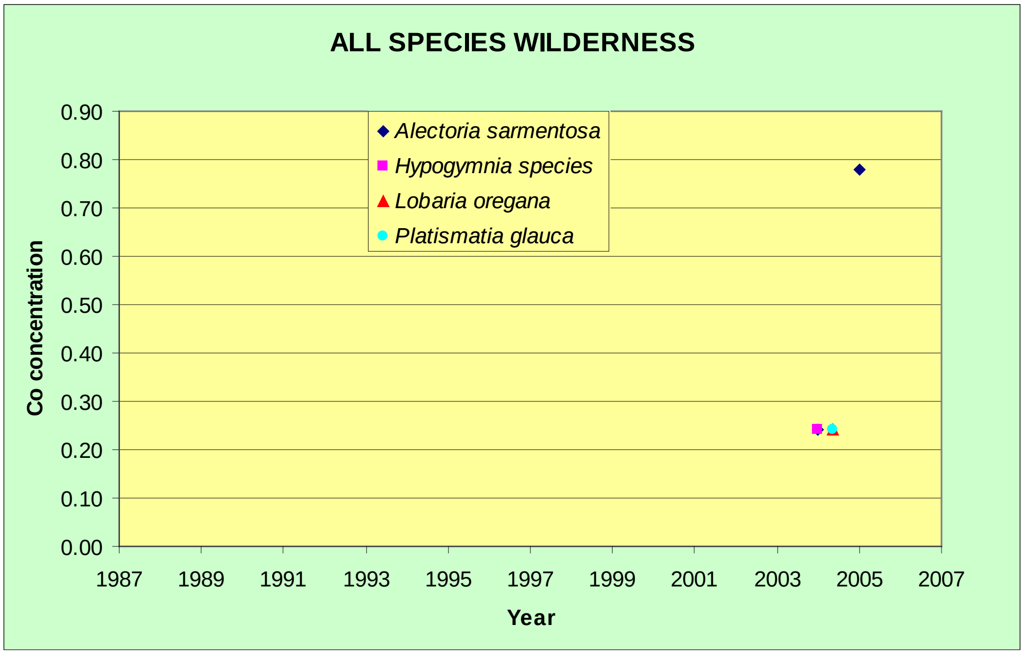

Figure XIII-1. Wilderness plot means of Co ppm in *All Species* per year.

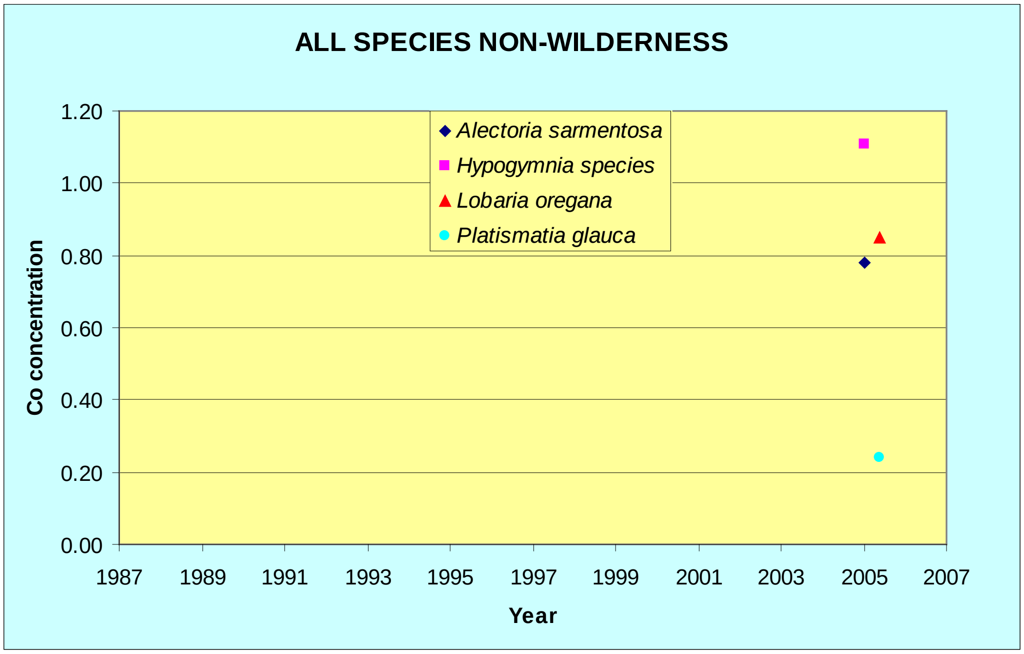

Figure XIII-2. Non-Wilderness plot means of Co ppm in *All Species* per year.

Alectoria sarmentosa

Table XIII-2. Wilderness and Non-Wilderness Means, Standard Errors, and 95% Confidence Intervals for the Co ppm content of *Alectoria sarmentosa* per year.

Co				95% CI	
Year	**Plot Type**	**Mean**	**Std. Error**	**Lower**	**Upper**
2004	Wilderness	0.24	0.0000	0.2400	0.2400
2005	Non-Wilderness	0.78	0.0000	0.7800	0.7800
2005	Wilderness	0.78	0.0000	0.7800	0.7800

No t-tests were performed on these data. The mean values for Co are below the detection limit of the ICP machine. Baseline in *Alectoria sarmentosa* is .78 ppm.

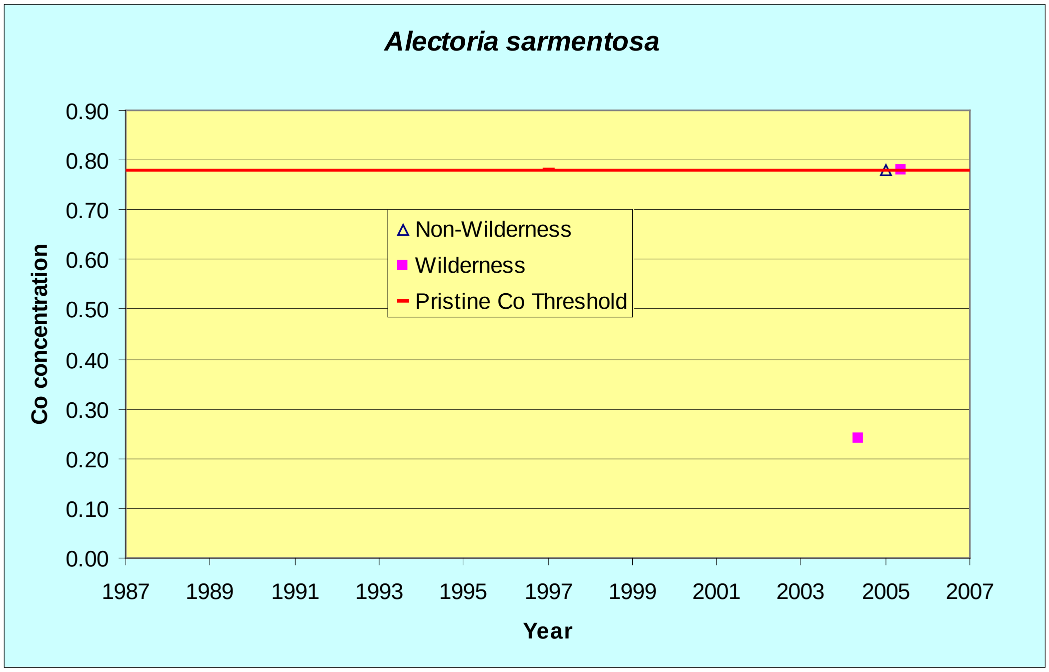

Figure XIII-3. Wilderness and Non-Wilderness yearly means of Co ppm in *Alectoria sarmentosa* per year.

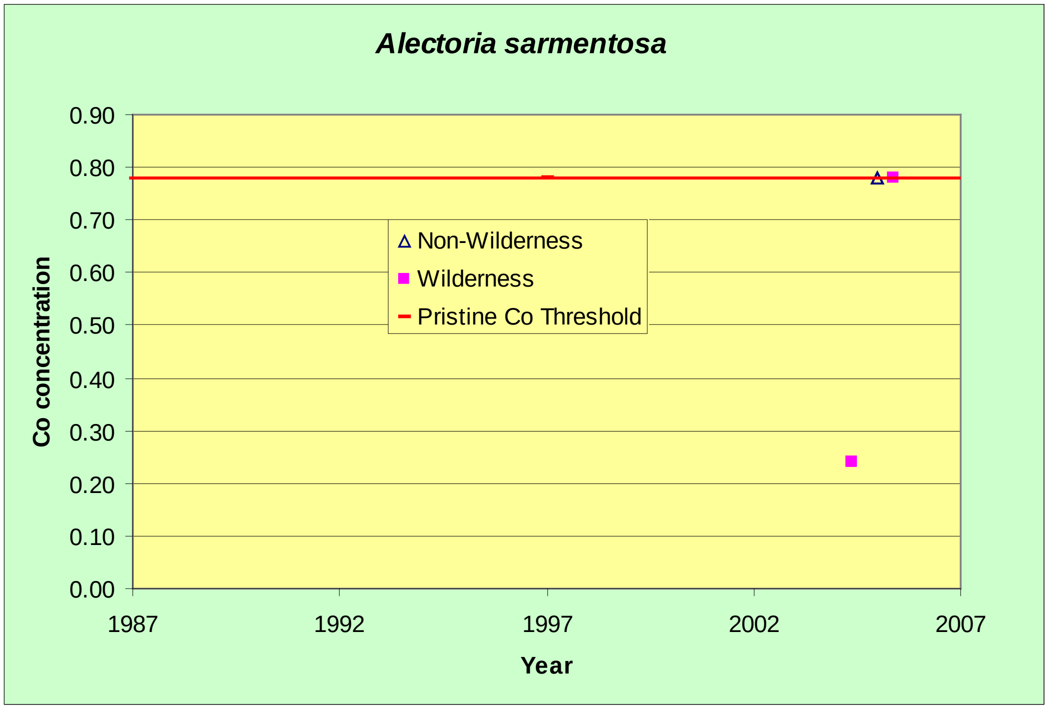

Figure XIII-4. Wilderness and Non-Wilderness plot means of Co ppm in *Alectoria sarmentosa* per year.

Hypogymnia species

In this series, all of the *Hypogymnia* species were included as a group.

Table XIII-3. Wilderness and Non-Wilderness Means, Standard Errors, and 95% Confidence Intervals for the Co ppm content of *Hypogymnia species* per year.

Co ppm				95% CI	
Year	**Plot Type**	**Mean**	**Std. Error**	**Lower**	**Upper**
2004	Wilderness	0.24	0.0000	0.2400	0.2400
2005	Non-Wilderness	1.11	0.1754	0.3530	1.8626
2005	Wilderness	0.84	0.0579	0.7044	0.9714

No t-tests were performed on these data. The mean values for Co are baseline in *Hypogymnia.*

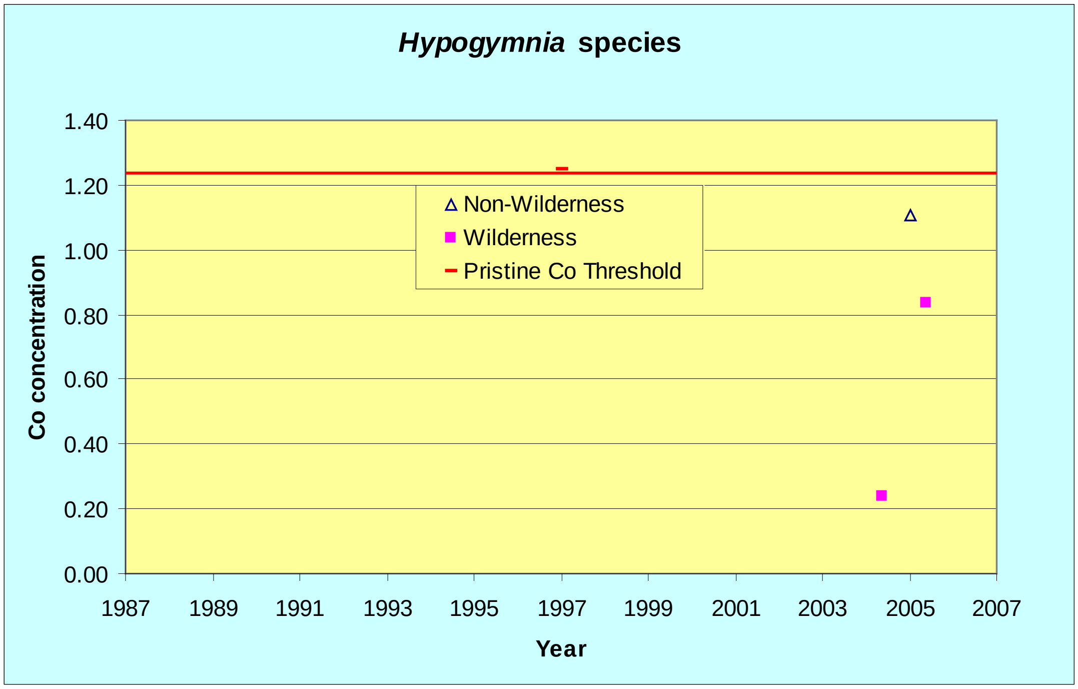

Figure XIII-5. Wilderness and Non-Wilderness yearly means of Co ppm in *Hypogymnia species* per year.

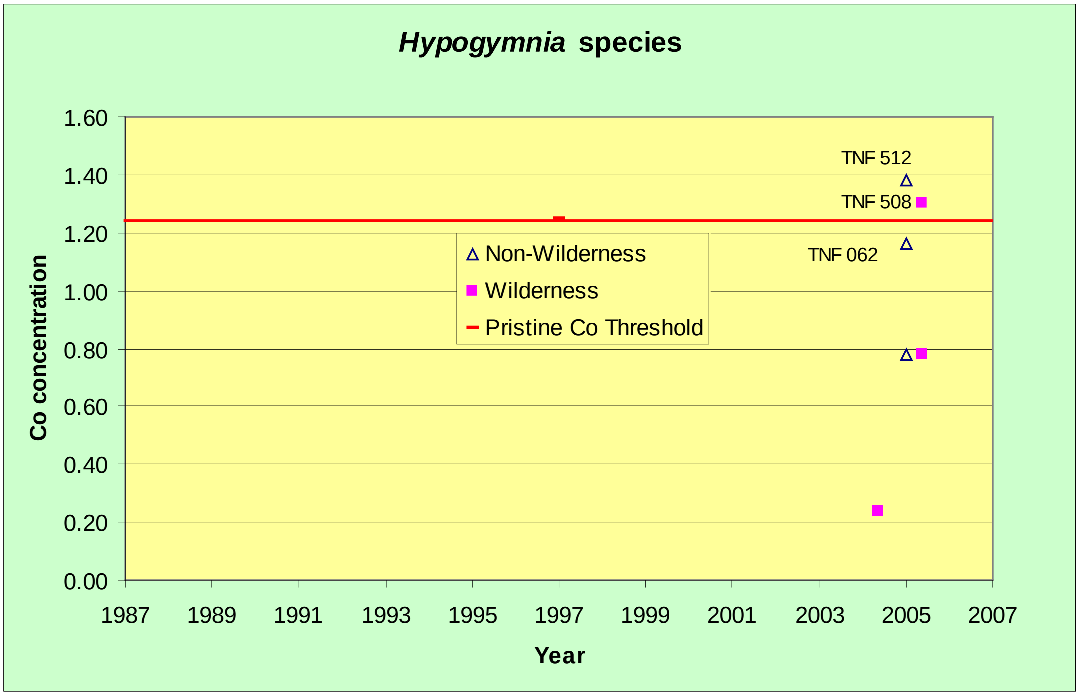

Figure XIII-6. Wilderness and Non-Wilderness plot means of Co ppm in *Hypogymnia species* per year.

Lobaria oregana

Table XIII-4. Wilderness and Non-Wilderness Means, Standard Errors, and 95% Confidence Intervals for the Co ppm content of *Lobaria oregana* per year.

Co ppm				95% CI	
Year	**Plot Type**	**Mean**	**Std. Error**	**Lower**	**Upper**
2004	Wilderness	0.24	0.0000	0.2400	0.2400
2005	Non-Wilderness	0.85	NA	NA	NA
2005	Wilderness	0.78	0.0000	0.7800	0.7800

No t-tests were performed on these data. The mean values for Co are baseline in *Lobaria oregana.*

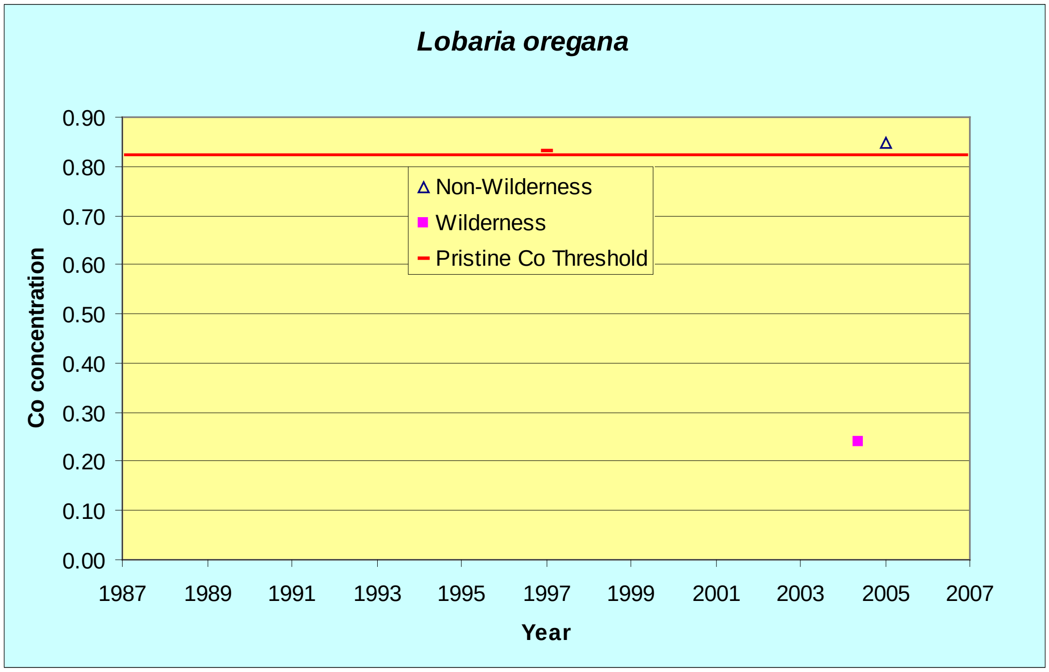

Figure XIII-7. Wilderness and Non-Wilderness yearly means of Co ppm in *Lobaria oregana* per year.

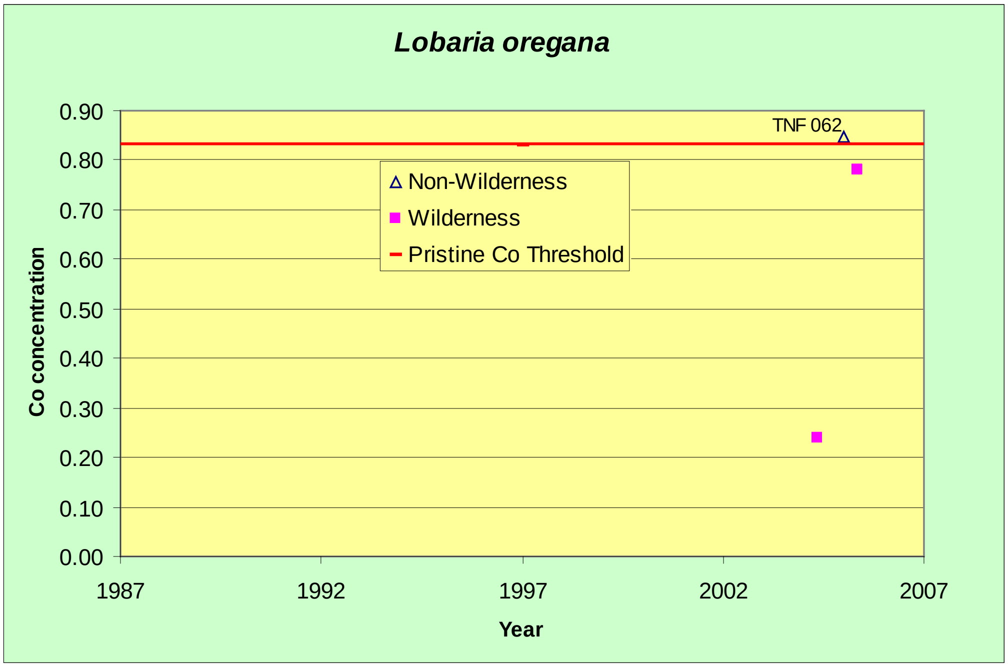

Figure XIII-8. Wilderness and Non-Wilderness plot means of Co ppm in *Lobaria oregana* per year.

Platismatia glauca

Table XIII-4. Wilderness and Non-Wilderness Means, Standard Errors, and 95% Confidence Intervals for the Co ppm content of *Platismatia glauca* per year.

Co ppm				**95% CI**	
Year	**Plot Type**	**Mean**	**Std. Error**	**Lower**	**Upper**
2004	Wilderness	0.24	0.0000	0.2400	0.2400
2005	Non-Wilderness	0.86	0.0611	0.7240	1.0006
2005	Wilderness	0.87	0.0592	0.7304	1.0101

No t-tests were performed on these data. The mean values for Co are baseline in *Platismatia glauca.*

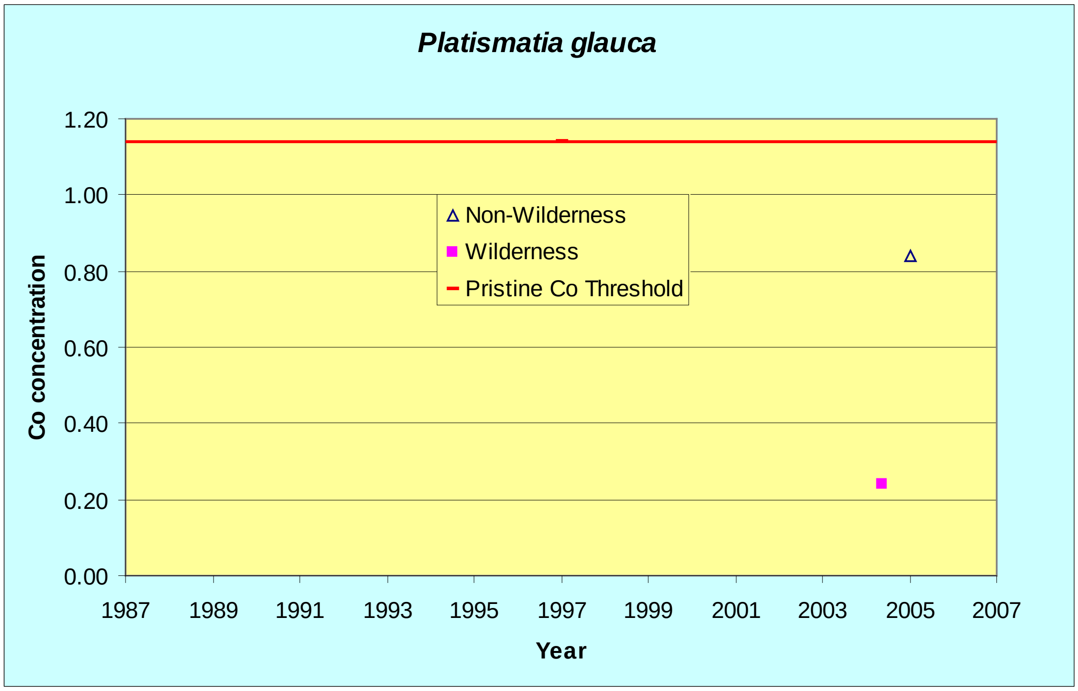

Figure XIII-9. Wilderness and Non-Wilderness yearly means of Co ppm in *Platismatia glauca* per year.

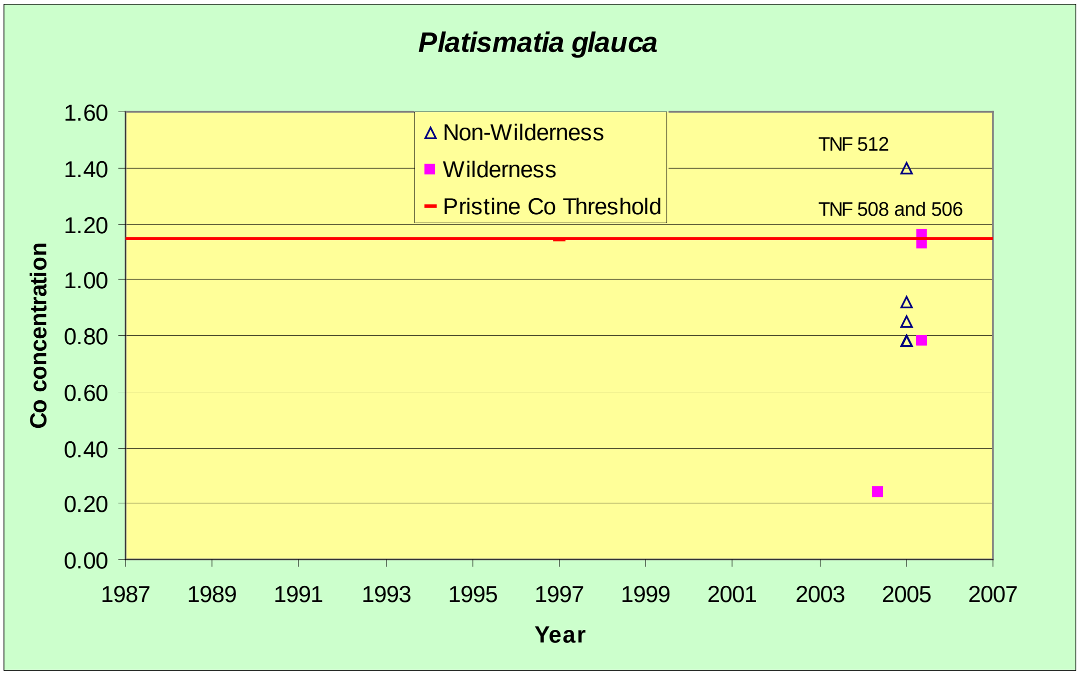

Figure XIII-10. Wilderness and Non-Wilderness plot means of Co ppm in *Platismatia glauca* per year.

Conclusions: for Colbalt (Co) and all lichen species
Background levels for Co are not available from the Pacific Northwest. Tongass thresholds are just above the ICP detection limit for Co, which indicates that background on the Tongass lichens are very low. The locations that indicate elevated levels may be enhanced due to crustal influences. Plot 512 from Greens Creek is elevated in both *Hypogymnia* and Plagla, indicating that the exposed rock from the tailings pile may be the source. Plot 62 from Russell Fiord is above threshold in Co for the *Hypogymnia* and Lobore samples. This plot is near the airstrip, the dirt road and Dangerous River Bridge, and receives windblown dusts from the surrounding glaciers and exposed rocks. Endicott River plots 508 (upper river) and 506 (near saltwater) are at threshold, and may be elevated above the ICP detection limit due to natural sources of the highly glaciated area.

XIV. Summary of results for Chromium (Cr) from all species on the Tongass National Forest

Chromium is a naturally occurring element found in rocks, animals, plants, soil, and volcanic dust and gases. It is present in the environment in different forms. The common forms are chromium 0, chromium III and chromium VI. Chromium III occurs naturally and is an essential nutrient for humans (USPHS 1990). Chromium VI and 0 are generally produced by industrial processes such as producing steel and brick linings for furnaces, and through the burning of coal and oil. In smaller amounts it is used in drilling muds for mining, rust and corrosion inhibitors, textiles and toner for copy machines. In the air, chromium compounds are present as a fine dust, and rain and snow help remove it from the air. The different types of chromium are not differentiated in the ICP analysis.

Provisional thresholds for Cr on the Tongass are: *Alectoria sarmentosa* (.73 ppm) *Hypogymnia* (2.38 ppm), *Lobaria oregana* (1.51 ppm) and *Platismatia glauca* (3.29 ppm).

Plots elevated above threshold for Cr are the following: from Sitka road system plots 236, 239, 242, 243, 244, 245, and 246 (Figures XIV-4, 6 and 8), Greens Creek plots 512 and 511b (Figures XIV-10), Berners Bay plot 113 (Figure XIV-4) Harlequin Lake plot 62 (Figures XIV-8 and 10), downtown Juneau plot 1000 (Figures XIV-10) and Yakutat road system plot 66 (Figure XIV-4 and 6).

XIV. SUMMARY OF Cr PPM DATA ANALYSIS

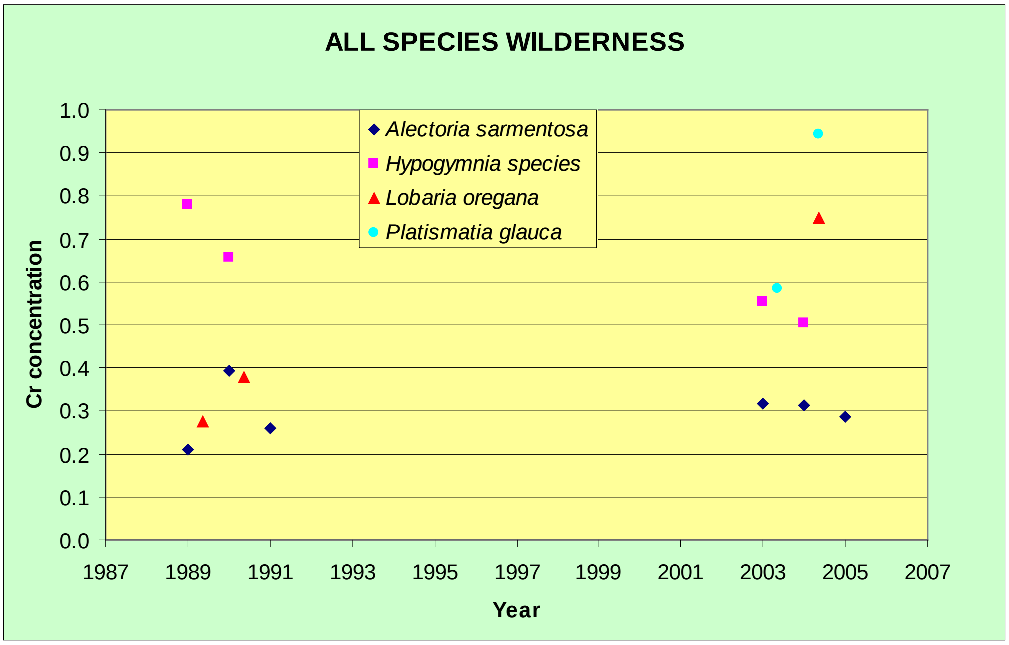

Figure XIV-1. Wilderness plot means of Cr ppm in *All Species* per year.

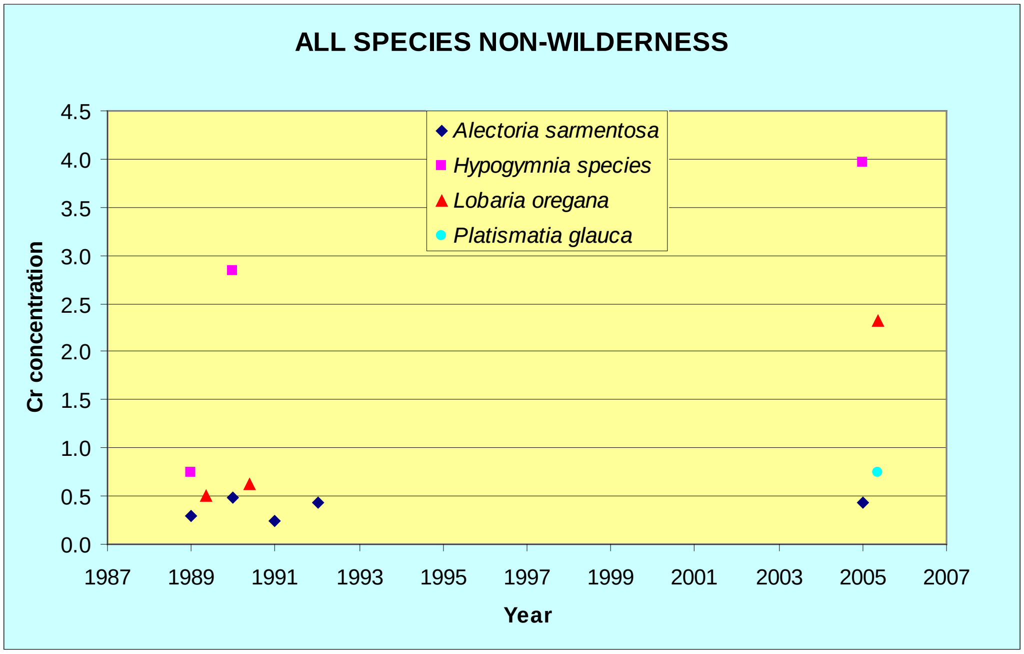

Figure XIV-2. Non-Wilderness plot means of Cr ppm in *All Species* per year.

Alectoria sarmentosa

Table XIV-1. Wilderness and Non-Wilderness Means, Standard Errors, and 95% Confidence Intervals for the Cr ppm content of *Alectoria sarmentosa* per year.

Cr ppm				95% CI	
Year	**Plot Type**	**Mean**	**Std. Error**	**Lower**	**Upper**
1989	Non-Wilderness	0.30	0.0422	0.1807	0.4153
1989	Wilderness	0.21	0.0712	0.0253	0.3914
1990	Non-Wilderness	0.49	0.0650	0.3587	0.6261
1990	Wilderness	0.39	0.0969	0.1573	0.6317
1991	Non-Wilderness	0.2420	0.0176	0.2050	0.2790
1991	Wilderness	0.26	0.0547	0.1063	0.4098
1992	Non-Wilderness	0.43	0.0633	0.2809	0.5801
2003	Wilderness	0.32	0.0148	0.1270	0.5040
2004	Wilderness	0.31	0.0214	0.2669	0.3556
2005	Non-Wilderness	0.44	0.0869	0.2152	0.6622
2005	Wilderness	0.29	0.0034	0.2783	0.2936

Summary of Statistical Tests:

t = -0.3201, df = 8, p-value = 0.7571

There is no evidence of a difference in Cr content in *Alectoria sarmentosa* from pre-2000 and post 2000 samples (p-value = 0.7571). Plots with repeated samples for cadmium in Alesar are: Karta River (#159), Pleasant Island (#145, 146), Pikes Lake RNA (# 69), Kootznoowoo (# 189, 190), Petersburg Creek (#116), Stikine-LeConte (#30, 31), Yakobi (#101), Tebenkof (#33) and Misty Fiords (#85, 86).

Relationships are not strong in the Cr content in *Alectoria sarmentosa* after accounting for latitude, longitude, elevation, year (Figures XIV-3, XIV-4 for year) and precipitation (see Brenner, 2006 for all graphed results).

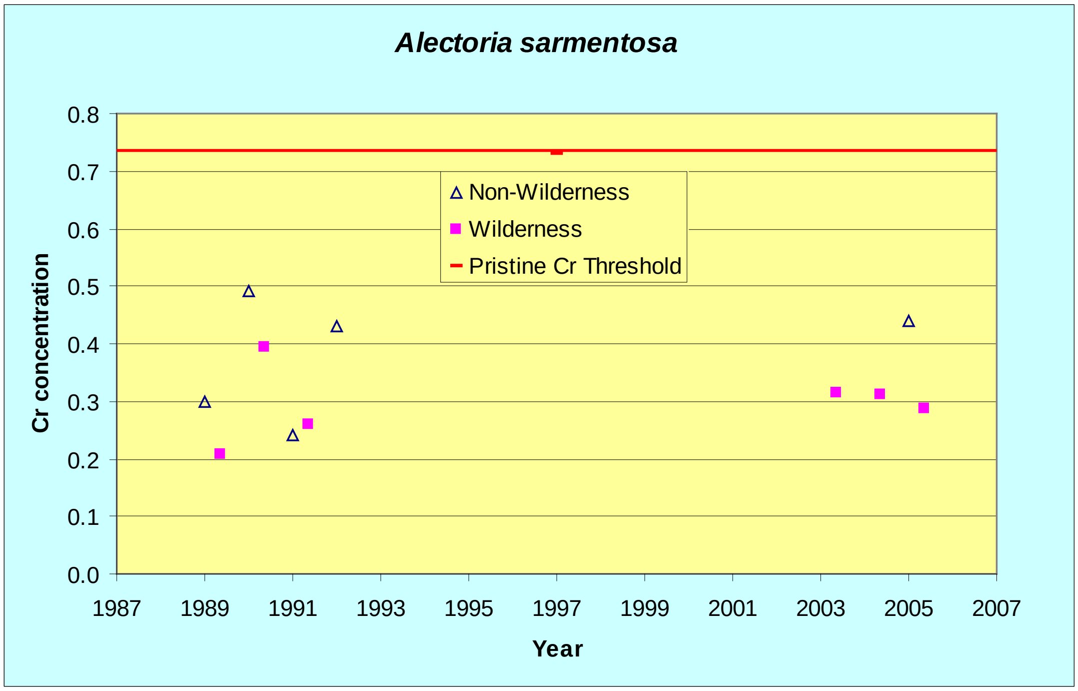

Figure XIV-3. Wilderness and Non-Wilderness yearly means of Cr ppm in *Alectoria sarmentosa* per year.

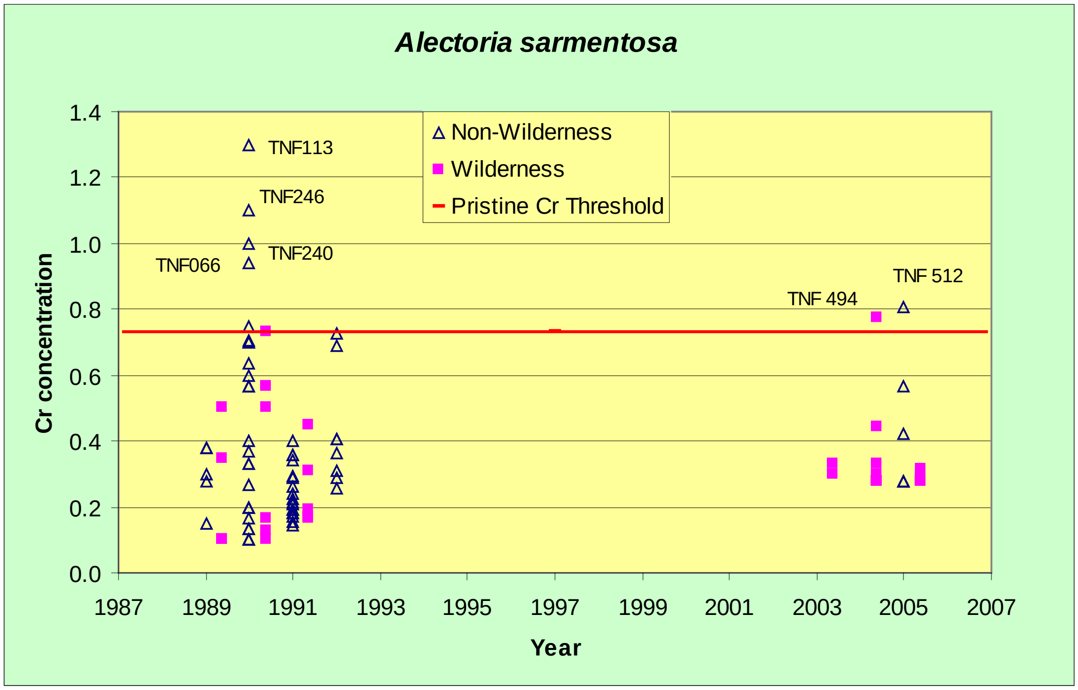

Figure XIV-4. Wilderness and Non-Wilderness plot means of Cr ppm in *Alectoria sarmentosa* per year.

Hypogymnia species

In this series, all of the *Hypogymnia* species were included as a group.

Table XIV-2. Wilderness and Non-Wilderness Means, Standard Errors, and 95% Confidence Intervals for the Cr ppm content of *Hypogymnia species* per year.

Cr ppm				95% CI	
Year	**Plot Type**	**Mean**	**Std. Error**	**Lower**	**Upper**
1989	Non-Wilderness	0.75	0.4500	4.9678	6.4678
1989	Wilderness	0.78	0.2223	0.1629	1.3971
1990	Non-Wilderness	2.84	0.6270	1.5275	4.1620
1990	Wilderness	0.66	0.1472	0.2969	1.0174
2003	Wilderness	0.55	NA	NA	NA
2004	Wilderness	0.50	0.1066	0.2285	0.7766
2005	Non-Wilderness	3.97	1.1188	0.8457	8.7817
2005	Wilderness	0.90	0.2141	0.4055	1.3927

No t-tests were performed on this data due to the lack of repeat samples of *Hypogymnia.*

Relationships are not strong in Cr content for *Hypogymnia* after accounting for latitude, longitude, elevation, year (Figures XIV-5, XIV-6 for year) and precipitation (see Brenner, 2006 for all graphed results).

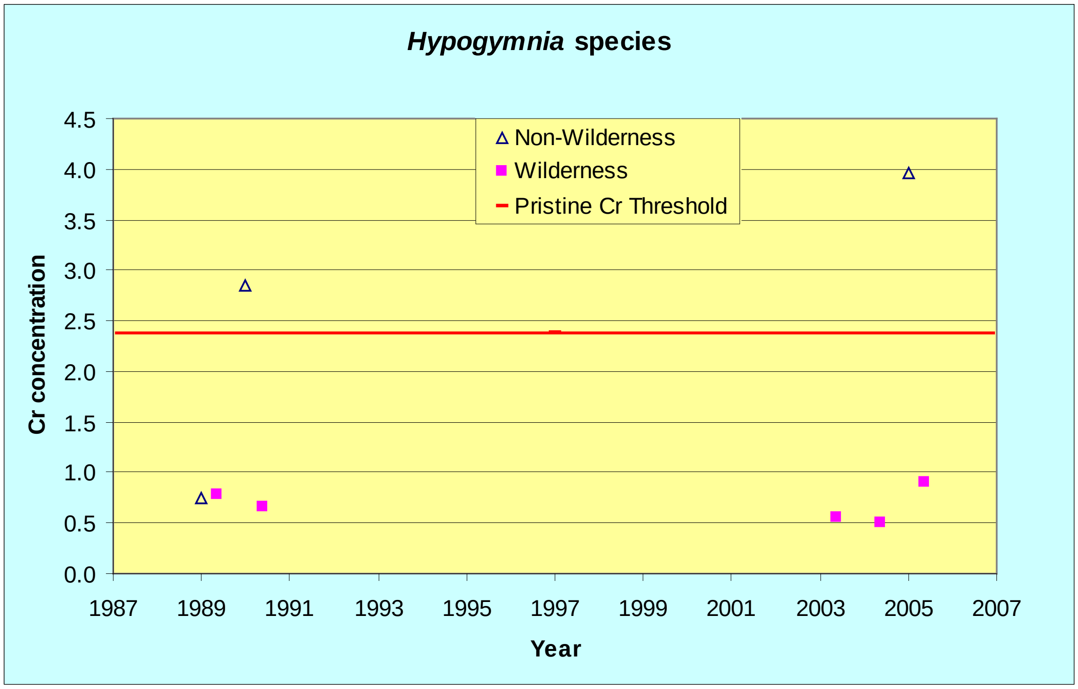

Figure XIV-5. Wilderness and Non-Wilderness yearly means of Cr ppm in *Hypogymnia species* per year.

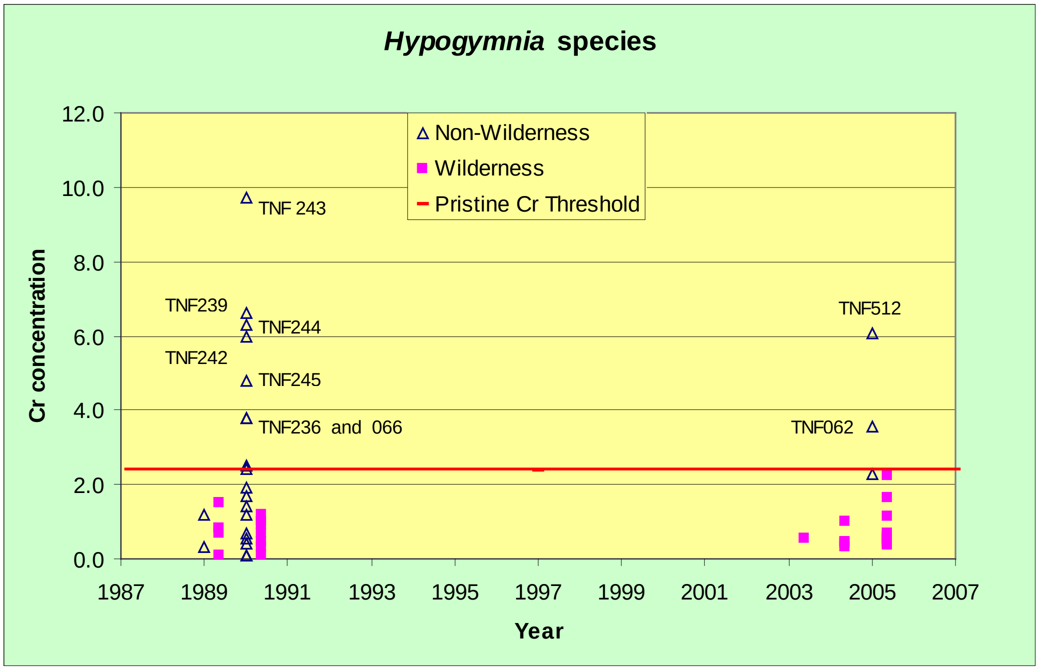

Figure XIV-6. Wilderness and Non-Wilderness plot means of Cr ppm in *Hypogymnia species* per year.

Lobaria oregana

Table XIV-3. Wilderness and Non-Wilderness Means, Standard Errors, and 95% Confidence Intervals for the Cr ppm content of *Lobaria oregana* per year.

Cr ppm				95% CI	
Year	**Plot Type**	**Mean**	**Std. Error**	**Lower**	**Upper**
1989	Non-Wilderness	0.51	0.0344	0.3990	0.6177
1989	Wilderness	0.28	0.1005	-0.0038	0.5545
1990	Non-Wilderness	0.62	0.1445	0.3005	0.9302
1990	Wilderness	0.38	0.1932	-0.1181	0.8753
2004	Wilderness	0.75	0.1450	0.3920	1.1017
2005	Non-Wilderness	2.32	NA	NA	NA
2005	Wilderness	0.41	0.0994	0.0943	0.7272

Summary of Statistical Tests:

t = -1.19, df = 4, p-value = 0.2999

There is no evidence of a difference in Cr ppm content in *Lobaria oregana* from pre-2000 and post 2000 samples (p-value = 0.2999). This analysis was for three wilderness areas that had repeated values for chromium in *Lobaria oregana*, Stikine-LeConte (#30, 31), Tebenkof (#33) and Misty Fiords (# 86, 88).

Relationships are not strong in the Cr content in *Lobaria oregana* after accounting for latitude, longitude, elevation, year (Figures XIV-7, XIV-8 for year) and precipitation (see Brenner, 2006 for all graphed results).

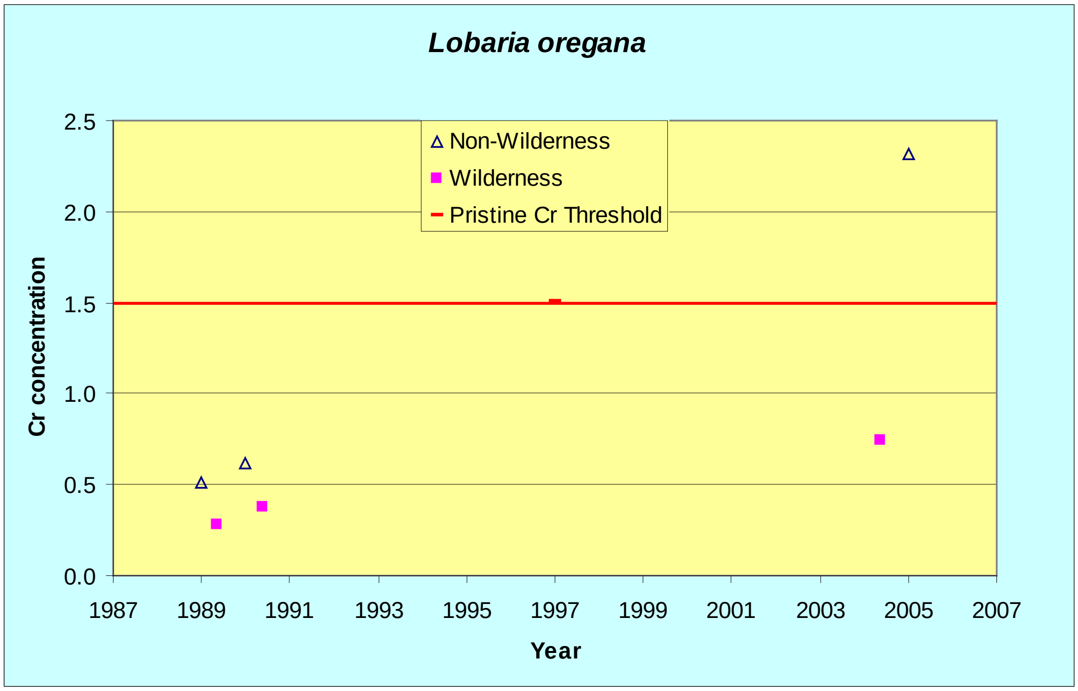

Figure XIV-7. Wilderness and Non-Wilderness yearly means of Cr ppm in *Lobaria oregana* per year.

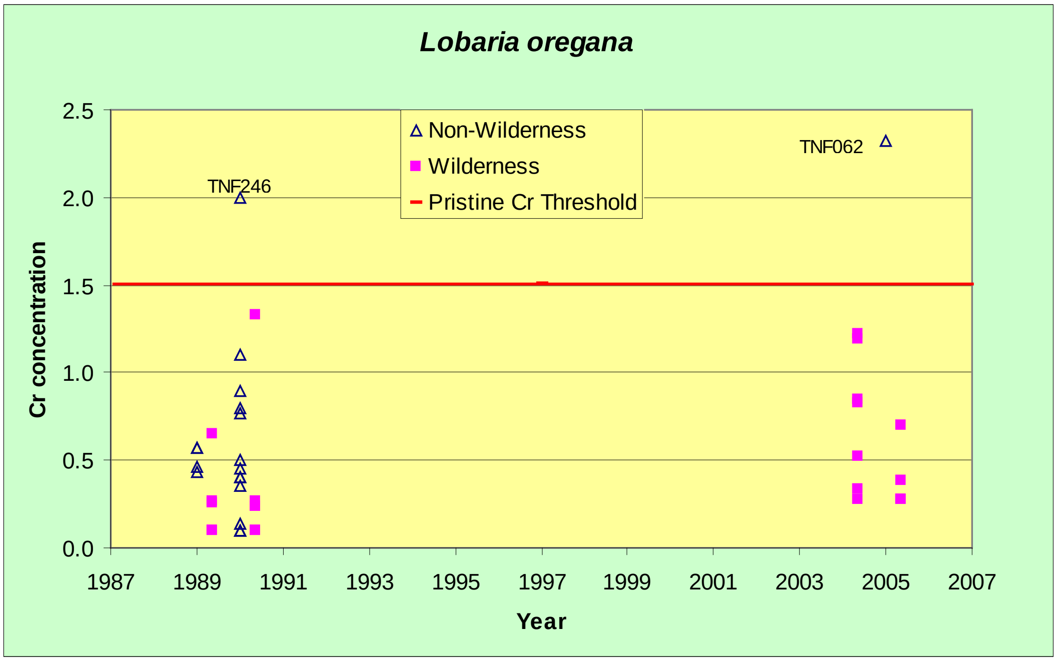

Figure XIV-8. Wilderness and Non-Wilderness plot means of Cr ppm in *Lobaria oregana* per year.

Platismatia glauca

Table XIV-4. Wilderness and Non-Wilderness Means, Standard Errors, and 95% Confidence Intervals for the Cr ppm content of *Platismatia glauca* per year.

Cr ppm				95% CI	
Year	**Plot Type**	**Mean**	**Std. Error**	**Lower**	**Upper**
2003	Wilderness	0.58	NA	NA	NA
2004	Wilderness	0.94	0.1798	0.5371	1.3504
2005	Non-Wilderness	3.02	0.5248	1.8331	4.2077
2005	Wilderness	1.17	0.3019	0.4538	1.8817

No t-tests were performed on these data. The mean values for Cr are baseline in *Platismatia glauca.*

Relationships are not strong in Cr content for Plagla after accounting for latitude, longitude, elevation, year (Figures XIV-9, XIV-10 for year) and precipitation (see Brenner, 2006 for all graphed results).

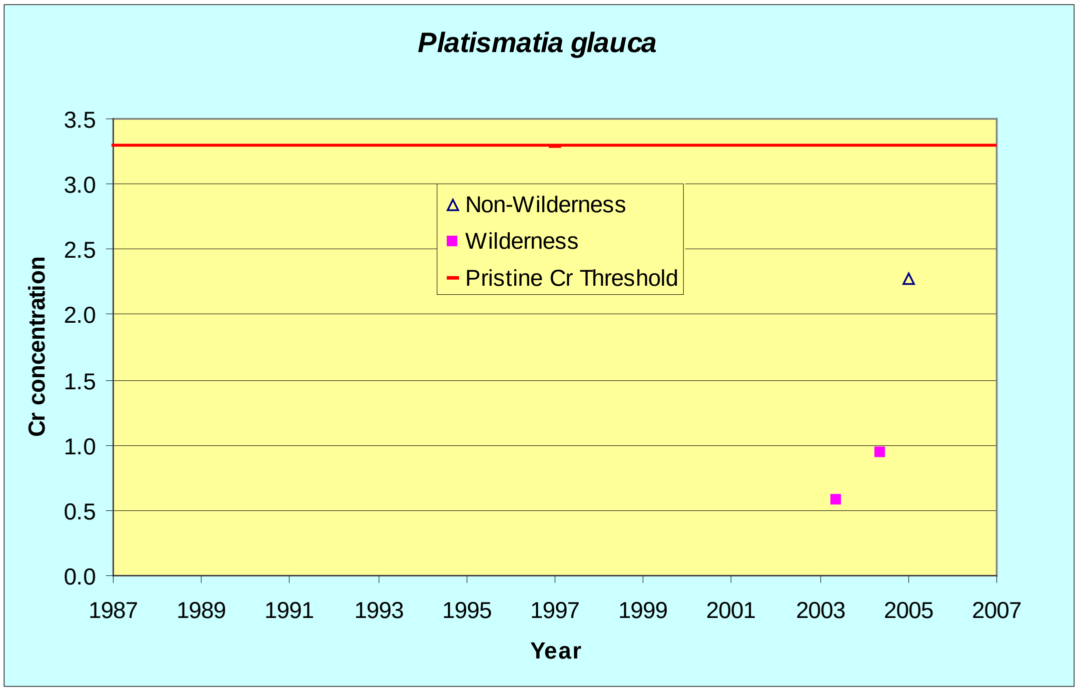

Figure XIV-9. Wilderness and Non-Wilderness yearly means of Cr ppm in *Platismatia glauca* per year.

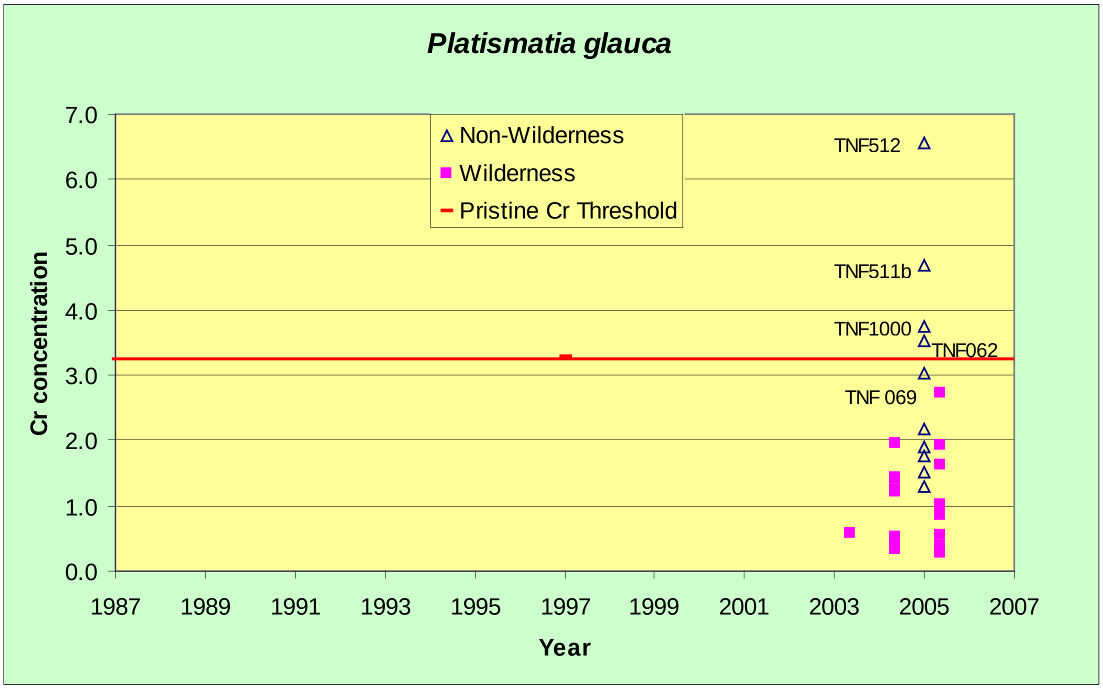

Figure XIV-10. Wilderness and Non-Wilderness plot means of Cr ppm in *Platismatia glauca* per year.

Conclusions: for Chromium (Cr) and all lichen species

Smelter and mine enhanced values for Cr are between 25 and 130 ppm (USDA 1999). The highest value for Cr on the Tongass is the Greens Creek tailing pile from Plagla at nearly 7ppm (Figure XIV-10). Precipitation has helped to remove the accumulated Cr from the lichens in this industrial area. Plot 62, just inside the Russell Fiords wilderness, is above threshold in three lichen species for Cr, but means levels are lower than Greens Creek area.

***Alectoria sarmentosa* (Alesar)**

Background for Cr in Alesar from the Pacific Northwest is .50 ppm, which is slightly lower than the Tongass threshold of .73 ppm (USDA 1999). Analysis from the second monitoring period contains Plot 494 on the Stikine River and plot 512 from Greens Creek above threshold for Cr in Alesar (Figure XIV-4). It is unclear why the Stikine River plot at Andrews Slough is elevated in Cr as no industrial sources are nearby. Elevated levels may pertain to the geology of the area and the glacial dusts that blow down the Stikine corridor. The Greens Creek tailing pile and the associated road are most likely the source of Cr in Alesar as it is emitted in the mining process and is a natural occurring substance in rock. From the baseline monitoring period, four plots are elevated above threshold; 113 (Berners Bay), 246 and 240 (Sitka road system near mill), and 66 (Yakutat road system near Greens Pond). Elevated Cr near roads is probably due to vehicle traffic and dust that potentially brings Cr into the air from where it eventually settles on the lichens nearby. The Yakutat area also receives windblown soils from the Yukon and could enhance certain elemental values. Berner's Bay elevated levels is unexplained, however this area was the site of old mines in the past century. It is now the site of a large mine, and so the geology may play a role in the elevated levels. Repeated sampling in that area may reveal changes in many elements as the mine continues to develop.

Hypogymnia

Background level of Cr in *Hypogymnia* from the Pacific Northwest is between 2 and 3 ppm (USDA 1999). Tongass threshold is between these values at 2.38 ppm. From the baseline monitoring period, plots 236, 239, 242, 243, 244, 245 (Sitka road system) and 66 (Yakutat Greens pond), are elevated above threshold. This can be explained by the close proximity to unpaved roads and proximity to industry (in the case of Sitka). The second monitoring period revealed two places, plot 62 near Harlequin Lake and plot 512 (Greens Creek tailing pile) as above threshold. Harlequin Lake is also high in Cr from Plagla. Therefore high Cr may be due to the close proximity to the Dangerous River Bridge, air traffic at the gravel airstrip, or windblown dusts from the north.

***Lobaria oregana* (Lobore)**

Background for Cr in Lobore is 1 ppm (USDA 1999). Tongass threshold is similar at 1.51 ppm. Plot 246 from the Sitka road system and plot 62 from Harlequin Lake were both above threshold level for Cr in Lobore at 2.0 ppm and above (Figure XIV-8). The Sitka road system vehicle traffic and proximity to the pulp mill can help explain elevated levels. The Alesar from this plot was also elevated in Cr. The plot near Harlequin Lake and the Dangerous River is elevated in Cr from Lobore, as well as *Hypogymnia* and Plagla (see Figures XIV-8, 6 and 10). See explanations for elevated Cr levels above under *Hypogymnia*.

***Platismatia glauca* (Plagla)**

Background for Plagla in the Pacific Northwest for Cr is 2.0 ppm (USDA 1999). Tongass threshold is slightly higher at 3.29 ppm. Several plots where Plagla was collected have elevated Cr above thresholds. Greens Creek plots 512 (tailings pile) and 511b (near portal) are both high in Cr (Figure XIV-10). This is most likely explained by the close proximity to the industry and the roads. Plot 1000 is 175 feet above the cruise ship docking area and downtown Juneau which could be sources of Cr. Harlequin Lake plot 62 is elevated in Cr for three lichen species (Figures XIV-6, 8 and 10). More repeated sampling may be needed to determine if this is part of the natural variation of Cr in areas that are near glaciers and interior dust storms

XV. Summary of results for Copper (Cu) from all species on the Tongass National Forest

Copper is a metal that occurs naturally in rock, soil, water, sediment, and air. On the average, the concentration of copper in the earth's crust is about 50 ppm (USPHS 1990). It is an essential element for all living organisims including humans and other animals. Many compounds exist, including both natural and man-made. The most commonly used compound is copper sulfate. Copper is extensively mined and processed in the US. Some copper in the environment is less tightly bound to dirt particals and can be taken up by plants and animals. Other copper compounds are so stringly attached to to dust and dirt, or embedded in minerals that they cannot easily be enhaled or absorbed.

Thresholds for Cu on the Tongass are the following: *Alectoria sarmentosa* (1.86 ppm), *Hypogymnia* (31.31 ppm), *Lobaria oregana* (10.18) and *Platismatia glauca* (7.55 ppm).

Lichens with plot means elevated in Cu above threshold in Alesar include: plot 512 (Greens Creek tailings pile), downtown Juneau above cruise ships (plot 1000) and Tebenkof Bay (plot 033) (Figure XV-4). Plots with elevated Cu in *Hypogymnia* include: Petersburg Creek wilderness (plot 237) Sitka road system (plot 239), and Greens Creek (Plot 512 and 511b) (Figure XV-6). Plots with elevated levels of Cu in Lobore include: Yakutat road system (064 and 066) and Harlequin Lake (062) (Figure XV-8). For Plagla, elevated Cu was found at Greens Creek (plots 511a, 511b, and 512) (Figure XV-10).

XV. SUMMARY OF Cu PPM DATA ANALYSIS

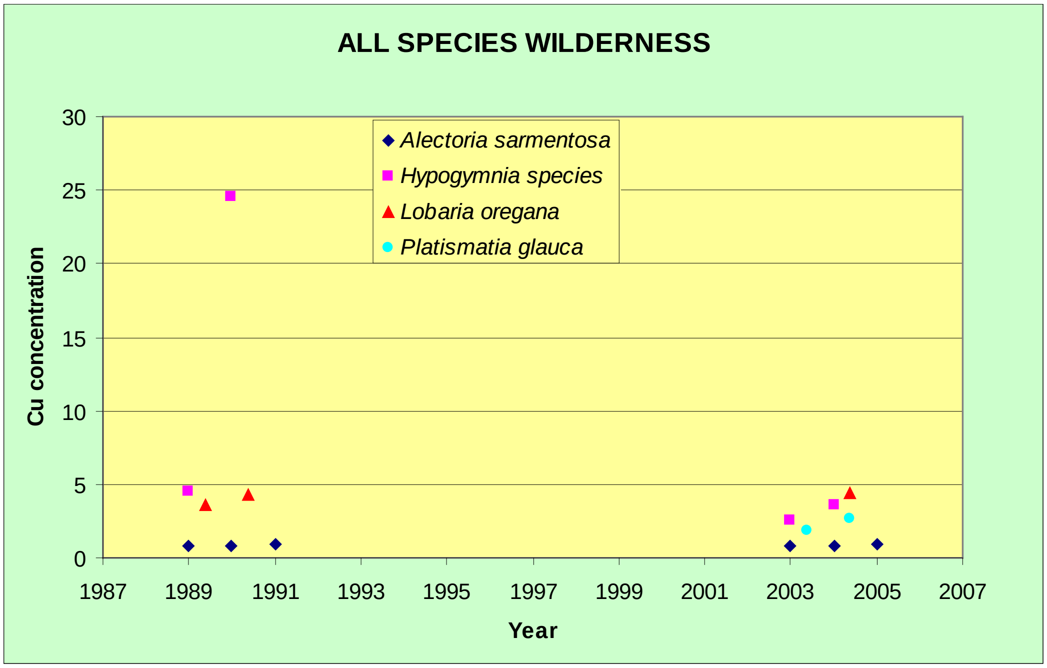

Figure XV-1. Wilderness plot means of Cu ppm in *All Species* per year.

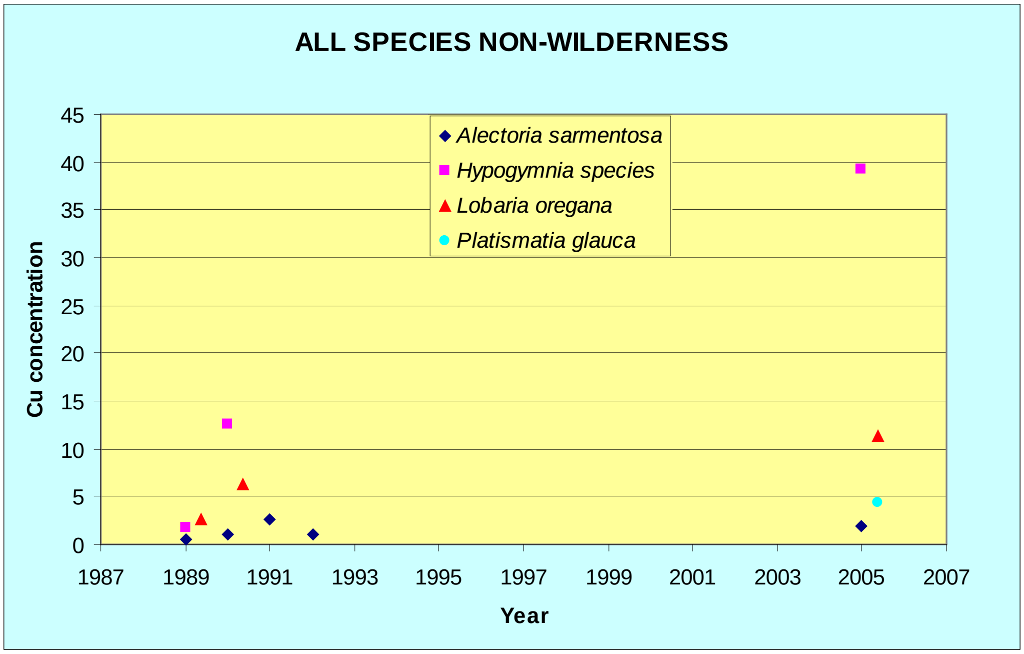

Figure XV-2. Non-Wilderness plot means of Cu ppm in *All Species* per year.

Alectoria sarmentosa

Table XV-1. Wilderness and Non-Wilderness Means, Standard Errors, and 95% Confidence Intervals for the Cu ppm content of *Alectoria sarmentosa* per year.

Cu ppm				95% CI	
Year	**Plot Type**	**Mean**	**Std. Error**	**Lower**	**Upper**
1989	Non-Wilderness	0.57	0.0882	0.3278	0.8178
1989	Wilderness	0.82	0.1500	0.4340	1.2053
1990	Non-Wilderness	1.13	0.1382	0.8430	1.4111
1990	Wilderness	0.81	0.1116	0.5357	1.0819
1991	Non-Wilderness	2.6288	1.6673	0.8741	6.1316
1991	Wilderness	0.98	0.0606	0.8124	1.1487
1992	Non-Wilderness	1.09	0.0759	0.9061	1.2649
2003	Wilderness	0.80	0.2785	2.7402	4.3372
2004	Wilderness	0.86	0.0944	0.6616	1.0522
2005	Non-Wilderness	1.88	0.4529	0.7204	3.0487
2005	Wilderness	0.96	0.1280	0.6719	1.2511

Summary of Statistical Tests:

t = -0.4902, df = 8, p-value = 0.6371

There is no evidence of a difference in Cu content in *Alectoria sarmentosa* from pre-2000 and post 2000 samples (p-value = 0.6371). Plots with repeated samples for copper in Alesar are: Karta River (#159), Pleasant Island (#145, 146), Pikes Lake RNA (# 69), Kootznoowoo (# 189, 190), Petersburg Creek (#116), Stikine-LeConte (#30, 31), Yakobi (#101), Tebenkof (#33) and Misty Fiords (#85, 86).

Relationships are not strong in the Cu content in *Alectoria sarmentosa* after accounting for latitude, longitude, elevation, year (Figures XV-3, XV-4 for year) and precipitation (see Brenner, 2006 for all graphed results).

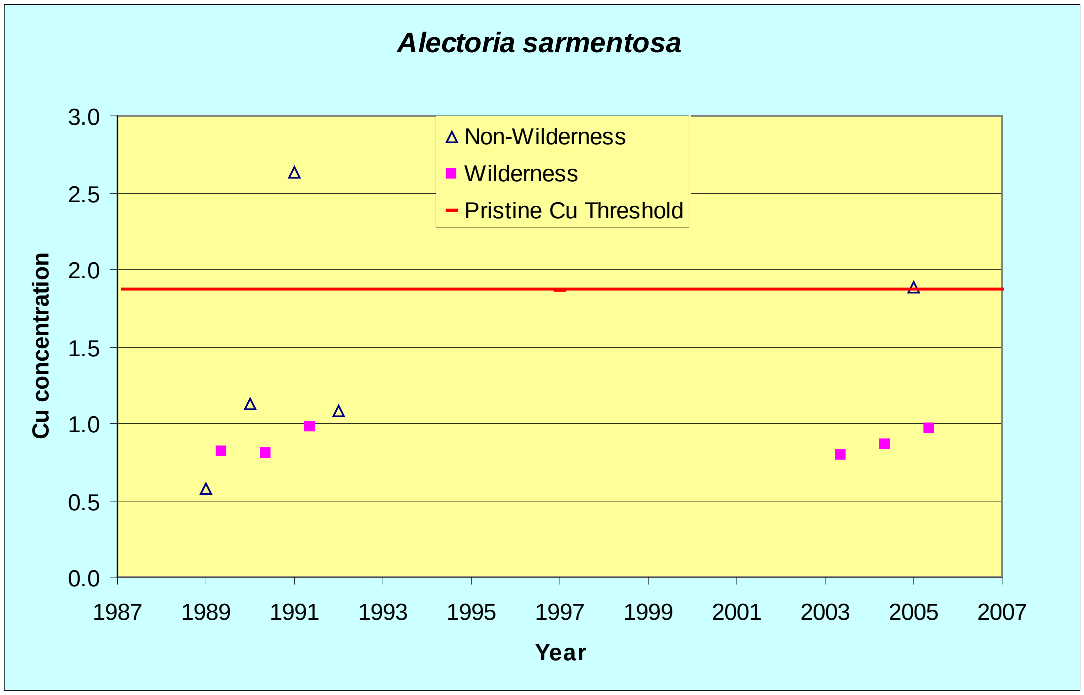

Figure XV-3. Wilderness and Non-Wilderness yearly means of Cu ppm in *Alectoria sarmentosa* per year.

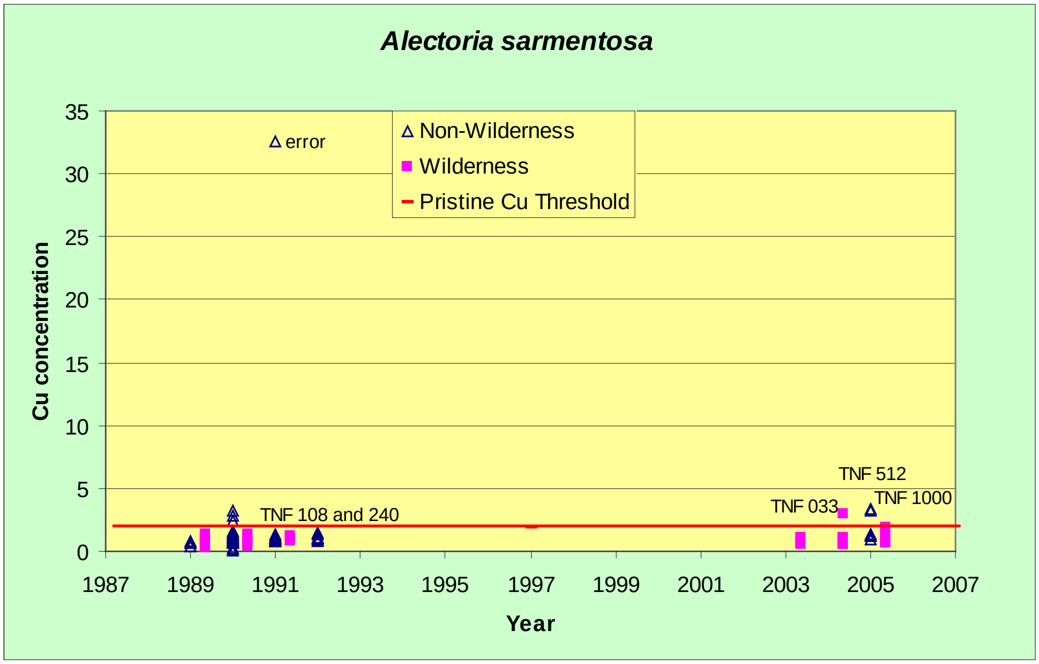

Figure XV-4. Wilderness and Non-Wilderness plot means of Cu ppm in *Alectoria sarmentosa* per year.

Hypogymnia species

In this series, all of the *Hypogymnia* species were included as a group.

Table XV-2. Wilderness and Non-Wilderness Means, Standard Errors, and 95% Confidence Intervals for the Cu ppm content of *Hypogymnia species* per year.

Cu ppm				95% CI	
Year	**Plot Type**	**Mean**	**Std. Error**	**Lower**	**Upper**
1989	Non-Wilderness	1.81	1.1650	12.9977	16.6077
1989	Wilderness	4.48	0.7630	2.3619	6.5988
1990	Non-Wilderness	12.63	4.8302	2.4776	22.7735
1990	Wilderness	24.51	21.0863	27.0854	76.1073
2003	Wilderness	2.55	NA	NA	NA
2004	Wilderness	3.57	0.2028	3.0491	4.0920
2005	Non-Wilderness	39.17	12.5573	14.8553	93.2039
2005	Wilderness	4.58	0.7303	2.8918	6.2601

No t-tests were performed on these data due to lack of repeat samples of *Hypogymnia*.

Relationships are not strong in Cu content for *Hypogymnia* after accounting for latitude, longitude, elevation, year (Figures XV-5, XV-6 for year) and precipitation (see Brenner, 2006 for all graphed results).

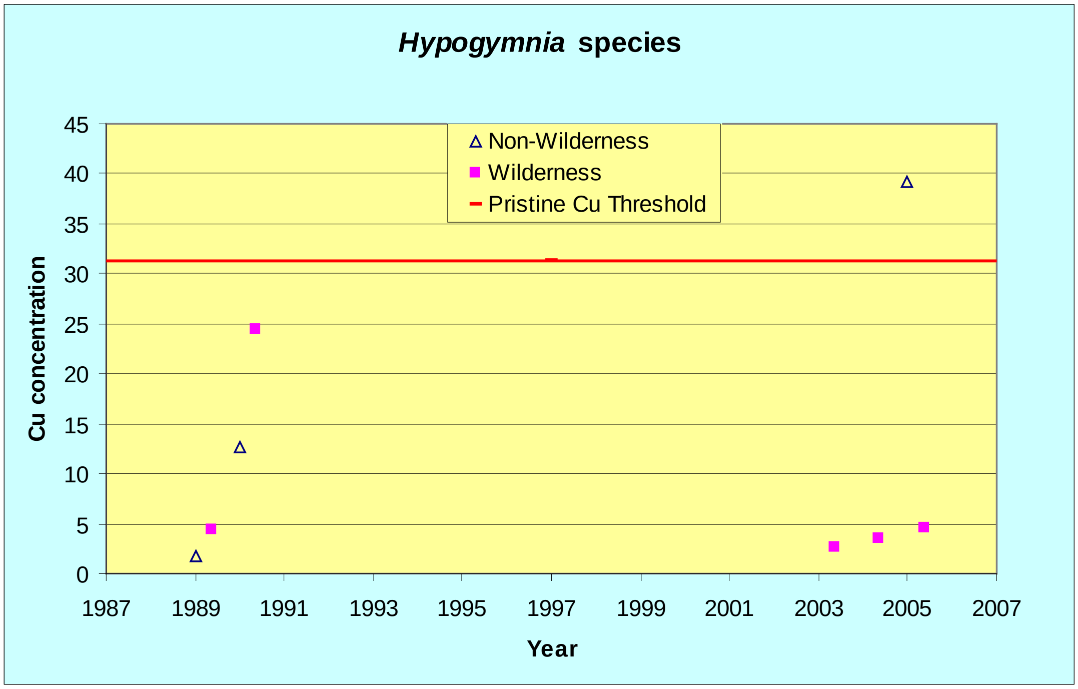

Figure XV-5. Wilderness and Non-Wilderness yearly means of Cu ppm in *Hypogymnia species* per year.

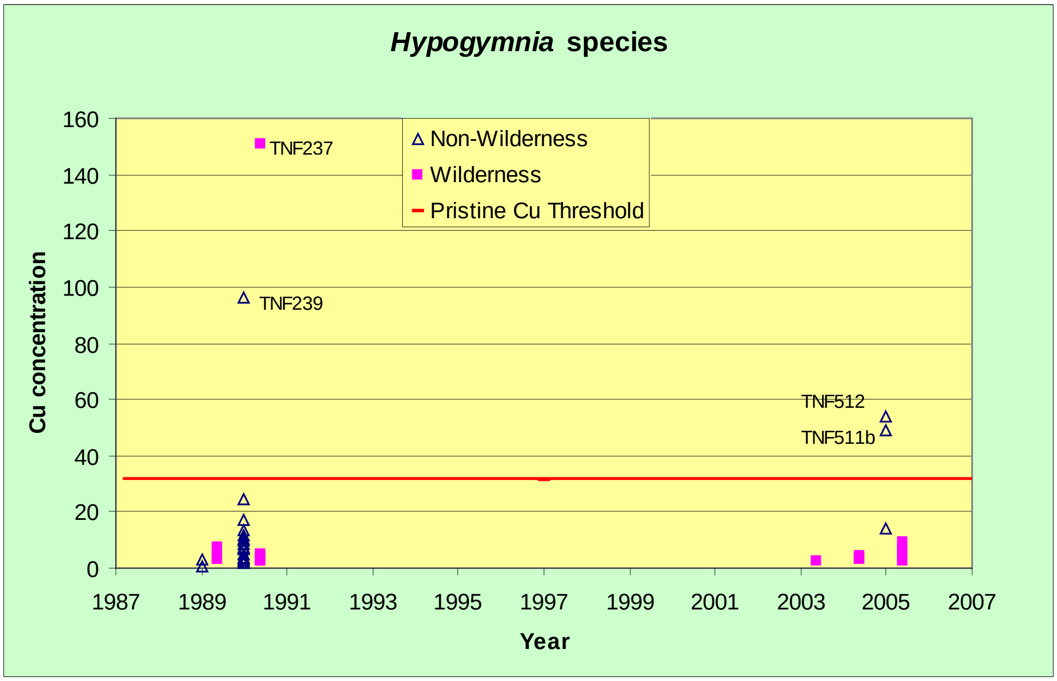

Figure XV-6. Wilderness and Non-Wilderness plot means of Cu ppm in *Hypogymnia species* per year.

Lobaria oregana

Table XV-3. Wilderness and Non-Wilderness Means, Standard Errors, and 95% Confidence Intervals for the Cu ppm content of *Lobaria oregana* per year.

Cu ppm				**95% CI**	
Year	**Plot Type**	**Mean**	**Std. Error**	**Lower**	**Upper**
1989	Non-Wilderness	2.57	0.9786	-0.5428	5.6861
1989	Wilderness	3.63	0.7151	1.6415	5.6126
1990	Non-Wilderness	6.20	0.9823	4.0605	8.3410
1990	Wilderness	4.34	1.1448	1.3957	7.2812
2004	Wilderness	4.36	0.9396	2.0595	6.6578
2005	Non-Wilderness	11.34	NA	NA	NA
2005	Wilderness	3.52	0.9518	0.4891	6.5474

Summary of Statistical Tests:

t = -0.438, df = 4, p-value = 0.684

There is *suggestive* evidence of a difference in Cu ppm content in *Lobaria oregana* from pre-2000 and post 2000 samples (p-value = 0.0684). This analysis was for wilderness areas that had repeated values for copper in *Lobaria oregana*, Russell Fiords (plot 62 near Harlequin Lake), Tebenkof (33) and Misty Fiords (86, 88). This is probably due to the Harlequin Lake plot 62 being above threshold in Cu during the second monitoring period.

Relationships are not strong in the Cu content in *Lobaria oregana* after accounting for latitude, longitude, elevation, year (Figures XV-7, XV-8 for year) and precipitation (see Brenner, 2006 for all graphed results

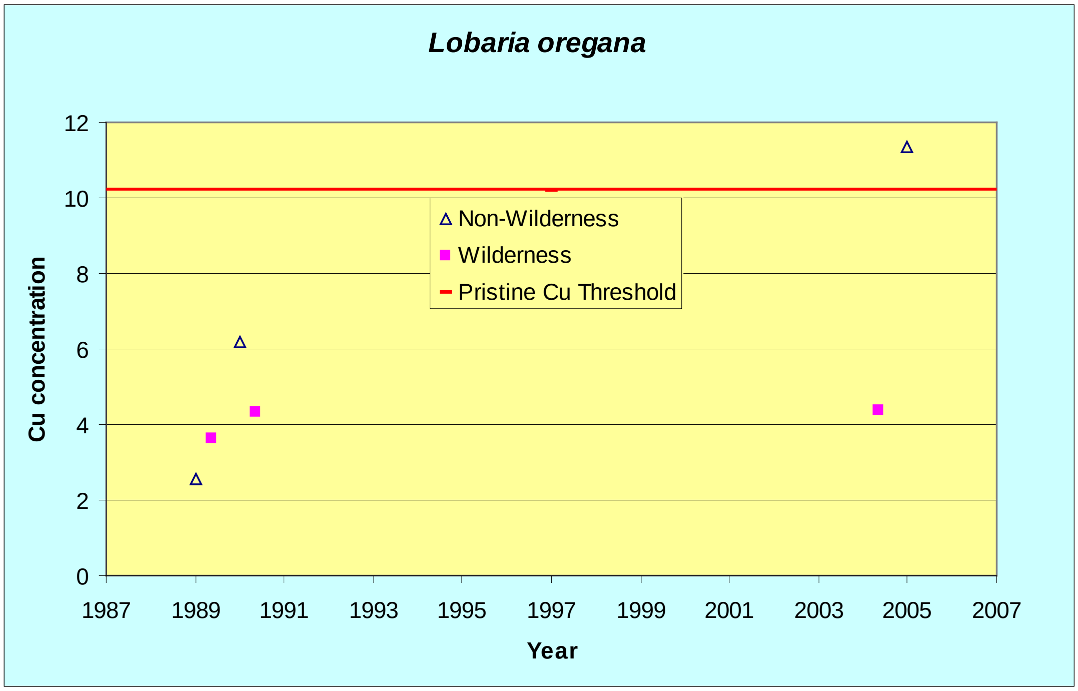

Figure XV-7. Wilderness and Non-Wilderness yearly means of Cu ppm in *Lobaria oregana* per year.

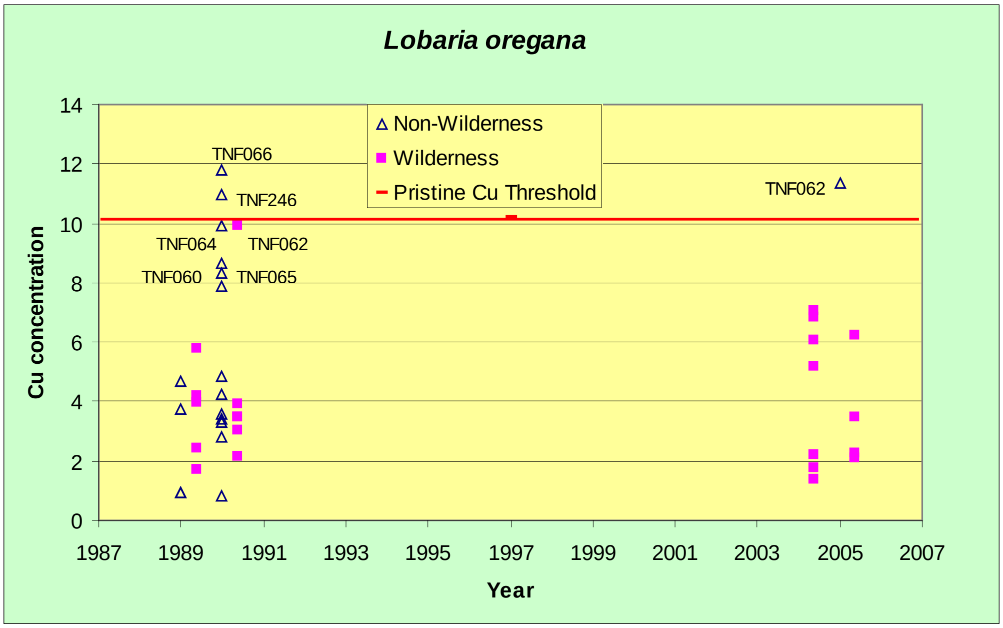

Figure XV-8. Wilderness and Non-Wilderness plot means of Cu ppm in *Lobaria oregana* per year.

Platismatia glauca

Table XV-5. Wilderness and Non-Wilderness Means, Standard Errors, and 95% Confidence Intervals for the Cu ppm content of *Platismatia glauca* per year.

Cu ppm				**95% CI**	
Year	**Plot Type**	**Mean**	**Std. Error**	**Lower**	**Upper**
2003	Wilderness	1.86	NA	NA	NA
2004	Wilderness	2.72	0.3458	1.9337	3.4983
2005	Non-Wilderness	21.42	9.3170	0.3387	42.4915
2005	Wilderness	3.67	0.7104	1.9930	5.3526

No t-tests were performed on these data. The mean values for Cu are baseline in *Platismatia glauca.*

Relationships are not strong in Cu content for Plagla after accounting for latitude, longitude, elevation, year (Figures XV-9, XV-10 for year) and precipitation (see Brenner, 2006 for all graphed results).

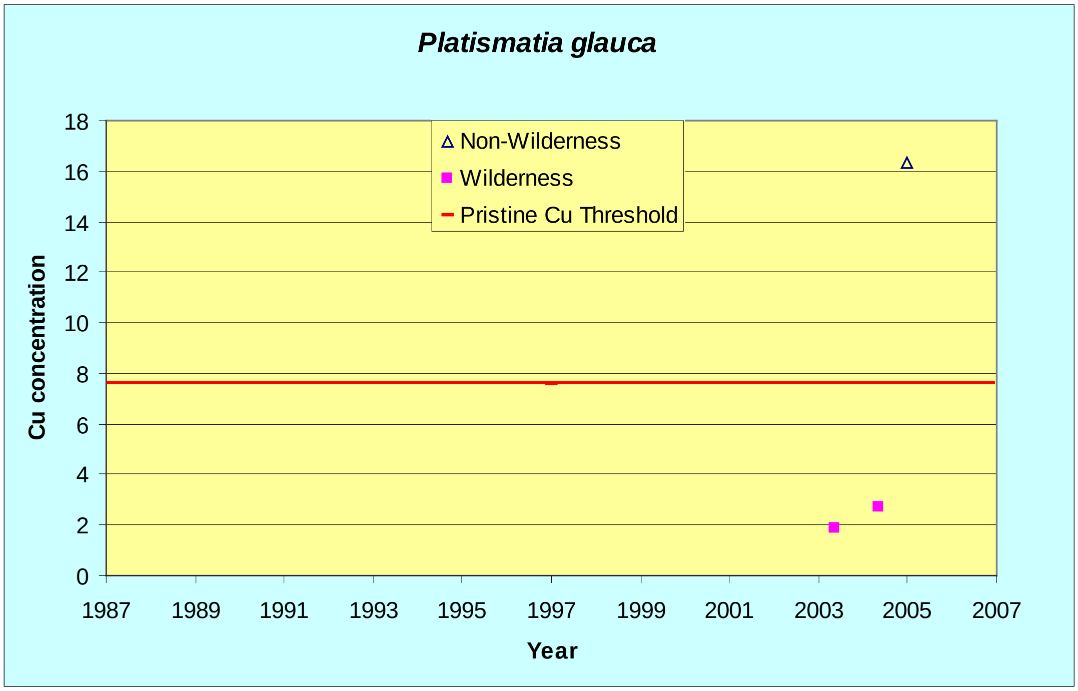

Figure XV-9. Wilderness and Non-Wilderness yearly means of Cu ppm in *Platismatia glauca* per year.

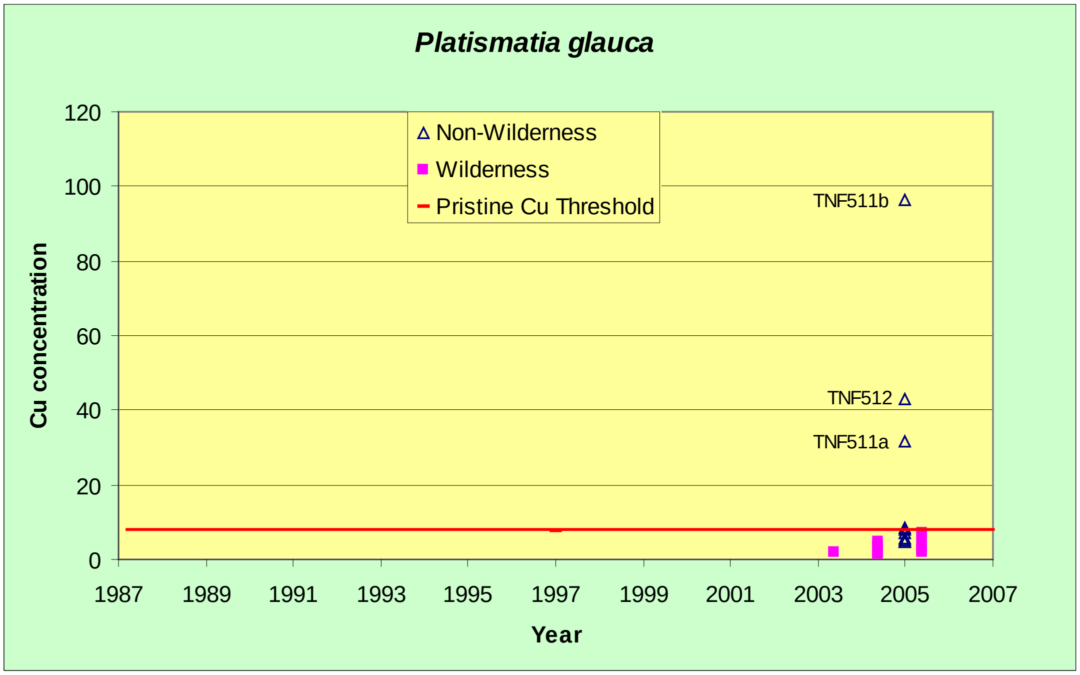

Figure XV-10. Wilderness and Non-Wilderness plot means of Cu ppm in *Platismatia glauca* per year.

Conclusions: for Copper (Cu) and all lichen species

Thresholds for copper on the Tongass are above baseline for the Pacific Northwest in all species of lichens. The closest in comparison is for *Alectoria sarmentosa*, with the threshold of 1.86 ppm similar to the Pacific Northwest baseline of 1.50 ppm (USDA 1999). Threshold for *Hypogymnia* (31.31 ppm) is within the range considered to be mine or smelter enhanced for Cu (15 to 1100 ppm). It is unclear why Cu in *Hypogymnia* on the Tongass is high, but it is possible that the geology near the Tongass plots is naturally high in copper and reflected in the lichens sampled

Alectoria sarmentosa

Alesar is not a good accumulator compared to other lichens. Mean Cu in plot 512 at Greens Creek tailings is most likely elevated due to windblown dusts from the tailings pile and the roads (Figure XV-4). High precipitation will also leach out metals from the lichens over time. Plot 1000 above the Juneau cruise ship docking area may be elevated slightly above threshold due to proximity to the old mine in the downtown area and other industrial activities. Plot 33 from Tebenkof is slightly elevated and this is unexplained at this time. This plot was also elevated in mean S and Al, and sources could be from the ocean (Figure V-4 and VII-4). Plots 108 and 240 are close to the pulp mill and elevated Cu could be from this industry and associated road dusts.

Hypogymnia

Background level of Cu in the Pacific Northwest is between 4 and 7 ppm (USDA 1999). In spite of the high rainfall in this region, threshold for Cu on the Tongass is within the range considered enhanced by mining and smelter activities worldwide (USDA 1999). Cu may be universally enhanced in southeast Alaska which could explain the overall elevated levels. Elevated mean Cu for Greens Creek plots 512 and 511b (above 40 ppm) can be explained by the close proximity to the tailings pile and the portal of the mine. Greens Creek levels are within the range considered enhanced by mining or smelter activities. Sitka road system plot 239 is close to the road system and pulp mill which could explain the slightly elevated Cu. Petersburg Creek plot 237 is elevated, possibly due to natural geologic sources at Petersburg Lake (Figure XV-6).

Lobaria oregana

Background Cu from the Pacific Northwest is 5.00 ppm (USDA 1999). The Tongass threshold is double this at 10.18 ppm. Plots elevated in Cu in Lobore include several from the Yakutat area associated with the roads (plots 66 and 64) (Figure XV-8). Plot 62 from the Russell Fiords wilderness is elevated in Cu, and could be attributed to the close proximity to the bridge. Copper is used in the preservation of wood and the Dangerous River bridge construction with treated wood may be another source of Cu. The surrounding geology could also be a source of Cu for this area, as this plot is also elevated in Al and Cr (Figures VII-8 and XIV-8 respectively).

Platismatia glauca

Threshold for Cu in Plagla on the Tongass is double the Cu background in the Pacific Northwest (USDA 1999). As stated above, SE Alaska and the Tongass may be regionally higher in Cu due to geologic features. Mean Cu is elevated above threshold from all plots at Greens Creek in Plagla (511a, 511b and 512) (Figure XV-10) and are within the range considered enhanced by mining or smelter activities (close to 100 ppm at the mine portal). Copper is part of the extracted ore material. It is unknown how much farther from the portal Cu has accumulated, but levels drop off between the portal and plot 511a established about 200 ft upstream from the portal (Figure XV-10 compare 100 ppm to 30 ppm). Levels from the tailing pile area are slightly higher than plot 511a, and this demonstrates that the copper in the tailings are accumulating in the lichens in spite of the long distance from the portal.

XVI. Summary of results for Iron (Fe) from all species on the Tongass National Forest

Iron (Fe) is an element found in the earth's crust. Iron enters the environment from anthropogenic sources including the production of steel, mining, and the fly ash from coal burning. Roadside environments can also be enhanced with iron due to the abrasion of metals from engines that eventually end up in exhaust (USDA 1999). Iron is also a micronutrient and is used in the metabolism of all living things.

Elemental thresholds for Fe on the Tongass are as follows: *Alectoria sarmentosa* (55.64 ppm), *Hypogymnia* (1990.78ppm), *Lobaria oregana* (1010.97 ppm) and *Platismatia glauca* (1773.56 ppm).

Plots with elevated mean Fe in lichens include: Alesar plots 107, 240, 247, (Sitka road system), 33 (Tebenkof wilderness), 221 (Douglas Island near Eaglecrest), 143 (near Whitestone Harbor on Chichagof), 219 (Rowan Bay-Kuiu Island), 508 (Upper Endicott River), 512 (Greens Creek tailings pile), 67 (Yakutat Road system), and 1000 and 1002 (175 and 600 ft above Juneau and cruise ship dock, respectively) (Figure VXI-4); *Hypogymnia* plot 243 (Sitka road system), and 512 (Greens Creek tailings pile)(Figure XVI-6); Lobore plot 62 (Harlequin Lake area) (Figure XVI-8); Plagla plots 512 and 511b (Greens Creek)(XVI-10).

XVI. SUMMARY OF Fe PPM DATA ANALYSIS

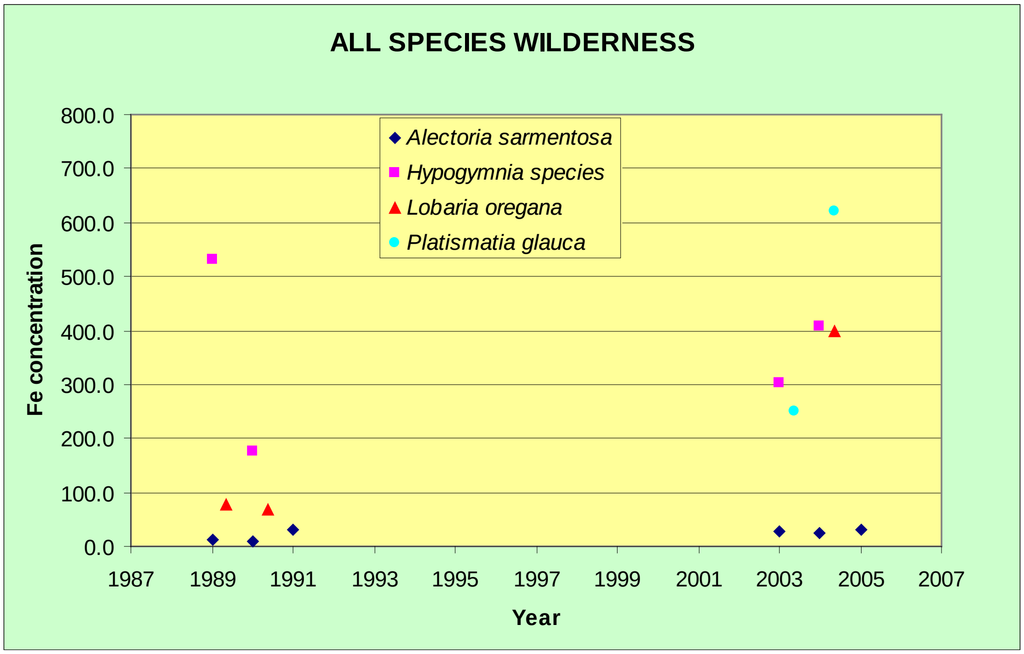

Figure XVI-1. Wilderness plot means of Fe ppm in *All Species* per year.

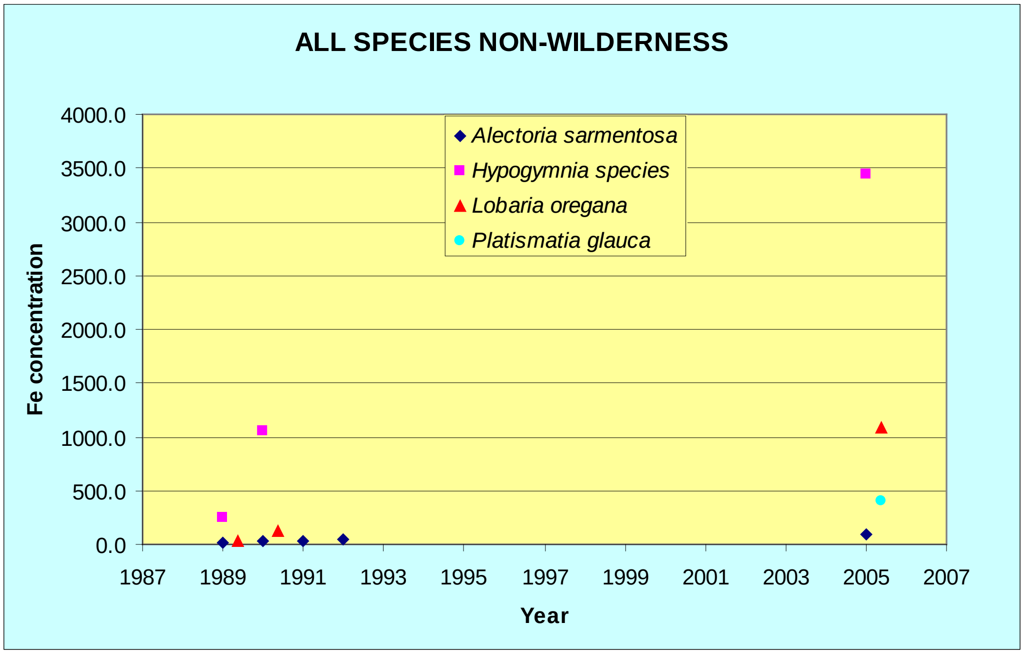

Figure XVI-2. Non-Wilderness plot means of Fe ppm in *All Species* per year.

Alectoria sarmentosa

Table XVI-1. Wilderness and Non-Wilderness Means, Standard Errors, and 95% Confidence Intervals for the Fe ppm content of *Alectoria sarmentosa* per year.

Fe ppm				**95% CI**	
Year	**Plot Type**	**Mean**	**Std. Error**	**Lower**	**Upper**
1989	Non-Wilderness	9.02	2.3762	2.4226	15.6174
1989	Wilderness	11.76	1.3771	8.2156	15.2955
1990	Non-Wilderness	36.82	6.8413	22.7529	50.8779
1990	Wilderness	10.75	2.4898	4.6564	16.8408
1991	Non-Wilderness	27.4185	3.2779	20.5320	34.3050
1991	Wilderness	29.94	8.6782	5.8489	54.0382
1992	Non-Wilderness	50.66	13.2521	19.3265	81.9989
2003	Wilderness	27.34	11.2036	115.0199	169.6901
2004	Wilderness	24.86	2.4647	19.7637	29.9611
2005	Non-Wilderness	85.57	33.1719	0.3037	170.8460
2005	Wilderness	31.94	9.2438	11.0272	52.8490

Summary of Statistical Tests:

t = -0.4902, df = 8, p-value = 0.6371

There is no evidence of a difference in Fe ppm content in *Alectoria sarmentosa* from pre-2000 and post 2000 samples (p-value = 0.6371). Plots with repeated samples for iron in Alesar are: Karta River (#159), Pleasant Island (#145, 146), Pikes Lake RNA (# 69), Kootznoowoo (# 189, 190), Petersburg Creek (#116), Stikine-LeConte (#30, 31), Yakobi (#101), Tebenkof (#33) and Misty Fiords (#85, 86).

Relationships are not strong in the Fe content in *Alectoria sarmentosa* after accounting for latitude, longitude, elevation, year (Figures XVI-3, XVI-4 for year) and precipitation (see Brenner, 2006 for all graphed results).

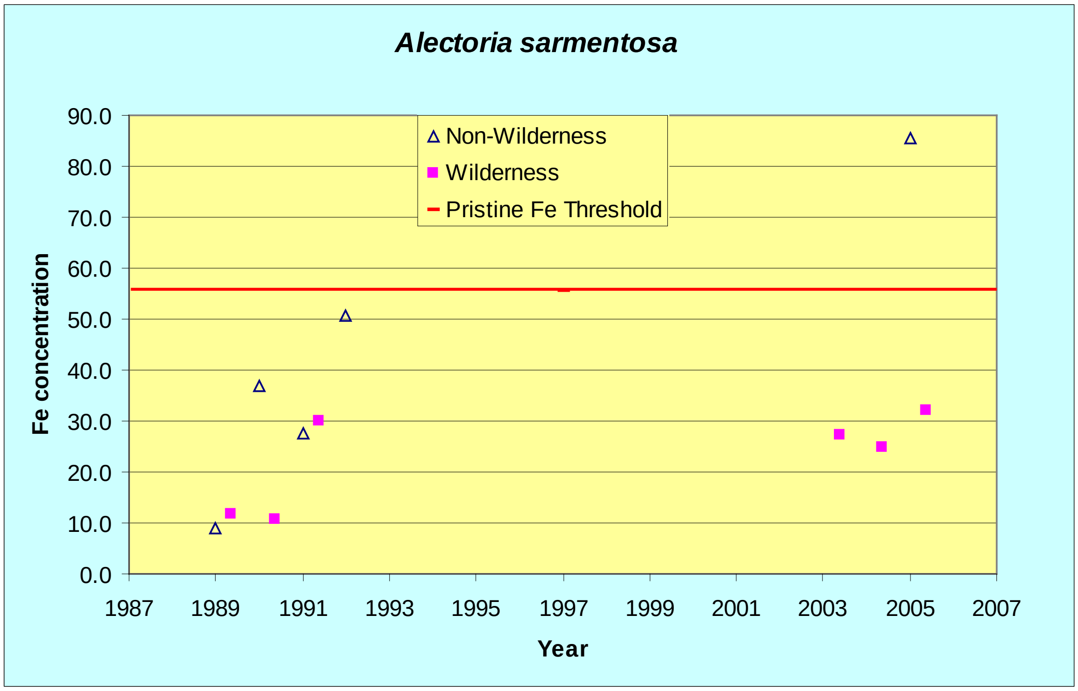

Figure XVI-3. Wilderness and Non-Wilderness yearly means of Fe ppm in *Alectoria sarmentosa* per year.

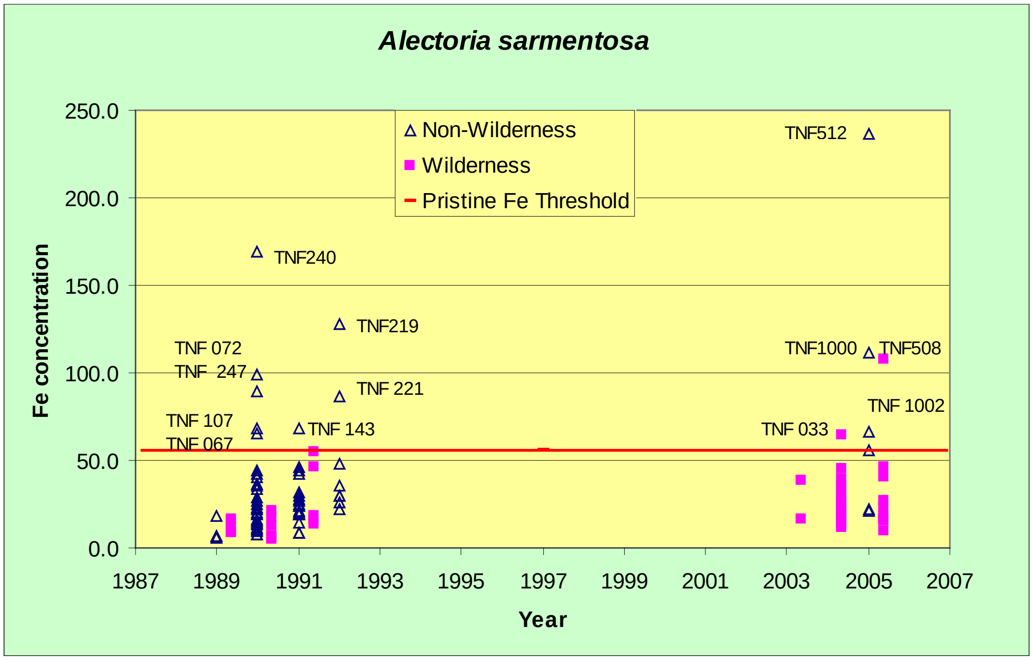

Figure XVI-4. Wilderness and Non-Wilderness plot means of Fe ppm in *Alectoria sarmentosa* per year.

***Hypogymnia* species**

In this series, all of the *Hypogymnia* species were included as a group.

Table XVI-2. Wilderness and Non-Wilderness Means, Standard Errors, and 95% Confidence Intervals for the Fe ppm content of *Hypogymnia species* per year.

Fe ppm				95% CI	
Year	**Plot Type**	**Mean**	**Std. Error**	**Lower**	**Upper**
1989	Non-Wilderness	243.50	235.5000	2748.8110	3235.8110
1989	Wilderness	531.55	266.0219	207.0451	1270.1451
1990	Non-Wilderness	1055.45	226.9311	578.6828	1532.2120
1990	Wilderness	177.24	39.7317	80.0182	274.4580
2003	Wilderness	302.79	NA	NA	NA
2004	Wilderness	408.95	96.8329	160.0304	657.8641
2005	Non-Wilderness	3441.40	1205.8310	1746.8740	8629.6740
2005	Wilderness	691.24	228.0810	165.2831	1217.1946

No t-tests were performed on this data due to lack of repeat samples of *Hypogymnia.*

Relationships are not strong in Fe content for *Hypogymnia* after accounting for latitude, longitude, elevation, year (Figures XVI-5, XVI-6 for year) and precipitation (see Brenner, 2006 for all graphed results).

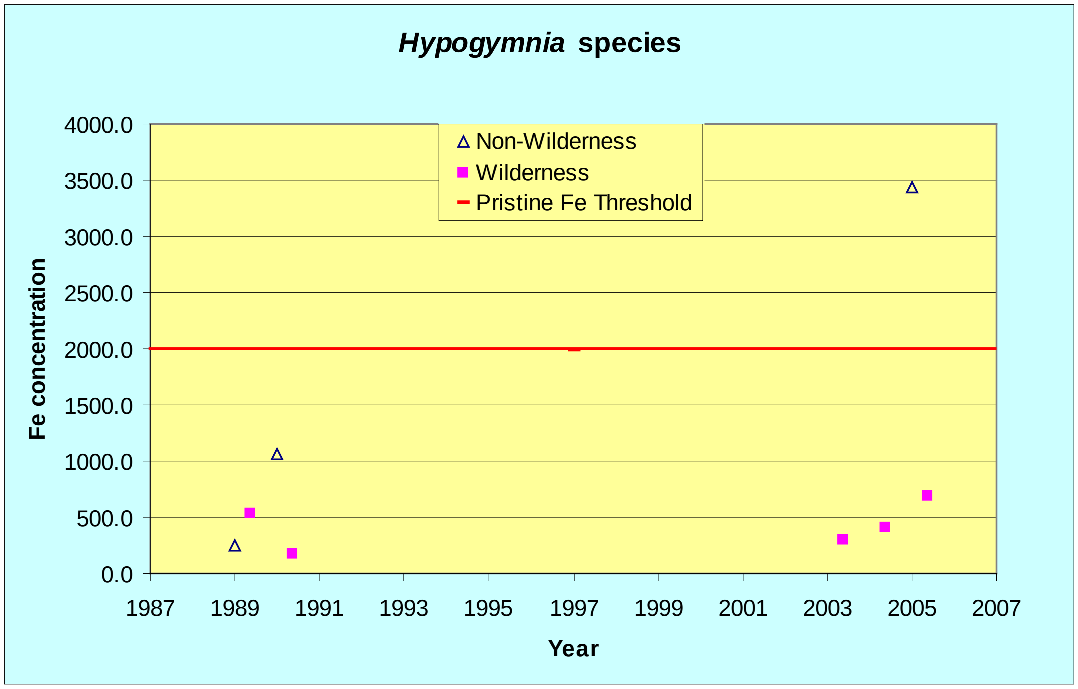

Figure XVI-5. Wilderness and Non-Wilderness yearly means of Fe ppm in *Hypogymnia species* per year.

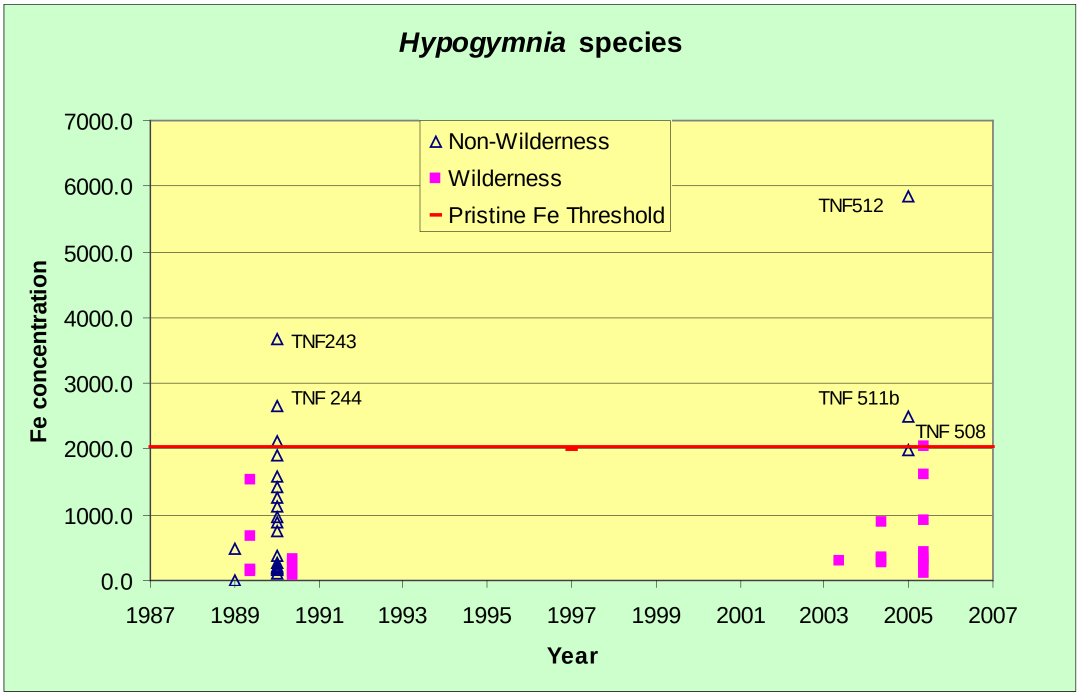

Figure XVI-6. Wilderness and Non-Wilderness plot means of Fe ppm in *Hypogymnia species* per year.

Lobaria oregana

Table XVI-3. Wilderness and Non-Wilderness Means, Standard Errors, and 95% Confidence Intervals for the Fe ppm content of *Lobaria oregana* per year.

Fe ppm				**95% CI**	
Year	**Plot Type**	**Mean**	**Std. Error**	**Lower**	**Upper**
1989	Non-Wilderness	37.50	10.4292	4.3096	70.6904
1989	Wilderness	77.84	29.7676	-4.8049	160.4915
1990	Non-Wilderness	120.93	31.1713	53.0132	188.8458
1990	Wilderness	67.70	45.0773	NA	183.5724
2004	Wilderness	399.92	138.4878	61.0566	738.7914
2005	Non-Wilderness	1086.01	NA	NA	NA
2005	Wilderness	156.50	104.4616	NA	488.9397

Summary of Statistical Tests:

t = -1.3283, df = 4, p-value = 0.2548

There is no evidence of a difference in Fe ppm content in *Lobaria oregana* from pre-2000 and post 2000 samples (p-value = 0.2548). This analysis was for wilderness areas that had repeated values for iron in *Lobaria oregana*, Russell Fiords (plot 62 near Harlequin Lake), Tebenkof (33) and Misty Fiords (86, 88).

Relationships are not strong in the Fe content in *Lobaria oregana* after accounting for latitude, longitude, elevation, year (Figures XVI-7, XVI-8 for year) and precipitation (see Brenner, 2006 for all graphed results

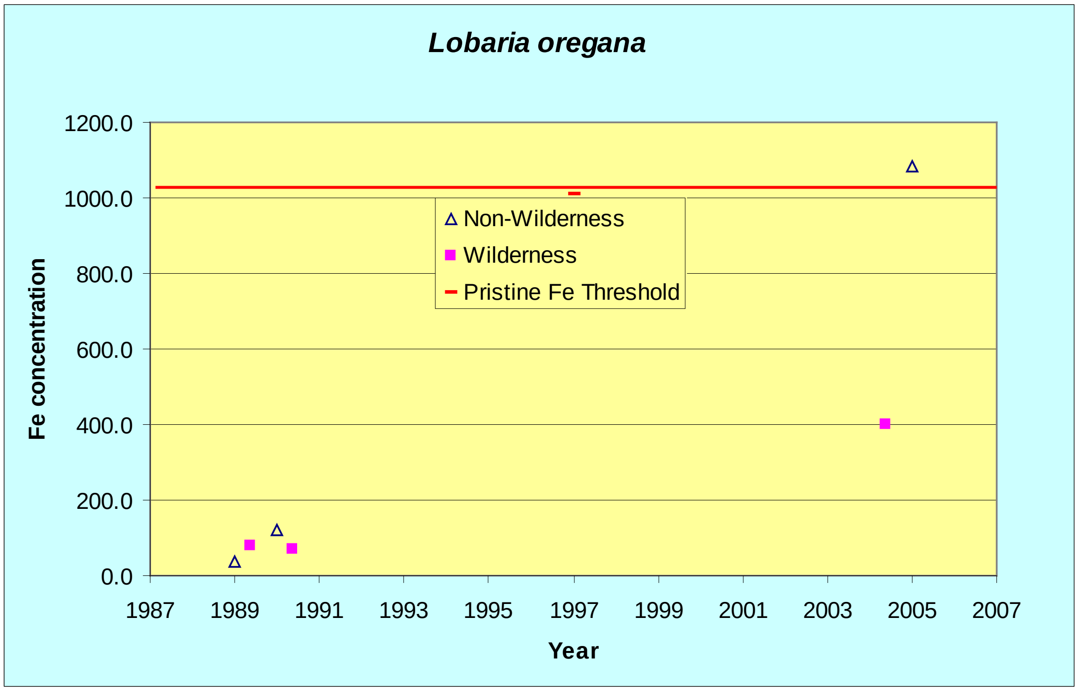

Figure XVI-7. Wilderness and Non-Wilderness yearly means of Fe ppm in *Lobaria oregana* per year.

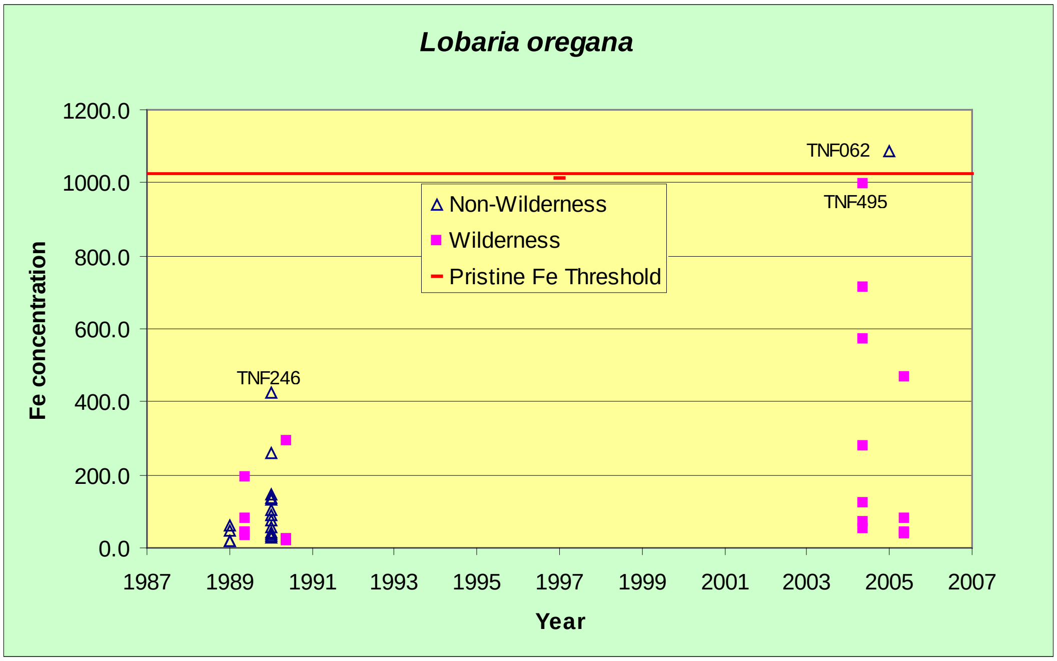

Figure XVI-8. Wilderness and Non-Wilderness plot means of Fe ppm in *Lobaria oregana* per year.

Platismatia glauca

Table XVI-4. Wilderness and Non-Wilderness Means, Standard Errors, and 95% Confidence Intervals for the Fe ppm content of *Platismatia glauca* per year.

Fe ppm				**95% CI**	
Year	**Plot Type**	**Mean**	**Std. Error**	**Lower**	**Upper**
2003	Wilderness	248.94	NA	NA	NA
2004	Wilderness	620.58	152.9757	274.5240	966.6342
2005	Non-Wilderness	1937.93	542.1553	711.4864	3164.3673
2005	Wilderness	764.37	251.0329	170.7707	1357.9677

No t-tests were performed on these data. The mean values for Fe are baseline in *Platismatia glauca.*

Relationships are not strong in Fe content for Plagla after accounting for latitude, longitude, elevation, year (Figures XVI-9, XVI-10 for year) and precipitation (see Brenner, 2006 for all graphed results).

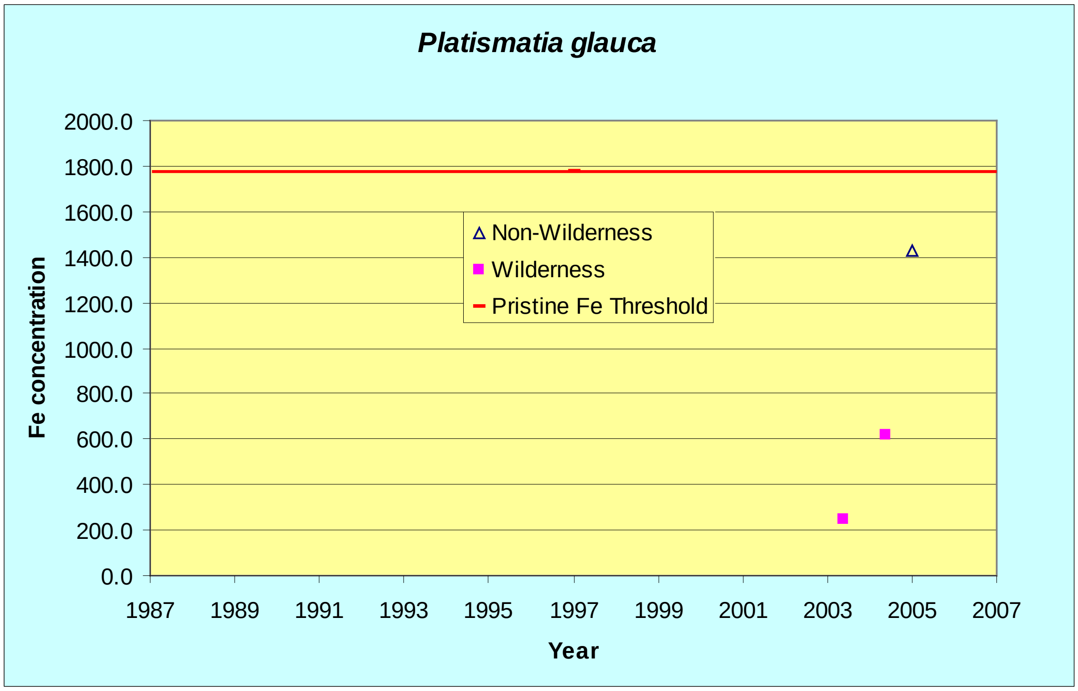

Figure XVI-9. Wilderness and Non-Wilderness yearly means of Fe ppm in *Platismatia glauca* per year.

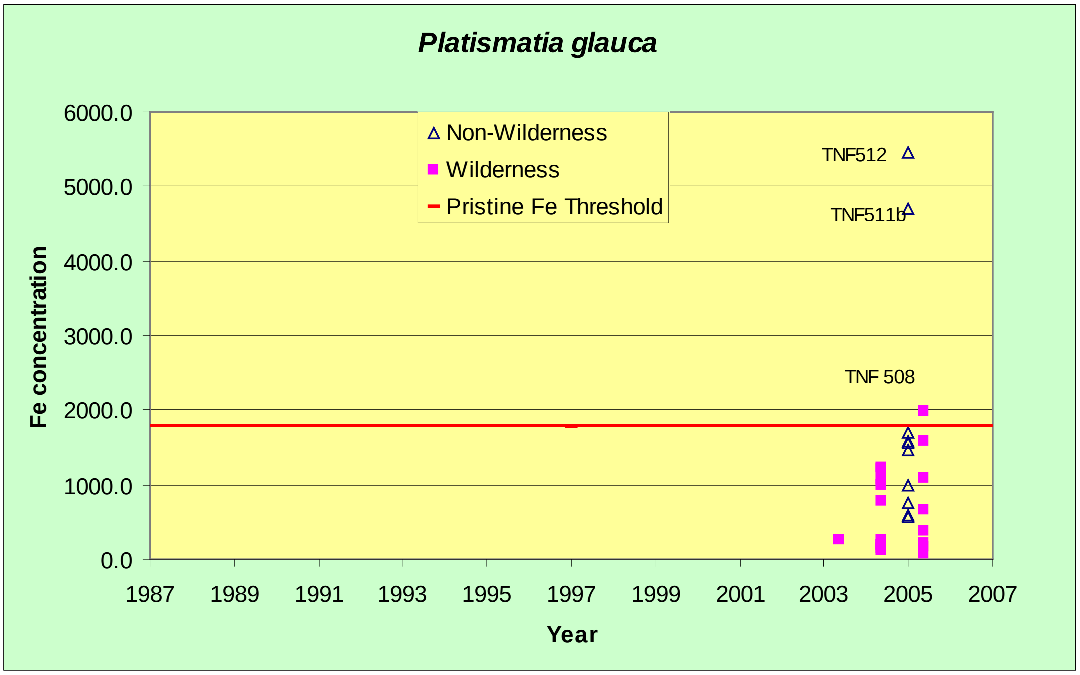

Figure XVI-10. Wilderness and Non-Wilderness plot means of Fe ppm in *Platismatia glauca* per year.

Conclusions: for Iron (Fe) and all lichen species

Enhanced Fe in lichens due to mining and smelter activities is between 400 and 16,000 ppm depending on the species (USDA 1999). Background Fe in *Platismatia glauca* and *Hypogymnia enteromorpha* from the Pacific Northwest are just within this enhanced range (700 ppm and 800 ppm respectively) (USDA 1999). The enhanced range for Fe is established from worldwide reports and a variety of lichen species. Most of the Tongass threshold levels for Fe in all species except Alesar are also within the range of enhanced values (Table XXXII-1 for thresholds by element) which may indicate that Fe is universally present in the region due to the geology and natural processes.

Alectoria sarmentosa

Background Fe in Alesar from the Pacific Northwest is 40 ppm (USDA 1999) which is slightly lower than the Tongass threshold of 55.64 ppm. Fe may be regionally enhanced as explained above. A few plots with Alesar around the Sitka mill and road system are elevated in Fe (240, 247 and 107). This can probably be attributed to the proximity to roads and machinery at the mill site at the time of lichen sampling. Plot 221 is on Douglas Island, near the road to Eaglecrest Ski Area, which probably contributes to elevated Fe. Similarly, plots 67 (Yakutat), 72 (Old Tom's Place POW), 143 (Whitestone Harbor area), and 219 (Rowan Bay Kuiu) are all close to existing unpaved roads which could contribute to elevated Fe (Figure XVI-4). The wilderness areas of Endicott River (plot 508) and Tebenkof (plot 33) are slightly elevated in Fe. Tebenkof was also elevated in Al, and like Al, Fe can be attributed to crustal sources rather than anthropogenic since no roads are near these areas. Endicott River wilderness plot 508 is elevated in many elements which indicate the air in this area must be geologically enhanced with windblown dusts. Plots above the cruise ship docking area in downtown Juneau (at 175 ft and 600 ft) may be elevated in Fe above threshold due to proximity to downtown exhaust, cruise ship emissions, and the nearby closed mine with exposed rock in the vicinity. Plot 512 is near the Greens Creek tailings pile and enhanced due to the ores associated with the present mining. Mean Fe in Alesar from the tailings pile are the highest on the Tongass, at nearly 250 ppm (Figure XVI-4).

Hypogymnia

Two plots (243 and 512) are elevated above threshold in Fe for *Hypogymnia* (Figure XVI-6). Plot 243 is on the Sitka road system which helps explain the Fe enhancement. Plot 512 is near the tailings pile at Greens Creek. Mean Fe level is near 6000 ppm which is well within the range reported for enhanced areas due to mining (USDA 1999).

***Lobaria oregana*.**

Plot 62 is elevated in Fe for Lobore (Figure XVI-8). This plot is in the Harlequin Lake area and may be enhanced with Fe from the airstrip activities, the nearby unpaved road or geologic sources.

Platismatia glauca

The lichen Plagla at Greens Creek tailings pile and mine portal (512 and 511b) is most likely enhanced in Fe due to proximity to the mined ore and associated roads and machinery (Figure XVI-10).

XVII. Summary of results for Potassium (K) from all species on the Tongass National Forest

Potassium (K) is an alkali metal that occurs naturally bound to elements in the earth's crust, seawater, and air. It is one of the most highly reactive metals and is rarely used alone for human purposes. Combined with other elements such as sodium or chloride, it forms compounds that are found in many items such as glass, soap and fertilizer. Air pollution from wood burning and industry contain potassium.

Provisional thresholds for K are the following: *Alectoria sarmentosa* (2413.25 ppm), *Hypogymnia* (3284.34 ppm), *Lobaria oregana* (8001.57 ppm) and *Platismatia glauca* (2523.88 ppm).

Several locations were elevated above threshold in K including: Alesar plots 1000 (175 ft above Juneau) and plot 33 (Tebenkof wilderness), on the edge of threshold for Alesar are plots 508 (Endicott River) and plot 113 (Berners Bay) (Figure XVIII-4); *Hypogymnia* plots 511b (Greens Creek portal), plots from the Sitka road system (242, 243, 239, 244, 241), Amalga Trail area (plot 111), and on the edge of threshold for *Hypogymnia* plot 245 (Sitka road system) and plot 508 (Endicott River) (Figure XVIII-6); Lobore plot 86 (Misty Fiords) and Berners Bay (plot 111)(Figure XVIII-8); Plagla plots 1000, 1001, 1002, 1003, and 1004 (Juneau Mt Roberts); 511a, 511b (Greens Creek), and plot 510 (Coronation Island) is on the edge of threshold (Figure XVIII-10).

XVII. SUMMARY OF K PPM DATA ANALYSIS

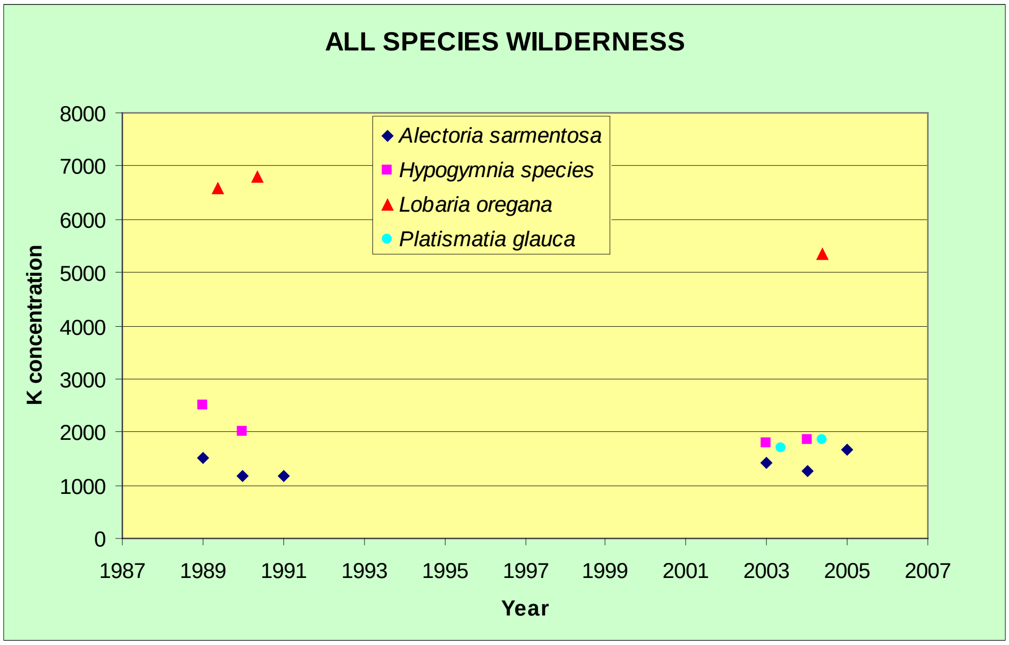

Figure XVII-1. Wilderness plot means of K ppm in *All Species* per year.

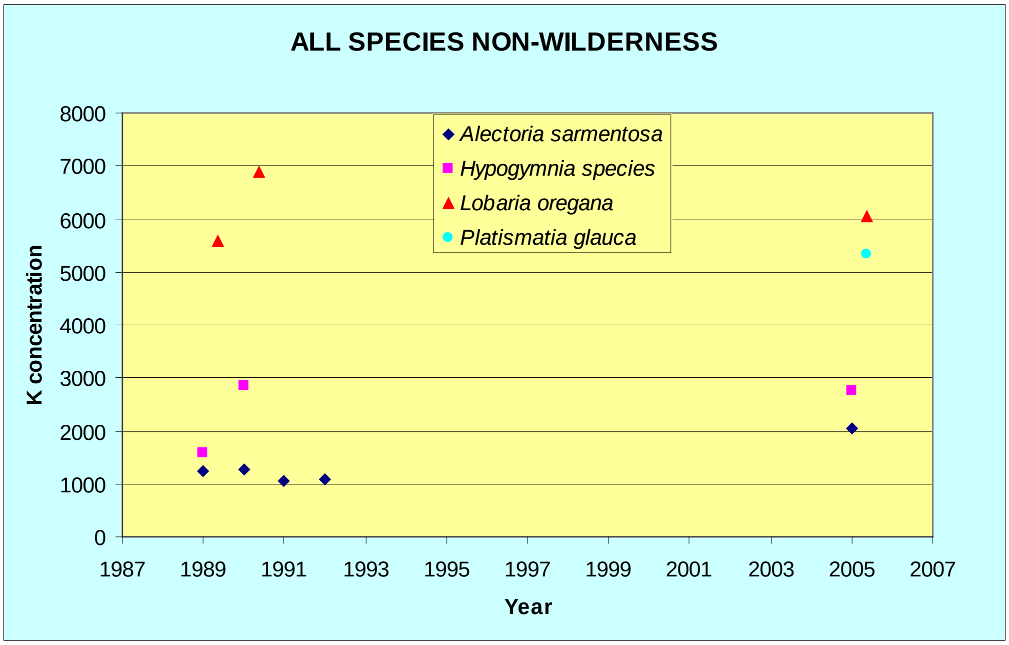

Figure XVII-2. Non-Wilderness plot means of K ppm in *All Species* per year.

Alectoria sarmentosa

Table XVII-1. Wilderness and Non-Wilderness Means, Standard Errors, and 95% Confidence Intervals for the K ppm content of *Alectoria sarmentosa* per year.

K ppm				**95% CI**	
Year	**Plot Type**	**Mean**	**Std. Error**	**Lower**	**Upper**
1989	Non-Wilderness	1255.68	65.1090	1074.9084	1436.4516
1989	Wilderness	1511.59	73.2470	1323.3010	1699.8760
1990	Non-Wilderness	1270.42	92.2713	1080.7533	1460.0862
1990	Wilderness	1171.00	131.7895	848.5190	1493.4734
1991	Non-Wilderness	1062.9554	21.8562	1017.0372	1108.8737
1991	Wilderness	1176.68	47.3177	1045.3063	1308.0564
1992	Non-Wilderness	1087.78	53.8311	960.4870	1215.0678
2003	Wilderness	1414.02	315.6833	2597.1204	5425.1537
2004	Wilderness	1278.47	216.0594	831.5146	1725.4203
2005	Non-Wilderness	2033.56	256.7456	1373.5769	2693.5481
2005	Wilderness	1683.25	173.8661	1289.9370	2076.5620

Summary of Statistical Tests:

t = -0.9586, df = 8, p-value = 0.3658

There is no evidence of a difference in K ppm content in *Alectoria sarmentosa* from pre-2000 and post 2000 samples (p-value = 0.3658). Plots with repeated samples for K in Alesar are: Karta River (#159), Pleasant Island (#145, 146), Pikes Lake RNA (# 69), Kootznoowoo (# 189, 190), Petersburg Creek (#116), Stikine-LeConte (#30, 31), Yakobi (#101), Tebenkof (#33) and Misty Fiords (#85, 86).

Relationships are not strong in the K content in *Alectoria sarmentosa* after accounting for latitude, longitude, elevation, year (Figures XVII-3, XVII-4 for year) and precipitation (see Brenner, 2006 for all graphed results).

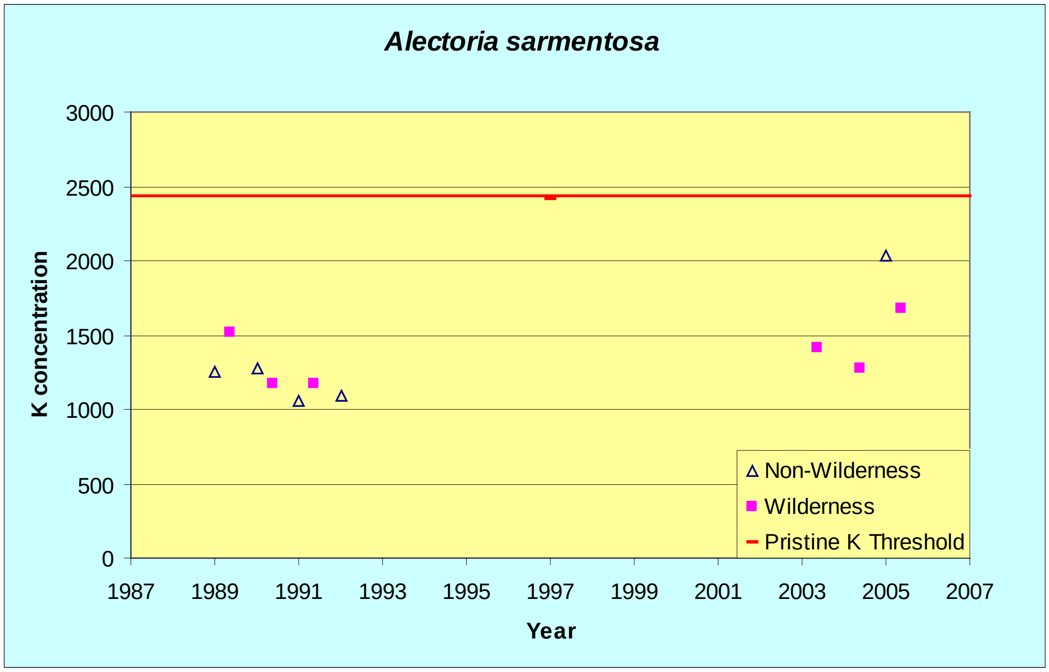

Figure XVII-3. Wilderness and Non-Wilderness yearly means of K ppm in *Alectoria sarmentosa* per year.

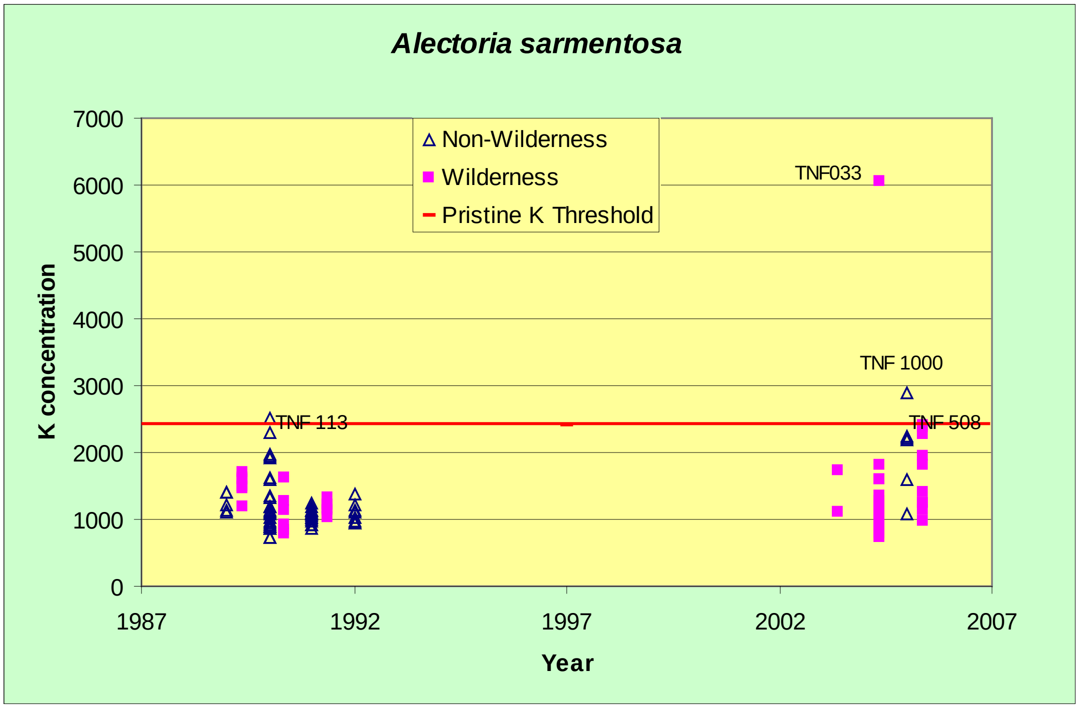

Figure XVII-4. Wilderness and Non-Wilderness plot means of K ppm in *Alectoria sarmentosa* per year.

Hypogymnia species

In this series, all of the *Hypogymnia* species were included as a group.

Table XVII-2. Wilderness and Non-Wilderness Means, Standard Errors, and 95% Confidence Intervals for the K ppm content of *Hypogymnia species* per year.

K ppm				**95% CI**	
Year	**Plot Type**	**Mean**	**Std. Error**	**Lower**	**Upper**
1989	Non-Wilderness	1592.00	234.0000	1381.2520	4565.2520
1989	Wilderness	2494.68	181.2406	1991.4787	2997.8879
1990	Non-Wilderness	2844.27	211.9626	2398.9549	3289.5889
1990	Wilderness	2004.57	206.6696	1498.8691	2510.2738
2003	Wilderness	1796.55	NA	NA	NA
2004	Wilderness	1867.89	73.4462	1679.0935	2056.6926
2005	Non-Wilderness	2773.52	507.6070	589.4602	4957.5732
2005	Wilderness	2566.66	125.3818	2277.5301	2855.7922

No t-tests were performed on these data due to lack of repeat samples of *Hypogymnia*.

Relationships are not strong in K content for *Hypogymnia* after accounting for latitude, longitude, elevation, year (Figures XVII-5, XVII-6 for year) and precipitation (see Brenner, 2006 for all graphed results).

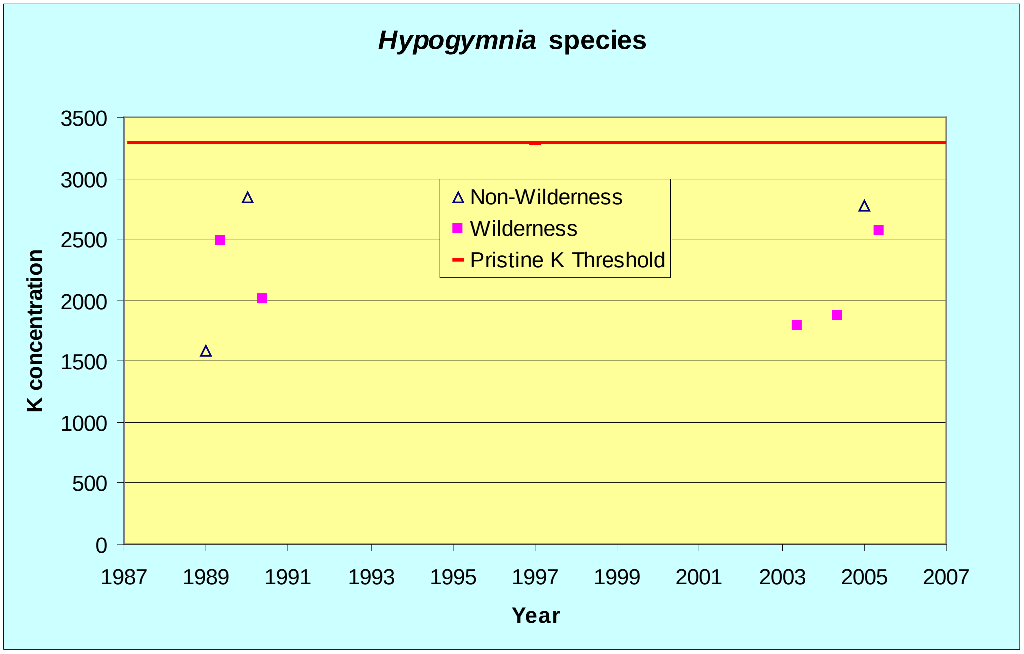

Figure XVII-5. Wilderness and Non-Wilderness yearly means of K ppm in *Hypogymnia species* per year.

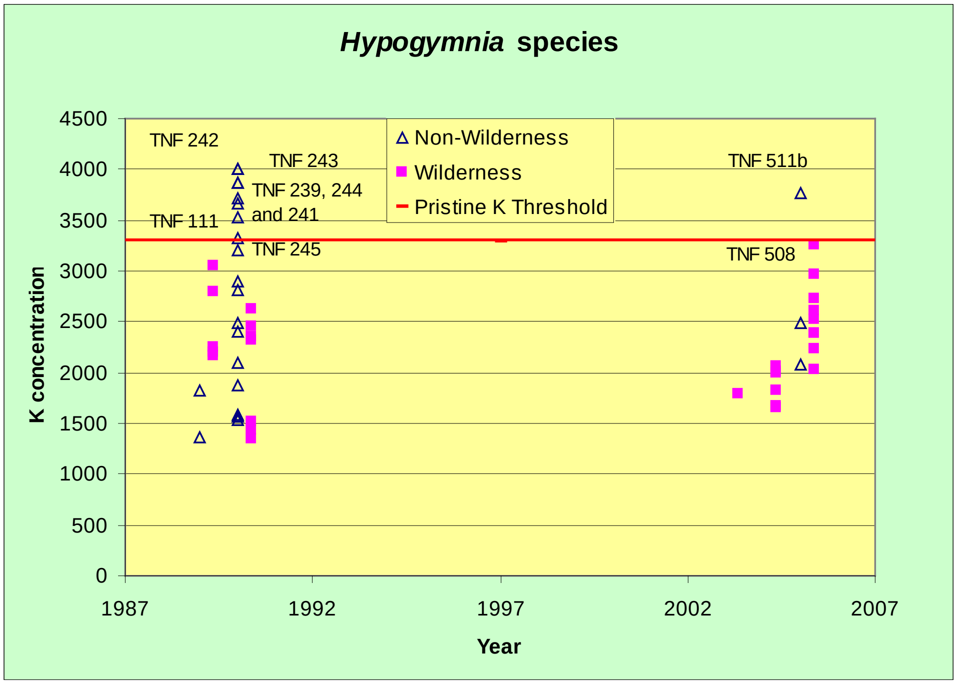

Figure XVII-6. Wilderness and Non-Wilderness plot means of K ppm in *Hypogymnia species* per year.

Lobaria oregana

Table XVII-3. Wilderness and Non-Wilderness Means, Standard Errors, and 95% Confidence Intervals for the K ppm content of *Lobaria oregana* per year.

K ppm				95% CI	
Year	**Plot Type**	**Mean**	**Std. Error**	**Lower**	**Upper**
1989	Non-Wilderness	5585.83	499.2121	3997.1175	7174.5491
1989	Wilderness	6591.09	289.6130	5786.9990	7395.1880
1990	Non-Wilderness	6882.89	258.5972	6319.4562	7446.3258
1990	Wilderness	6804.17	315.5482	5993.0241	7615.3093
2004	Wilderness	5348.35	403.0401	4362.1477	6334.5547
2005	Non-Wilderness	6039.78	NA	NA	NA
2005	Wilderness	7313.54	415.7546	5990.4207	8636.6543

Summary of Statistical Tests:

t = 0.2312, df = 4, p-value = 0.8285

There is no evidence of a difference in K ppm content in *Lobaria oregana* from pre-2000 and post 2000 samples (p-value = 0.8285). This analysis was for wilderness areas that had repeated values for K in *Lobaria oregana*, Russell Fiords (plot 62 near Harlequin Lake), Tebenkof (33) and Misty Fiords (86, 88).

Relationships are not strong in the K content in *Lobaria oregana* after accounting for latitude, longitude, elevation, year (Figures XVII-7, XVII-8 for year) and precipitation (see Brenner, 2006 for all graphed results).

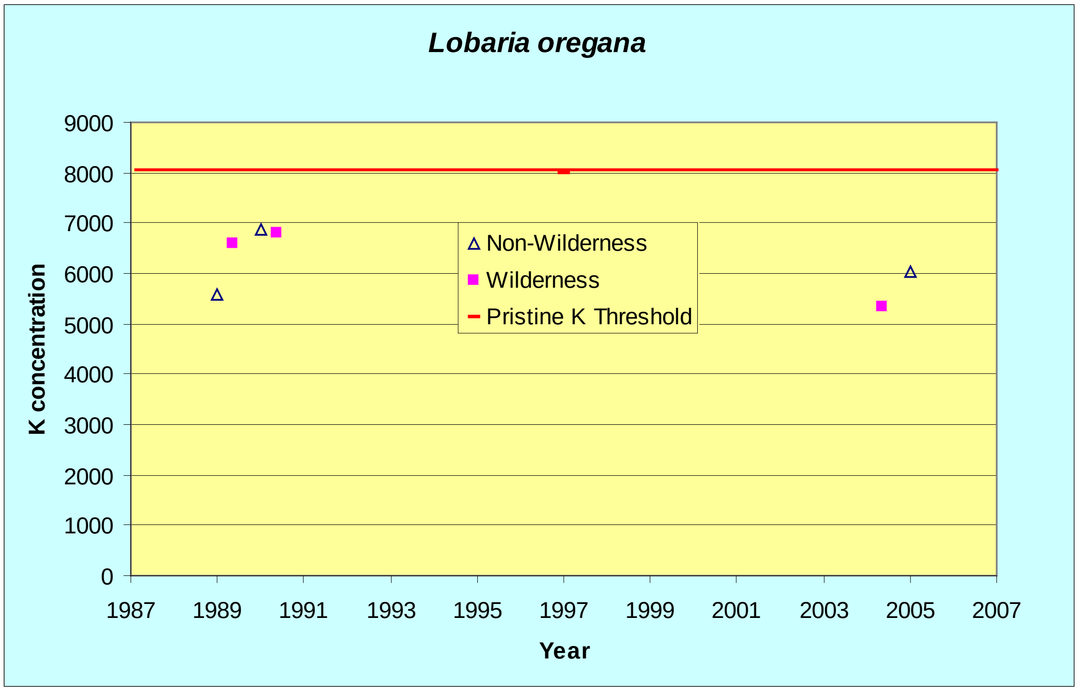

Figure XVII-7. Wilderness and Non-Wilderness yearly means of K ppm in *Lobaria oregana* per year.

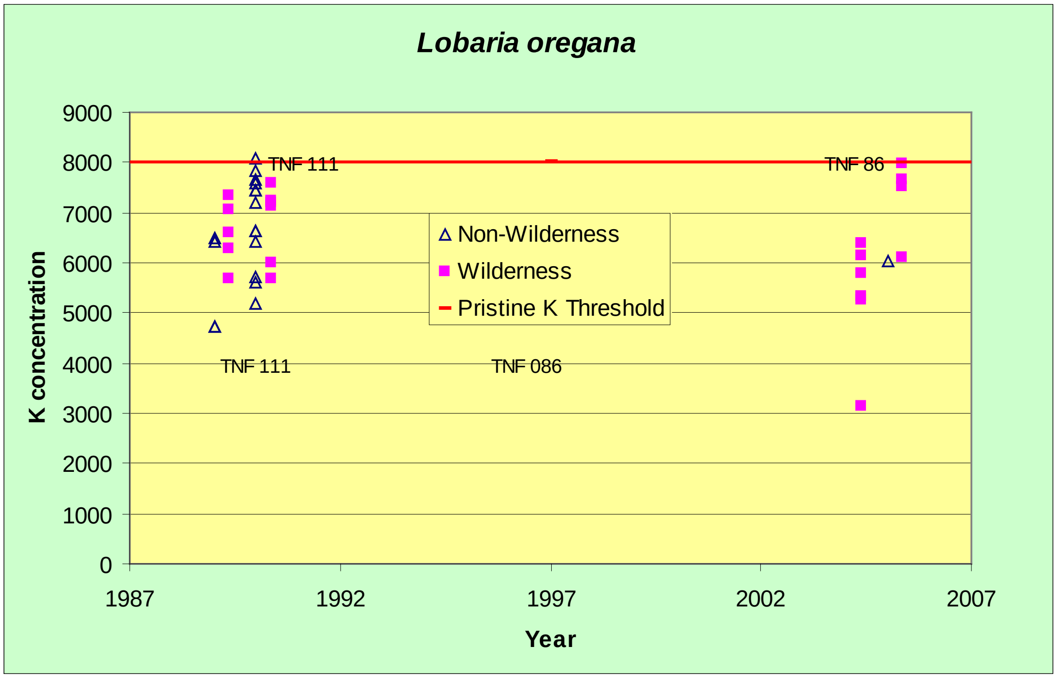

Figure XVII-8. Wilderness and Non-Wilderness plot means of K ppm in *Lobaria oregana* per year.

Platismatia glauca

Table XVII-4. Wilderness and Non-Wilderness Means, Standard Errors, and 95% Confidence Intervals for the K ppm content of *Platismatia glauca* per year.

K ppm				**95% CI**	
Year	**Plot Type**	**Mean**	**Std. Error**	**Lower**	**Upper**
2003	Wilderness	1701.63	NA	NA	NA
2004	Wilderness	1847.07	98.5653	1624.1006	2070.0410
2005	Non-Wilderness	2937.66	283.6815	2295.9287	3579.3930
2005	Wilderness	2246.19	93.7031	2024.6150	2467.7600

No t-tests were performed on these data. The mean values for K are baseline in *Platismatia glauca.*

Relationships are not strong in K content for Plagla after accounting for latitude, longitude, elevation, year (Figures XVII-9, XVII-10 for year) and precipitation (see Brenner, 2006 for all graphed results).

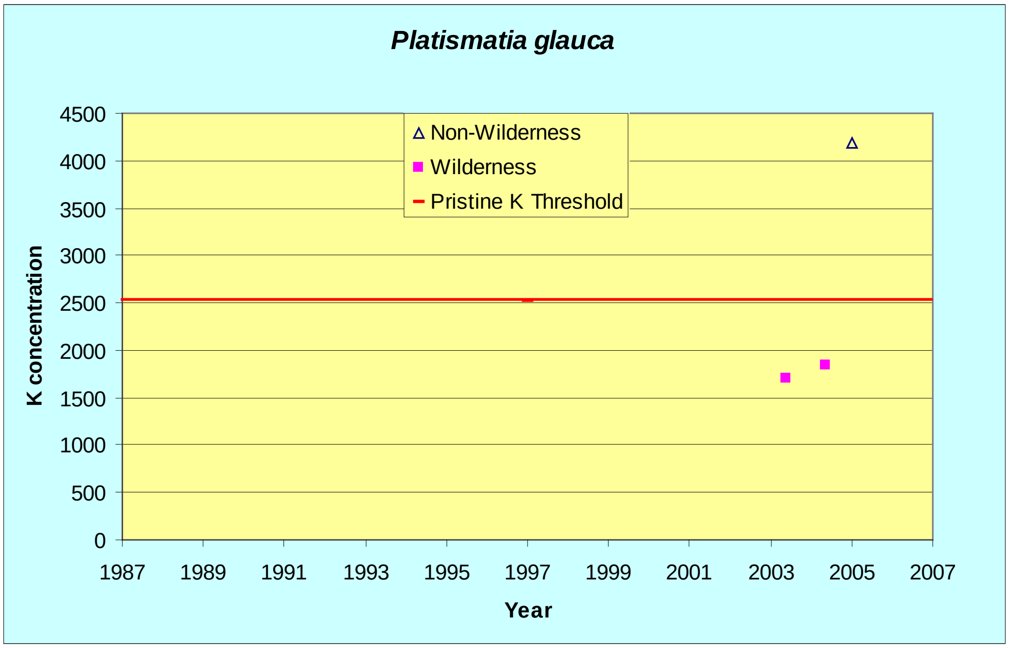

Figure XVII-9. Wilderness and Non-Wilderness yearly means of K ppm in *Platismatia glauca* per year.

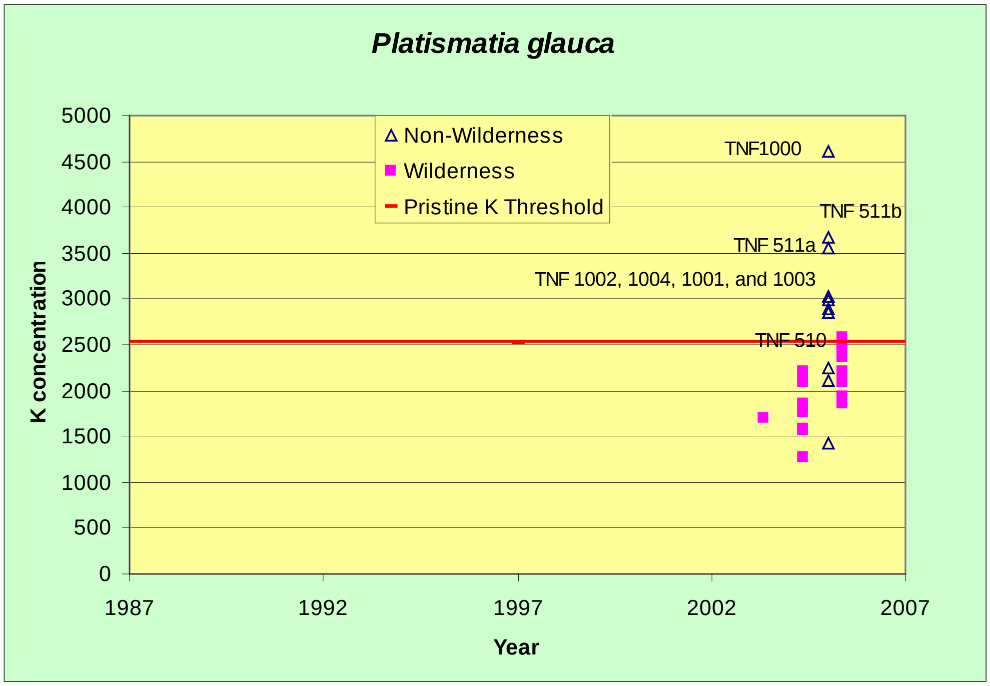

Figure XVII-10. Wilderness and Non-Wilderness plot means of K ppm in *Platismatia glauca* per year.

Conclusions: for Potassium (K) and all lichen species

Lichens enhanced in K from seashore environments range between 5000 to 9500 ppm from various lichen species worldwide (USDA 1999). Potassium constitutes about 1.10% by weight of the dissolved salts in seawater. From the Tongass, K threshold for *Lobaria oregana* (8001.57 ppm) is within the enhanced range, while the other lichen species analyzed are below the enhanced range. Compared to the Pacific Northwest region, Tongass lichens are at or above background for K (USDA 1999).

Alectoria sarmentosa

Background K in the Pacific Northwest for Alesar is 1500 ppm while the Tongass threshold is 2413.25 ppm. Although not considered high enough to be K enhanced, it is suggestive that the hyper maritime environment of the Tongass does universally influence the K in lichens. However, there are some places that have above threshold that may not be associated with just seaside enhanced K such as the downtown Juneau area plot 1000 (175 above town). Elevated levels may be due to the wood smoke and other combustion occurring in the downtown area. Tebenkof plot 33 is very high in K, nearly 6000 ppm, which is within the range of what is considered seaside enhanced (USDA 1999). Other Alesar collected from beach plots are not above threshold for K, so it is unclear as to why Tebenkof is the only elevated beach plot. More sampling is recommended.

Hypogymnia

Background K in *Hypogymnia* from the Pacific Northwest is between 2400 and 4000 ppm (USDA 1999). The Tongass threshold for K (3284.34 ppm) is within background for the Pacific Northwest. Plots above threshold for K include several along the Sitka road system and near the pulp mill from the 1990's (plots 242, 243, 239, 244, and 241). Potassium may be elevated due to wood stove pollution, proximity to industry, or the seashore environment close to the road system of Sitka. Plot 111 from Amalga Trail in Juneau is elevated in K, and is unexplained at this time. Plot 511b near the Greens Creek mine is elevated in K and could be attributed to industrial or burning activities in the area.

Plot 508 from Endicott River is just at threshold, and could be part of the natural variation in K since it is miles inland from saltwater.

Lobaria oregana

Background K in the Pacific Northwest is 7000 ppm for Lobore (USDA 1999). Tongass threshold is slightly above this at 8001.57ppm, and is within what is considered seaside enhanced Lobore from other literature (USDA 1999). Two plots were near threshold in Lobore, (86 from Misty Fiords at Hughs Lake, and 111 from Amalga Trail), and could be part of the natural variation rather than enhanced from human use (Figure XVIII-8).

Platismatia glauca

Background K in Plagla from the Pacific Northwest is almost equal to the threshold for K on the Tongass (2500 ppm and 2523.88 ppm respectively). Potassium pollution from woodstoves and other combustion in downtown Juneau may be the cause for elevated levels from all five plots on Mt Roberts. The plot closest to sea level (plot 1000) has the highest mean levels of K in Plagla (over 4500 ppm) , and levels at the four higher elevation plots have similar but lower mean K (Figure XVIII-10). Plots near the Greens Creek portal and upstream from the portal (plots 511a and 511b) also are elevated in K, which may be attributed to industrial sources at the mine. Plot 510 from Coronation is just at threshold and may be due to seaside environment or part of the natural variation.

.

XVIII. Summary of results for Lithium (Li) from all species on the Tongass National Forest

Lithium is a soft alkali metal. In nature, it does not occur in pure element form due to its high reactivity. Lithium forms a minor part of igneous rocks, with the largest concentrations in granite. It also occurs in trace amounts in seawater. Lithium compounds are used for the manufacturing of lubricating grease compounded with petroleum and other lubricating oils (Kamienski et al 2004). Lithium minerals are also used in glass and ceramic industries. Lithium chloride and fluoride compounds are used in welding and brazing.

Lithium is analyzed in lichens for the first time on the Tongass. Instrumental readings were refined between 2004 and 2005 at the laboratory. Detectable level was lowered in 2005 to .100 ppm. In 2004, detectable level was at .400 ppm. All results for Alesar are below the lowest detectable limit (see Figure XVIII-4). Threshold for Li are established from the 2004 and 2005 samples for *Hypogymnia* (.71 ppm), *Lobaria oregana* (.59 ppm) and *Platismatia glauca* (.60 ppm).

Above threshold for Li are the following: *Hypogymnia* (plot 62 from Russell Fiords) and just on the edge of threshold (plot 512 from Greens Creek tailings pile) (Figure XVIII-6); Lobore plot 62 from Russell Fiord (Figure XVIII-8); and Plagla plot 512 (Greens Creek tailings pile), 62 (Russell Fiord) and on the edge of threshold for 511b (Greens Creek portal) (Figure XVIII-10).

XVIII. SUMMARY OF Li PPM DATA ANALYSIS

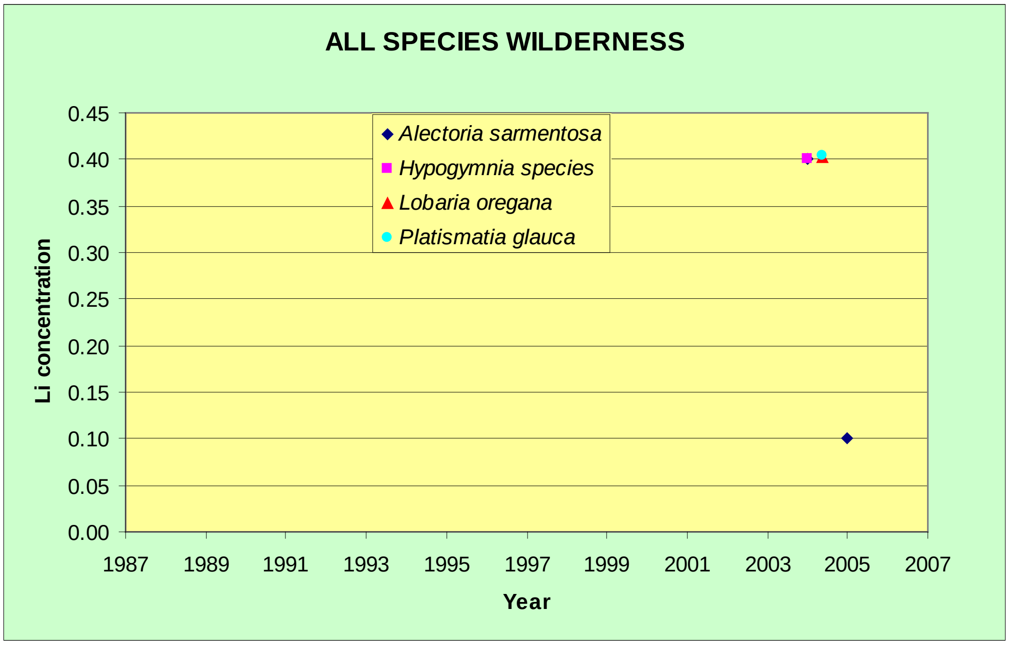

Figure XVIII-1. Wilderness plot means of Li ppm in *All Species* per year.

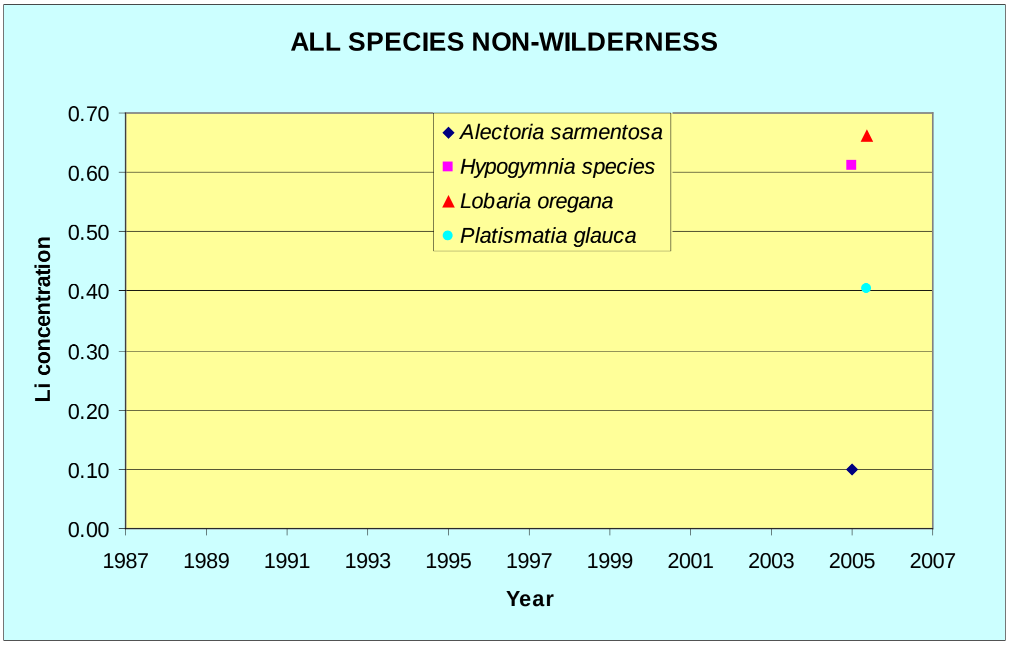

Figure XVIII-2. Non-Wilderness plot means of Li ppm in *All Species* per year.

Alectoria sarmentosa

Table XVIII-1. Wilderness and Non-Wilderness Means, Standard Errors, and 95% Confidence Intervals for the Li ppm content of *Alectoria sarmentosa* per year.

Li ppm				**95% CI**	
Year	**Plot Type**	**Mean**	**Std. Error**	**Lower**	**Upper**
2004	Wilderness	0.40	0.0000	0.4000	0.4000
2005	Non-Wilderness	0.10	0.0000	0.1000	0.1000
2005	Wilderness	0.10	0.0000	0.1000	0.1000

No t-tests were performed due to the levels of Li in Alesar being below instrumental detection limits.

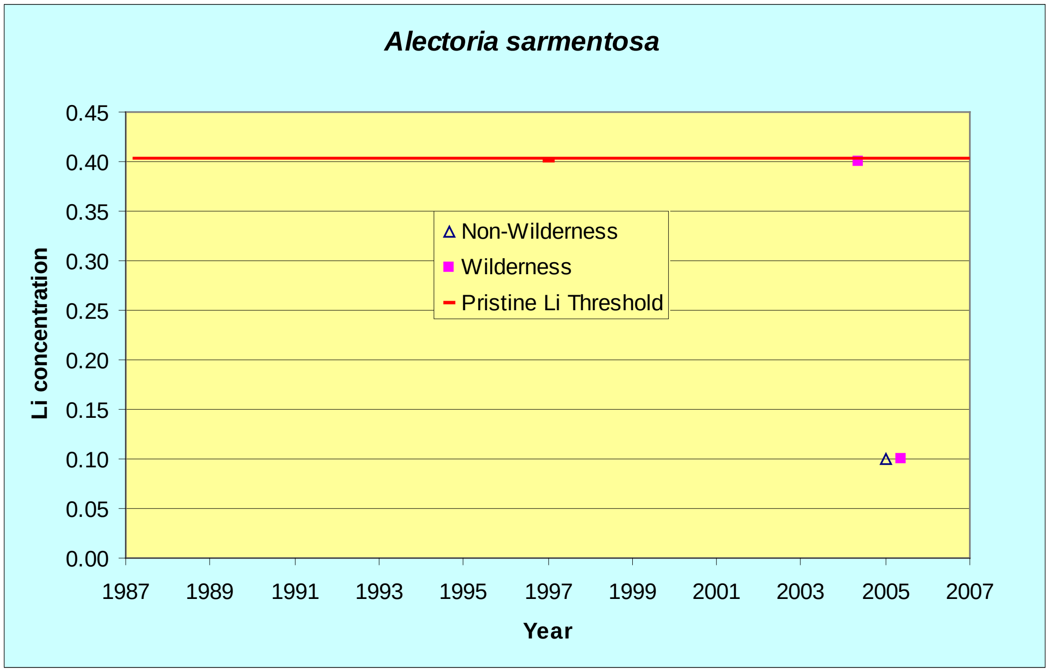

Figure XVIII-3. Wilderness and Non-Wilderness yearly means of Li ppm in *Alectoria sarmentosa* per year.

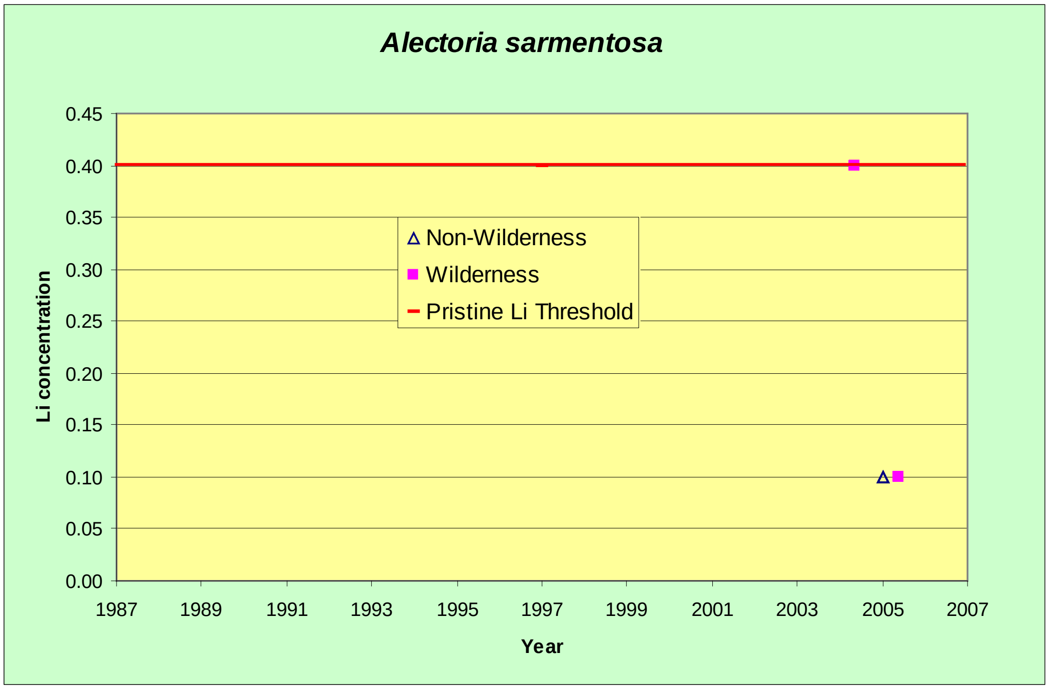

Figure XVIII-4. Wilderness and Non-Wilderness plot means of Li ppm in *Alectoria sarmentosa* per year.

Hypogymnia species

In this series, all of the *Hypogymnia* species were included as a group.

Table XVIII-2. Wilderness and Non-Wilderness Means, Standard Errors, and 95% Confidence Intervals for the Li ppm content of *Hypogymnia species* per year.

Li ppm				95% CI	
Year	**Plot Type**	**Mean**	**Std. Error**	**Lower**	**Upper**
2004	Wilderness	0.40	0.0000	0.4000	0.4000
2005	Non-Wilderness	0.61	0.1421	0.0004	1.2221
2005	Wilderness	0.22	0.0576	0.0835	0.3494

No t-test was performed due to the lack of repeat samples.

Relationships are not strong in Li content for *Hypogymnia* after accounting for latitude, longitude, elevation, year (Figures XVIII-5, XVIII-6 for year) and precipitation (see Brenner, 2006 for all graphed results).

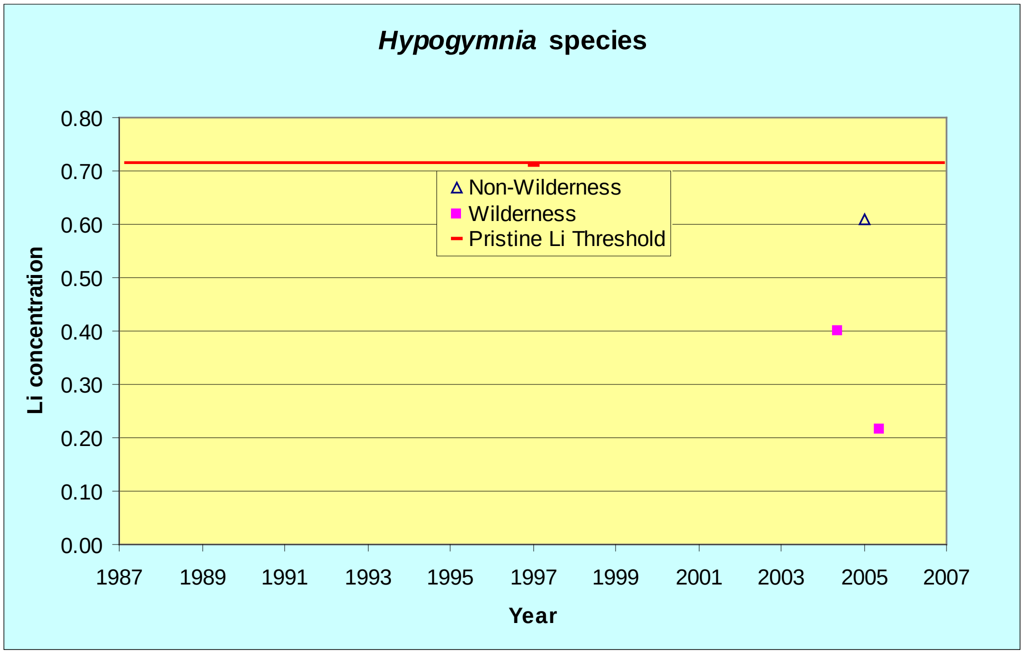

Figure XVIII-5. Wilderness and Non-Wilderness yearly means of Li ppm in *Hypogymnia species* per year.

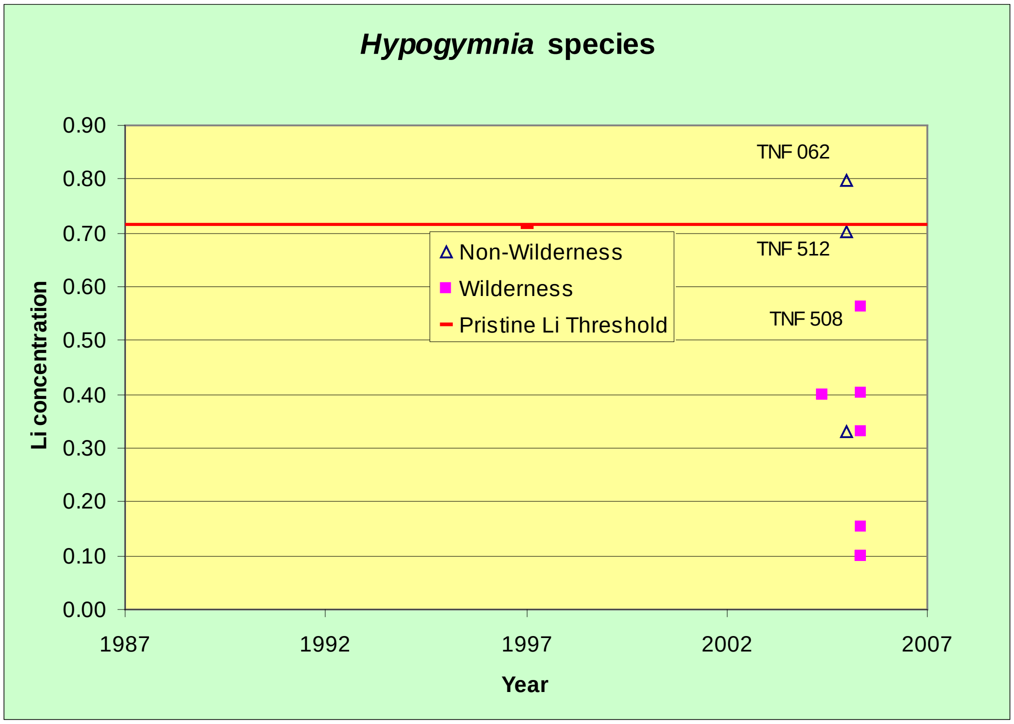

Figure XVIII-6. Wilderness and Non-Wilderness plot means of Li ppm in *Hypogymnia species* per year.

Lobaria oregana

Table XVIII-3. Wilderness and Non-Wilderness Means, Standard Errors, and 95% Confidence Intervals for the Li ppm content of *Lobaria oregana* per year.

Li ppm				**95% CI**	
Year	**Plot Type**	**Mean**	**Std. Error**	**Lower**	**Upper**
2004	Wilderness	0.40	0.0029	0.3959	0.4098
2005	Non-Wilderness	0.66	NA	NA	NA
2005	Wilderness	0.1315	0.0315	0.0313	0.2317

No t-test was performed due to the lack of repeat samples.

Relationships are not strong in Li content for Lobore after accounting for latitude, longitude, elevation, year (Figures XVIII-5, XVIII-6 for year) and precipitation (see Brenner, 2006 for all graphed results).

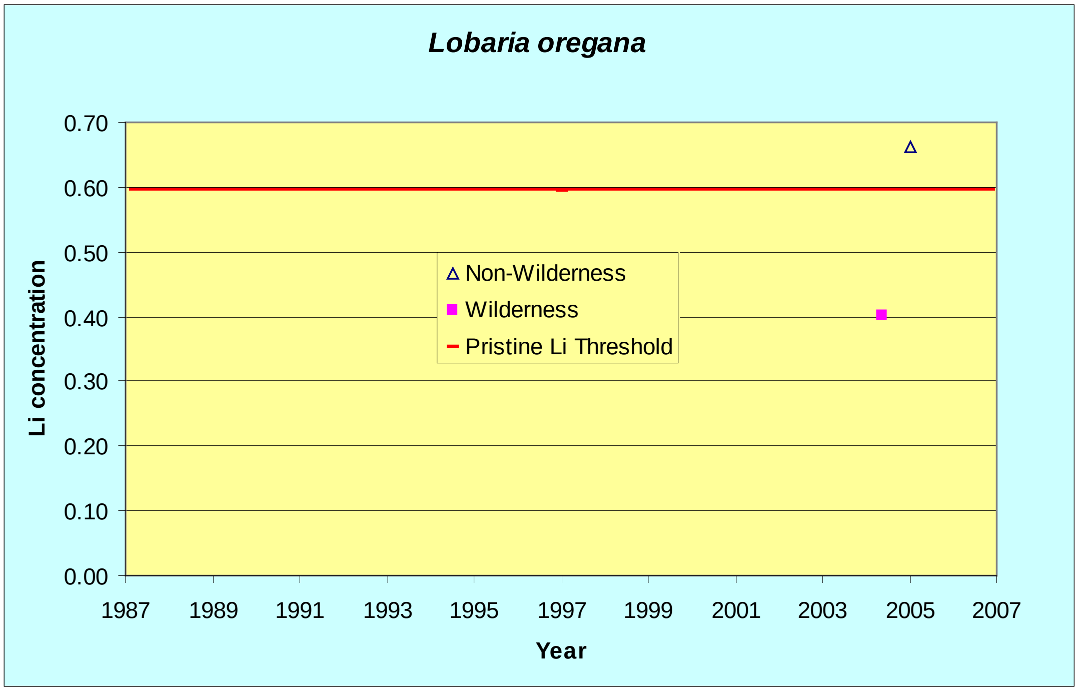

Figure XVIII-7. Wilderness and Non-Wilderness yearly means of Li ppm in *Lobaria oregana* per year.

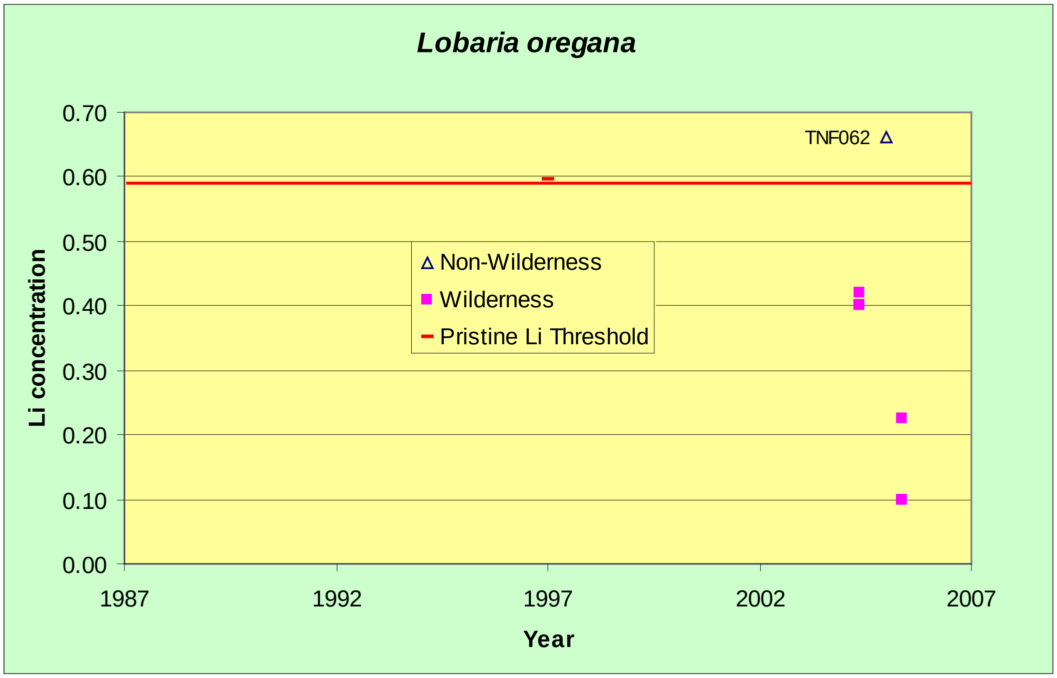

Figure XVIII-8. Wilderness and Non-Wilderness plot means of Li ppm in *Lobaria oregana* per year.

Platismatia glauca

Table XVIII-4. Wilderness and Non-Wilderness Means, Standard Errors, and 95% Confidence Intervals for the Li ppm content of *Platismatia glauca* per year.

Li ppm				**95% CI**	
Year	**Plot Type**	**Mean**	**Std. Error**	**Lower**	**Upper**
2004	Wilderness	0.40	0.0041	0.3948	0.4134
2005	Non-Wilderness	0.40	0.0667	0.2492	0.5511
2005	Wilderness	0.26	0.0622	0.1095	0.4038

No t-test was performed due to the lack of repeatsamples.

Relationships are not strong in Li content for Plagla after accounting for latitude, longitude, elevation, year (Figures XVIII-5, XVIII-6 for year) and precipitation (see Brenner, 2006 for all graphed results).

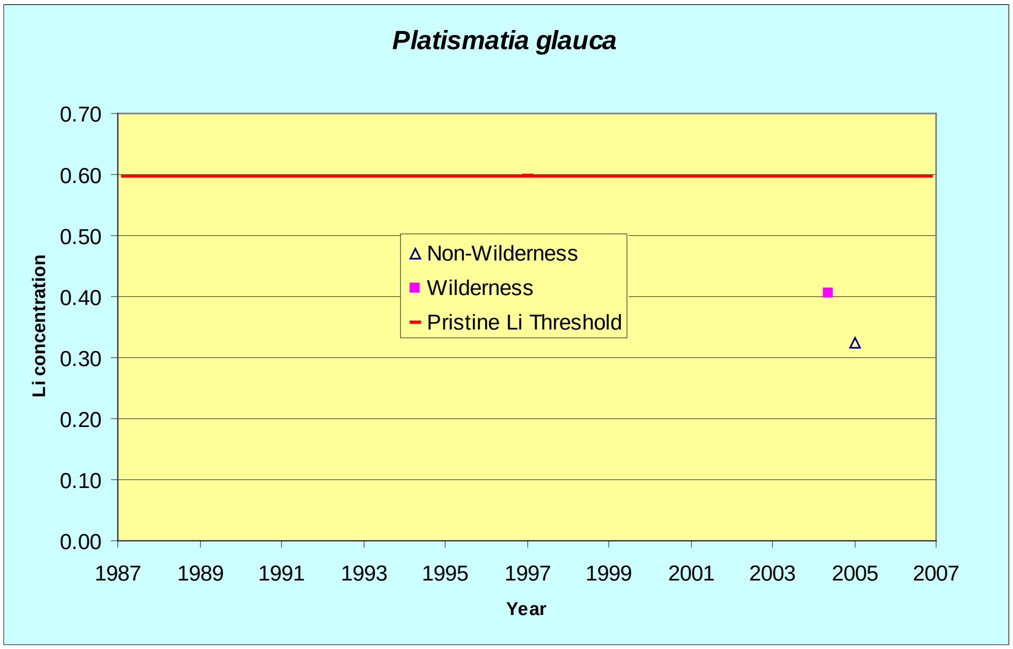

Figure XVIII-9. Wilderness and Non-Wilderness yearly means of Li ppm in *Platismatia glauca* per year.

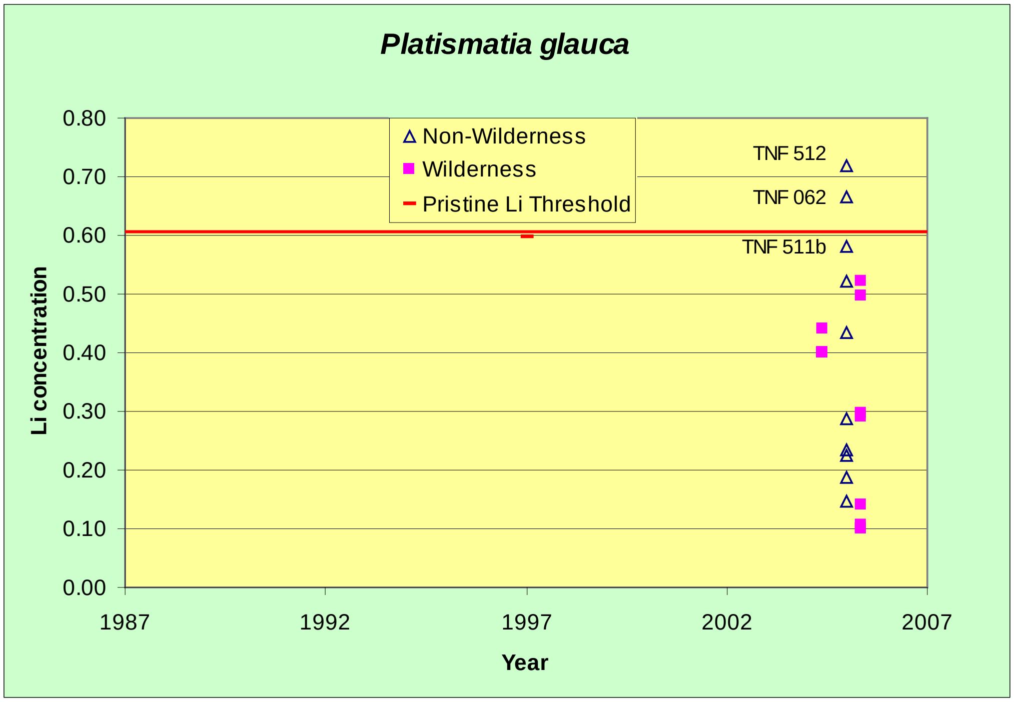

Figure XVIII-10. Wilderness and Non-Wilderness plot means of Li ppm in *Platismatia glauca* per year.

Conclusions: for Lithium (Li) and all lichen species

Levels for Li are below detectable limits in Alesar, and therefore this lichen is not a good Li indicator. Few plots are elevated in Li. Those elevated are near industry or from plots that have strong geological influence as the likely source. Background level for Li from the Pacific Northwhest or worldwide is available.

Hypogymnia

Plot 62 from Harlequin Lake is elevated above the Li threshold established for the Tongass (Figure XVIII-6). This plot is also high in other elements, possibly due to the windblown dusts and exposed location of this area to the glaciated terrain around Russell Fiords. Plot 512 near Greens Creek tailings pile is just at threshold for Li, and could be part of the natural variation or due to the proximity to industrial sources of the mine.

Lobaria oregana

Plot 62 from Russell Fiord is the only plot elevated above threshold for Li (Figure XVIII-8). This may be due to the sources indicated above under *Hypogymnia*.

Platismatia glauca

Plots 512 (Greens Creek tailings) is elevated above threshold, while plot 511b (portal) is just at threshold level (Figure XVIII-10). Both plots may be elevated due to the mining industry and exposed rock and road dust in the area. Plot 62 from Russell Fiords is elevated and most likely due to natural sources (see above *Hypogymnia*).

XVIII. Summary of results for Magnesium (Mg) from all species on the Tongass National Forest

Magnesium is an alkaline earth metal and is abundant on earth. Compounds are in the earth's crust and seawater. Like calcium, Mg levels in lichens tend to be enriched near ocean environments (USDA 1999). Ultra-mafic rocks and soils are higher in Mg than other rocks (Kabata-Pendias and Pendias 1984). Magnesium is also an essential mineral to human health.

Provisional threshold for Mg in lichens from the Tongass are the following: *Alectoria sarmentosa* (740.83 ppm), *Hypogymnia* (2127.70 ppm), *Lobaria oregana* (735.79 ppm), and *Platismatia glauca* (1717.08 ppm).

Plot means above threshold Mg are the following: Alesar plot 516 (South POW) and 510 (Warren Island) and on the edge of threshold plot 32 from Tebenkof (Figure XIX-4); *Hypogymnia* plots 513 (Coronation Island), and 246 (Sitka road system, and on the edge for plot 509 (Warren Island) (Figure XIX-6); Lobore plots 62 (Russell Fiords) and 246 (Sitka road system)(Figure XIX-8); Plagla plot 510 from Warren Island (Figure XIX-10).

XIX. SUMMARY OF Mg PPM DATA ANALYSIS

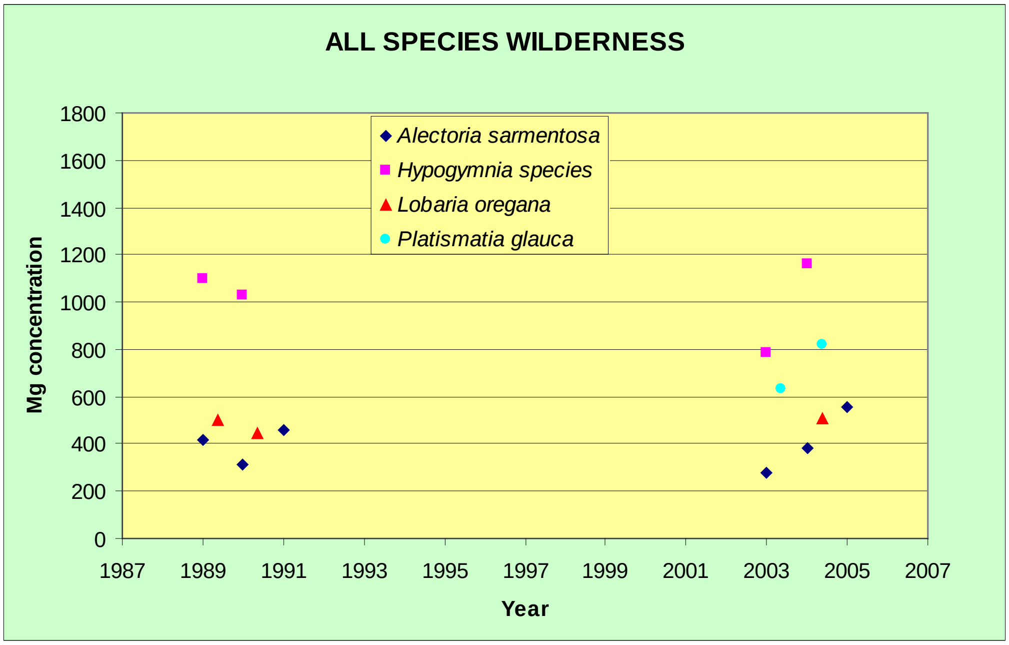

Figure XIX-1. Wilderness plot means of Mg ppm in *All Species* per year.

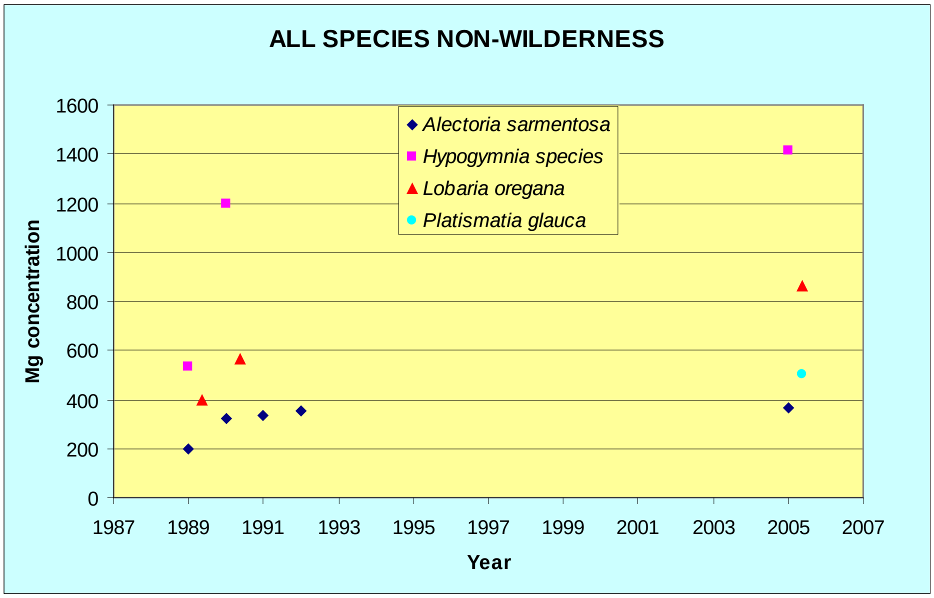

Figure XIX-2. Non-Wilderness plot means of Mg ppm in *All Species* per year.

Alectoria sarmentosa

Table XIX-1. Wilderness and Non-Wilderness Means, Standard Errors, and 95% Confidence Intervals for the Mg ppm content of *Alectoria sarmentosa* per year.

Mg ppm				**95% CI**	
Year	**Plot Type**	**Mean**	**Std. Error**	**Lower**	**Upper**
1989	Non-Wilderness	201.49	27.3259	125.6211	277.3589
1989	Wilderness	416.41	85.9430	195.4821	637.3290
1990	Non-Wilderness	322.90	28.6000	264.1091	381.6855
1990	Wilderness	310.33	32.3227	231.2434	389.4251
1991	Non-Wilderness	337.5974	32.7559	268.7798	406.4149
1991	Wilderness	458.77	46.2202	330.4383	587.0939
1992	Non-Wilderness	351.58	26.5861	288.7141	414.4465
2003	Wilderness	277.54	60.6483	493.0685	1048.1518
2004	Wilderness	384.78	24.7150	333.6580	435.9117
2005	Non-Wilderness	364.65	17.6155	319.3713	409.9354
2005	Wilderness	558.30	86.7444	362.0721	754.5309

Summary of Statistical Tests:

t = 0.9446, df = 8, p-value = 0.3725

There is no evidence of a difference in Mg ppm content in *Alectoria sarmentosa* from pre-2000 and post 2000 samples (p-value = 0.3725). Plots with repeated samples for Mg in Alesar are: Karta River (#159), Pleasant Island (#145, 146), Pikes Lake RNA (# 69), Kootznoowoo (# 189, 190), Petersburg Creek (#116), Stikine-LeConte (#30, 31), Yakobi (#101), Tebenkof (#33) and Misty Fiords (#85, 86).

Relationships are not strong in the Mg content in *Alectoria sarmentosa* after accounting for latitude, longitude, elevation, year (Figures XIX-3, XIX-4 for year) and precipitation (see Brenner, 2006 for all graphed results).

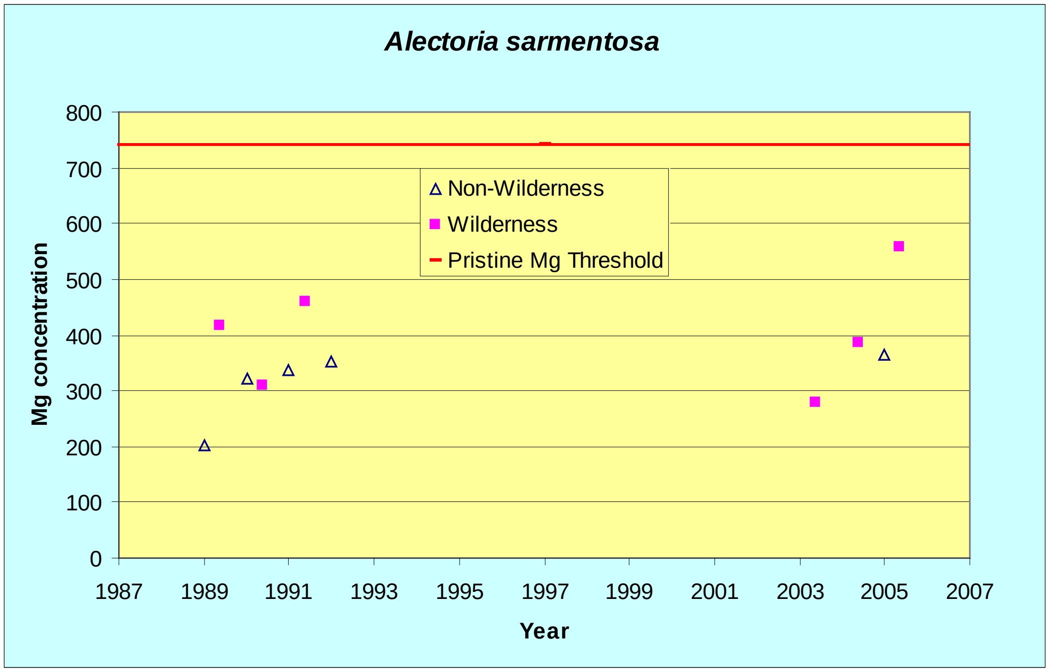

Figure XIX-3. Wilderness and Non-Wilderness yearly means of Mg ppm in *Alectoria sarmentosa* per year.

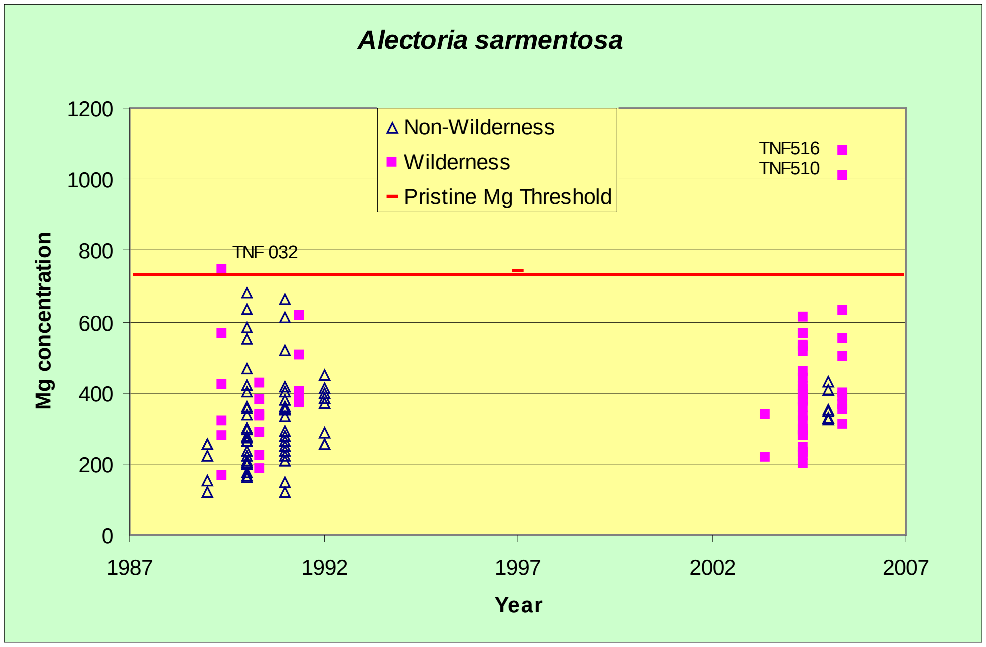

Figure XIX-4. Wilderness and Non-Wilderness plot means of Mg ppm in *Alectoria sarmentosa* per year.

Hypogymnia species

In this series, all of the *Hypogymnia* species were included as a group.

Table XIX-2. Wilderness and Non-Wilderness Means, Standard Errors, and 95% Confidence Intervals for the Mg ppm content of *Hypogymnia species* per year.

Mg ppm				**95% CI**	
Year	**Plot Type**	**Mean**	**Std. Error**	**Lower**	**Upper**
1989	Non-Wilderness	534.50	299.5000	3271.0080	4340.0080
1989	Wilderness	1101.33	126.8623	749.1070	1453.5597
1990	Non-Wilderness	1199.58	120.6124	946.1817	1452.9762
1990	Wilderness	1028.44	121.1508	731.9928	1324.8834
2003	Wilderness	788.53	NA	NA	NA
2004	Wilderness	1160.34	143.6093	791.1828	1529.5017
2005	Non-Wilderness	1412.92	157.5674	734.9587	2090.8747
2005	Wilderness	1554.76	165.1665	1173.8865	1935.6357

No t-tests were performed due to lack of repeat samples.

Relationships are not strong in Mg content for *Hypogymnia* after accounting for latitude, longitude, elevation, year (Figures XIX-5, XIX-6 for year) and precipitation (see Brenner, 2006 for all graphed results).

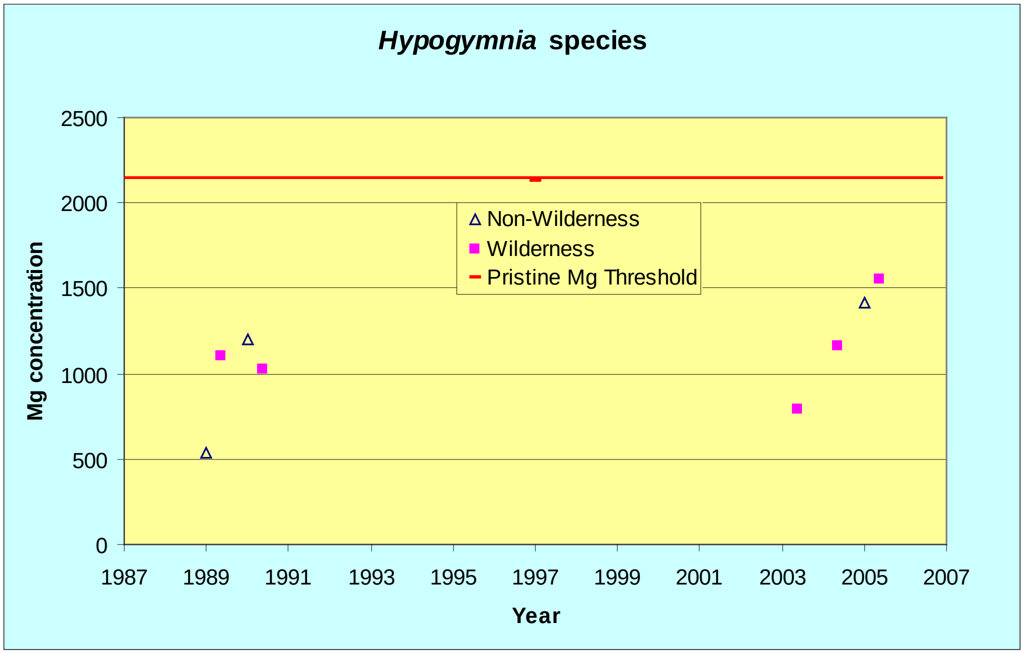

Figure XIX-5. Wilderness and Non-Wilderness yearly means of Mg ppm in *Hypogymnia species* per year.

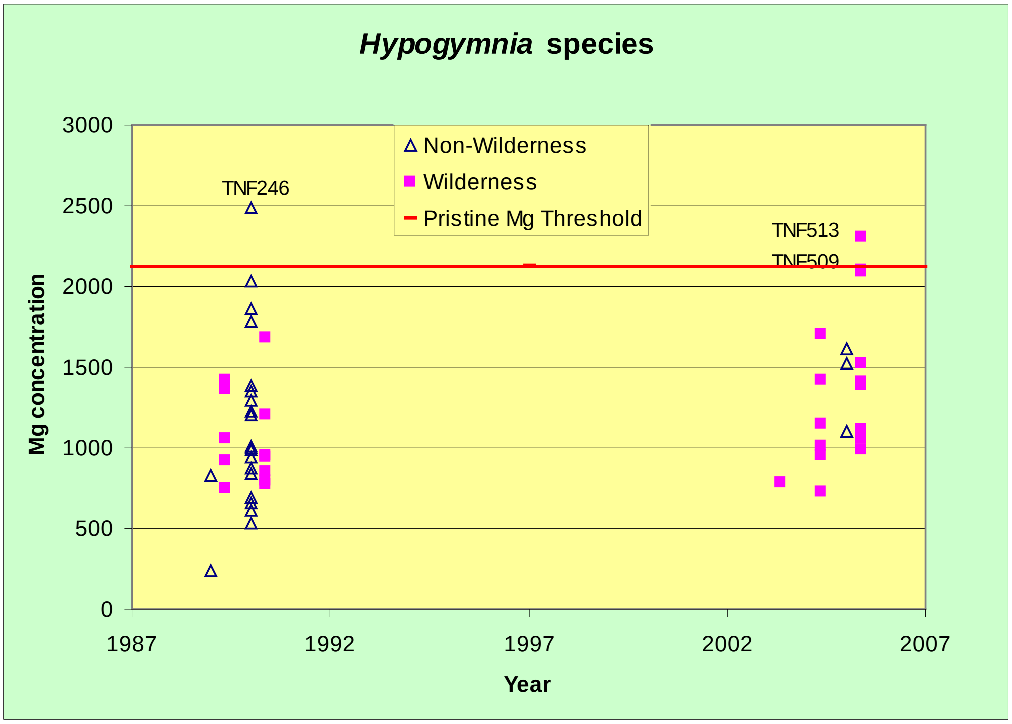

Figure XIX-6. Wilderness and Non-Wilderness plot means of Mg ppm in *Hypogymnia species* per year.

Lobaria oregana

Table XIX-3. Wilderness and Non-Wilderness Means, Standard Errors, and 95% Confidence Intervals for the Mg ppm content of *Lobaria oregana* per year.

Mg ppm				**95% CI**	
Year	**Plot Type**	**Mean**	**Std. Error**	**Lower**	**Upper**
1989	Non-Wilderness	399.92	21.1915	332.4758	467.3576
1989	Wilderness	500.10	51.8422	356.1631	644.0369
1990	Non-Wilderness	562.60	36.7034	482.6328	642.5723
1990	Wilderness	447.67	22.7190	389.2708	506.0731
2004	Wilderness	504.17	55.9632	367.2364	641.1105
2005	Non-Wilderness	864.42	NA	NA	NA
2005	Wilderness	534.6888	51.7891	369.8729	699.5047

Summary of Statistical Tests:

t = -0.2692, df = 4, p-value = 0.8011

There is no evidence of a difference in Mg ppm content in *Lobaria oregana* from pre-2000 and post 2000 samples (p-value = 0.8011). This analysis was for wilderness areas that had repeated values for Mg in *Lobaria oregana*, Russell Fiords (plot 62 near Harlequin Lake), Tebenkof (33) and Misty Fiords (86, 88).

Relationships are not strong in the Mg content in *Lobaria oregana* after accounting for latitude, longitude, elevation, year (Figures XIX-7, XIX-8 for year) and precipitation (see Brenner, 2006 for all graphed results).

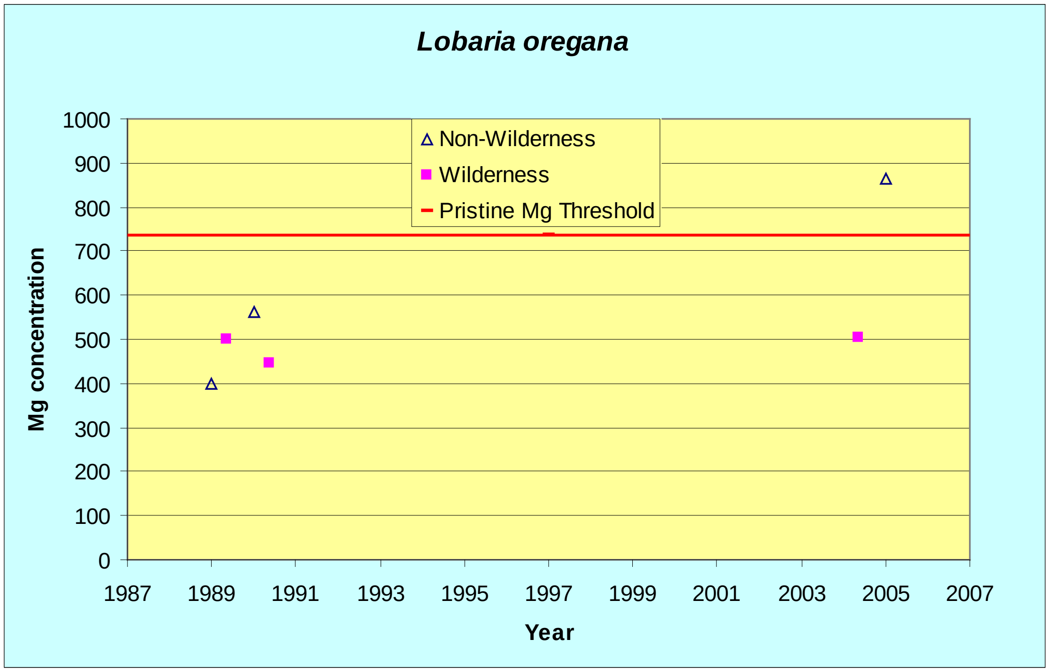

Figure XIX-7. Wilderness and Non-Wilderness yearly means of Mg ppm in *Lobaria oregana* per year.

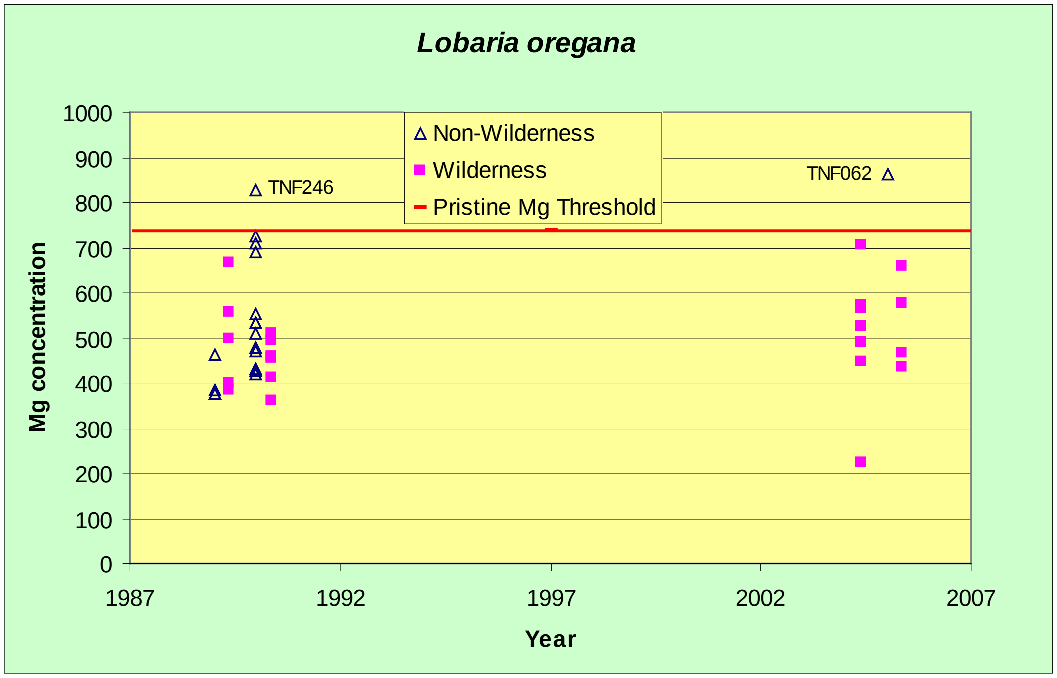

Figure XIX-8. Wilderness and Non-Wilderness plot means of Mg ppm in *Lobaria oregana* per year.

Platismatia glauca

Table XIX-4. Wilderness and Non-Wilderness Means, Standard Errors, and 95% Confidence Intervals for the Mg ppm content of *Platismatia glauca* per year.

Mg ppm				**95% CI**	
Year	**Plot Type**	**Mean**	**Std. Error**	**Lower**	**Upper**
2003	Wilderness	631.63	NA	NA	NA
2004	Wilderness	821.80	71.2282	660.6702	982.9288
2005	Non-Wilderness	960.25	112.0473	706.7770	1213.7144
2005	Wilderness	1147.34	155.5752	779.4636	1515.2176

No t-tests were performed on these data. The values for Mg are baseline in *Platismatia glauca.*

Relationships are not strong in Mg content for Plagla after accounting for latitude, longitude, elevation, year (Figures XIX-9, XIX-10 for year) and precipitation (see Brenner, 2006 for all graphed results).

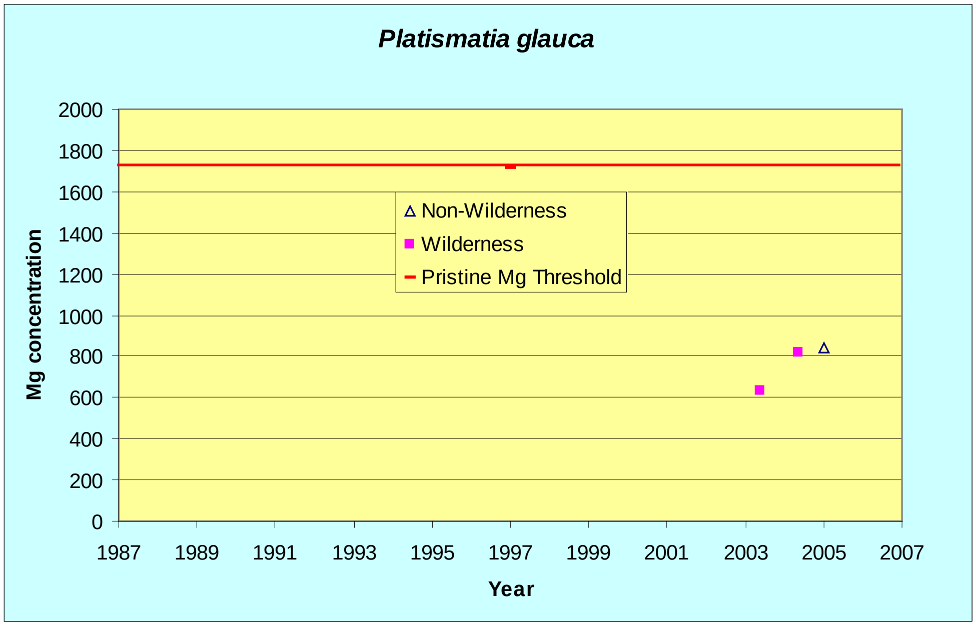

Figure XIX-9. Wilderness and Non-Wilderness yearly means of Mg ppm in *Platismatia glauca* per year.

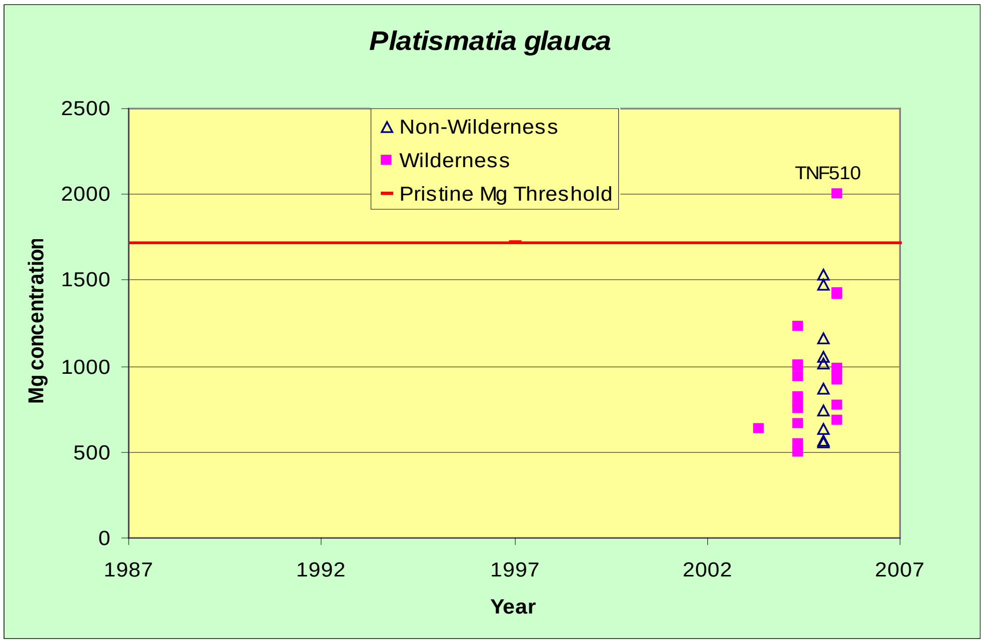

Figure XIX-10. Wilderness and Non-Wilderness plot means of Mg ppm in *Platismatia glauca* per year.

Conclusions: for Magnesium (Mg) and all lichen species

Seashore enhanced lichens have Mg between 1000 ppm and 12,000 ppm for undefined lichen species (USDA 1999), suggesting that 1000 ppm is the general cutoff between background and enhanced levels of this element (Neibor and Richardson (1981). *Hypogymnia* and *Platismatia glauca* were above 1000 ppm for Mg threshold, suggesting that the Tongass may be universally enhanced in Mg due to the maritime influence. Elevated levels of Mg on the Tongass are apparently part of the natural variation of this element in lichens.

Alectoria sarmentosa

The background for Mg in Alesar from the Pacific Northwest is 250 ppm, and the Tongass threshold is well above this at 740.83 ppm (USDA 1999). This suggests that Alesar is also regionally enhanced with Mg on the Tongass due to the hypermaritime environment. South Prince of Wales wilderness plot 516 near the shoreline is elevated above threshold (over 1000 ppm) for Mg, and could be attributed to the close proximity to the ocean (Figure XIX-4). Similarly, Warren Island plot 510 is located on the beachfringe at Warren Cove, and could be elevated due to the saltwater influence. Plot 32 from Tebenkof Bay is also near saltwater and is just at Mg threshold, and can be attributed to the natural variation of saltwater influence.

Hypogymnia

Background for *Hypogymnia* in the Pacific Northwest is between 500 and 800 ppm (USDA 1999). Threshold for Mg in *Hypogymnia* is elevated at 2127.70 ppm compared to the Pacific Northwest and is within the range indicating seashore enhancement (USDA 1999). Plot 513 from Coronation Island at Egg Harbor is a forested beach area that is elevated in Mg (over 2000 ppm); most likely due to the ocean influence (Figure XIX-6). Plot 246 from the Sitka road system may be enhanced as it is located on the road along the shoreline. This plot was elevated in many other elements attributed to the proximity to industry and automobile exhaust. Plot 509 from Warren Island is just under threshold for Mg, and higher levels could be a part of the natural variation of Mg in this seaside habitat.

Lobaria oregana

Background for Lobore in the Pacific Northwest is 450 ppm, and Tongass threshold is nearly double at 735 ppm (USDA 1999). Elevated Mg above provisional threshold may indicate the enhancement of lichens in this region due to the hypermaritime environment. Plot 246 from the Sitka road system is elevated in Mg for *Hypogymnia* and Lobore, possibly for the same reasons. Elevated Mg at plot 62 from the Harlequin Lake may be due to the nearby road and associated windblown soils and glacial dusts.

Platismatia glauca

Background for Mg in Plagla from the Pacific Northwest is 500 ppm (USDA 1999), and the Tongass threshold is nearly triple this level at 1717.08 ppm. Plot 510 from Warren Island is elevated in both Plagla and Alesar (Figures XIX-8 and 10 respectively). This beach forest plot may be exposed to seashore spray.

XX. Summary of results for Manganese (Mn) from all species on the Tongass National Forest

Manganese (Mn) is a naturally occurring substance that does not occur as a pure metal in the environement. Instead it occurs combined with other chemicals such as oxygyn, sulfur and chlorine (USPHS 1992). Rocks containing high levels of manganese compounds are mined and used to make manganese metal. It is mixed with iron to make various types of steel. It may be present in abraded dust from automobile engines (USDA 1999). Some manganese compounds are used in the production of batteries, ceramics, pesticides, fertilizers and dietary supplements. It is also released into the air when fossil fuels are burned (USPHS 1992).

Tongass thresholds for Mn in lichens are the following: *Alectoria sarmentosa* (188.24 ppm), *Hypogymnia* (860.85 ppm), *Lobaria oregana* (168.00 ppm), and *Platismatia glauca* (483.70 ppm).

Locations with mean Mn above threshold are the following: Alesar plot 29 from Petersburg Lake, plot 111 from Amalga Trail, and on the edge of threshold plot 116 from Petersburg Lake; *Hypogymnia* plot 189 from Kootznoowoo and on the edge of threshold plot 190 from Kootznoowoo; Lobore plots 37 and 178 from Cape Fanshaw are on the edge of threshold; Plagla plot 31 from the Stikine River.

XX. SUMMARY OF Mn PPM DATA ANALYSIS

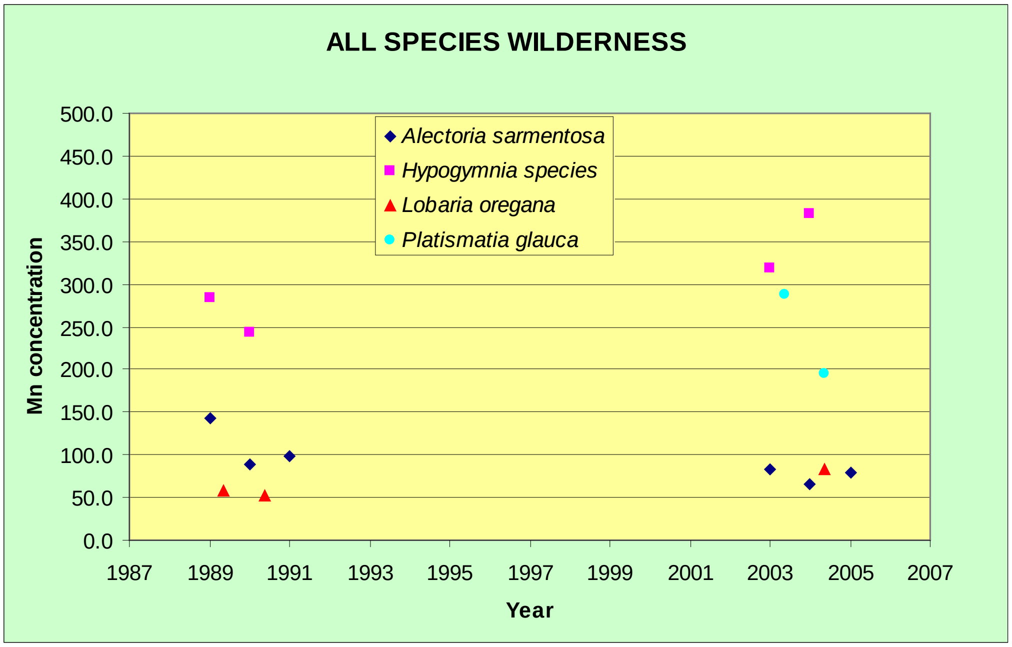

Figure XX-1. Wilderness plot means of Mn ppm in *All Species* per year.

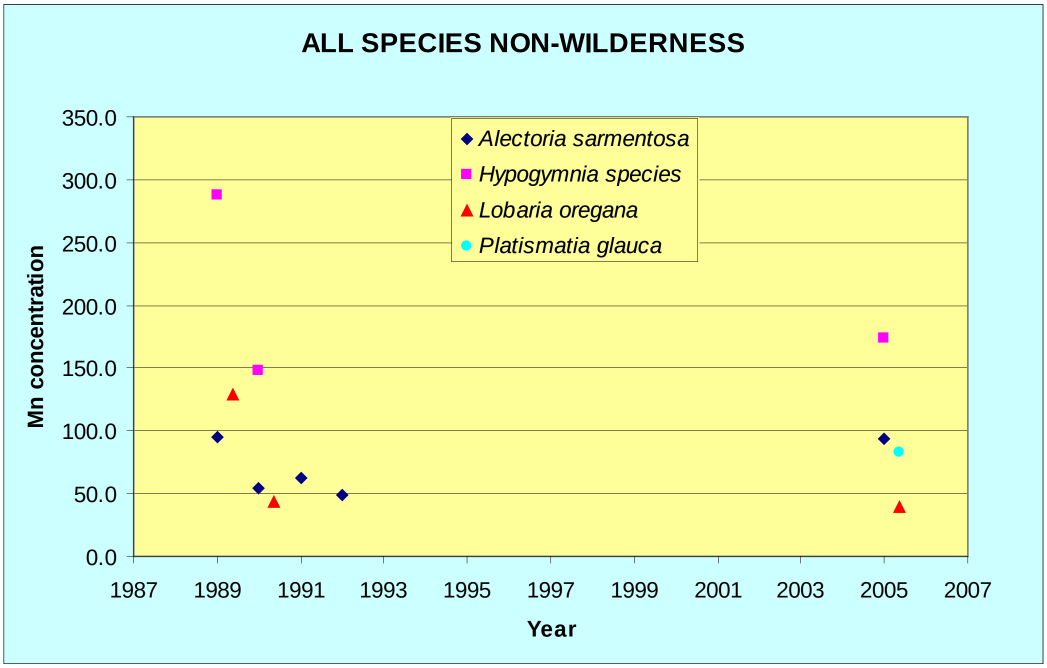

Figure XX-2. Non-Wilderness plot means of Mn ppm in *All Species* per year.

Alectoria sarmentosa

Table XX-1. Wilderness and Non-Wilderness Means, Standard Errors, and 95% Confidence Intervals for the Mn ppm content of *Alectoria sarmentosa* per year.

Mn ppm				**95% CI**	
Year	**Plot Type**	**Mean**	**Std. Error**	**Lower**	**Upper**
1989	Non-Wilderness	95.34	8.0985	72.8550	117.8250
1989	Wilderness	142.28	32.4231	58.9316	225.6239
1990	Non-Wilderness	54.44	11.3047	31.2013	77.6755
1990	Wilderness	89.00	23.6286	31.1840	146.8179
1991	Non-Wilderness	62.2600	8.9156	43.5290	80.9910
1991	Wilderness	98.32	18.8259	46.0557	150.5939
1992	Non-Wilderness	Mn	49.23	14.8371	14.1507
2003	Wilderness	83.84	0.4025	78.7306	88.9591
2004	Wilderness	64.91	10.8394	42.4861	87.3323
2005	Non-Wilderness	93.57	19.2022	44.2128	142.9343
2005	Wilderness	79.77	16.7386	41.9016	117.6321

Summary of Statistical Tests:

t = -0.9515, df = 8, p-value = 0.3692

There is no evidence of a difference in Mn content in *Alectoria sarmentosa* from pre-2000 and post 2000 samples (p-value = 0.3692). Plots with repeated samples for Mn in Alesar are: Karta River (#159), Pleasant Island (#145, 146), Pikes Lake RNA (# 69), Kootznoowoo (# 189, 190), Petersburg Creek (#116), Stikine-LeConte (#30, 31), Yakobi (#101), Tebenkof (#33) and Misty Fiords (#85, 86).

Relationships are not strong in the Mn content in *Alectoria sarmentosa* after accounting for latitude, longitude, elevation, year (Figures XX-3, XX-4 for year) and precipitation (see Brenner, 2006 for all graphed results).

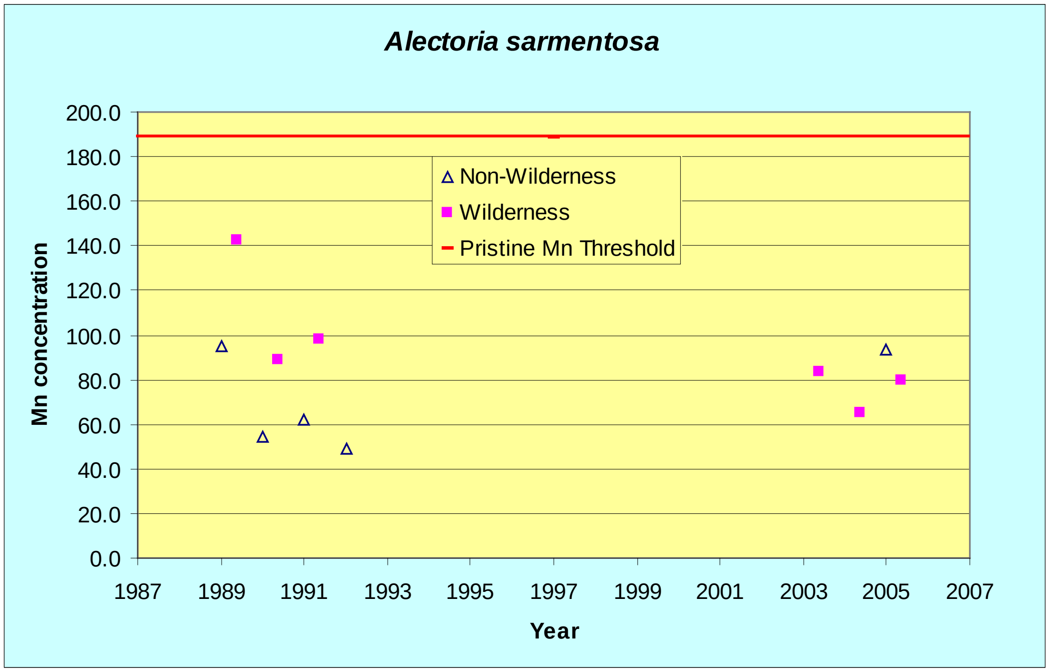

Figure XX-3. Wilderness and Non-Wilderness yearly means of Mn ppm in *Alectoria sarmentosa* per year.

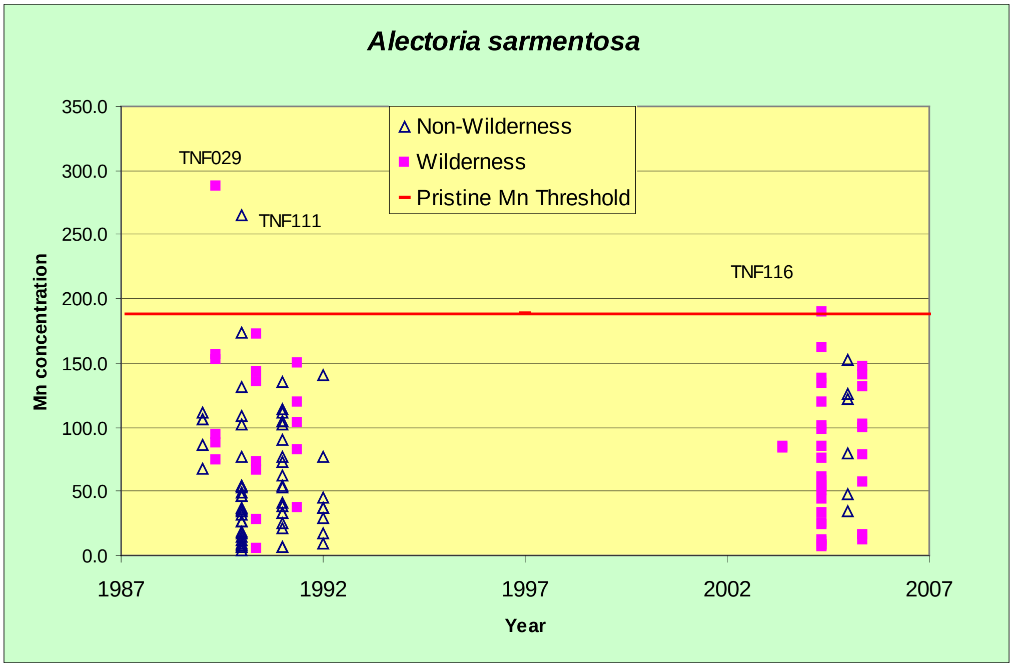

Figure XX-4. Wilderness and Non-Wilderness plot means of Mn ppm in *Alectoria sarmentosa* per year.

Hypogymnia species

In this series, all of the *Hypogymnia* species were included as a group.

Table XX-2. Wilderness and Non-Wilderness Means, Standard Errors, and 95% Confidence Intervals for the Mn ppm content of *Hypogymnia species* per year.

Mn ppm				95% CI	
Year	**Plot Type**	**Mean**	**Std. Error**	**Lower**	**Upper**
1989	Non-Wilderness	287.00	169.0000	1860.3490	2434.3490
1989	Wilderness	284.58	56.9713	126.4058	442.7609
1990	Non-Wilderness	147.90	36.2956	71.6494	224.1576
1990	Wilderness	242.52	56.3119	104.7337	380.3140
2003	Wilderness	318.23	NA	NA	NA
2004	Wilderness	381.90	62.5739	221.0461	542.7489
2005	Non-Wilderness	173.83	38.5061	8.1562	339.5131
2005	Wilderness	432.29	102.9860	194.8039	669.7764

No t-tests were performed due to lack of repeat samples.

Relationships are not strong in Mn content for *Hypogymnia* after accounting for latitude, longitude, elevation, year (Figures XX-5, XX-6 for year) and precipitation (see Brenner, 2006 for all graphed results).

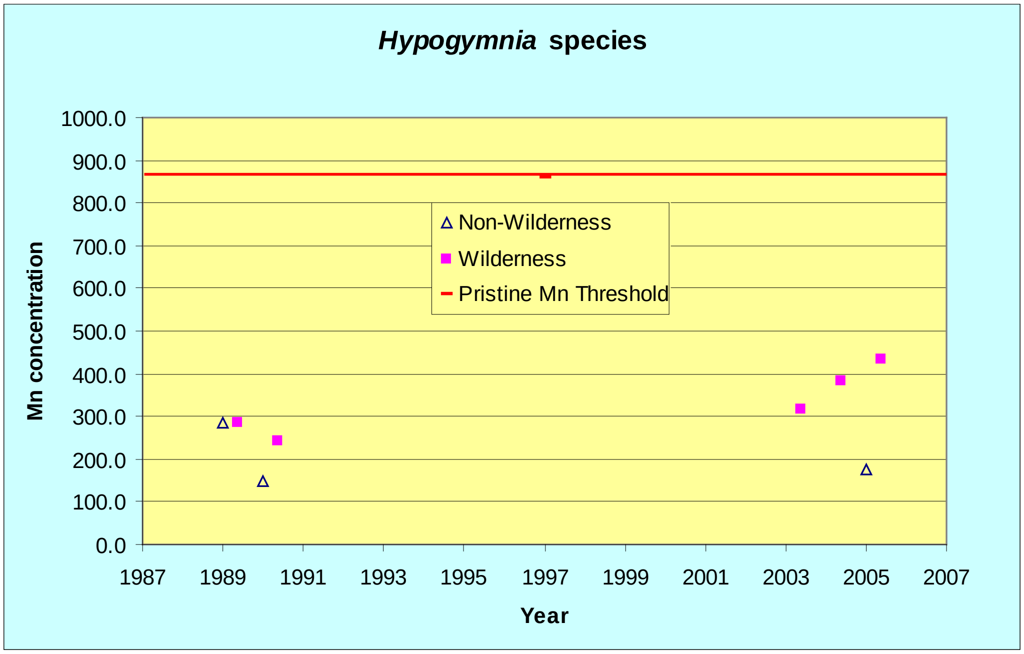

Figure XX-5. Wilderness and Non-Wilderness yearly means of Mn ppm in *Hypogymnia species* per year.

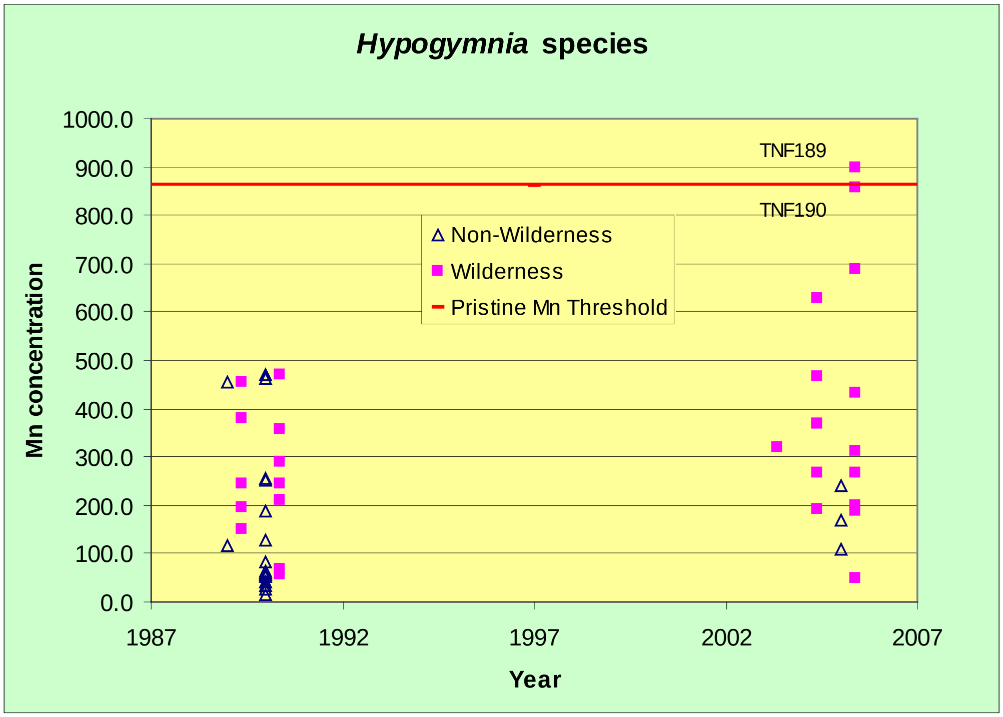

Figure XX-6. Wilderness and Non-Wilderness plot means of Mn ppm in *Hypogymnia species* per year.

Lobaria oregana

Table XX-3. Wilderness and Non-Wilderness Means, Standard Errors, and 95% Confidence Intervals for the Mn ppm content of *Lobaria oregana* per year.

Mn ppm				**95% CI**	
Year	**Plot Type**	**Mean**	**Std. Error**	**Lower**	**Upper**
1989	Non-Wilderness	129.42	22.5883	57.5308	201.3026
1989	Wilderness	58.81	12.0128	25.4606	92.1661
1990	Non-Wilderness	43.58	8.8066	24.3890	62.7648
1990	Wilderness	51.84	9.9798	26.1863	77.4942
2004	Wilderness	82.33	13.2018	50.0224	114.6297
2005	Non-Wilderness	39.24	NA	NA	NA
2005	Wilderness	71.0396	14.6810	24.3182	117.7611

Summary of Statistical Tests:

t = -1.9289, df = 4, p-value = 0.126

There is no evidence of a difference in Mn content in *Lobaria oregana* from pre-2000 and post 2000 samples (p-value = 0.1260).). This analysis was for wilderness areas that had repeated values for Mn in *Lobaria oregana*, Russell Fiords (plot 62 near Harlequin Lake), Tebenkof (33) and Misty Fiords (86, 88).

Relationships are not strong in the Mn content in Lobore after accounting for latitude, longitude, elevation, year (Figures XX-7, XX-8 for year) and precipitation (see Brenner, 2006 for all graphed results).

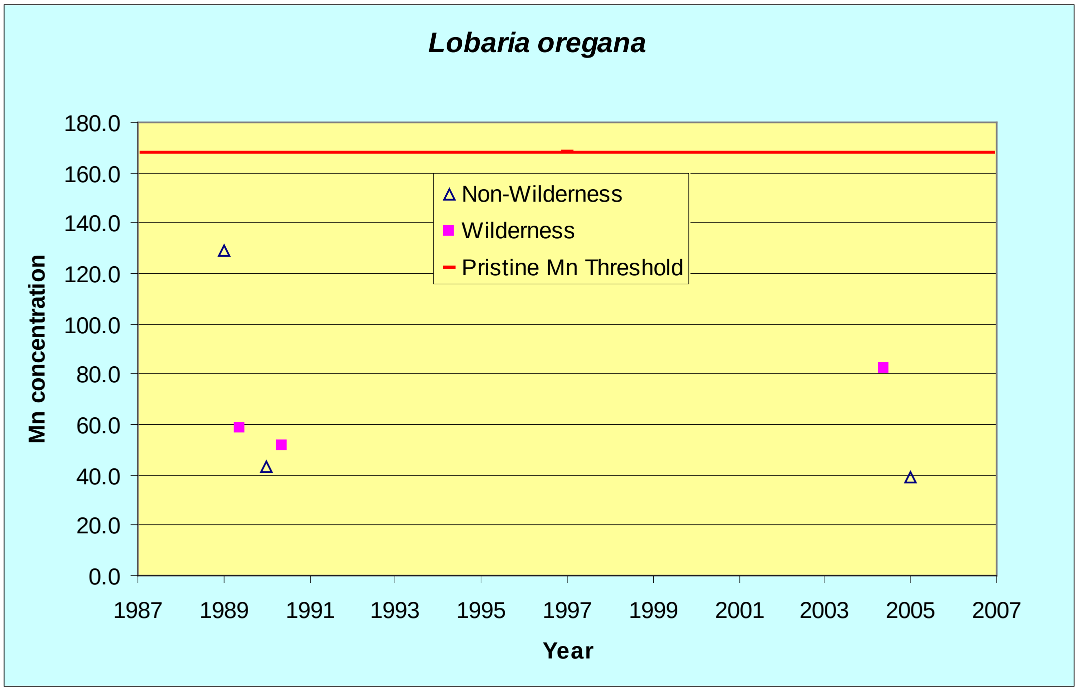

Figure XX-7. Wilderness and Non-Wilderness yearly means of Mn ppm in *Lobaria oregana* per year.

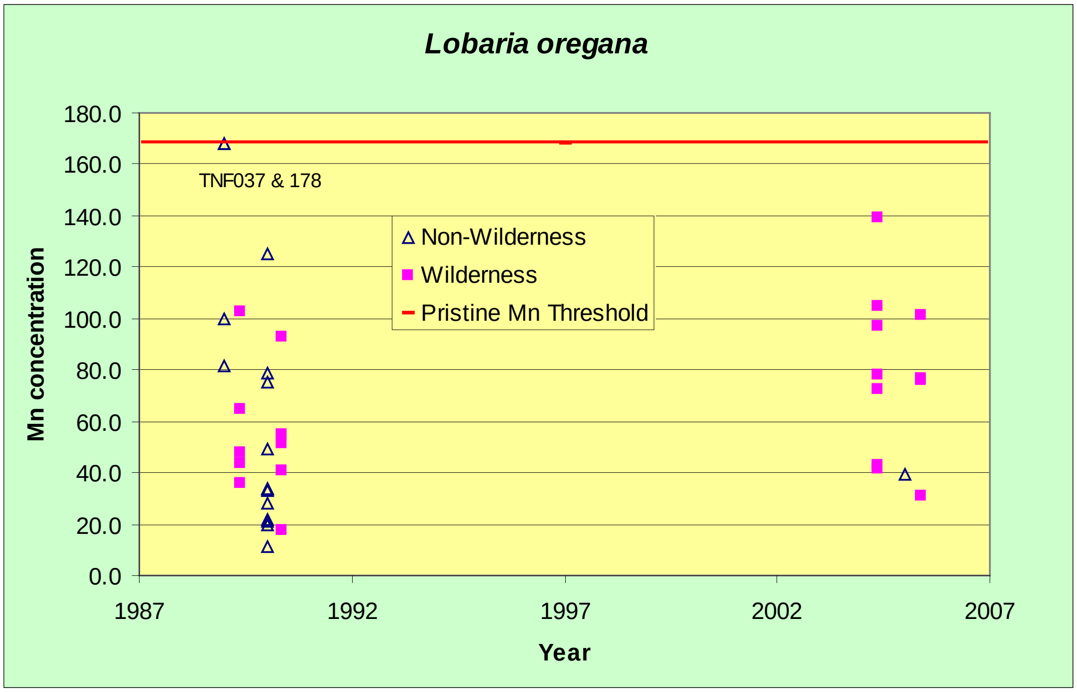

Figure XX-8. Wilderness and Non-Wilderness plot means of Mn ppm in *Lobaria oregana* per year.

Platismatia glauca

Table XX-4. Wilderness and Non-Wilderness Means, Standard Errors, and 95% Confidence Intervals for the Mn ppm content of *Platismatia glauca* per year.

Mn ppm				**95% CI**	
Year	**Plot Type**	**Mean**	**Std. Error**	**Lower**	**Upper**
2003	Wilderness	287.02	NA	NA	NA
2004	Wilderness	195.17	49.4364	83.3405	307.0063
2005	Non-Wilderness	155.24	21.9739	105.5308	204.9476
2005	Wilderness	148.13	51.7702	25.7136	270.5479

No t-tests were performed on these data. The mean values for Mn are baseline in *Platismatia glauca.*

Relationships are not strong in Mn content for Plagla after accounting for latitude, longitude, elevation, year (Figures XX-9, XX-10 for year) and precipitation (see Brenner, 2006 for all graphed results).

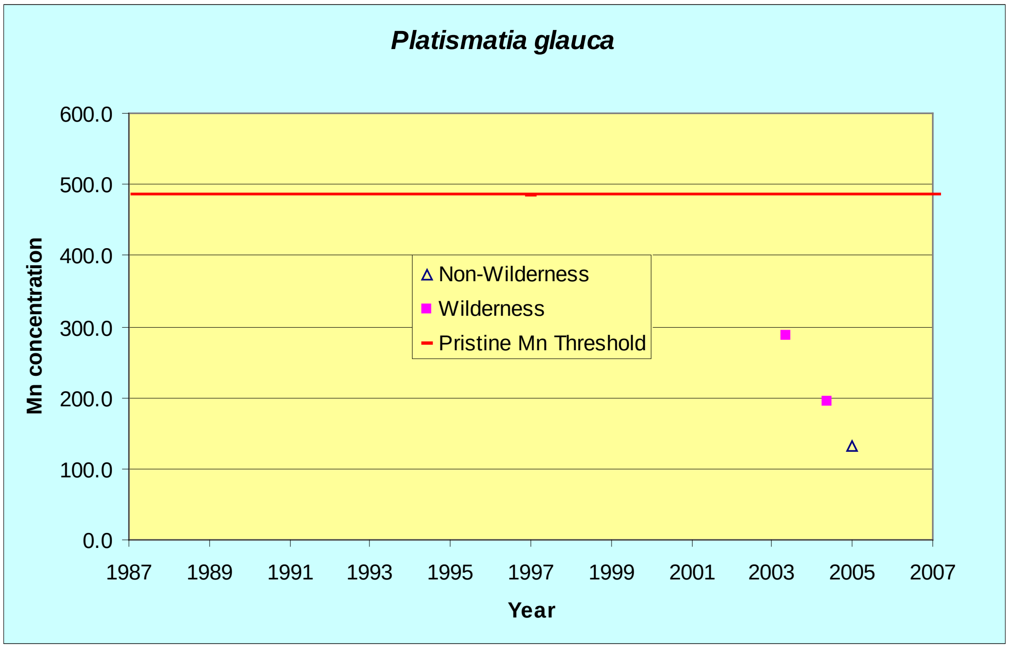

Figure XX-9. Wilderness and Non-Wilderness yearly means of Mn ppm in *Platismatia glauca* per year.

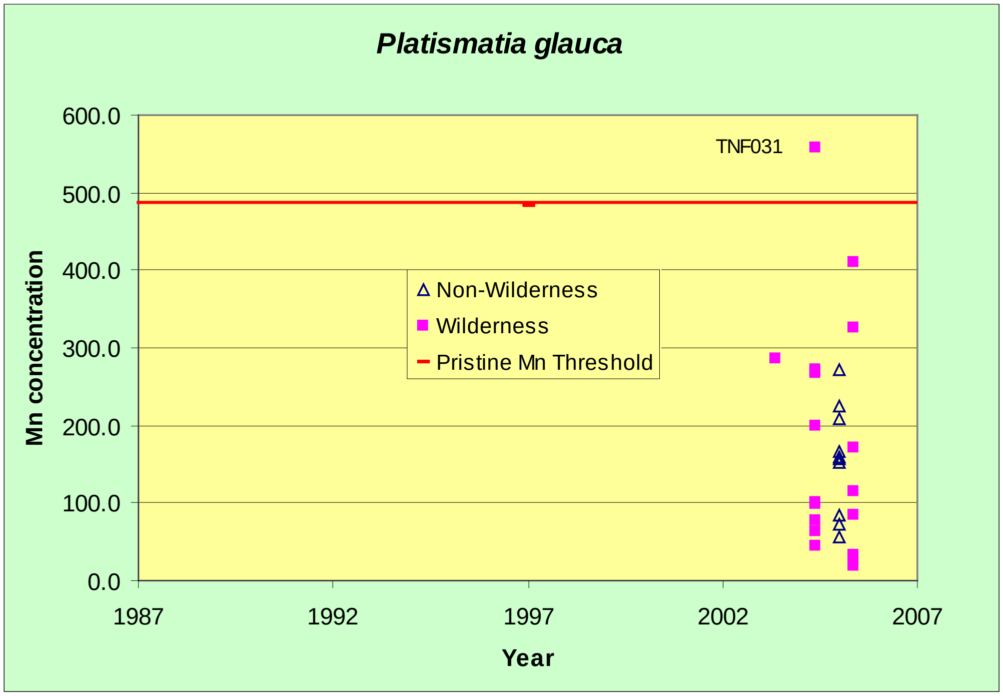

Figure XX-10. Wilderness and Non-Wilderness plot means of Mn ppm in *Platismatia glauca* per year.

.

Conclusions: for Manganese (Mn) and all lichen species

Seashore enhancement of Mn in undefined lichen species ranges from 300 to 350 ppm (USDA 1999). Industrial enhanced Mn levels ranges between 350 to 5000 ppm (USDA 1999). On the Tongass, Plagla and *Hypogymnia* indicate some seashore enhancement within the threshold levels, while Alesar and Lobore are less than the lower range for seashore enhanced.

Alectoria sarmentosa

Background Mn in the Pacific Northwest is lower than the threshold for the Tongass (80 ppm and 188.24 ppm respectively). Higher overall Mn on the Tongass may be due to the hypermaritime environment. Plot 29 from a muskeg on the southeast side of Petersburg Lake is not near any pollution source, other than an occasional float plane visit to the lake. Therefore elevated levels must be part of the natural variation in Mn for Alesar. Plot 111 from the Amalga trail is not near pollution source; therefore elevated levels can be attributed to a crustal source.

Hypogymnia

Threshold of Mn in *Hypogymnia* on the Tongass is many times higher than the background in the Pacific Northwest, indicating a seashore and crustal source of this element (860.85 ppm and 50 to 75 ppm respectively) (USDA 1999). Tongass threshold for Mn is at the lower range of what is considered urban or industrially enhanced levels of Mn in lichens (USDA 1999). Since none of the plots near industrial areas of southeast Alaska are elevated with Mn, it is presumed that this is also background for the region for Mn and *Hypogymnia*. Plots 189 and 190 from Kootznoowoo are elevated above and just at Mn threshold, probably explained by natural sources (Figure XX-6).

Lobaria oregana

Background level for Mn in Lobore from the Pacific Northwest is much lower that the threshold for the Tongass (60 ppm compared to 168 ppm) (USDA 1999). Again, Tongass lichens appear to be universally enhanced with Mn due to seashore or crustal sources. Two plots are on the edge of threshold (37 and 178) from Cape Fanshaw probably due to natural sources (Figure XX-8).

Platismatia glauca

Background level for Mn in Plagla is lower than the Tongass threshold (150 ppm compared to 483.70 ppm) (USDA 1999). Plot 31 from the Stikine River (south of Shakes Slough on the main river) is elevated in Mn, most likely due to crustal sources from nearby glaciers and exposed rocks.

XXI. Summary of results for Molybdenum (Mo) from all species on the Tongass National Forest

Molybdenum is a shiny, silvery white element that has a melting point of 4730 degrees F, which is 2000 degrees higher than the melting point of steel. The most important ore source of molybdenum is molybdenite, and is mined in the US, Chile and China. A minor amount also comes from wulfenite, and also as a by-product of copper mining. The two largest uses of molybdenum are as an alloy in stainless steel (water distribution systems to kitchen utensils) and in alloy-steels (automobile parts and construction equipment). Molybdenum is an element necessary for plants and animals to survive.

Provisional thresholds were established for Mo in lichens, but in this case are based on the detection limit of the ICP machine. Detection limits were lower in 2004 (.24 ppm) and higher in 2005 (.54 ppm) due to laboratory funtions. Therefore all values of Mo in lichens were compared the the higher threshold of .54 ppm for all lichen species.

The two places where Mo is elevated above the detection limit of the ICP machine are from Greens Creek portal (plot 511b) and the tailings pile (plot 512) in *Hypogymnia* (Figure XXI-6).

XXI. SUMMARY OF Mo PPM DATA ANALYSIS

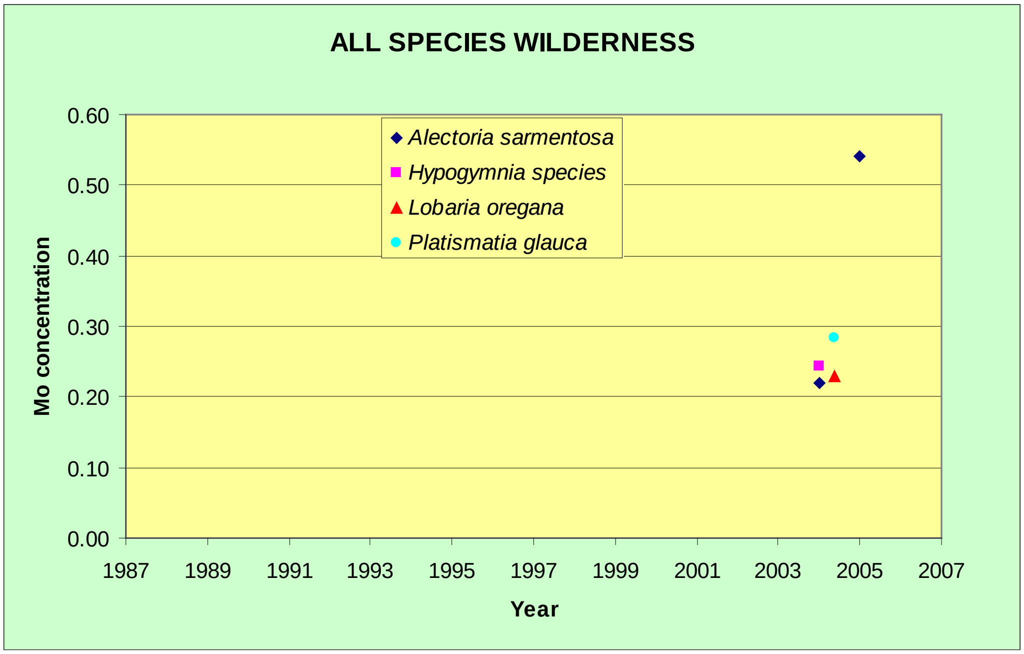

Figure XXI-1. Wilderness plot means of Mo ppm in *All Species* per year.

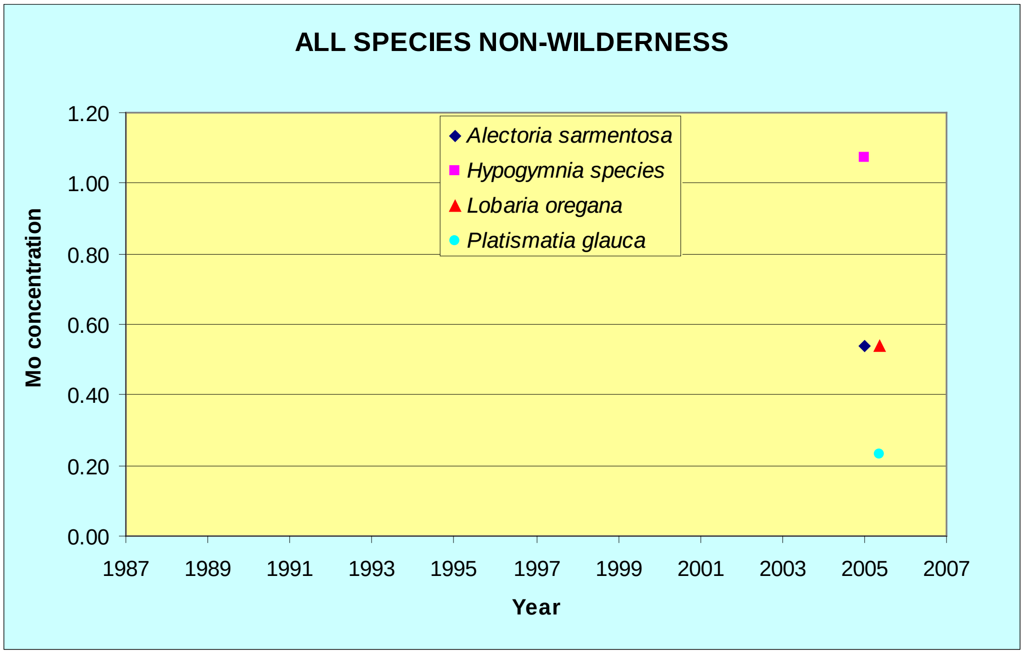

Figure XXI-2. Non-Wilderness plot means of Mo ppm in *All Species* per year.

Alectoria sarmentosa

Table XXI-1. Wilderness and Non-Wilderness Means, Standard Errors, and 95% Confidence Intervals for the Mo ppm content of *Alectoria sarmentosa* per year.

Mo ppm				**95% CI**	
Year	**Plot Type**	**Mean**	**Std. Error**	**Lower**	**Upper**
2004	Wilderness	0.22	0.0000	0.2200	0.2200
2005	Non-Wilderness	0.54	0.0008	0.5388	0.5427
2005	Wilderness	0.54	0.0000	0.5400	0.5400

No t-tests or regression were performed on these data. The mean values for Mo are baseline in *Alectoria sarmentosa.*

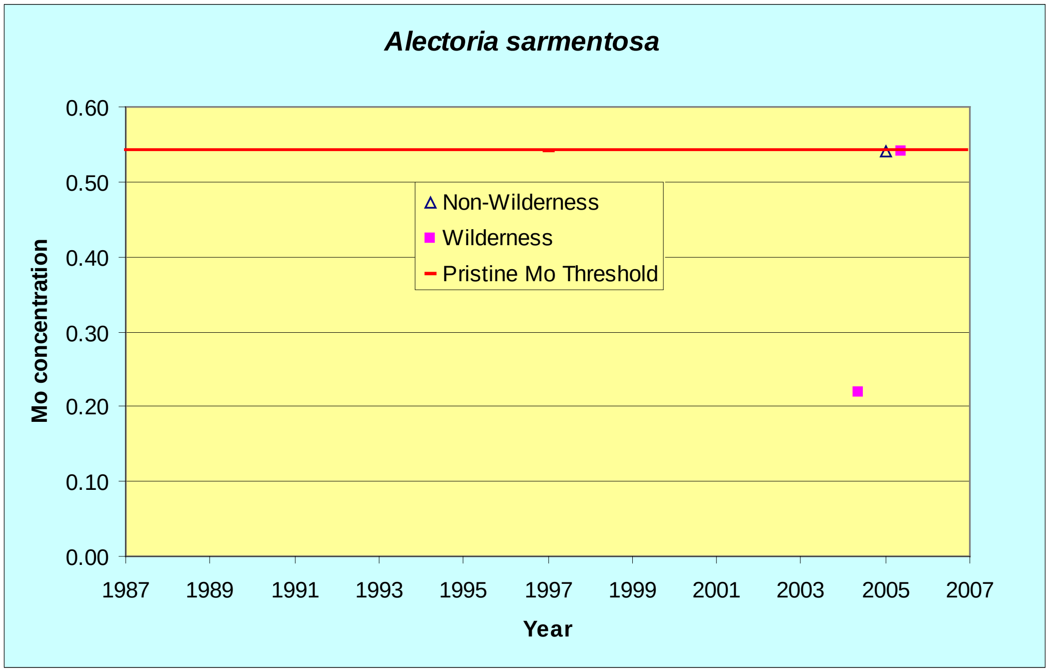

Figure XXI-3. Wilderness and Non-Wilderness yearly means of Mo ppm in *Alectoria sarmentosa* per year.

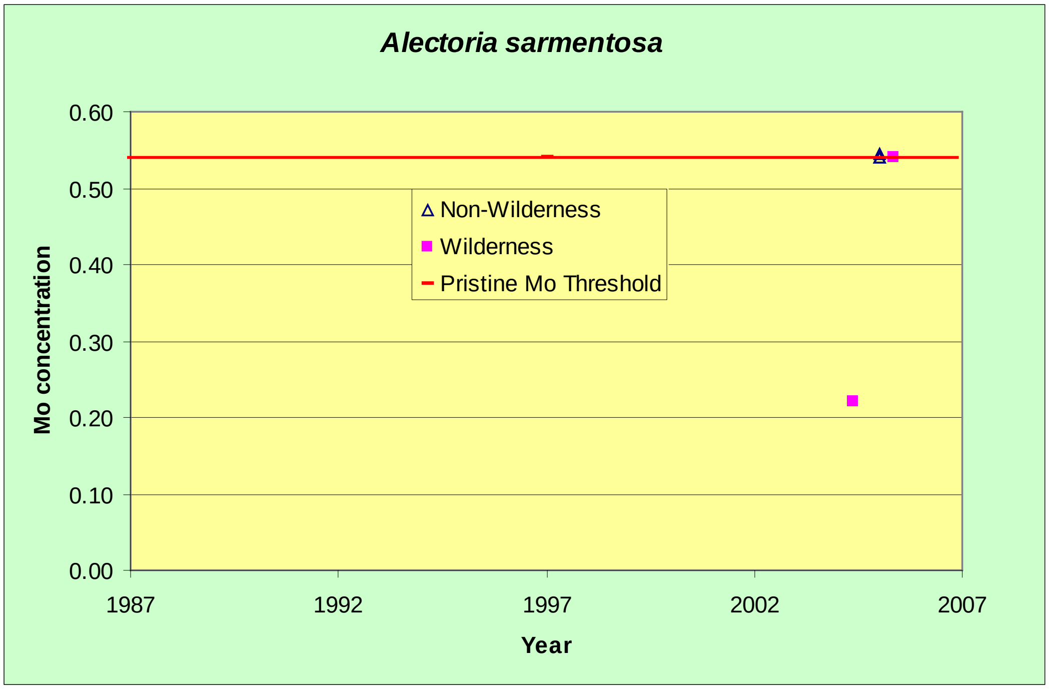

Figure XXI-4. Wilderness and Non-Wilderness plot means of Mo ppm in *Alectoria sarmentosa* per year.

Hypogymnia species

In this series, all of the *Hypogymnia* species were included as a group.

Table XXI-2. Wilderness and Non-Wilderness Means, Standard Errors, and 95% Confidence Intervals for the Mo ppm content of *Hypogymnia species* per year.

Mo ppm				95% CI	
Year	**Plot Type**	**Mean**	**Std. Error**	**Lower**	**Upper**
2004	Wilderness	0.24	0.0104	0.2168	0.2704
2005	Non-Wilderness	1.07	0.2828	0.1433	2.2907
2005	Wilderness	0.54	0.0000	0.5400	0.5400

No t-tests or regression were performed on these data. The mean values for Mo are baseline in *Hypogymnia.*

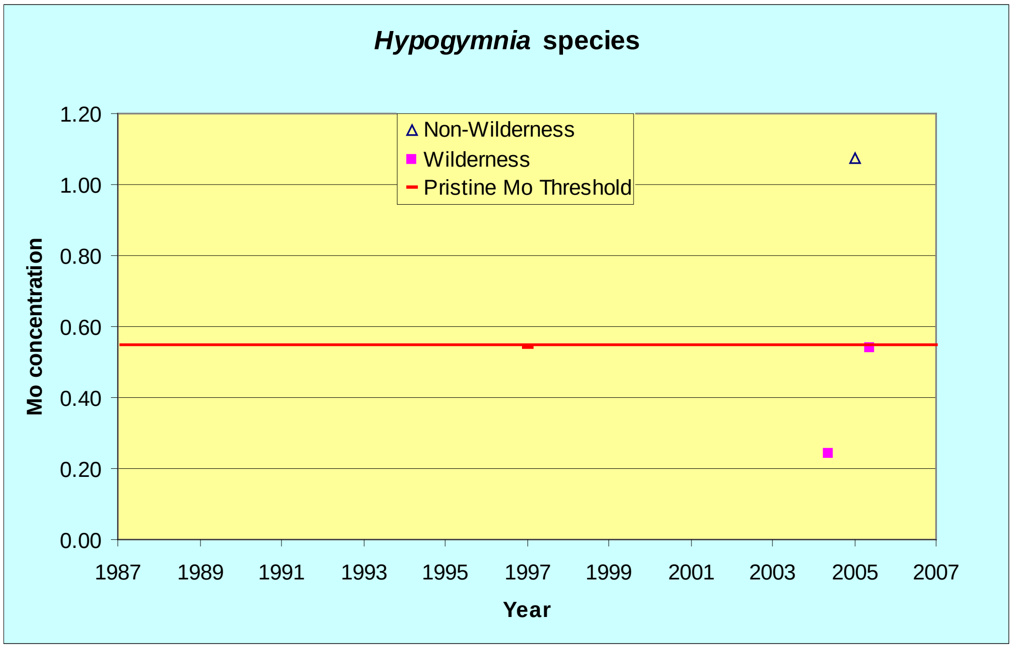

Figure XXI-5. Wilderness and Non-Wilderness yearly means of Mo ppm in *Hypogymnia species* per year.

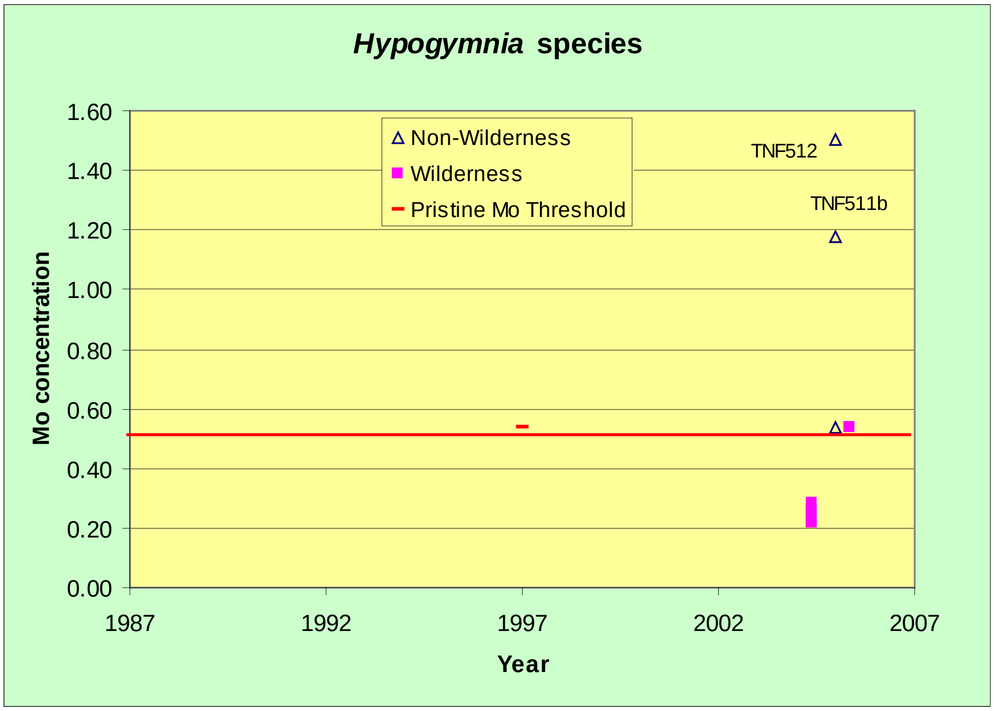

Figure XXI-6. Wilderness and Non-Wilderness plot means of Mo ppm in *Hypogymnia species* per year.

Lobaria oregana

Table XXI-3. Wilderness and Non-Wilderness Means, Standard Errors, and 95% Confidence Intervals for the Mo ppm content of *Lobaria oregana* per year.

Mo ppm				**95% CI**	
Year	**Plot Type**	**Mean**	**Std. Error**	**Lower**	**Upper**
2004	Wilderness	0.23	0.0081	0.2097	0.2494
2005	Non-Wilderness	0.54	NA	NA	NA
2005	Wilderness	0.5400	0.0000	0.5400	0.5400

No t-tests or regression were performed on these data. The mean values for Mo are baseline in *Lobaria oregana.*

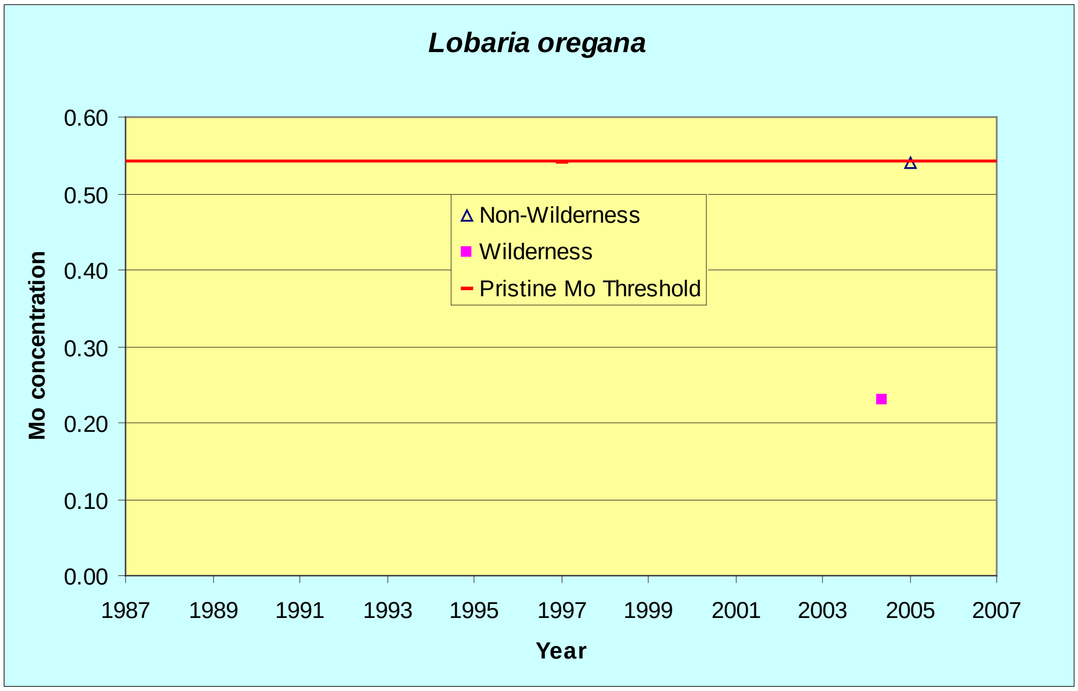

Figure XXI-7. Wilderness and Non-Wilderness yearly means of Mo ppm in *Lobaria oregana* per year.

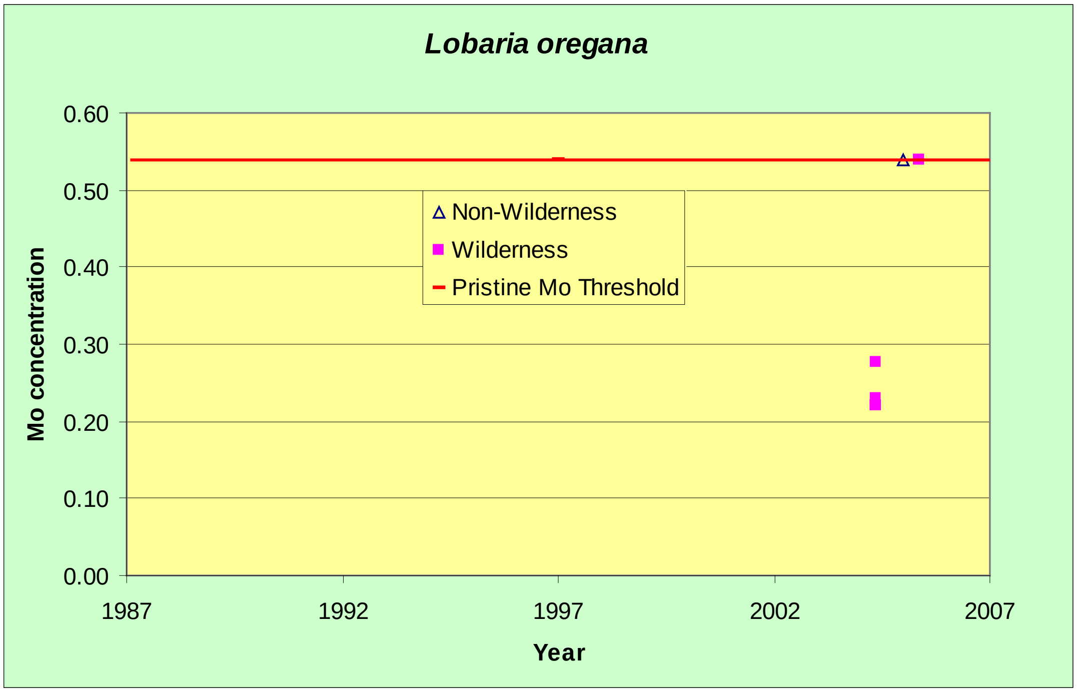

Figure XXI-8. Wilderness and Non-Wilderness plot means of Mo ppm in *Lobaria oregana* per year.

Platismatia glauca

Table XXI-4. Wilderness and Non-Wilderness Means, Standard Errors, and 95% Confidence Intervals for the Mo ppm content of *Platismatia glauca* per year.

Mo ppm				**95% CI**	
Year	**Plot Type**	**Mean**	**Std. Error**	**Lower**	**Upper**
2004	Wilderness	0.28	0.0215	0.2339	0.3310
2005	Non-Wilderness	0.79	0.1801	0.3858	1.2006
2005	Wilderness	0.54	0.0000	0.5400	0.5400

No t-tests or regression were performed on these data. The mean values for Mo are baseline in *Platismatia glauca.*

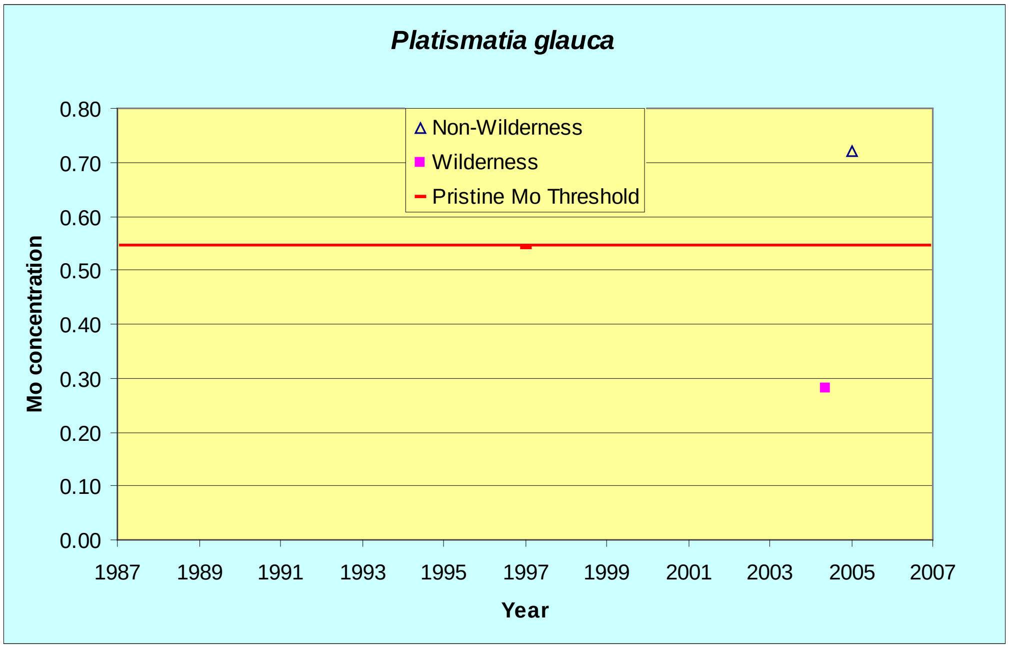

Figure XXI-9. Wilderness and Non-Wilderness yearly means of Mo ppm in *Platismatia glauca* per year.

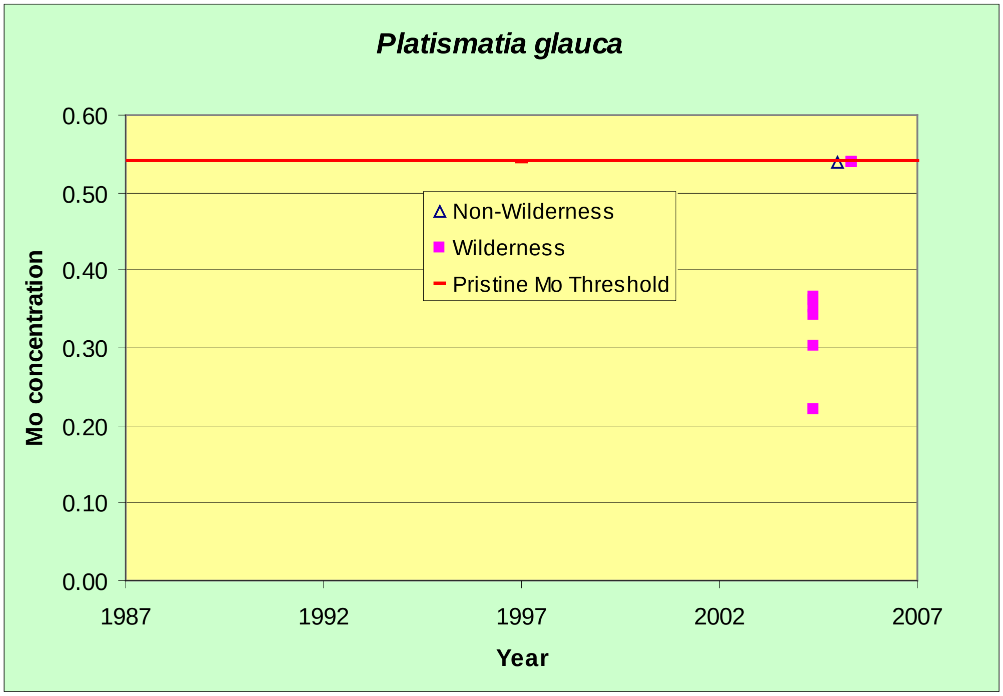

Figure XXI-10. Wilderness and Non-Wilderness plot means of Mo ppm in *Platismatia glauca* per year.

Conclusions: for Molybdenum (Mo) and all lichen species

Thresholds of Mo in *Alectoria sarmentosa*, *Lobaria oregana* and *Platismatia glauca* are based on the ICP analysis detection limits. There are no background data for Mo in lichens from the Pacific Northwest (USDA 1999). Therefore, it is difficult to assume that the Mo levels at Greens Creek are above what is considered background for lichens from other regions. It is presumed that enhancement of Mo comes from exposed crustal sources in this area.

XVII. Summary of results for Sodium (Na) from all species on the Tongass National Forest

Sodium is the most abundant alkali metal on earth and quickly iodizes in the air. Therefore, it is never found in its pure element in nature. It is present in great quantities in the earth's oceans as sodium chloride. It is also a component to many minerals and is an essential element for animal life.

Provisional threshold for Na are the following: *Alectoria sarmentosa* (893.16 ppm), *Hypogymnia* (929.13 ppm), *Lobaria oregana* (394.30 ppm), and *Platismatia glauca* (693.21 ppm).

Locations with Na levels above Tongass thresholds include: Alesar plots 142 and 143 (Whitestone Harbor area-Chichagof Island), and plots 99 and 100 (West Chichagof wilderness) (Figure XXII-4); *Hypogymnia* plot 79 from Kell Bay, Kuiu Island (Figure XXII-6), Lobore plots 79 (Kell Bay) and 246 (Sitka road system) (Figure XXII-8); and Plagla plot 510 from Warren Island wilderness (Figure XXII-10).

XXII. SUMMARY OF Na PPM DATA ANALYSIS

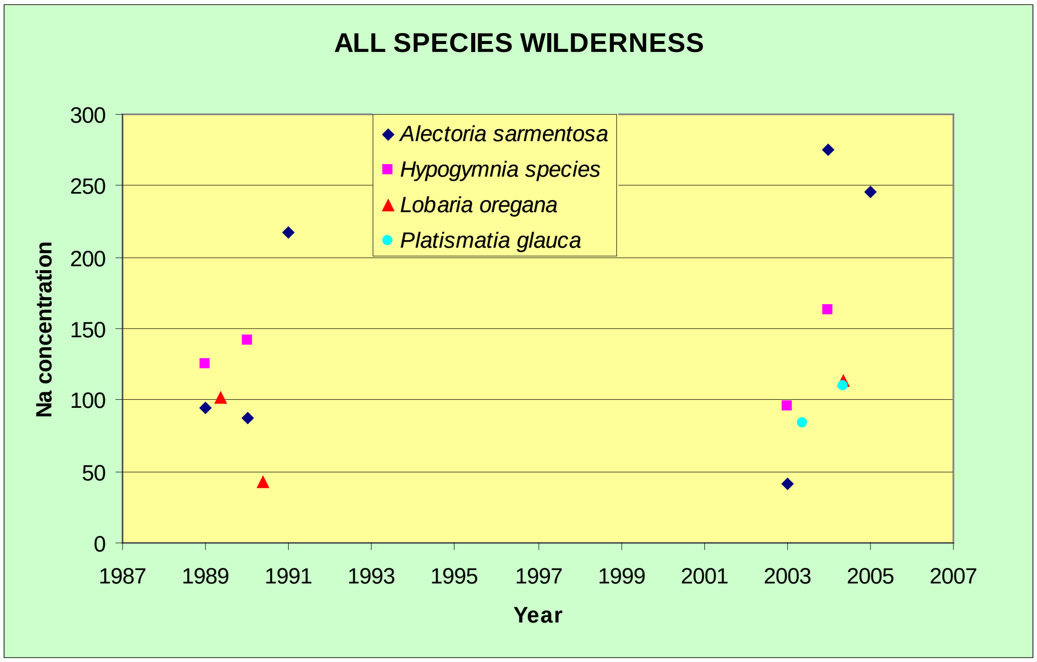

Figure XXII-1. Wilderness plot means of Na ppm in *All Species* per year.

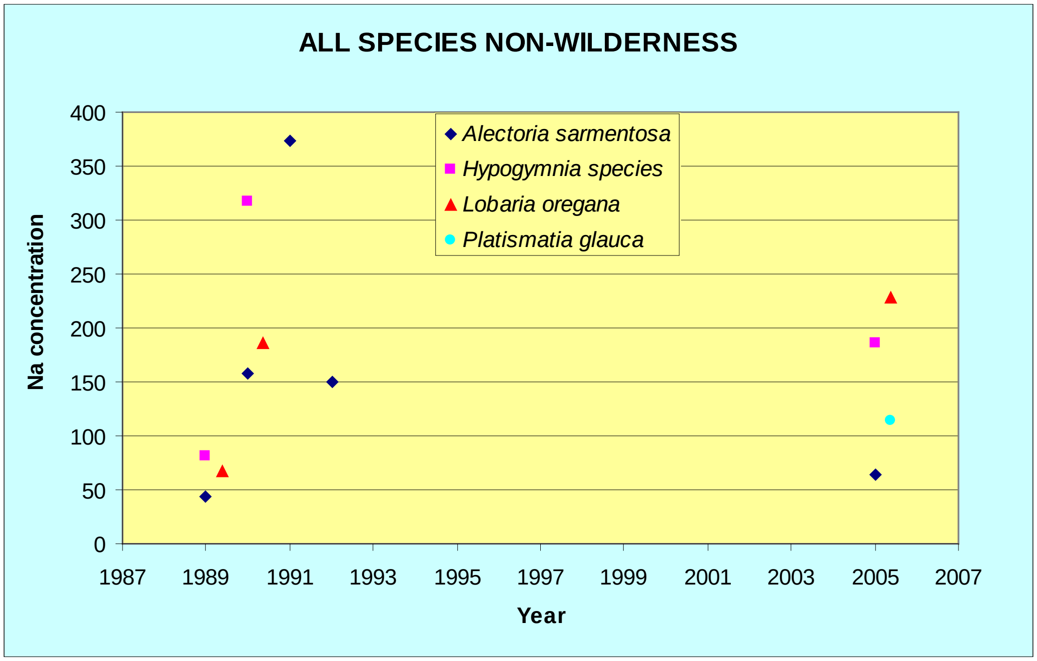

Figure XXII-2. Non-Wilderness plot means of Na ppm in *All Species* per year.

Alectoria sarmentosa

Table XXII-1. Wilderness and Non-Wilderness Means, Standard Errors, and 95% Confidence Intervals for the Na ppm content of *Alectoria sarmentosa* per year.

Na ppm				95% CI	
Year	**Plot Type**	**Mean**	**Std. Error**	**Lower**	**Upper**
1989	Non-Wilderness	43.61	11.0530	12.9220	74.2980
1989	Wilderness	94.19	39.4578	7.2406	195.6184
1990	Non-Wilderness	157.51	29.1796	97.5313	217.4903
1990	Wilderness	87.57	53.8385	44.1692	219.3068
1991	Non-Wilderness	373.3452	211.0759	70.1089	816.7992
1991	Wilderness	217.74	51.5771	74.5424	360.9444
1992	Non-Wilderness	150.68	31.1323	77.0637	224.2959
2003	Wilderness	41.03	0.8856	29.7732	52.2780
2004	Wilderness	274.96	71.8197	126.3855	423.5261
2005	Non-Wilderness	63.52	22.2502	6.3219	120.7139
2005	Wilderness	246.22	65.1305	98.8841	393.5551

Summary of Statistical Tests:

t = -0.244, df = 8, p-value = 0.8134

There is no evidence of a difference in Na content in *Alectoria sarmentosa* from pre-2000 and post 2000 samples (p-value = 0.8134). Plots with repeated samples for Na in Alesar are: Karta River (#159), Pleasant Island (#145, 146), Pikes Lake RNA (# 69), Kootznoowoo (# 189, 190), Petersburg Creek (#116), Stikine-LeConte (#30, 31), Yakobi (#101), Tebenkof (#33) and Misty Fiords (#85, 86).

Relationships are not strong in the Na content in *Alectoria sarmentosa* after accounting for latitude, longitude, elevation, year (Figures XXII-3, XXII-4 for year) and precipitation (see Brenner, 2006 for all graphed results).

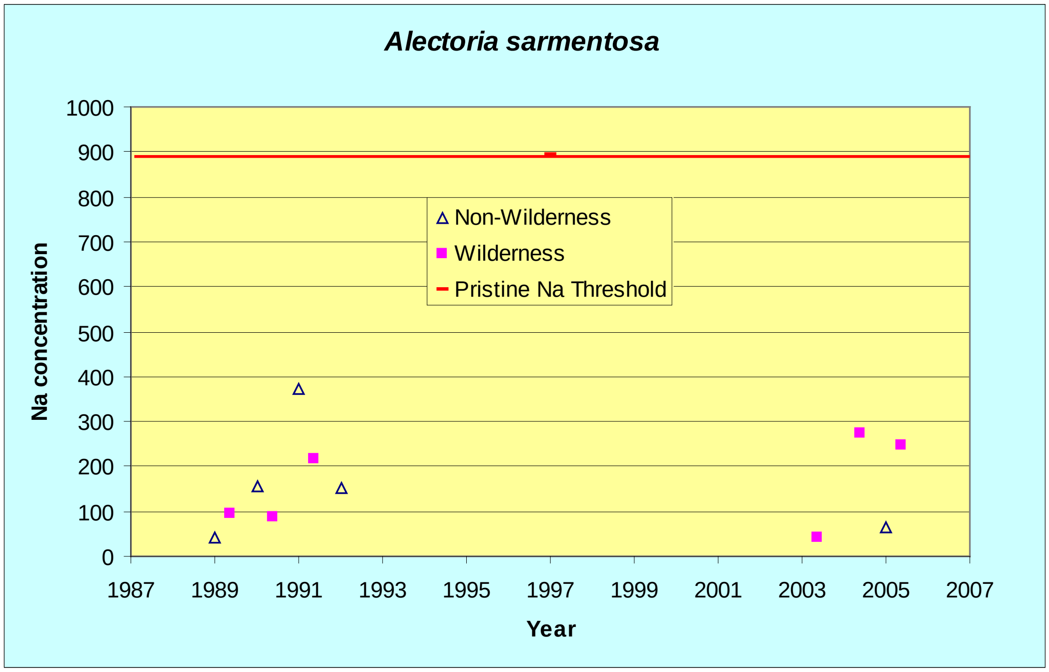

Figure XXII-3. Wilderness and Non-Wilderness yearly means of Na ppm in *Alectoria sarmentosa* per year.

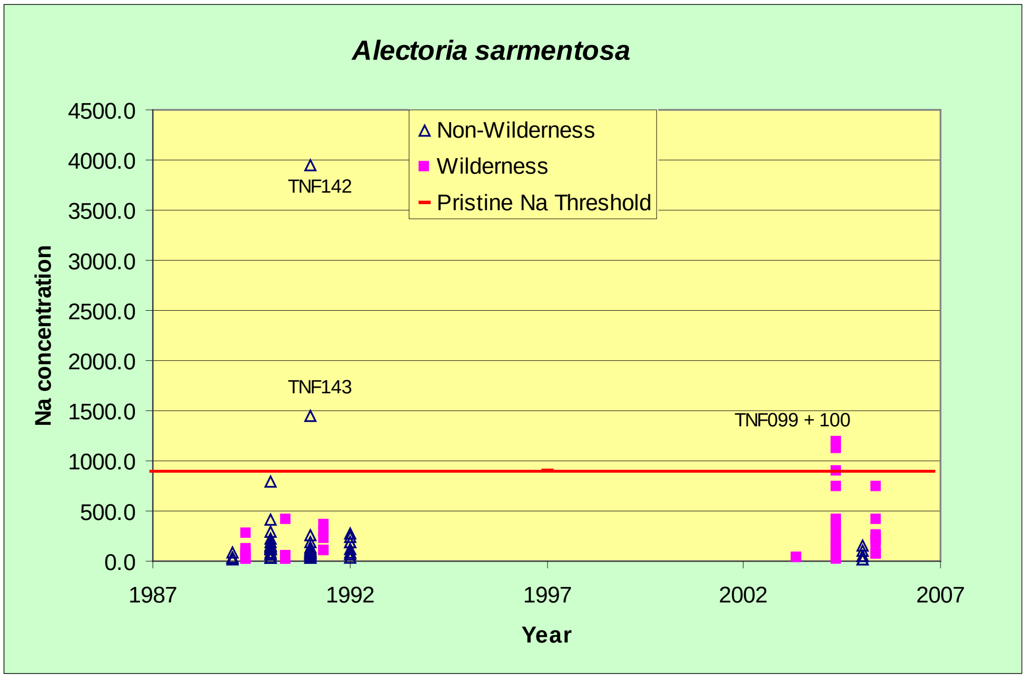

Figure XXII-4. Wilderness and Non-Wilderness plot means of Na ppm in *Alectoria sarmentosa* per year.

Hypogymnia species

In this series, all of the *Hypogymnia* species were included as a group.

Table XXII-2. Wilderness and Non-Wilderness Means, Standard Errors, and 95% Confidence Intervals for the Na ppm content of *Hypogymnia species* per year.

Na ppm				**95% CI**	
Year	**Plot Type**	**Mean**	**Std. Error**	**Lower**	**Upper**
1989	Non-Wilderness	80.50	57.5000	650.1068	811.1068
1989	Wilderness	124.68	31.5730	37.0226	212.3440
1990	Non-Wilderness	317.78	81.4198	146.7241	488.8373
1990	Wilderness	141.86	75.2562	42.2883	326.0025
2003	Wilderness	95.31	NA	NA	NA
2004	Wilderness	163.16	35.4967	71.9172	254.4116
2005	Non-Wilderness	185.51	37.7393	23.1328	347.8906
2005	Wilderness	278.23	48.8804	165.5076	390.9444

No t-tests were performed due to the lack of repeat samples.

Relationships are not strong in Na content for *Hypogymnia* after accounting for latitude, longitude, elevation, year (Figures XXII-5, XXII-6 for year) and precipitation (see Brenner, 2006 for all graphed results).

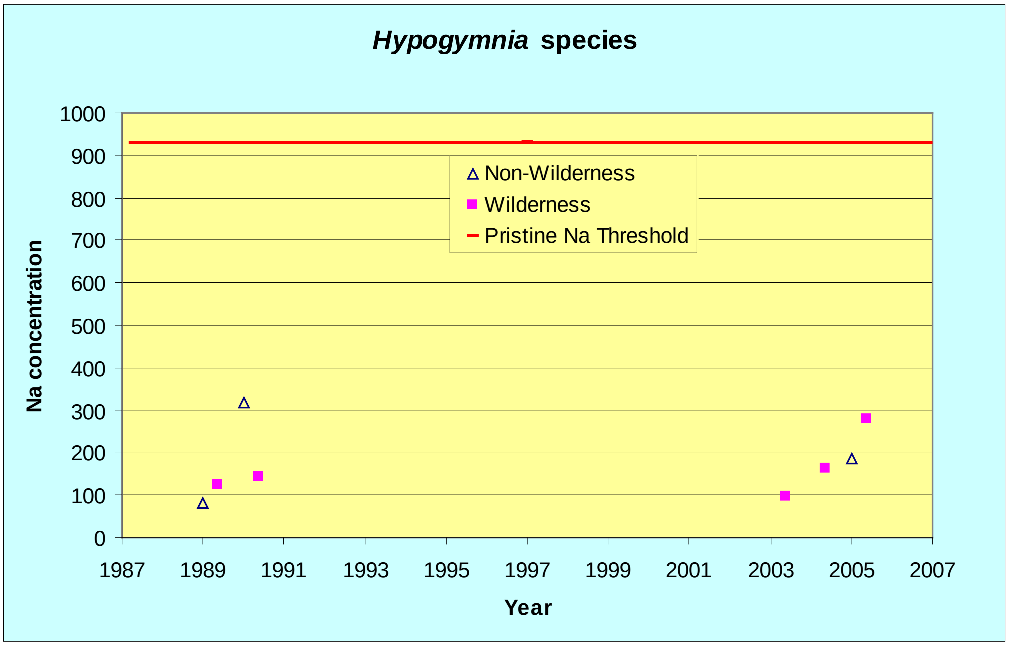

Figure XXII-5. Wilderness and Non-Wilderness yearly means of Na ppm in *Hypogymnia species* per year.

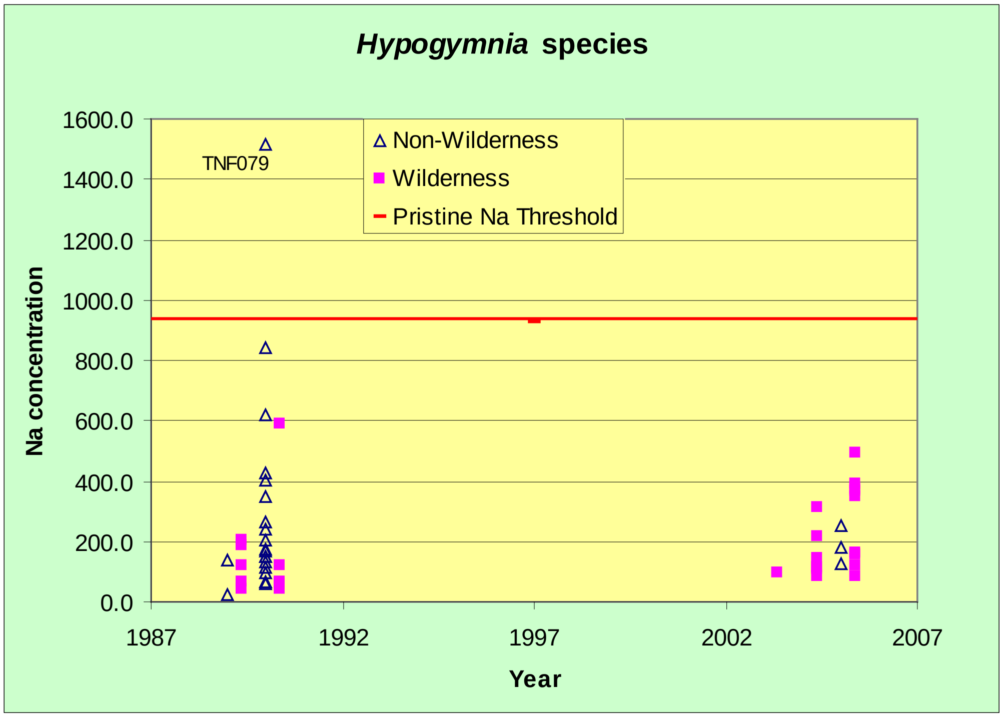

Figure XXII-6. Wilderness and Non-Wilderness plot means of Na ppm in *Hypogymnia species* per year.

Lobaria oregana

Table XXII-3. Wilderness and Non-Wilderness Means, Standard Errors, and 95% Confidence Intervals for the Na ppm content of *Lobaria oregana* per year.

Na ppm				**95% CI**	
Year	**Plot Type**	**Mean**	**Std. Error**	**Lower**	**Upper**
1989	Non-Wilderness	67.75	9.9083	36.2175	99.2825
1989	Wilderness	101.25	41.1489	NA	215.5010
1990	Non-Wilderness	186.03	51.5276	73.7568	298.2945
1990	Wilderness	42.22	4.3542	31.0257	53.4115
2004	Wilderness	113.72	20.5302	63.4887	163.9599
2005	Non-Wilderness	227.55	NA	NA	NA
2005	Wilderness	156.6590	62.7977	NA	356.5093

Summary of Statistical Tests:

t = -2.5951, df = 4, p-value = 0.0604

There is suggestive evidence of a difference in Na content in *Lobaria oregana* from pre-2000 and post 2000 samples (p-value = 0.0604).). This analysis was for wilderness areas that had repeated values for Na in *Lobaria oregana:* Russell Fiords (plot 62 near Harlequin Lake), Tebenkof (33) and Misty Fiords (86, 88). This is most likely due to the Misty Fiords plots 86 and 88 having seemingly higher Na content in Lobore for the second monitoring period than the first (44 and 124 ppm for plot 86, and 44 and 85 ppm for plot 88).)

Relationships are not strong in the Na content in *Lobaria oregana* after accounting for latitude, longitude, elevation, year (Figures XXII-7, XXII-8 for year) and precipitation (see Brenner, 2006 for all graphed results

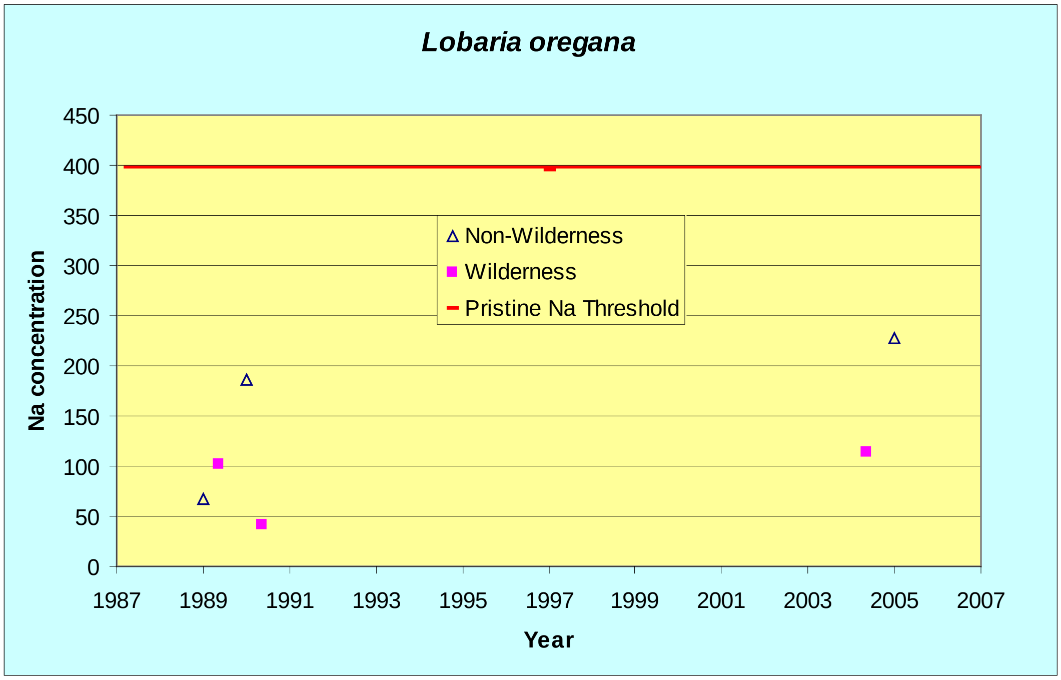

Figure XXII-7. Wilderness and Non-Wilderness yearly means of Na ppm in *Lobaria oregana* per year.

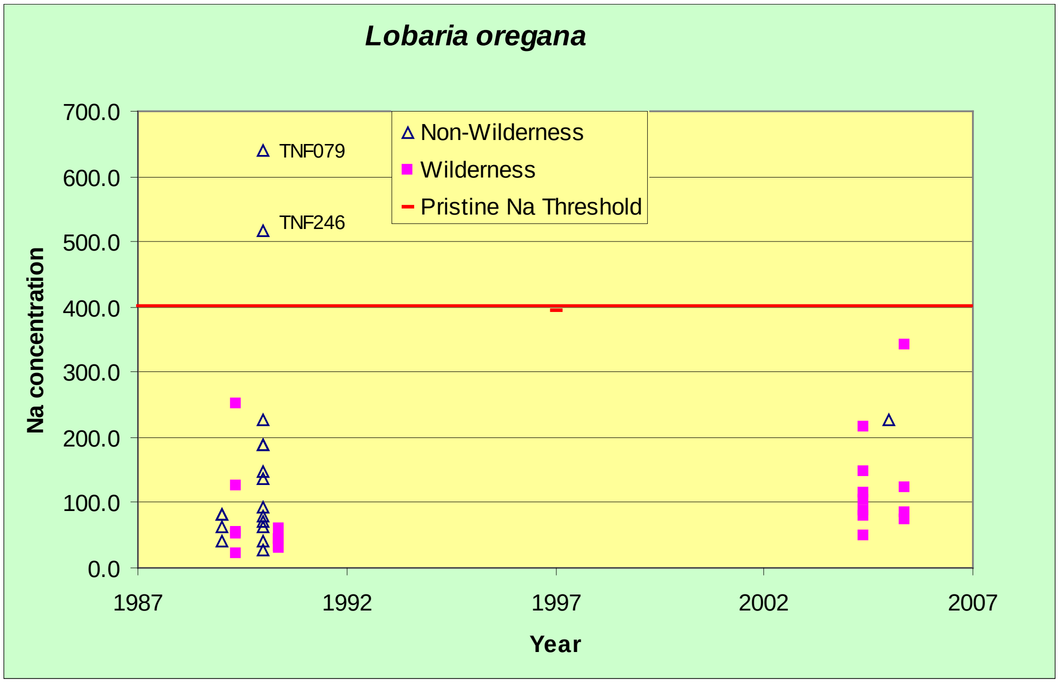

Figure XXII-8. Wilderness and Non-Wilderness plot means of Na ppm in *Lobaria oregana* per year.

Platismatia glauca

Table XXII-4. Wilderness and Non-Wilderness Means, Standard Errors, and 95% Confidence Intervals for the Na ppm content of *Platismatia glauca* per year.

Na ppm				**95% CI**	
Year	**Plot Type**	**Mean**	**Std. Error**	**Lower**	**Upper**
2003	Wilderness	84.24	NA	NA	NA
2004	Wilderness	109.80	27.2354	48.1855	171.4071
2005	Non-Wilderness	116.53	15.7153	80.9790	152.0797
2005	Wilderness	278.81	101.5439	38.6939	518.9202

No t-tests were performed on these data. The mean values for Na are baseline in *Platismatia glauca.*

Relationships are not strong in Na content for Plagla after accounting for latitude, longitude, elevation, year (Figures XXII-9, XXII-10 for year) and precipitation (see Brenner, 2006 for all graphed results).

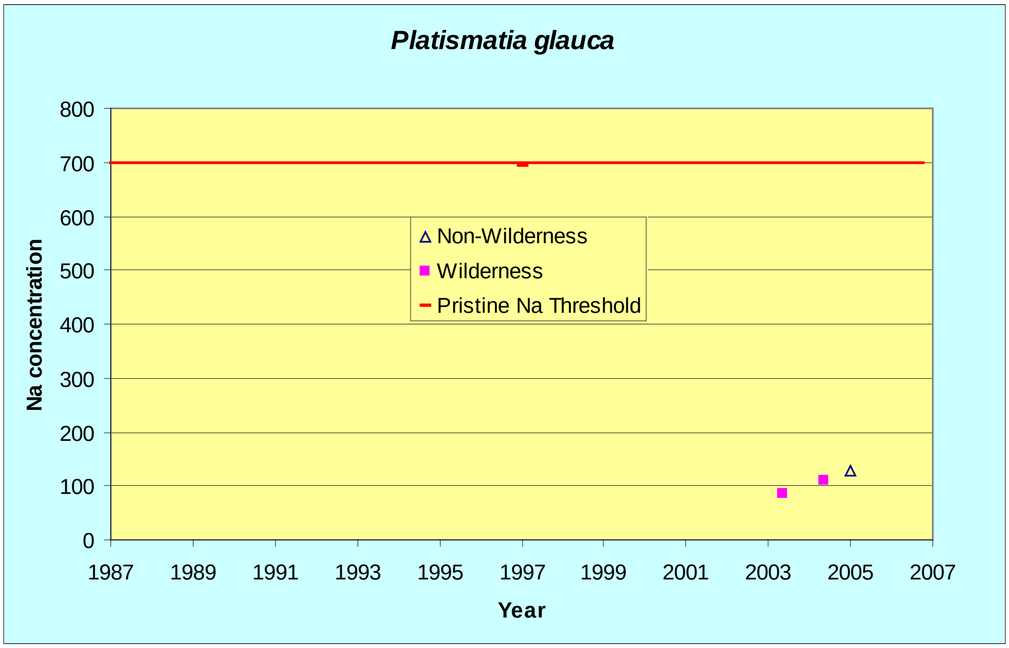

Figure XXII-9. Wilderness and Non-Wilderness yearly means of Na ppm in *Platismatia glauca* per year.

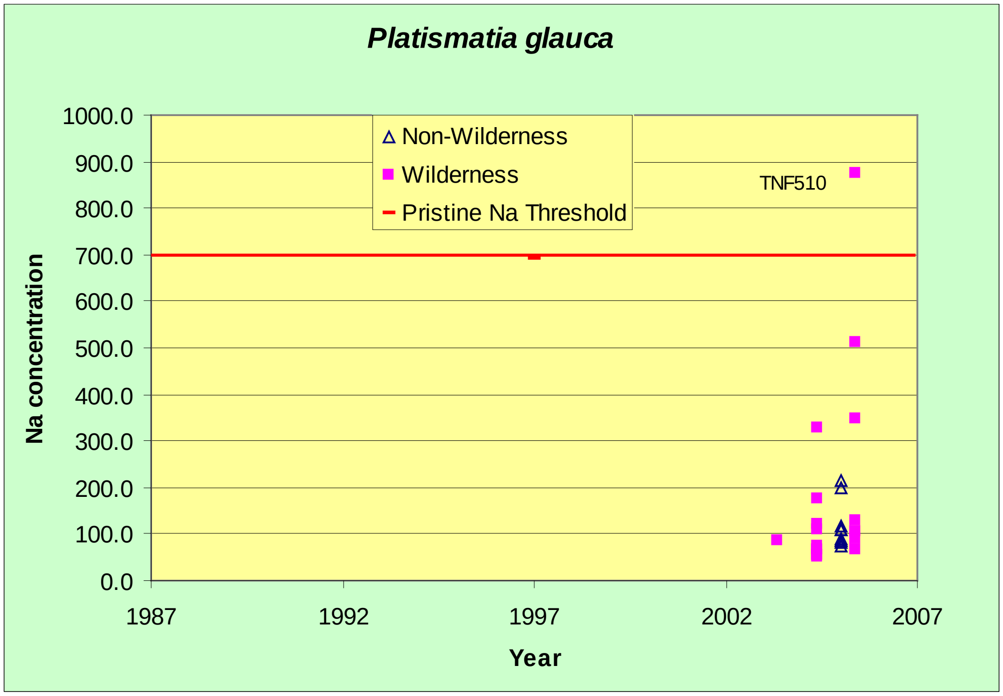

Figure XXII-10. Wilderness and Non-Wilderness plot means of Na ppm in *Platismatia glauca* per year.

Conclusions: for Sodium (Na) and all lichen species

Sodium, like calcium and magnesium, has demonstrated to be enhanced in lichens near seashores (USDA 1999). However, all Tongass thresholds are below the lower end of the enhanced range of sodium due to seashore influences (< 1000 ppm) (USDA 1999).

Alectoria sarmentosa

Background level for Na in the Pacific Northwest for Alesar is 75 ppm and the Tongass threshold is 893.16 ppm (USDA 1999). The difference can be attributed to the hypermaritime environment of the Tongass, but threshold levels are still below what is considered seashore enhanced (USDA 1999). This may be due to the high rainfall in the region. Some individual plots with Alesar are well within the enhanced range for sodium. Whitestone area on Chichagof Island has sodium levels above 1000 ppm and as high as 4000 ppm (Figure XXII-4). This may be part of the natural variation of Na on the Tongass, or may be due to some other unknown environmental factors of the area. Plots 99 and 100 from West Chichagof are on an island exposed to the open Pacific and this could explain the higher than threshold Na levels.

Hypogymnia

Plot 79 from Kell Bay (Kuiu Island) is exposed to Chatham Straits which may contribute to higher Na levels for this lichen. Elevated Na may also be part of the natural variation as mean Na is just above threshold (Figure XXII-6)

Lobaria oregana

Background Na in Lobore for the Pacific Northwest is well below the Tongass threshold for Na (150 ppm and 394.30 ppm respectively) (USDA 1999). There may be a slight change in Na levels from the pre-2000 monitoring period to the post-2000 monitoring period, but the change is barely significant (p-value = 0.0604). This is most likely from the two plots from Misty Fiords that show higher Na levels from the second monitoring period. Wilderness areas have not contained known anthropogenic sources of Na and are more likely due to natural variation. Sodium levels in the plot 246 from the Sitka road system sampled in the early 1990's may be elevated above threshold due to the pulp mill influence and the sodium sulfide that is emitted in the pulp bleaching process.

Platismatia glauca

Background for Na in Plagla from the Pacific Northwest is 90 ppm (USDA 1999). Threshold levels for Na are well above this at 693.21ppm, indicating Na is enhanced in the region due to the hyper maritime environment. Warren Island plot 510 is at the beachfringe of Warren Cove. This island is very exposed to the open Pacific. However, it is interesting that Na levels were not equally as high on Coronation Island beach plots as this island is also exposed to the open Pacific. Amount of precipitation between both islands may factor into this variation.

.

XXIII. Summary of results for Nickle (Ni) from all species on the Tongass National Forest

Nickel is a metal that contains properties that make it very desirable for combining with other metals to make alloys. Some metals used with nickel are iron, copper, chromium and zinc. Most nickel is used to make stainless steel, but it is also used in making metal coins, jewelry and in other industries. Nickel combined with other elements occurs naturally in the earth's crust, in all soils, and is also emitted from volcanoes (USPHS 1995). Nickle is also found in ocean waters as lumps of minerals on the ocean floor known as sea floor nodules dissolve into the water (Rona 2003). It is also released into the air through mining, oil-burning power plants, coal burning power plants, and trash incinerators.

Provisional thresholds for Ni are the following: *Alectoria sarmentosa* (.96 ppm), *Hypogymnia* (4.26 ppm), *Lobaria oregana* (1.65 ppm), and *Platismatia glauca* (2.65 ppm).

Plots with lichens above threshold for Ni include: Alesar plots 107, 108, and 240 (Sitka road system), plot 29 (Petersburg Creek), and plot 1000 (Juneau Mt Roberts 175 ft)(Figure XXIII-4); *Hypogymnia* plots 108, 236, 239, 243, 244 and 245 (Sitka road system), and 512 (Greens Creek tailings pile)(XXIII-6); Lobore plot 62 (Russell Fiord Harlequin Lake) (Figure XXIII-8); Plagla plots 511a, 511b and 512 (Greens Creek), plots 1000 and 1001 (Mt Roberts) and plot 62 (Russell Fiords)(Figure XXIII-10).

XXIII. SUMMARY OF Ni PPM DATA ANALYSIS

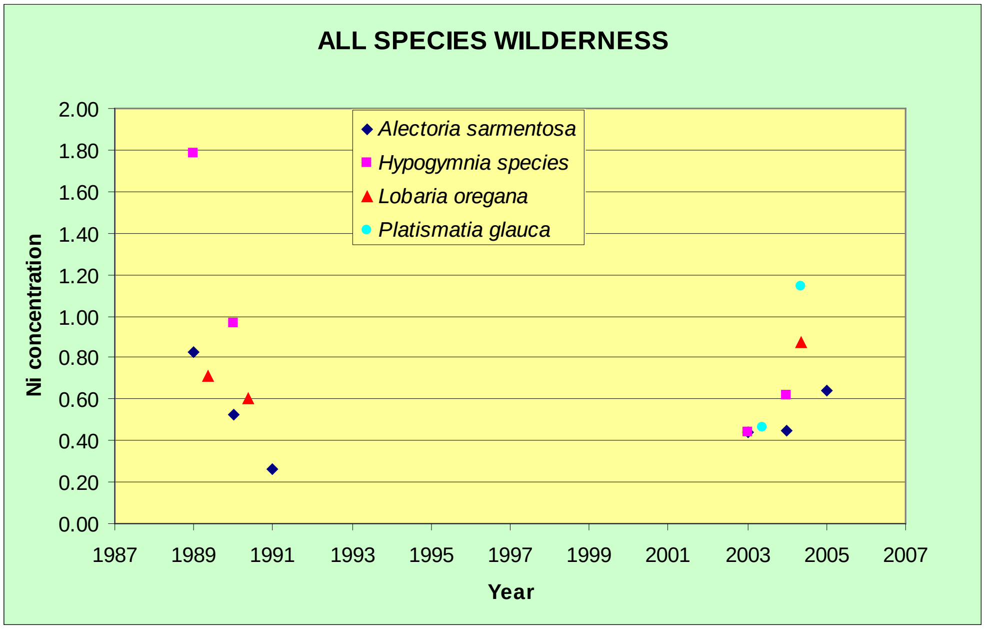

Figure XXIII-1. Wilderness plot means of Ni ppm in *All Species* per year.

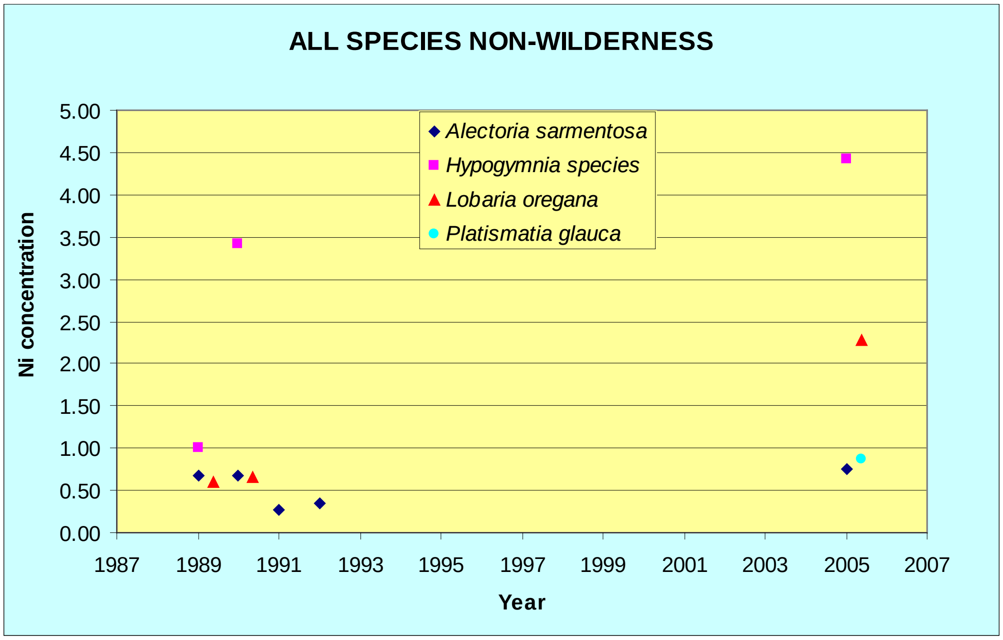

Figure XXIII-2. Non-Wilderness plot means of Ni ppm in *All Species* per year.

Alectoria sarmentosa

Table XXIII-1. Wilderness and Non-Wilderness Means, Standard Errors, and 95% Confidence Intervals for the Ni ppm content of *Alectoria sarmentosa* per year.

Ni ppm				**95% CI**	
Year	**Plot Type**	**Mean**	**Std. Error**	**Lower**	**Upper**
1989	Non-Wilderness	0.67	0.0526	0.5213	0.8131
1989	Wilderness	0.82	0.1291	0.4920	1.1559
1990	Non-Wilderness	0.67	0.0807	0.5013	0.8330
1990	Wilderness	0.52	0.0255	0.4618	0.5863
1991	Non-Wilderness	0.2682	0.0212	0.2237	0.3127
1991	Wilderness	0.27	0.0195	0.2115	0.3201
1992	Non-Wilderness	0.35	0.0361	0.2643	0.4349
2003	Wilderness	0.44	0.0000	0.4400	0.4400
2004	Wilderness	0.45	0.0095	0.4311	0.4705
2005	Non-Wilderness	0.75	0.0986	0.5004	1.0072
2005	Wilderness	0.64	0.0000	0.6400	0.6400

Summary of Statistical Tests:

t = -1.2513, df = 8, p-value = 0.2462

There is no evidence of a difference in Ni content in *Alectoria sarmentosa* from pre-2000 and post 2000 samples (p-value = 0.2462). Plots with repeated samples for Ni in Alesar are: Karta River (#159), Pleasant Island (#145, 146), Pikes Lake RNA (# 69), Kootznoowoo (# 189, 190), Petersburg Creek (#116), Stikine-LeConte (#30, 31), Yakobi (#101), Tebenkof (#33) and Misty Fiords (#85, 86).

Relationships are not strong in the Ni content in *Alectoria sarmentosa* after accounting for latitude, longitude, elevation, year (Figures XXIII-3, XXIII-4 for year) and precipitation (see Brenner, 2006 for all graphed results).

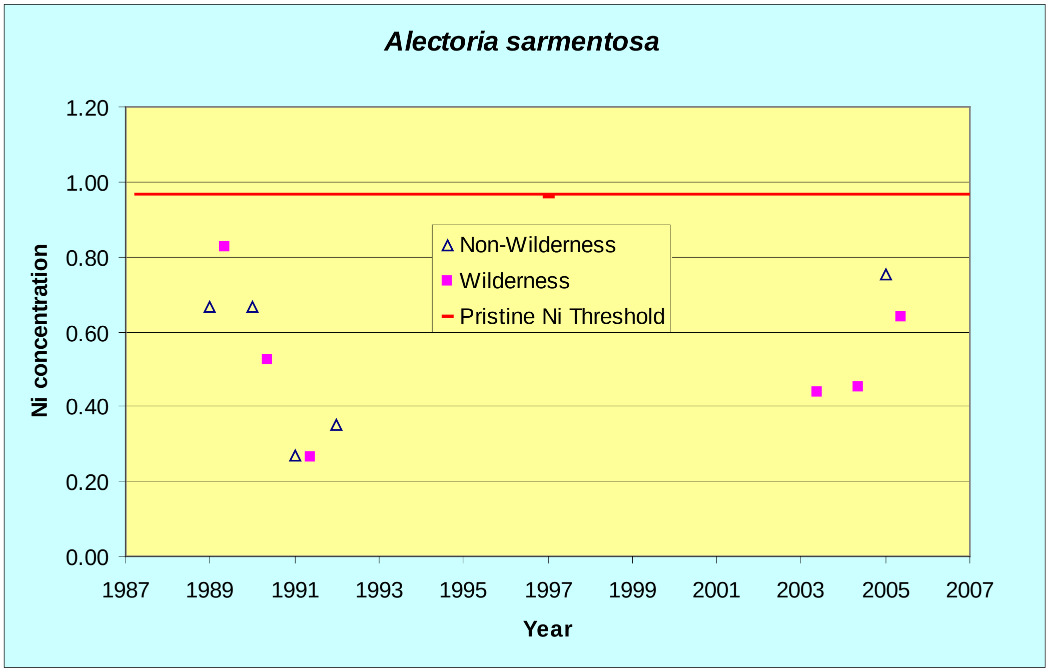

Figure XXIII-3. Wilderness and Non-Wilderness yearly means of Ni ppm in *Alectoria sarmentosa* per year.

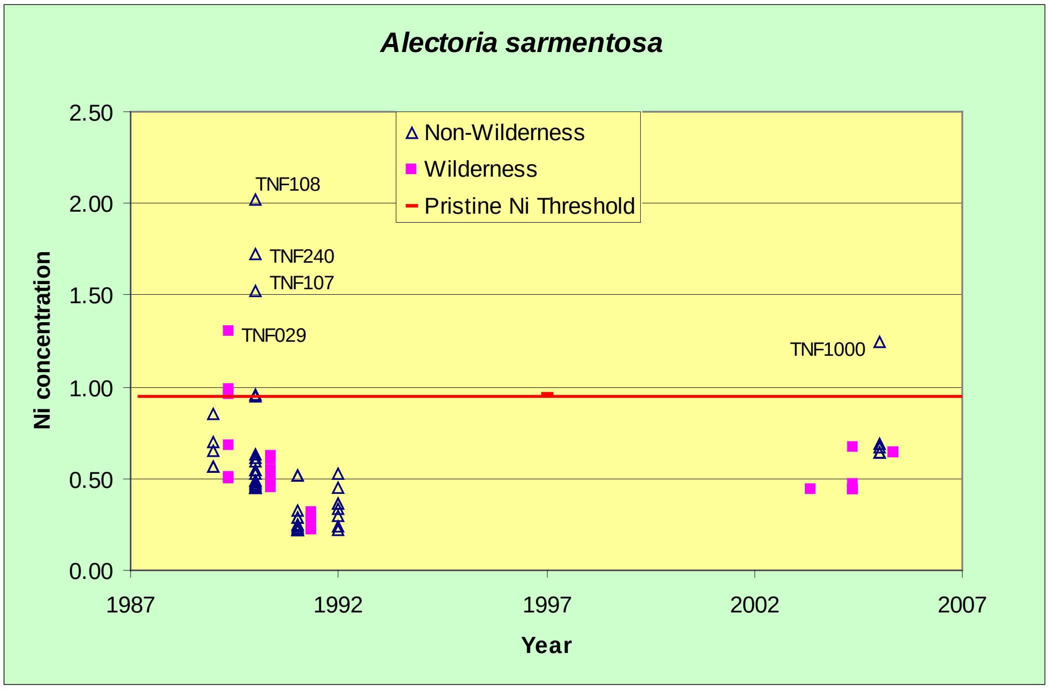

Figure XXIII-4. Wilderness and Non-Wilderness plot means of Ni ppm in *Alectoria sarmentosa* per year.

Hypogymnia species

In this series, all of the *Hypogymnia* species were included as a group.

Table XXIII-2. Wilderness and Non-Wilderness Means, Standard Errors, and 95% Confidence Intervals for the Ni ppm content of *Hypogymnia species* per year.

Ni ppm				95% CI	
Year	**Plot Type**	**Mean**	**Std. Error**	**Lower**	**Upper**
1989	Non-Wilderness	1.00	0.4450	4.6593	6.6493
1989	Wilderness	1.78	0.6156	0.0726	3.4910
1990	Non-Wilderness	3.42	0.6978	1.9523	4.8844
1990	Wilderness	0.96	0.2020	0.4672	1.4557
2003	Wilderness	0.44	NA	NA	NA
2004	Wilderness	0.62	0.0628	0.4591	0.7818
2005	Non-Wilderness	4.42	0.1727	3.6736	5.1598
2005	Wilderness	1.17	0.2816	0.5226	1.8214

No t-tests were performed due to lack of repeat samples.

Relationships are not strong in Ni content for *Hypogymnia* after accounting for latitude, longitude, elevation, year (Figures XXIII-5, XXIII-6 for year) and precipitation (see Brenner, 2006 for all graphed results).

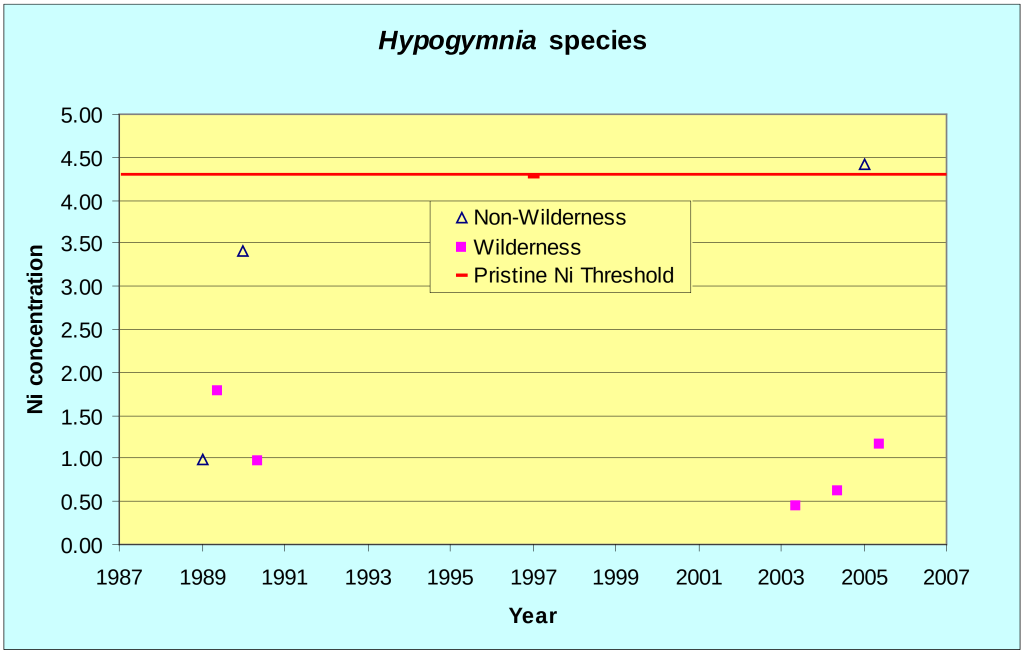

Figure XXIII-5. Wilderness and Non-Wilderness yearly means of Ni ppm in *Hypogymnia species* per year.

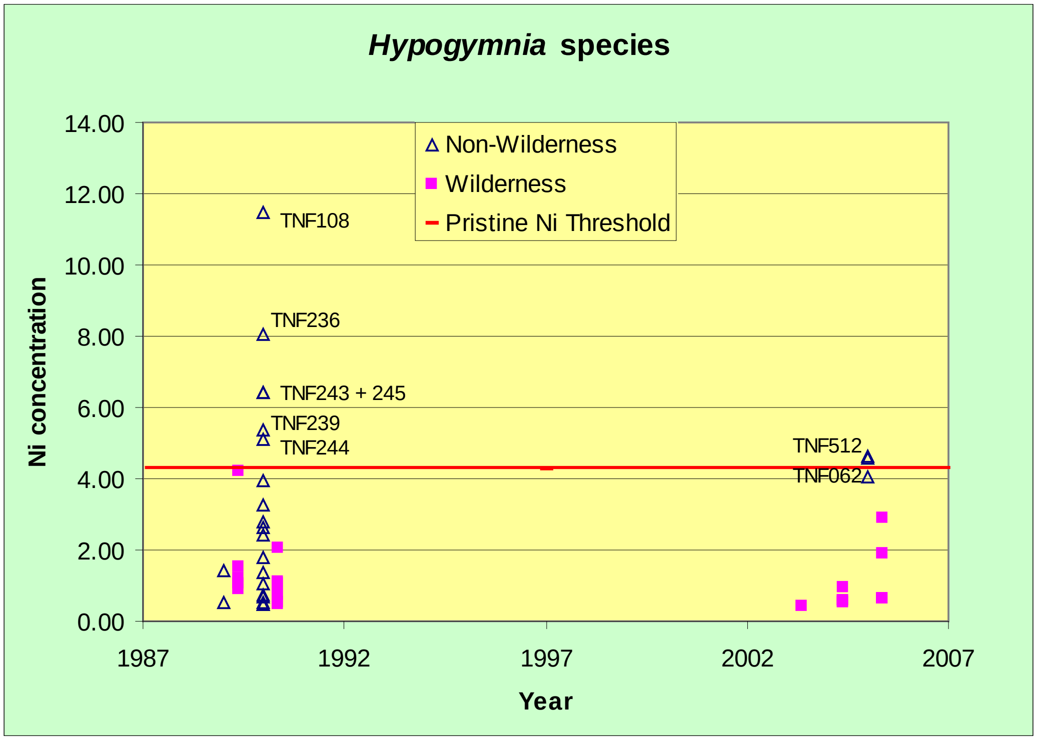

Figure XXIII-6. Wilderness and Non-Wilderness plot means of Ni ppm in *Hypogymnia species* per year.

Lobaria oregana

Table XXIII-3. Wilderness and Non-Wilderness Means, Standard Errors, and 95% Confidence Intervals for the Ni ppm content of *Lobaria oregana* per year.

Ni ppm				95% CI	
Year	**Plot Type**	**Mean**	**Std. Error**	**Lower**	**Upper**
1989	Non-Wilderness	0.60	0.0511	0.4417	0.7666
1989	Wilderness	0.71	0.1613	0.2597	1.1553
1990	Non-Wilderness	0.66	0.0597	0.5250	0.7854
1990	Wilderness	0.60	0.0694	0.4203	0.7771
2004	Wilderness	0.87	0.1459	0.5167	1.2305
2005	Non-Wilderness	2.27	NA	NA	NA
2005	Wilderness	0.7168	0.0768	0.4725	0.9610

Summary of Statistical Tests:

t = -2.0942, df = 4, p-value = 0.1043

There is no evidence of a difference in Ni content in *Lobaria oregana* from pre-2000 and post 2000 samples (p-value = 0.1043). This analysis was for wilderness areas that had repeated values for Ni in *Lobaria oregana:* Russell Fiords (plot 62 near Harlequin Lake), Tebenkof (33) and Misty Fiords (86, 88).

Relationships are not strong in the Ni content in Lobore after accounting for latitude, longitude, elevation, year (Figures XXIII-7, XXIII-8 for year) and precipitation (see Brenner, 2006 for all graphed results).

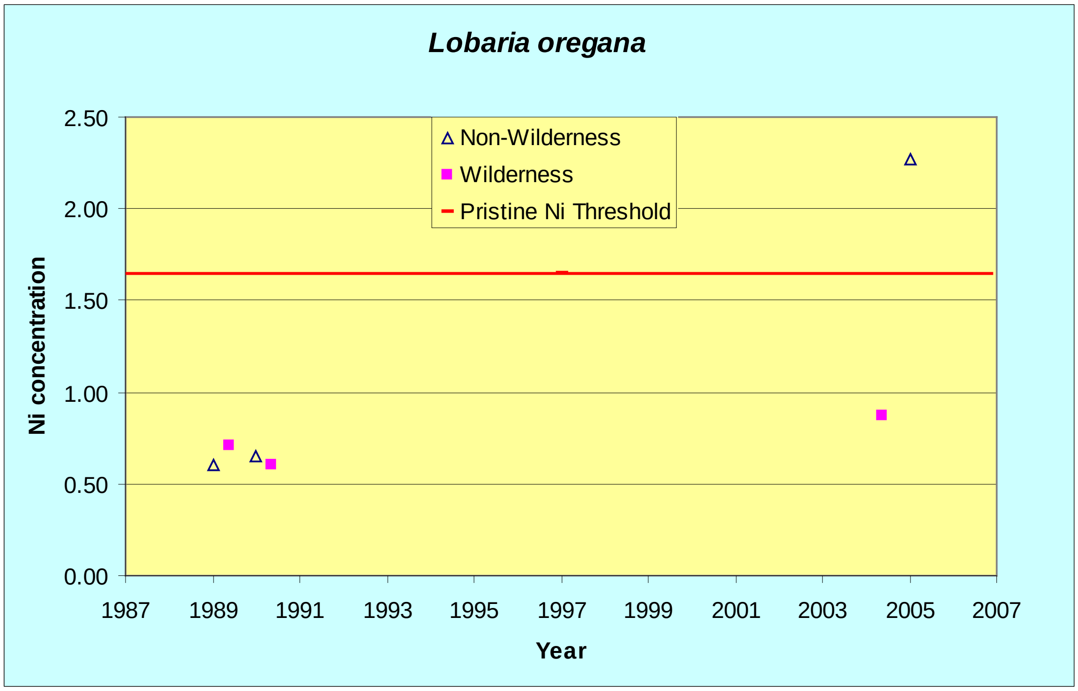

Figure XXIII-7. Wilderness and Non-Wilderness yearly means of Ni ppm in *Lobaria oregana* per year.

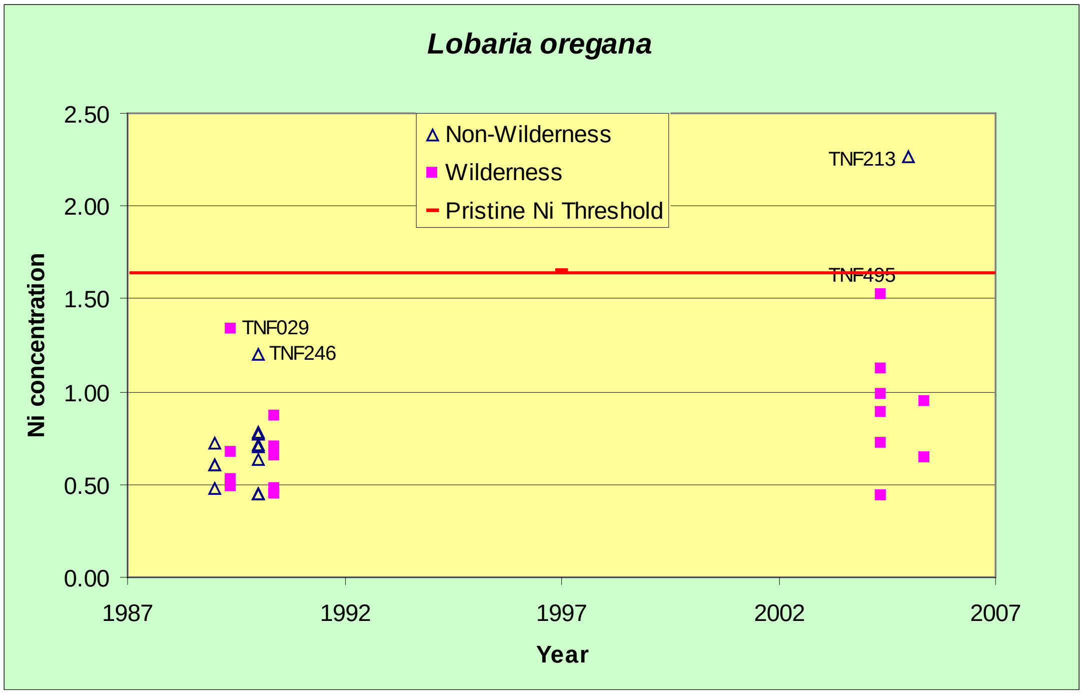

Figure XXIII-8. Wilderness and Non-Wilderness plot means of Ni ppm in *Lobaria oregana* per year.

Platismatia glauca

Table XXIII-4. Wilderness and Non-Wilderness Means, Standard Errors, and 95% Confidence Intervals for the Ni ppm content of *Platismatia glauca* per year.

Ni ppm				**95% CI**	
Year	**Plot Type**	**Mean**	**Std. Error**	**Lower**	**Upper**
2003	Wilderness	0.46	NA	NA	NA
2004	Wilderness	1.14	0.2169	0.6531	1.6344
2005	Non-Wilderness	3.08	0.2923	2.4230	3.7454
2005	Wilderness	1.14	0.2565	0.5321	1.7451

No t-tests were performed on these data. The mean values for Ni are baseline in *Platismatia glauca.*

Relationships are not strong in Ni content for Plagla after accounting for latitude, longitude, elevation, year (Figures XXIII-9, XXIII-10 for year) and precipitation (see Brenner, 2006 for all graphed results).

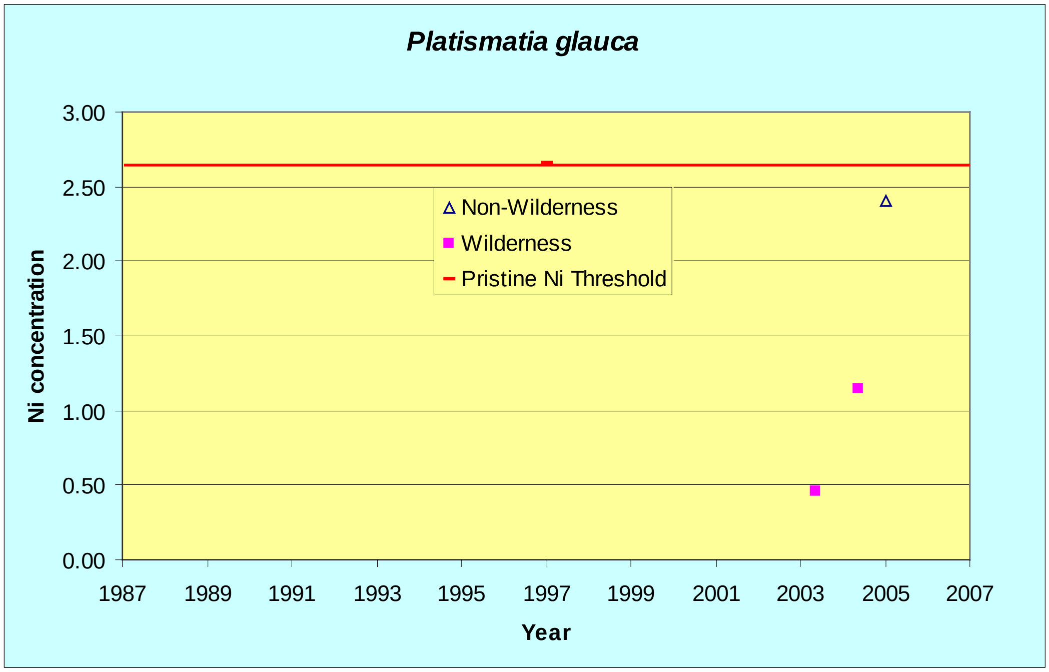

Figure XXIII-9. Wilderness and Non-Wilderness yearly means of Ni ppm in *Platismatia glauca* per year.

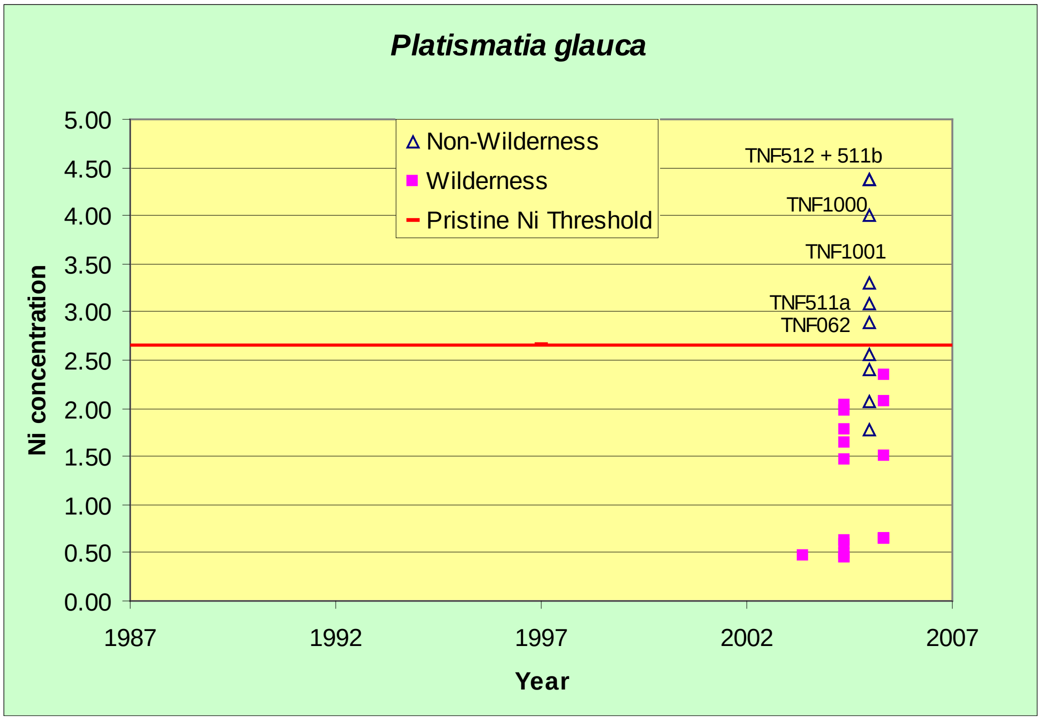

Figure XXIII-10. Wilderness and Non-Wilderness plot means of Ni ppm in *Platismatia glauca* per year.

Conclusions: for Nickle (Ni) and all lichen species
Nickel enhanced lichens due to mine and smelter activities contain between 10 and 300 ppm for undefined lichen species (USDA 1999). Lichens may also be enhanced near seashore habitats with levels ranging from 10 to 120 ppm (USDA 1999). Given the region's active geologic processes and hypermaritime environment, provisional threshold levels are understandably above the background levels for Ni in the Pacific Northwest.

Alectoria sarmentosa

Background levels for Ni in Alesar from the Pacific Northwest are at .60 ppm (USDA 1999). This is slightly lower than the Tongass Ni threshold of .96 ppm. Plots with lichens elevated in Ni from the Sitka road system (107, 108, and 240) may be further enhanced due to the proximity to the pulp mill and vehicle and marine traffic near the ferry terminal (Figure XXIII-4). Lichens from plot 29 from the Petersburg Lake area is elevated above threshold in Ni, which is unexplained at this time. This plot is also elevated in manganese, and may be due to the natural variation of these elements in lichens from this wilderness. Plot 1000 from Juneau's Mt Roberts may be Ni enhanced due to the nearby industrial area of Juneau and extinct gold mine, and the nearby cruise ship docking area. Nickel is present in stack gases from oil burning and vehicle exhaust. The other plots higher up the slope of Mt Roberts are not elevated in Ni. This helps explain that naturally occurring Ni is not present in large quantities around this mountain, but rather is emitted from the urban sources at lower elevations.

Hypogymnia

Background level is higher for Ni in *Hypogymnia* than other lichens in the Pacific Northwest because this genus is a better accumulator of contaminants (1.5 to 4.0 ppm) (USDA 1999). Tongass Ni threshold is 4.26 ppm. Elevated above threshold for Ni include lichens from the Sitka area around the pulp mill and ferry terminal (plots 108, 236, 239, 243, and 244), and can be explained in part by the proximity to these industrial areas (Figure XXIII-6). These plots have not been remonitored. Plot 512 from Greens

Creek tailings pile is elevated just above threshold due to the exposed ore, but is not within the range of being enhanced due to mining and smelter activities worldwide.

Lobaria oregana

The background for Ni in Lobore from the Pacific Northwest is .60 ppm (USDA 1999), and the Tongass threshold is higher at 1.65 ppm. Plot 62 from Russell Fiords is elevated above threshold in Ni, possibly due to the nearby airstrip or road (Figure XXIII-8). Geology of the area may also play a role in Ni enhancement in Russell Fiords.

Platismatia glauca

Background Ni from the Pacific Northwest in Plagla is 2.0 ppm and Tongass threshold is slightly higher at 2.65 ppm (USDA 1999). All plots from Greens Creek are elevated in Ni, which can be explained by the proximity to the mining industry and exposed ore in the area and on the roads (Figure XXIII-10). Plots on Mt Roberts are elevated most likely due to the proximity to the extinct mine, cruise ship docking area and downtown Juneau automobile pollution. Plot 1000 is 175 feet above sea level. Plot 1001 is at the 600 ft level. The Alesar collected at the 1001 plot is not elevated in Ni, yet the Alesar is from the 175 ft level (Plot 1000) (Figure XXIII-4). Levels of Ni are apparently higher from Plagla in plot 1000 than 1001(Figure XXIII-10) indicating a possible gradient in exposure and absorption due to elevation and proximity to pollution source. More plots at closer intervals would help explain a possible depositional pattern.

XXIV. Summary of results for Phosphorus (P) from all species on the Tongass National Forest

Phosphorus (P) occurs naturally in many phosphate minerals. Due to its high reactivity, phosphorus is never found as a free element in nature. The most important commercial use of phosphorus-based chemicals is the production of fertilizers. Phosphorus compounds are also widely used in explosives, nerve agents, friction matches, fireworks, pesticides, toothpaste, and detergents. Phosphorus is also emmitted in ash from wood burning stoves. Phosphorus is a component of DNA and RNA and is an essential element for all living cells.

Tongass thresholds for P are the following: *Alectoria sarmentosa* (913.75 ppm), *Hypogymnia* (1597.23 ppm), *Lobaria oregana* (2532.49 ppm) and *Platismatia glauca* (1115.00 ppm).

Plots with lichens elevated above threshold for P include the following: Alesar plots 107 (Sitka road system) 113 (Berners Bay), 33 (Tebenkof Bay) and 1002 (Mt Roberts 600 ft elevation) (Figure XXIV-4); *Hypogymnia* plots 236, 241, and 243 (Sitka road system), and plot 111 (Amalga trail-Juneau) (Figure XXIV-6); Lobore plot 32 (Tebenkof Bay) (Figure XXIV-8), and Plagla plots 1000, 1001, 1002, and 1004 (Juneau Mt Roberts) and 511b (Greens Creek portal area). Just at threshold is plot 508 from Endicott River wilderness (Figure XXIV-10).

XXIV. SUMMARY OF P PPM DATA ANALYSIS

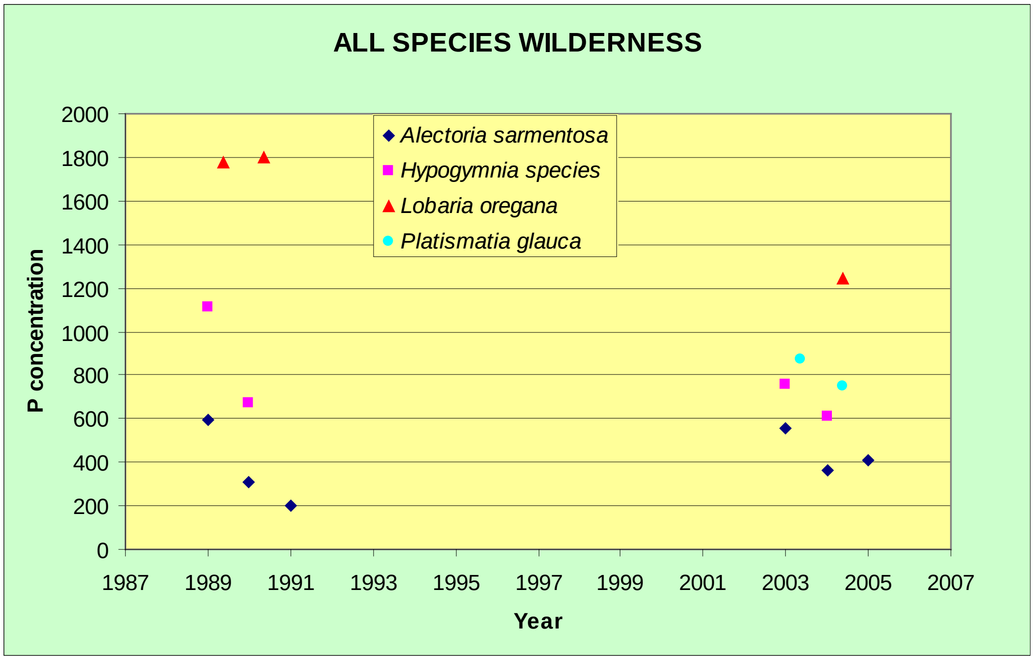

Figure XXIV-1. Wilderness plot means of P ppm in *All Species* per year.

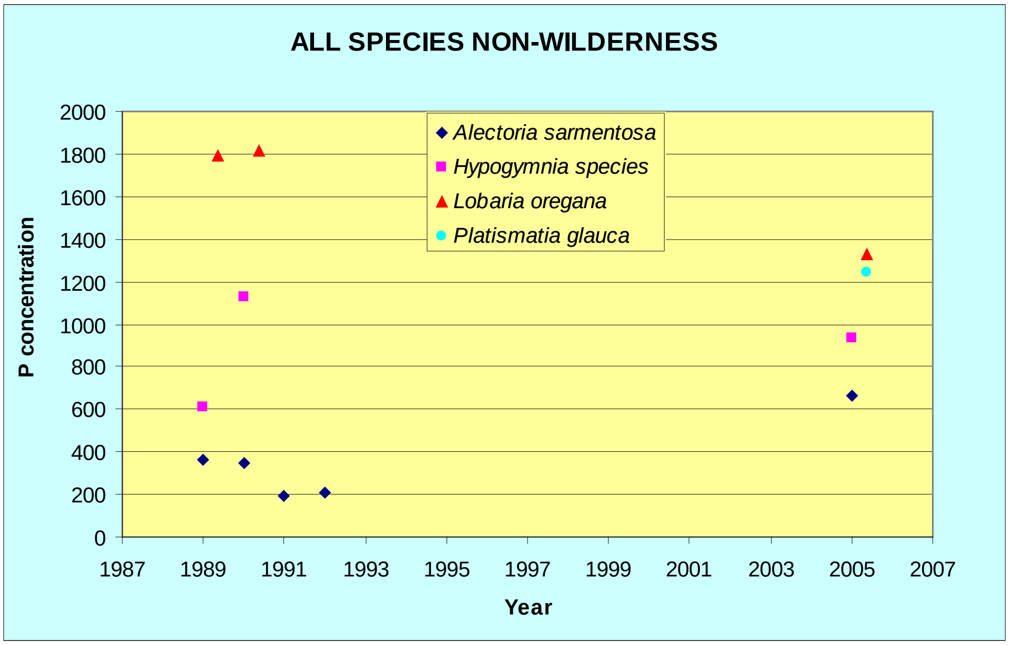

Figure XXIV-2. Non-Wilderness plot means of P ppm in *All Species* per year.

Alectoria sarmentosa

Table XXIV-1. Wilderness and Non-Wilderness Means, Standard Errors, and 95% Confidence Intervals for the P ppm content of *Alectoria sarmentosa* per year.

P ppm				**95% CI**	
Year	**Plot Type**	**Mean**	**Std. Error**	**Lower**	**Upper**
1989	Non-Wilderness	362.74	76.1446	151.3287	574.1513
1989	Wilderness	591.78	75.3888	397.9846	785.5710
1990	Non-Wilderness	347.73	54.0382	236.6527	458.8071
1990	Wilderness	310.38	78.9222	117.2687	503.4999
1991	Non-Wilderness	193.6281	8.3143	176.1603	211.0958
1991	Wilderness	201.61	7.6276	180.4274	222.7826
1992	Non-Wilderness	205.66	10.3293	181.2375	230.0873
2003	Wilderness	557.05	125.3892	1036.1663	2150.2746
2004	Wilderness	360.82	85.1815	184.6071	537.0299
2005	Non-Wilderness	663.69	125.3194	341.5496	985.8371
2005	Wilderness	408.23	60.3982	271.5982	544.8588

Summary of Statistical Tests:

t = -1.1626, df = 8, p-value = 0.2785

There is no evidence of a difference in P content in *Alectoria sarmentosa* from pre-2000 and post 2000 samples (p-value = 0.2785). Plots with repeated samples for P in Alesar are: Karta River (#159), Pleasant Island (#145, 146), Pikes Lake RNA (# 69), Kootznoowoo (# 189, 190), Petersburg Creek (#116), Stikine-LeConte (#30, 31), Yakobi (#101), Tebenkof (#33) and Misty Fiords (#85, 86).

Relationships are not strong in the P content in *Alectoria sarmentosa* after accounting for latitude, longitude, elevation, year (Figures XXIV-3, XXIV-4 for year) and precipitation (see Brenner, 2006 for all graphed results).

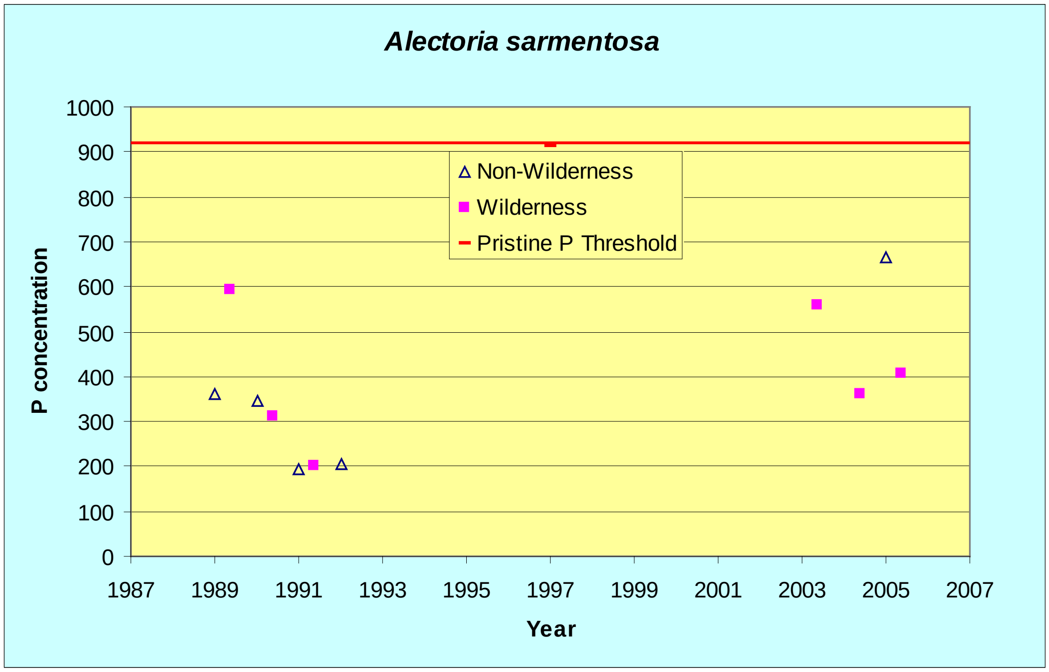

Figure XXIV-3. Wilderness and Non-Wilderness yearly means of P ppm in *Alectoria sarmentosa* per year.

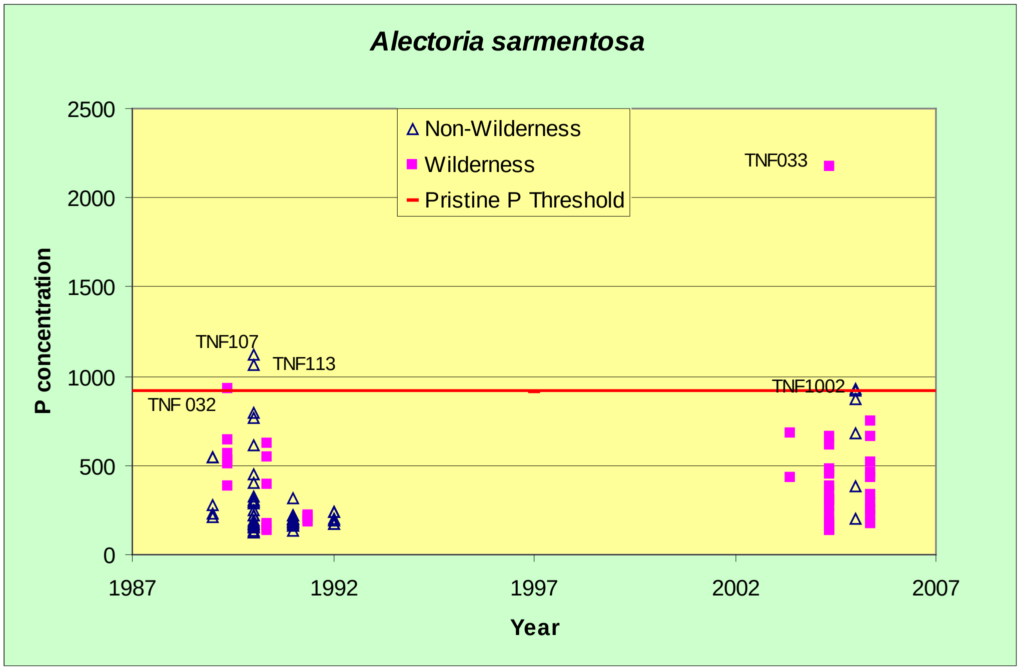

Figure XXIV-4. Wilderness and Non-Wilderness plot means of P ppm in *Alectoria sarmentosa* per year.

Hypogymnia species

In this series, all of the *Hypogymnia* species were included as a group.

Table XXIV-2. Wilderness and Non-Wilderness Means, Standard Errors, and 95% Confidence Intervals for the P ppm content of *Hypogymnia species* per year.

P ppm				**95% CI**	
Year	**Plot Type**	**Mean**	**Std. Error**	**Lower**	**Upper**
1989	Non-Wilderness	612.50	196.5000	1884.2690	3109.2690
1989	Wilderness	1113.47	93.3430	854.3049	1372.6284
1990	Non-Wilderness	1128.13	115.4113	885.6615	1370.6017
1990	Wilderness	675.38	128.8464	360.1051	990.6568
2003	Wilderness	758.09	NA	NA	NA
2004	Wilderness	613.87	108.4177	335.1760	892.5690
2005	Non-Wilderness	931.34	176.3951	172.3731	1690.3069
2005	Wilderness	909.76	123.1564	625.7609	1193.7591

No t-tests were performed due to lack of repeat samples.

Relationships are not strong in P content for *Hypogymnia* after accounting for latitude, longitude, elevation, year (Figures XXIV-5, XXIV-6 for year) and precipitation (see Brenner, 2006 for all graphed results).

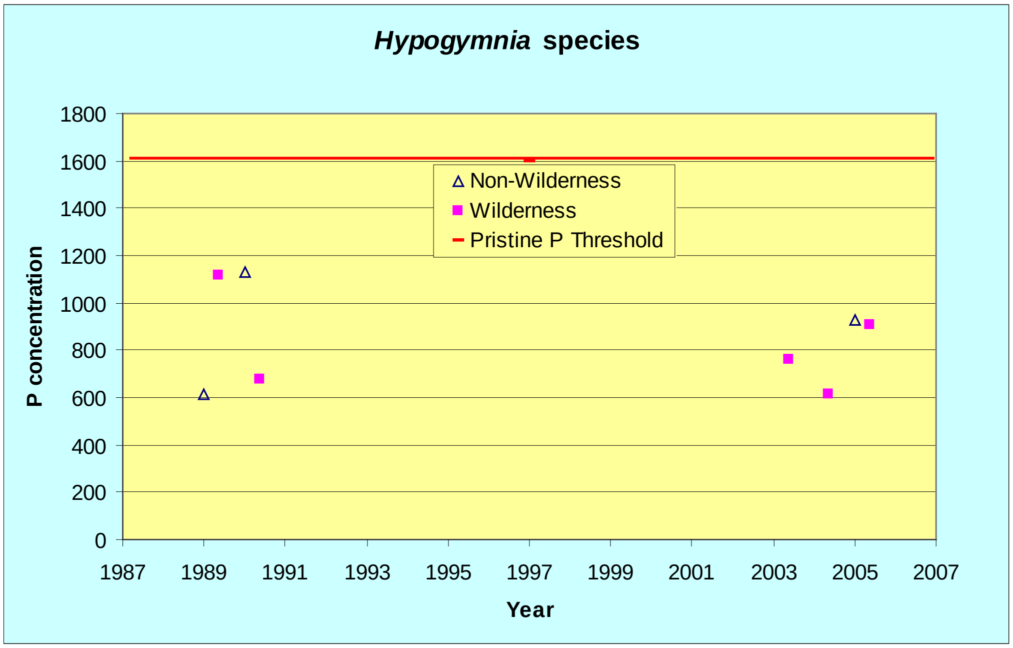

Figure XXIV-5. Wilderness and Non-Wilderness yearly means of P ppm in *Hypogymnia* species per year.

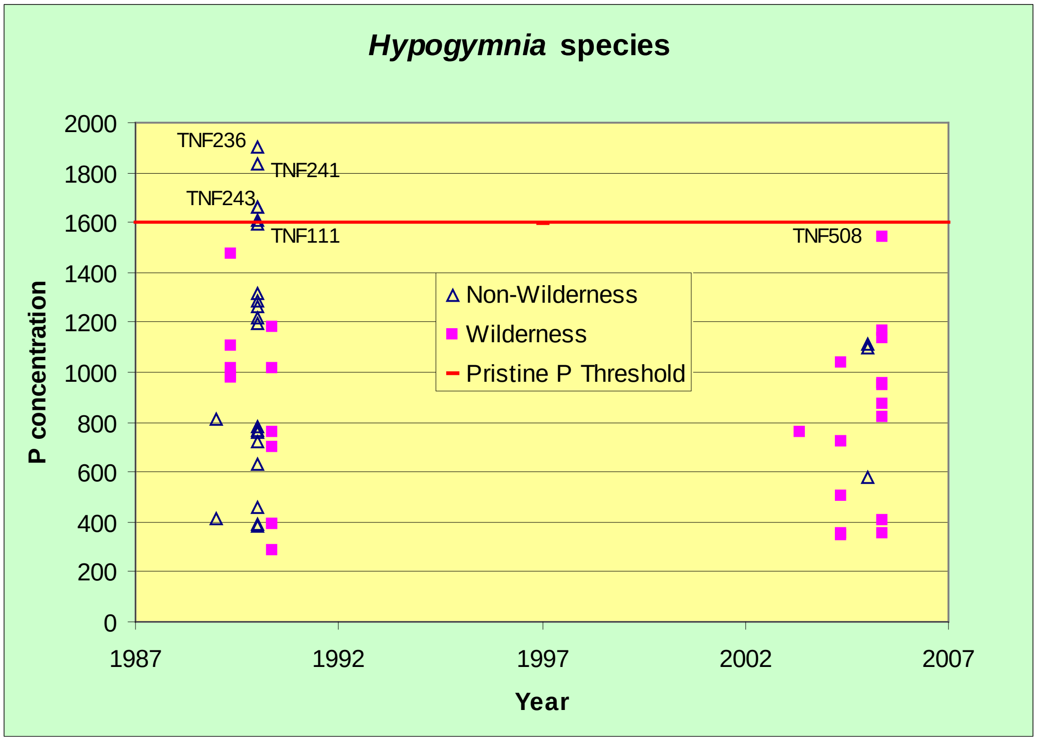

Figure XXIV-6. Wilderness and Non-Wilderness plot means of P ppm in *Hypogymnia* species per year.

Lobaria oregana

Table XXIV-3. Wilderness and Non-Wilderness Means, Standard Errors, and 95% Confidence Intervals for the P ppm content of *Lobaria oregana* per year.

P ppm				**95% CI**	
Year	**Plot Type**	**Mean**	**Std. Error**	**Lower**	**Upper**
1989	Non-Wilderness	1792.25	155.4934	1297.4005	2287.0995
1989	Wilderness	1778.58	279.1520	1003.5260	2553.6270
1990	Non-Wilderness	1811.46	90.0948	1615.1554	2007.7549
1990	Wilderness	1801.65	236.4482	1193.8434	2409.4621
2004	Wilderness	1246.71	118.4279	956.9247	1536.4898
2005	Non-Wilderness	1328.60	NA	NA	NA
2005	Wilderness	1902.3562	154.3054	1411.2875	2393.4250

Summary of Statistical Tests:

t = -0.4222, df = 4, p-value = 0.6946

There is no evidence of a difference in P content in *Lobaria oregana* from pre-2000 and post 2000 samples (p-value = 0.6946). This analysis was for wilderness areas that had repeated values for P in *Lobaria oregana:* Russell Fiords (plot 62 near Harlequin Lake), Tebenkof (33) and Misty Fiords (86, 88).

Relationships are not strong in the P content in *Lobaria oregana* after accounting for latitude, longitude, elevation, year (Figures XXIV-7, XXIV-8 for year) and precipitation (see Brenner, 2006 for all graphed results).

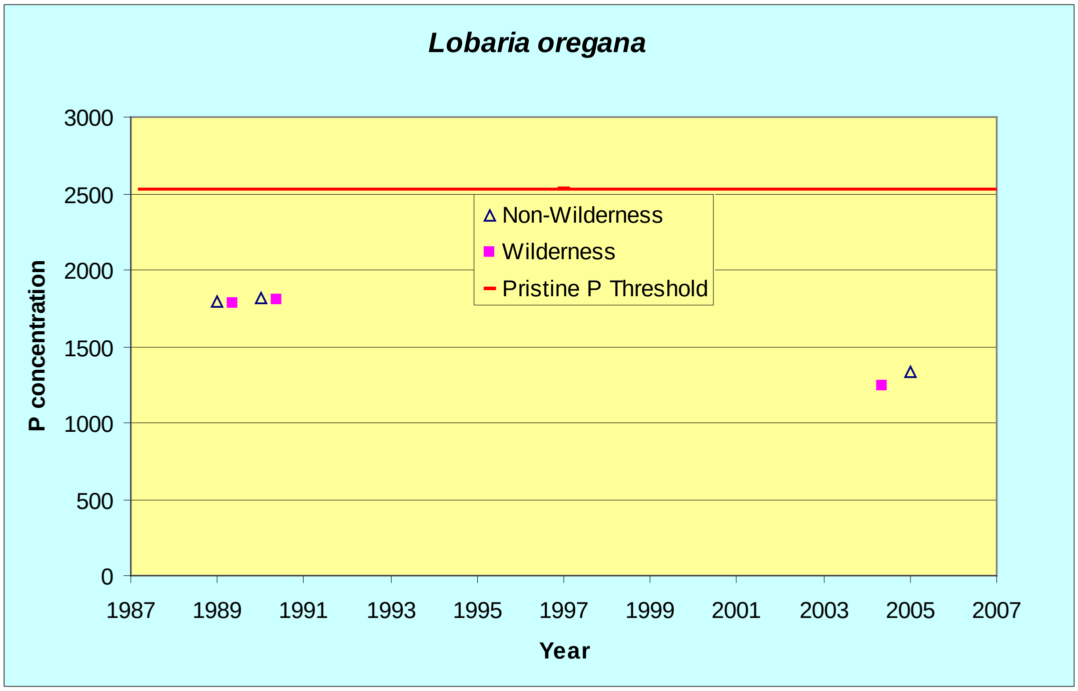

Figure XXIV-7. Wilderness and Non-Wilderness yearly means of P ppm in *Lobaria oregana* per year.

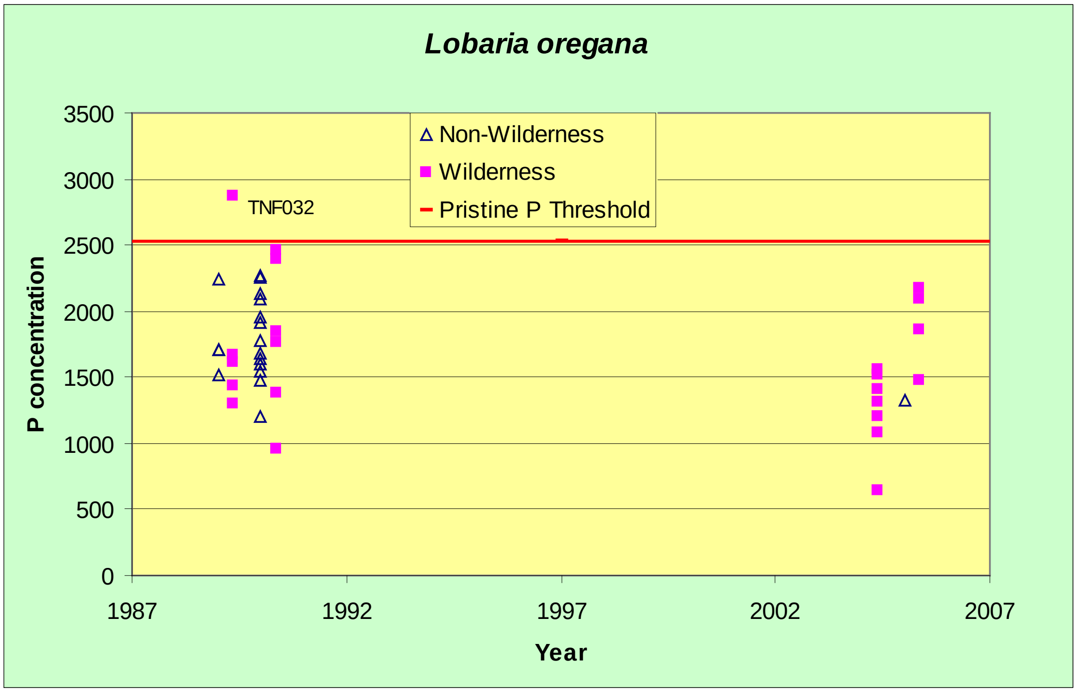

Figure XXIV-8. Wilderness and Non-Wilderness plot means of P ppm in *Lobaria oregana* per year.

Platismatia glauca

Table XXIV-4. Wilderness and Non-Wilderness Means, Standard Errors, and 95% Confidence Intervals for the P ppm content of *Platismatia glauca* per year.

P ppm				**95% CI**	
Year	**Plot Type**	**Mean**	**Std. Error**	**Lower**	**Upper**
2003	Wilderness	876.00	NA	NA	NA
2004	Wilderness	745.43	53.9139	623.4636	867.3868
2005	Non-Wilderness	1104.47	124.6367	822.5221	1386.4179
2005	Wilderness	889.42	71.8006	719.6347	1059.1978

No t-tests were performed on these data. The mean values for P are baseline in *Platismatia glauca.*

Relationships are not strong in P content for Plagla after accounting for latitude, longitude, elevation, year (Figures XXIV-9, XXIV-10 for year) and precipitation (see Brenner, 2006 for all graphed results)

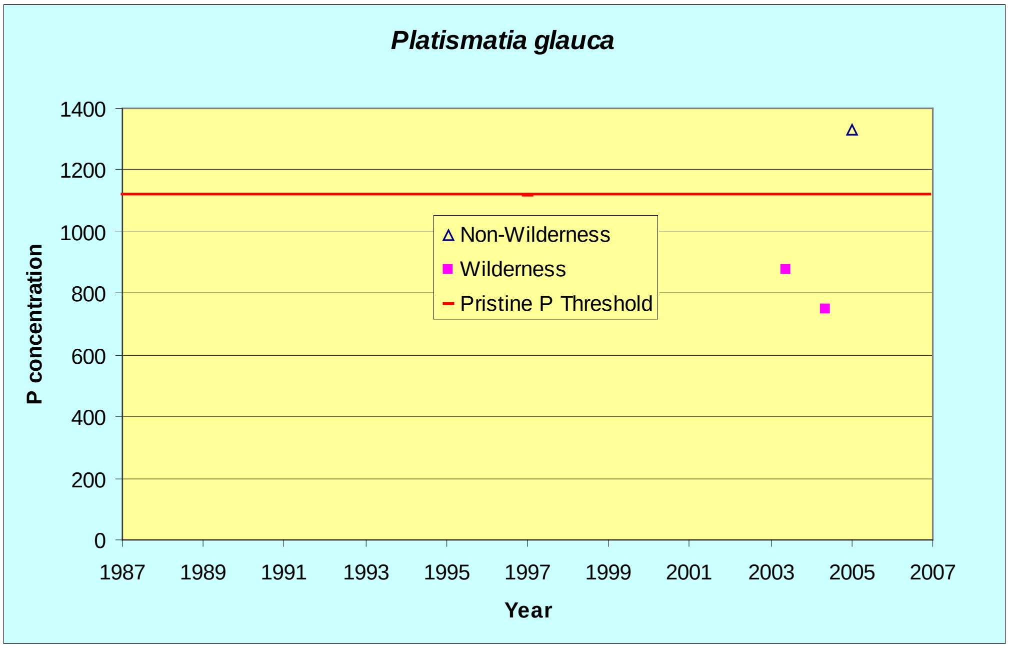

Figure XXIV-9. Wilderness and Non-Wilderness yearly means of P ppm in *Platismatia glauca* per year.

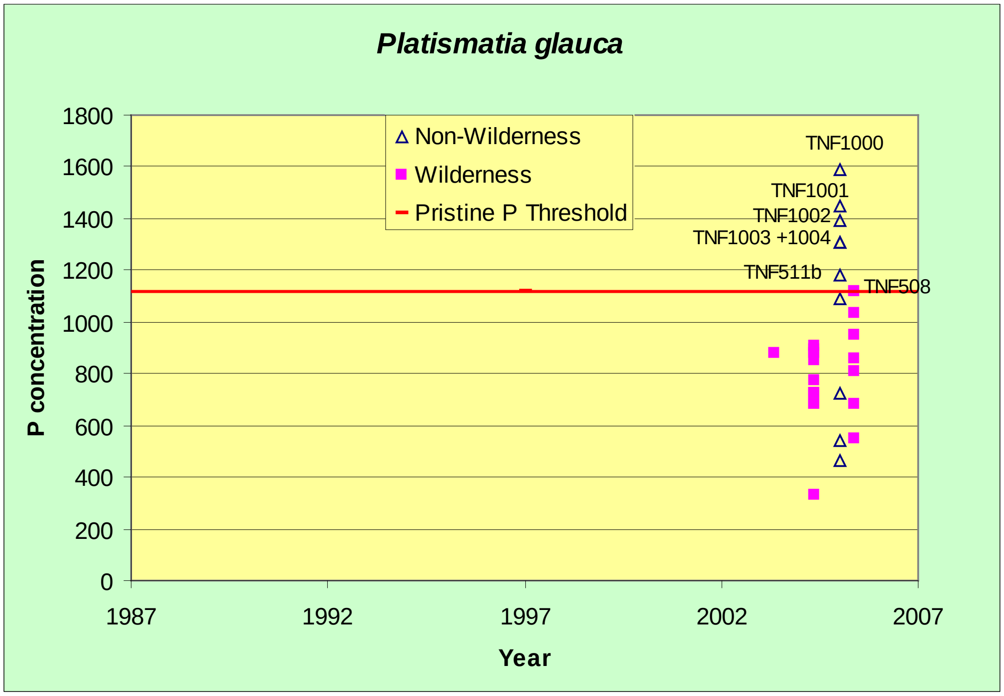

Figure XXIV-10. Wilderness and Non-Wilderness plot means of P ppm in *Platismatia glauca* per year.

Conclusions: for Phosphorus (P) and all lichen species

Phosphorus may be locally enhanced in lichens from areas that contain native rock phosphates or in areas where P is used in industry (USDA 1999). Phosphorus thresholds on the Tongass are generally higher than background levels found in the Pacific Northwest, but are generally within the background range determined by Neiboer and others (between 200 and 2000 ppm) (1978). Enhanced levels for P are not given by Neiboer and others (1978) nor Neiboer and Richardson (1981). Levels of P above the threshold established for each lichen species on the Tongass may be due to natural geologic sources or local human activity such as road dust and wood smoke. There are no phosphate refineries in the region.

Alectoria sarmentosa

Threshold of P in Alesar are above background levels from the Pacific Northwest (913.75 ppm and 500 ppm respectively) (USDA 1999). Tebenkof plot 33 from 2004 is elevated above threshold and the reasons for this are unknown (Figure XXIV-4). Plot 32 from the 1990’s in Tebenkof is just at threshold for P and may just be part of the natural variation. Elevated levels of P from lichens on the Sitka road system may be due to the old pulp mill and associated roads (Plot 107). The Berners Bay lichens from plot 113 may be elevated due to past mining activities, or natural variation. Alesar from Plot 1002 (Mt Roberts 600 ft elevation) is at threshold level. However, elevated levels were found in one other lichen species for the same plot (see below under Plagla).

Hypogymnia

Threshold of P (1597.23 ppm) for *Hypogymnia* on the Tongass is just above the range of background levels reported from the Pacific Northwest (between 900 and 1500 ppm) (USDA 1999). Plots with elevated P in *Hypogymnia* include several from the Sitka road system and pulp mill area, most likely associated with these sources (plots 236, 241, and 243) (Figure XXIV-6). These plots have not been revisited. *Hypogymnia* from Amalga Trail near Juneau (plot 111) is right at threshold and may be part of the natural variation of P.

Lobaria oregana

Threshold of P in Lobore is slightly higher than background P in the Pacific Northwest (2532. 49 ppm and 2000 ppm respectively). Plot 32 from Tebenkof Bay is elevated above threshold (Figure XXIV-8), as was plot 33 from Tebenkof in Alesar in 2004(Figure XXIV-4). Plot 32 was not revisited. Both plots are in the beach fringe and in wilderness. Therefore, the elevated levels may be part of the natural variation of this region

Platismatia glauca

Background from Pacific Northwest for P is just about equal to the Tongass threshold for P (1100 ppm and 1115.00 ppm respectively). The lichens from some of the polluted areas on the Tongass show elevated levels of P, even though other lichen species generally do not from the same locations. Plagla is a better accumulator than the other biomonitoring species and therefore, elements are more readily detected. Plagla from Mt Roberts is particularly striking as all five plots show elevated levels of P above threshold (Figure XXIV-10). This may indicate that wood smoke may be related to the P enhancement other than natural background of the region. Elevated levels associated with Greens Creek at the portal (511b) may be a function of the explosives used in the mining process over time. Plagla from plot 508 at Endicott wilderness may be due to the calcareous geology of the Chilkat Peninsula and associated windblown soils

XVIV. Summary of results for Lead (Pb) from all species on the Tongass National Forest

Lead is a naturally occurring metal found in small amounts in the earth's crust. Lead combines with other elements to make lead compounds or lead salts. Some of these substances can burn such as organic lead compounds in some gasolines (USPHS 1999). Lead was banned from use in gasoline in 1996. Lead is used in the production of batteries, ammunition, sheet lead, solder, some brass and bronze products, radiation shields, ultrasound machines, intravenous pumps, fetal monitors, surgical equipment and ceramic glazes (USPHD 1999). Lead used by industry comes from mined ores or recycled scrap metal or batteries.

Lead is released into the environment from the burning of coal or oil, industrial processes, and burning solid wastes. If the particles are small enough, airborne lead can travel thousands of miles. Although lead does occur naturally in the environment from windblown dusts and volcanoes, most high lead levels found throughout the environment comes from human activities. Even though lead is banned in gasoline, lead from past gasoline exhausts sticks to soil particles on roads for years (USPHS 1999).

Provisional Pb thresholds in lichens are the following: *Alectoria sarmentosa* (5.00 ppm); *Hypogymnia* (10.13 ppm); *Lobaria oregana* (3.52 ppm); and *Platismatia glauca* (3.52 ppm).

Lichens elevated in Pb on the Tongass are the following: Alesar plots 512 (Greens Creek tailings pile), 221 (Douglas Island) and 247 (Sitka pulp mill area)(Figure XXV-4); Hypogymnia plots 239, 241, 242, 243, and 244 (Sitka pulp mill and road system) and 511b and 512 (Greens Creek mine)(Figure XXV-6); Lobore plot 246 (Sitka pulp mill)(Figure XXV-8); and Plagla plots 511a, 511b and 512 (Greens Creek mine)(Figure XXV-10).

XXV. SUMMARY OF Pb PPM DATA ANALYSIS

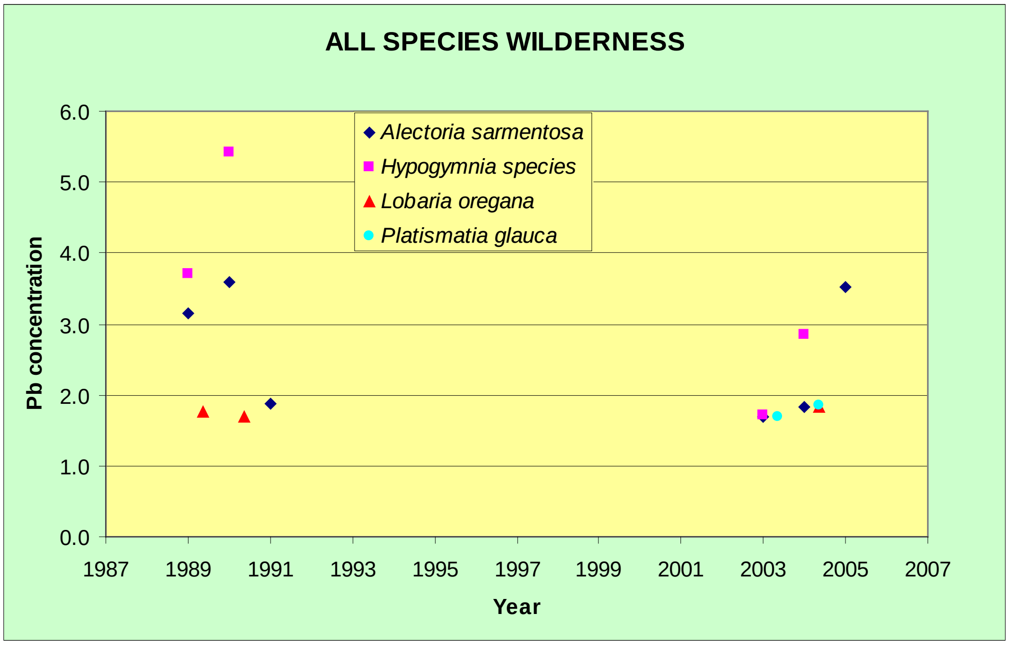

Figure XXV-1. Wilderness plot means of Pb ppm in *All Species* per year.

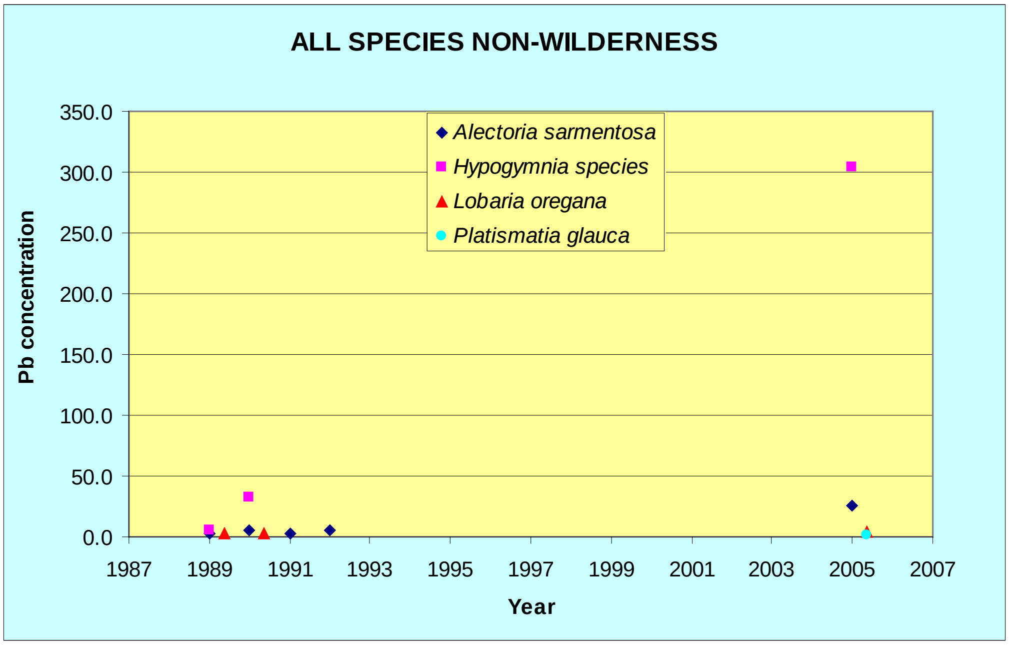

Figure XXV-2. Non-Wilderness plot means of Pb ppm in *All Species* per year.

Alectoria sarmentosa

Table XXV-1. Wilderness and Non-Wilderness Means, Standard Errors, and 95% Confidence Intervals for the Pb ppm content of *Alectoria sarmentosa* per year.

Pb ppm				**95% CI**	
Year	**Plot Type**	**Mean**	**Std. Error**	**Lower**	**Upper**
1989	Non-Wilderness	2.61	0.2909	1.8024	3.4176
1989	Wilderness	3.15	0.6994	1.3521	4.9479
1990	Non-Wilderness	4.90	2.0678	0.6526	9.1534
1990	Wilderness	3.59	0.7418	1.7698	5.4002
1991	Non-Wilderness	2.8615	0.4264	1.9658	3.7572
1991	Wilderness	1.89	0.0626	1.7122	2.0595
1992	Non-Wilderness	5.83	4.1444	3.9717	15.6282
2003	Wilderness	1.68	0.0000	1.6800	1.6800
2004	Wilderness	1.83	0.0669	1.6959	1.9728
2005	Non-Wilderness	25.90	22.1260	30.9809	82.7722
2005	Wilderness	3.52	0.0000	3.5200	3.5200

Summary of Statistical Tests:

$t = -0.2358$, df = 8, p-value = 0.8195

There is no evidence of a difference in Pb content in *Alectoria sarmentosa* from pre-2000 and post 2000 samples (p-value = 0.8195). Plots with repeated samples for Pb in Alesar are: Karta River (#159), Pleasant Island (#145, 146), Pikes Lake RNA (# 69), Kootznoowoo (# 189, 190), Petersburg Creek (#116), Stikine-LeConte (#30, 31), Yakobi (#101), Tebenkof (#33) and Misty Fiords (#85, 86).

Relationships are not strong in the Pb content in *Alectoria sarmentosa* after accounting for latitude, longitude, elevation, year (Figures XXV-3, XXV-4 for year) and precipitation (see Brenner, 2006 for all graphed results).

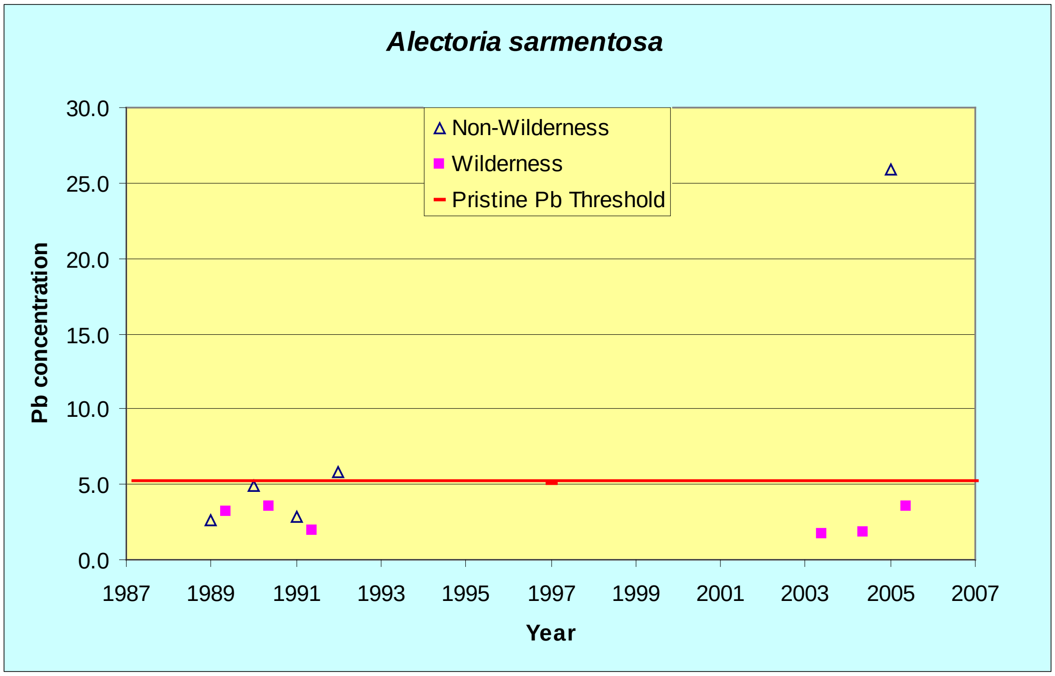

Figure XXV-3. Wilderness and Non-Wilderness yearly means of Pb ppm in *Alectoria sarmentosa* per year.

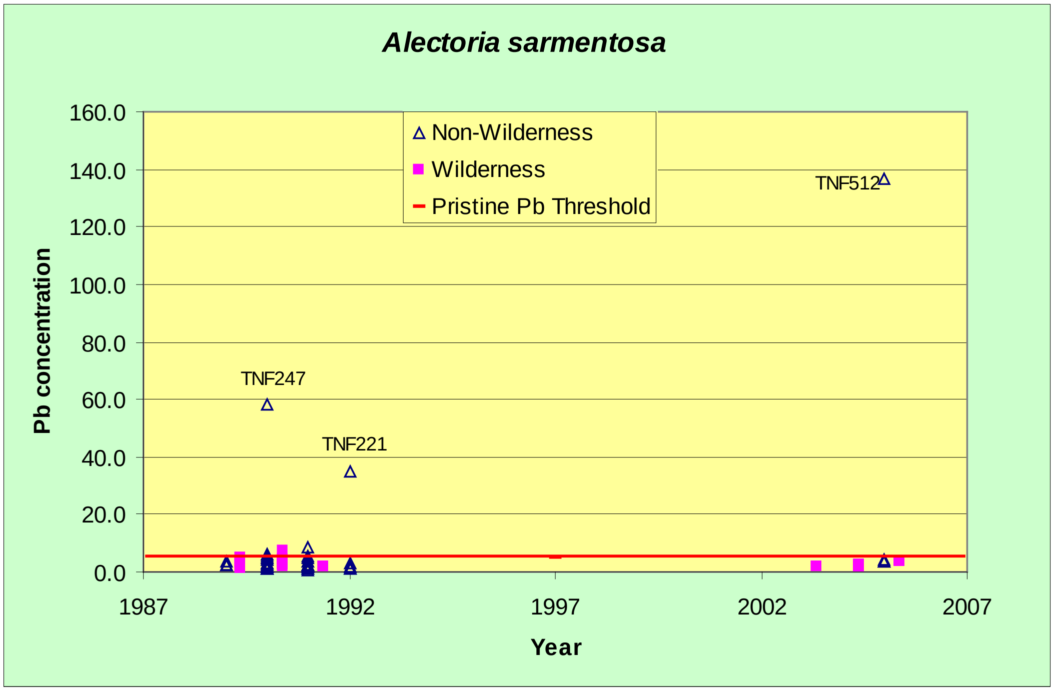

Figure XXV-4. Wilderness and Non-Wilderness plot means of Pb ppm in *Alectoria sarmentosa* per year.

Hypogymnia species

In this series, all of the *Hypogymnia* species were included as a group.

Table XXV-2. Wilderness and Non-Wilderness Means, Standard Errors, and 95% Confidence Intervals for the Pb ppm content of *Hypogymnia species* per year.

Pb ppm				**95% CI**	
Year	**Plot Type**	**Mean**	**Std. Error**	**Lower**	**Upper**
1989	Non-Wilderness	5.50	2.5000	26.2655	37.2655
1989	Wilderness	3.70	0.3000	2.8671	4.5329
1990	Non-Wilderness	33.05	10.9320	10.0853	56.0200
1990	Wilderness	5.43	1.3087	2.2262	8.6309
2003	Wilderness	1.72	NA	NA	NA
2004	Wilderness	2.86	0.2110	2.3131	3.3980
2005	Non-Wilderness	303.60	150.2443	342.8472	950.0506
2005	Wilderness	3.52	0.0000	3.5200	3.5200

No t-tests were performed due to the lack of repeat samples

Relationships are not strong in Pb content for *Hypogymnia* after accounting for latitude, longitude, elevation, year (Figures XXV-5, XXV-6 for year) and precipitation (see Brenner, 2006 for all graphed results).

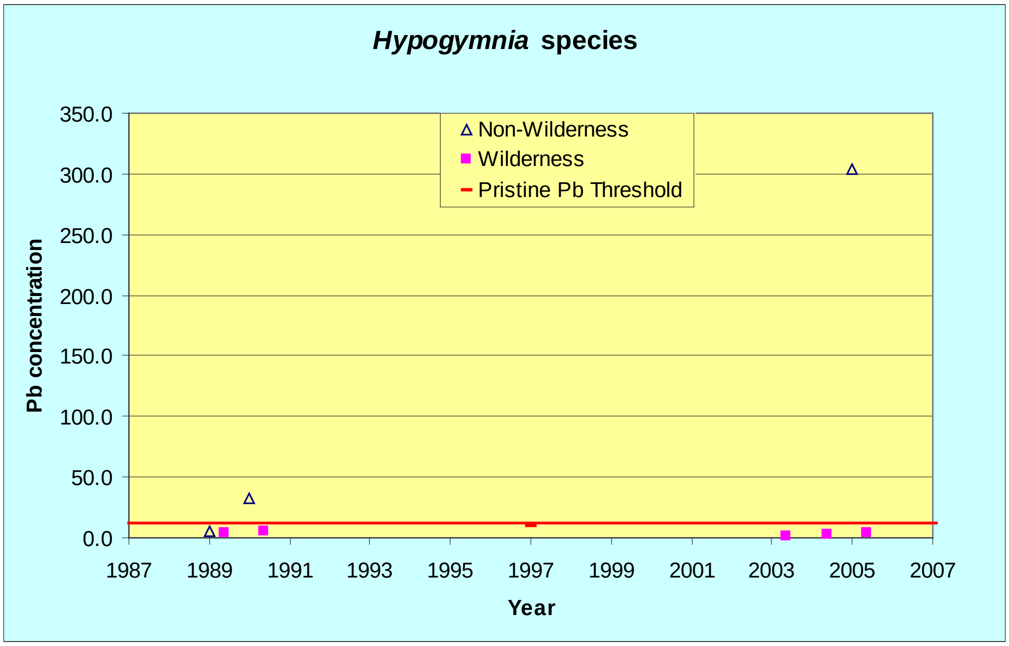

Figure XXV-5. Wilderness and Non-Wilderness yearly means of Pb ppm in *Hypogymnia species* per year.

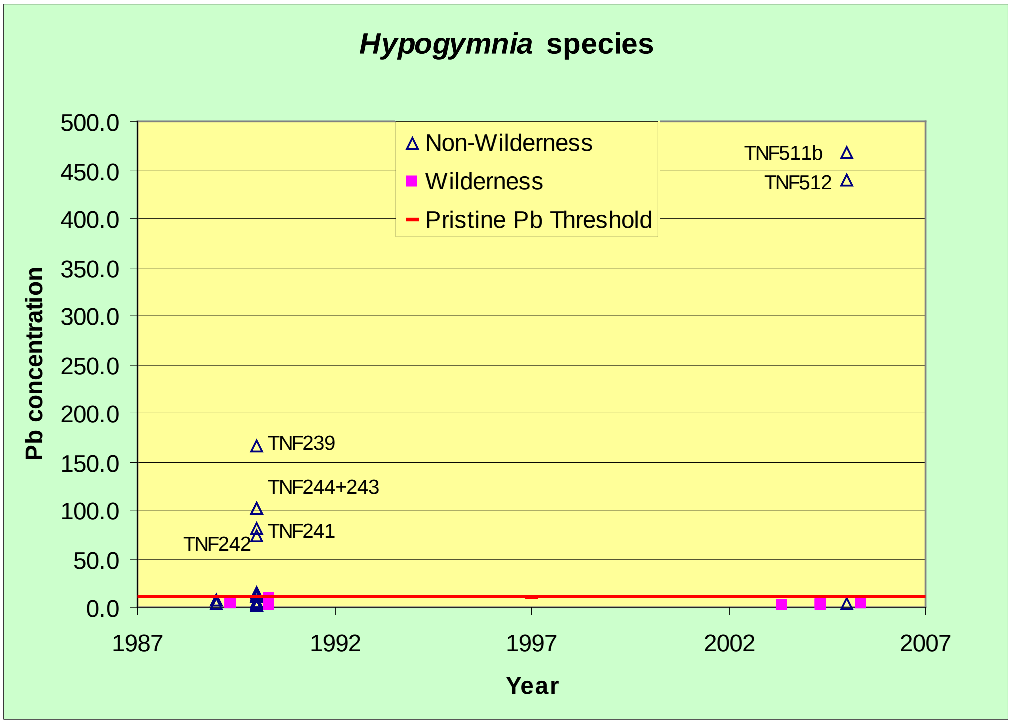

Figure XXV-6. Wilderness and Non-Wilderness plot means of Pb ppm in *Hypogymnia species* per year.

Lobaria oregana

Table XXV-3. Wilderness and Non-Wilderness Means, Standard Errors, and 95% Confidence Intervals for the Pb ppm content of *Lobaria oregana* per year.

Pb ppm				**95% CI**	
Year	**Plot Type**	**Mean**	**Std. Error**	**Lower**	**Upper**
1989	Non-Wilderness	2.42	0.1596	1.9088	2.9245
1989	Wilderness	1.76	0.1939	1.2216	2.2984
1990	Non-Wilderness	2.52	1.3759	-0.4785	5.5170
1990	Wilderness	1.70	0.2546	1.0434	2.3522
2004	Wilderness	1.82	0.1388	1.4792	2.1583
2005	Non-Wilderness	3.52	NA	NA	NA
2005	Wilderness	3.5200	0.0000	3.5200	3.5200

Summary of Statistical Tests:

t = -2.189, df = 4, p-value = 0.0938

There is suggestive evidence of a difference in Pb content in *Lobaria oregana* from pre-2000 and post 2000 samples (p-value = 0.0938). This analysis was for wilderness areas that had repeated values for Pb in *Lobaria oregana:* Russell Fiords (plot 62 near Harlequin Lake), Tebenkof (33) and Misty Fiords (86, 88).

Relationships are not strong in the Pb content in *Lobaria oregana* after accounting for latitude, longitude, elevation, year (Figures XXV-7, XXV-8 for year) and precipitation (see Brenner, 2006 for all graphed results).

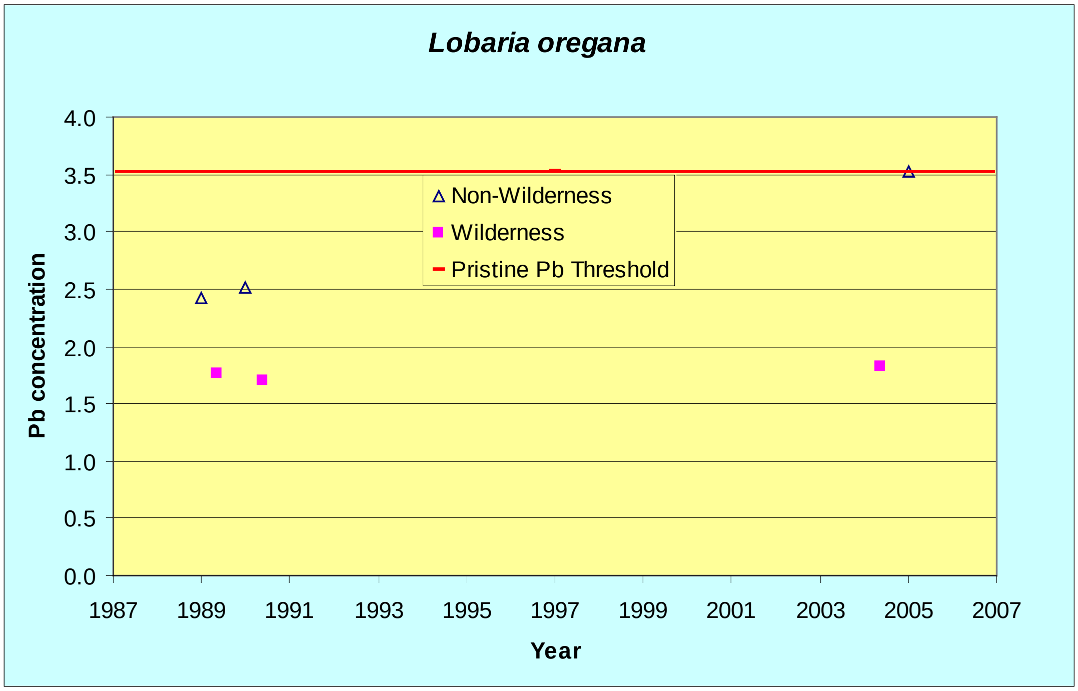

Figure XXV-7. Wilderness and Non-Wilderness yearly means of Pb ppm in *Lobaria oregana* per year.

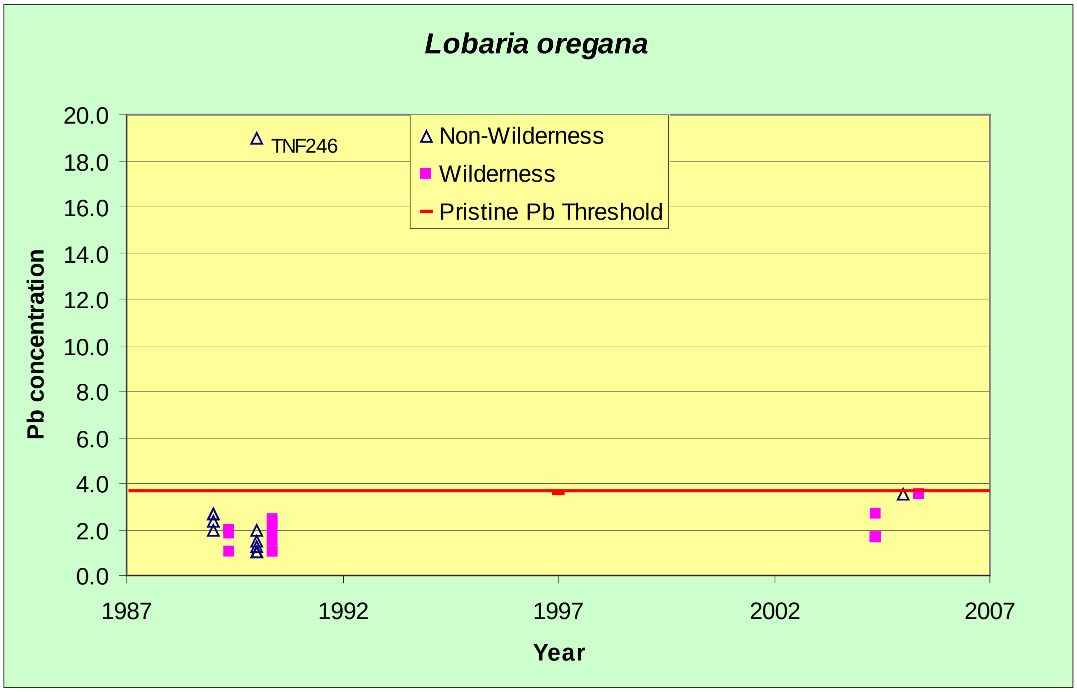

Figure XXV-8. Wilderness and Non-Wilderness plot means of Pb ppm in *Lobaria oregana* per year.

Platismatia glauca

Table XXV-4. Wilderness and Non-Wilderness Means, Standard Errors, and 95% Confidence Intervals for the Pb ppm content of *Platismatia glauca* per year.

Pb ppm				**95% CI**	
Year	**Plot Type**	**Mean**	**Std. Error**	**Lower**	**Upper**
2003	Wilderness	1.68	NA	NA	NA
2004	Wilderness	1.86	0.1405	1.5452	2.1809
2005	Non-Wilderness	155.62	85.2947	37.3316	348.5685
2005	Wilderness	3.52	0.0000	3.5200	3.5200

No t-tests were performed on these data. The mean values for Pb are baseline in *Platismatia glauca.*

Relationships are not strong in Pb content for Plagla after accounting for latitude, longitude, elevation, year (Figures XXV-9, XXV-10 for year) and precipitation (see Brenner, 2006 for all graphed results).

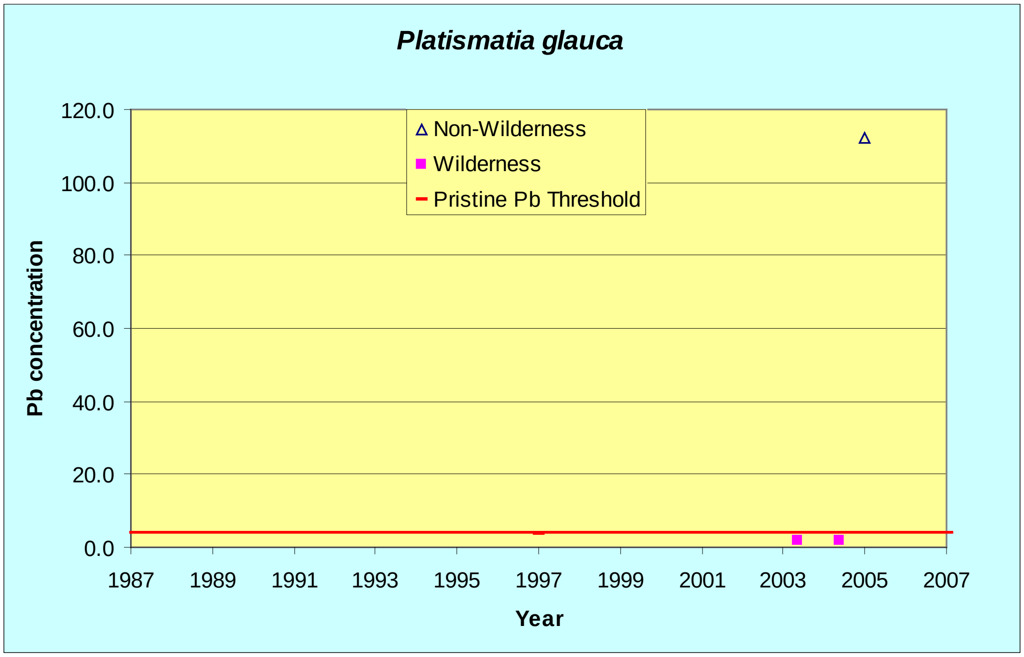

Figure XXV-9. Wilderness and Non-Wilderness yearly means of Pb ppm in *Platismatia glauca* per year.

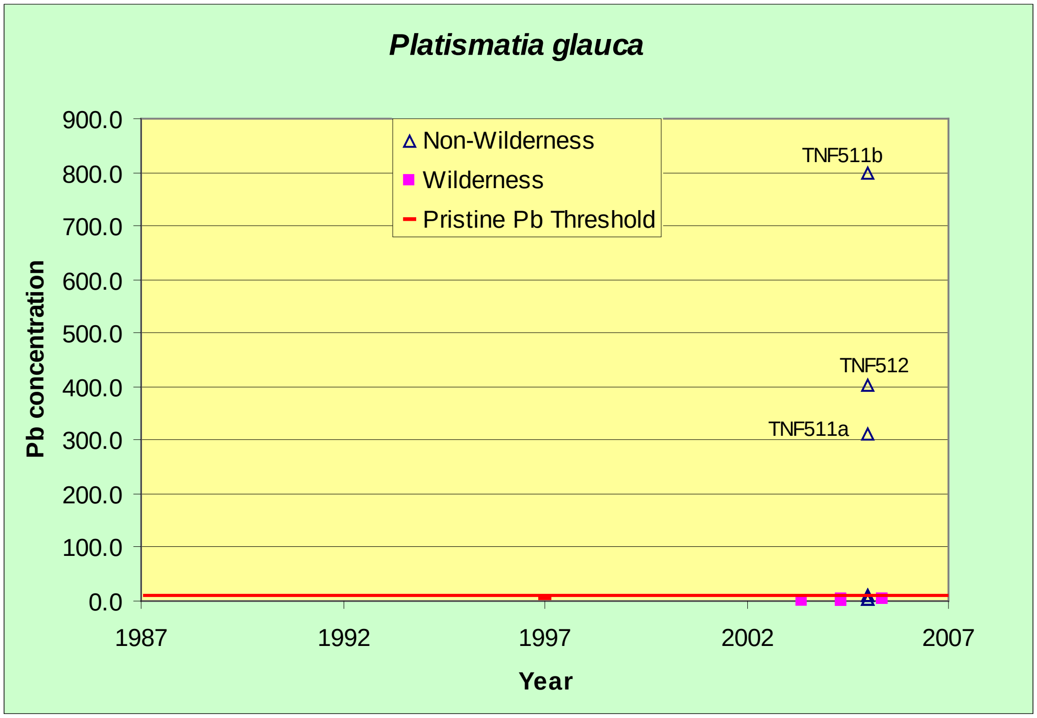

Figure XXV-10. Wilderness and Non-Wilderness plot means of Pb ppm in *Platismatia glauca* per year.

Conclusions: for Lead (Pb) and all lichen species

Lobaria oregana and *Platismatia glauca* were below the detection limits of Pb for the ICP machine for 2005 analysis. In 2004, detection levels in the ICP machine were lower. The provisional thresholds established for the Tongass used the higher 2005 detection level for Plagla and Lobore (around 3.52 ppm). The other lichen species (Alesar and *Hypogymnia*) contain enough Pb to be detected by the ICP analysis. Thresholds are established from generally “pristine” areas. However, some of the wilderness areas on the Tongass contain Pb levels above the ICP detection limit that raises the thresholds for some lichens to a higher value. Lichens can be enhanced with Pb in marine areas (Davidson et al 1985) where many of the wilderness plots are near. Lead from roadways can also travel attached to soil particles for some distance. In Europe, long range atmospheric transport of Pb from densely populated areas has resulted in regionally enhanced levels (Rühling et al 1985). Levels of Pb in lichens from areas enhanced due to urban or industrial sources range between 100 and 12,000 ppm (USDA 1999). A similar range exists for lichens near mining or smelter activities worldwide (USDA 1999). Most of the lichens sampled at Greens Creek mine were above 100 ppm and are considered enhanced due to this industry (see below).

Alectoria sarmentosa

Background for Pb in Alesar from the Pacific Northwest is equal to the Pb threshold in Alesar for the Tongass (5.0 ppm) (USDA 1999). Lichens with enhanced Pb include the Alesar from the Greens Creek tailings pile plot 512 (above 130 ppm) (Figure XXIV-4). Even though Alesar is not as good of accumulator as other species, Pb does accumulate in Alesar in the Greens Creek mine area. It is difficult to equate the amount of Pb accumulated to the amount of Pb actually being emitted into the environment due to this industry. Plot 221 from Douglas Island also is elevated above threshold but is not in the range due to mining or other activates. Elevated levels could be due to the proximity to unpaved roads. Similarly elevated in Pb, the Sitka plot 247 is near the road system and the closed pulp mill, and has not been revisited.

Hypogymnia

Background Pb in *Hypogymnia* from the Pacific Northwest range between 15 and 20 ppm (USDA 1999). The Tongass threshold is within this range of 10 ppm. Plots with *Hypogymnia* from the Sitka road system and closed pulp mill display elevated levels above threshold (239, 241, 242, 243 and 244) (Figure XXIV-6). Levels are just within what is considered enhanced due to urban or industrial levels (above 100 ppm) (USDA 1999). Greens Creek *Hypogymnia* from plots 511b (portal) and 512 (tailings pile) are both very elevated (above 400 ppm) and considered enhanced due to the mining industry.

Lobaria oregana

Background Pb in Lobore from the Pacific Northwest is lower than the Tongass threshold for Pb (1.75 ppm and 3.52 ppm). However, as stated above, the 2004 levels were lower as the detection limit in the ICP machine had changed for the 2005 samples to a higher value, and so the threshold may be slightly inflated. Plot 246 from the Sitka road system was the only plot with Lobore elevated in Pb (Figure XXIV-8).

Platismatia glauca

Background Pb in Plagla from the Pacific Northwest is well above the threshold established for the Tongass (25 ppm and 3.52 ppm respectively). Even though Pb may be elevated in lichens close to the ocean (Davidson et al 1985) the Tongass Pb threshold does not display regional enhancement due to the hypermaritime environment. Greens Creek is the only place Pb is elevated above threshold in Plagla (Figure XXIV-10). Levels are between 300 and 800 ppm, and are within enhancement due to industry. The highest Pb is in lichens at the mine portal. Lead appears to decrease rapidly from the portal as the levels found in Plagla about 200 ft from the portal (plot 511a) are much lower(from 800 ppm at 511b to 300 ppm at plot 511a) (Figure XXIV-10). It is not known how far from the mining activities Pb accumulates in lichens

XVIV. Summary of results for Rubidium (Rb) from all species on the Tongass National Forest

Rubidium is a soft, silvery-white metallic element of the alkali group and is the second most electropositive and alkaline element. It occurs in the earth’s crust and in small amounts in seawater. It occurs abundantly but is so widespread that it is usually obtained through lithium production (Barbalace 2007).

Lichens were analyzed for rubidium during the second monitoring period. All lichens were below detection limit of the ICP machinery (below 53 ppm) and will not be covered further in this report. Thereofre, the provisional threshold for Rb is 53 ppm for all lichen species.

XXVII. Summary of results for Silicon (Si) from all species on the Tongass National Forest

Silicon is one the of earth's most common elements. Silicon does not occur naturally in element form, but rather combined with oxygyn to form a compound called silica. Silica occurs in a free form (ie in sand and quartz) or combines with a variety of metallic oxides called silicates. Airborne silica dust particals vary in size, shape and abrasive properties.

Silicon was not analysed during the first monitoring period. Threshold levels for lichens on the Tongass are the following based on 2003 to 2005 data: *Alectoria sarmentosa* (132.75 ppm); *Hypogymnia* 563.82 ppm), *Lobaria oregana* 681.18 ppm); and *Platismatia glauca* (635.83 ppm).

Lichens from plots elevated in silicon are the following: Alesar plot 512 (Greens Creek) and 508 (Endicott River) (Figure XXVII-4); *Hypogymnia* plots 512 (Greens Creek tailings pile) and 62 (Russell Fiords)(Figure XXVII-6); Lobore plot 495 (Stikine River Flemer cabin)(XXVII-8); and Plagla plot 31 (Stikine River)(XXVII-10).

XXVII. SUMMARY OF Si PPM DATA ANALYSIS

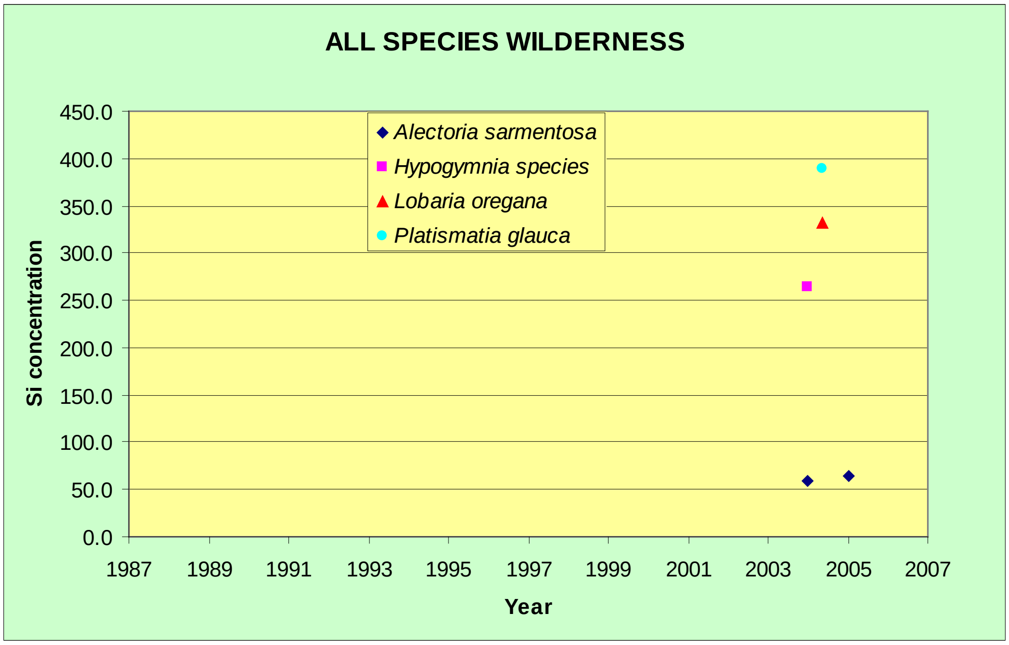

Figure XXVII-1. Wilderness plot means of Si ppm in *All Species* per year.

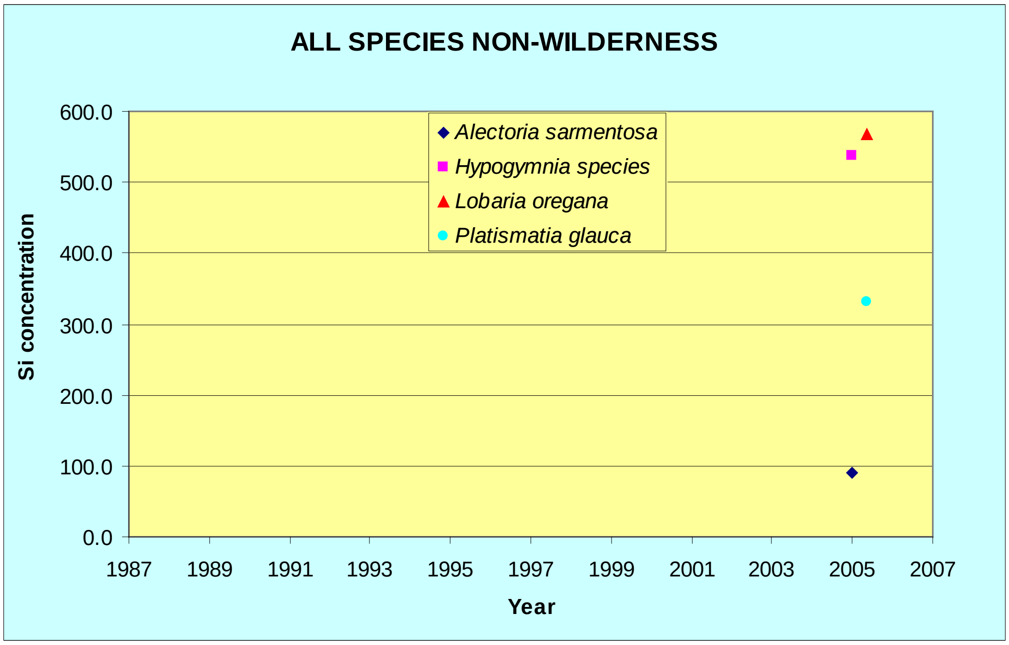

Figure XXVII-2. Non-Wilderness plot means of Si ppm in *All Species* per year.

Alectoria sarmentosa

Table XXVII-1. Wilderness and Non-Wilderness Means, Standard Errors, and 95% Confidence Intervals for the Si ppm content of *Alectoria sarmentosa* per year.

Si ppm				**95% CI**	
Year	**Plot Type**	**Mean**	**Std. Error**	**Lower**	**Upper**
2004	Wilderness	59.88	4.6889	50.1827	69.5822
2005	Non-Wilderness	91.17	24.4854	28.2296	154.1131
2005	Wilderness	64.13	13.1451	34.3891	93.8617

No t-tests were performed on these data. The mean values for Si are baseline in *Alectoria sarmentosa.*

Relationships are not strong in Si content for Alesar after accounting for latitude, longitude, elevation, year (Figures XXVII-3, XXVII-4 for year) and precipitation (see Brenner, 2006 for all graphed results).

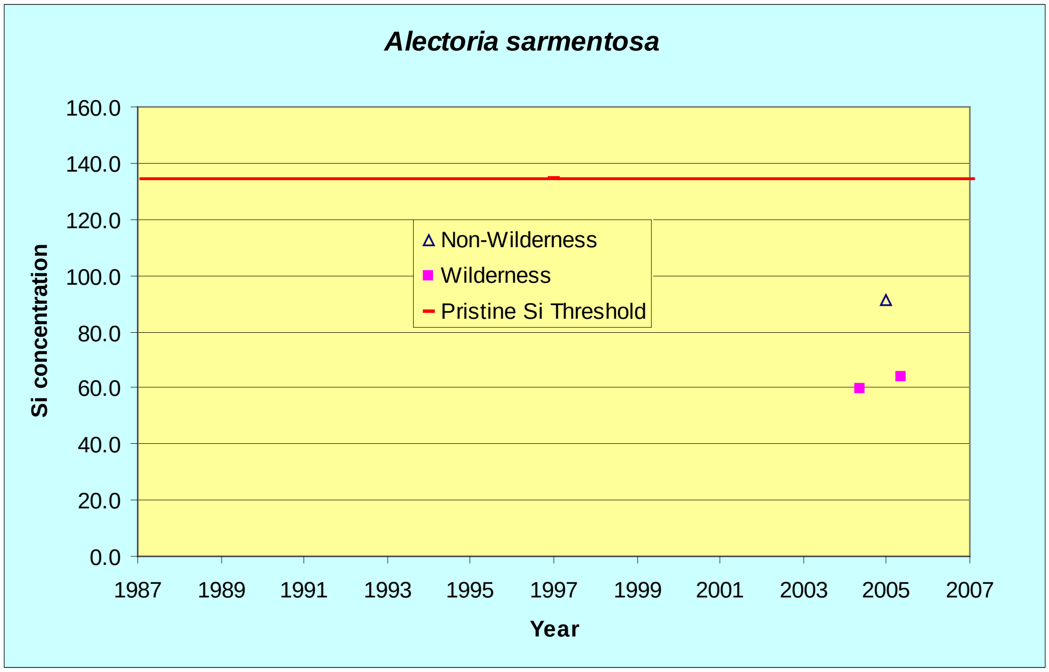

Figure XXVII-3. Wilderness and Non-Wilderness yearly means of Si ppm in *Alectoria sarmentosa* per year.

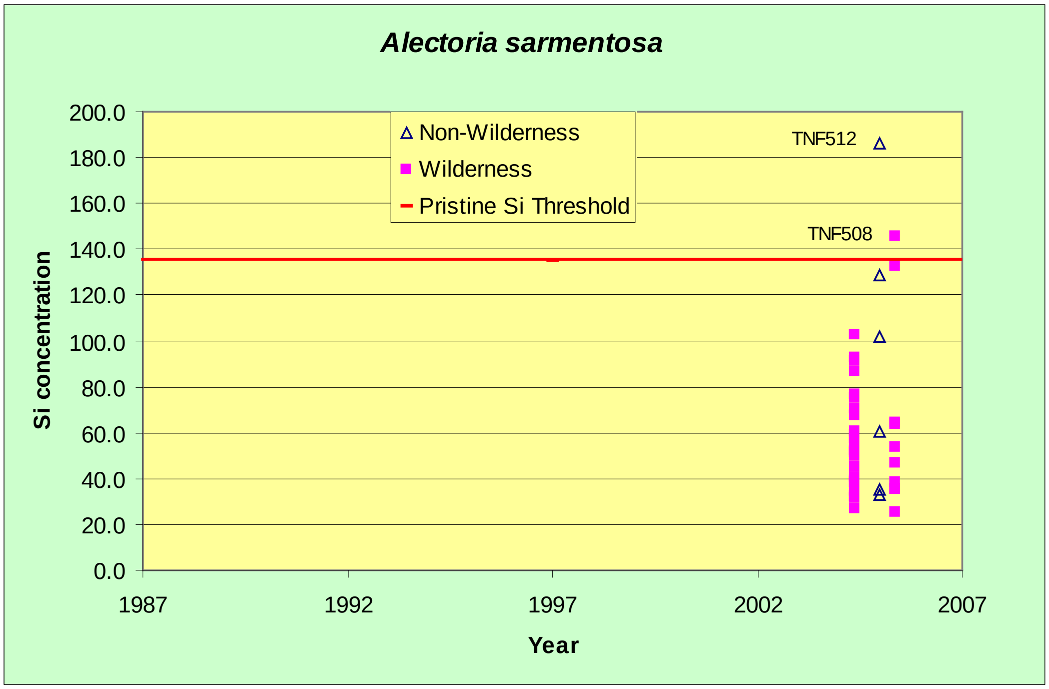

Figure XXVII-4. Wilderness and Non-Wilderness plot means of Si ppm in *Alectoria sarmentosa* per year.

Hypogymnia species

In this series, all of the *Hypogymnia* species were included as a group.

Table XXVII-2. Wilderness and Non-Wilderness Means, Standard Errors, and 95% Confidence Intervals for the Si ppm content of *Hypogymnia species* per year.

Si ppm				95% CI	
Year	**Plot Type**	**Mean**	**Std. Error**	**Lower**	**Upper**
2004	Wilderness	264.42	32.8639	179.9358	348.8947
2005	Non-Wilderness	537.33	97.8674	116.2390	958.4176
2005	Wilderness	309.10	46.4001	202.1028	416.1005

No t-tests were performed on these data. The mean values for Si are baseline in *Hypogymnia.*

Relationships are not strong in Si content for *Hypogymnia* after accounting for latitude, longitude, elevation, year (Figures XXVII-5, XXVII-6 for year) and precipitation (see Brenner, 2006 for all graphed results).

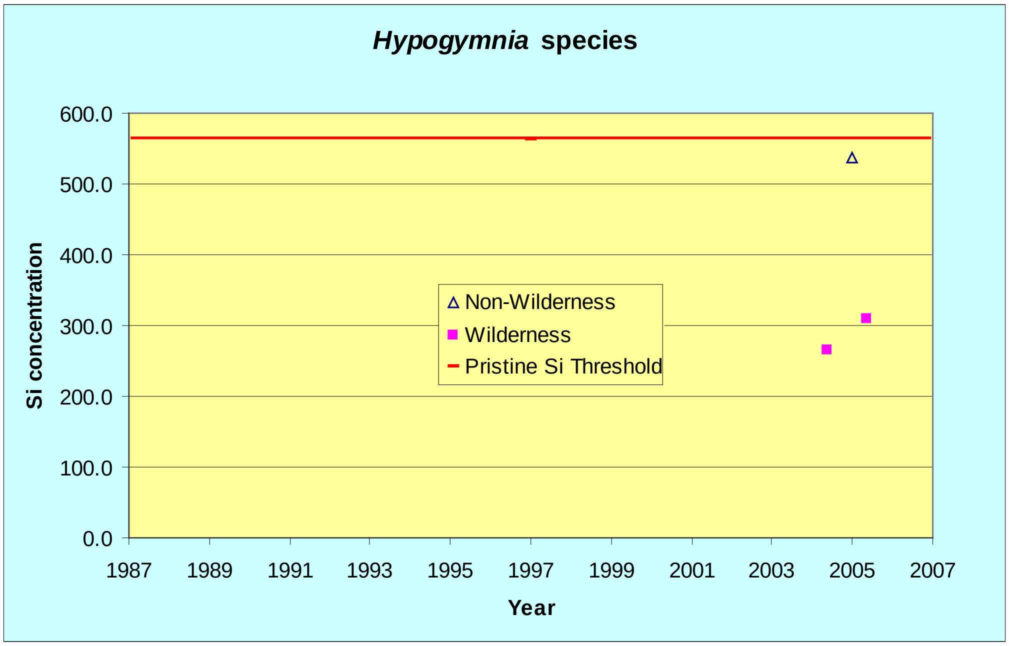

Figure XXVII-5. Wilderness and Non-Wilderness yearly means of Si ppm in *Hypogymnia species* per year.

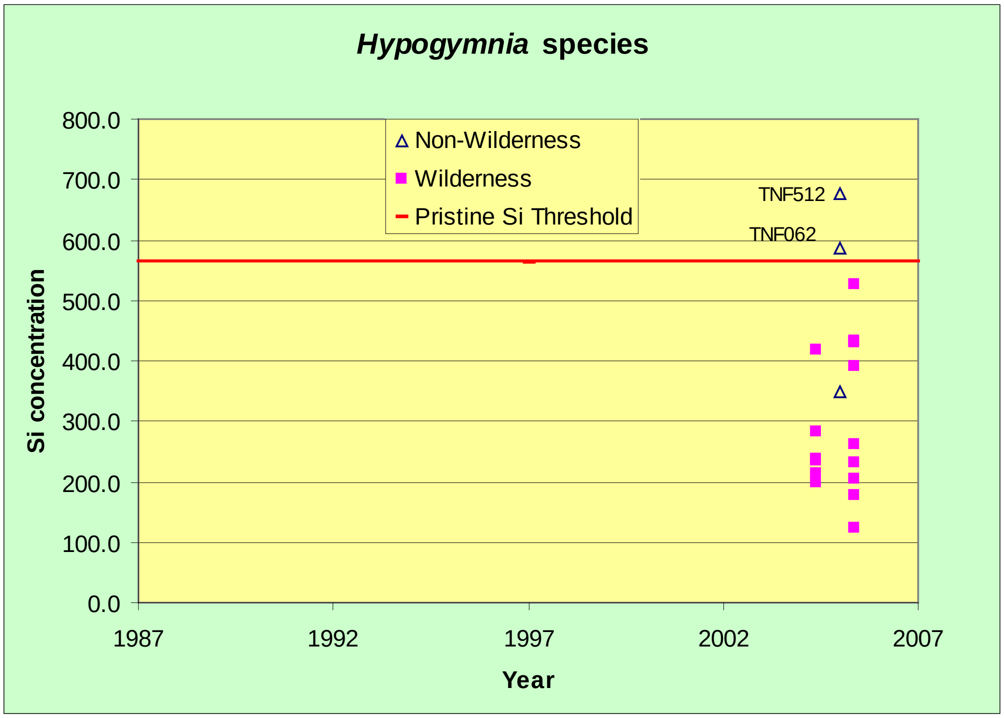

Figure XXVII-6. Wilderness and Non-Wilderness plot means of Si ppm in *Hypogymnia species* per year.

Lobaria oregana

Table XXVII-4. Wilderness and Non-Wilderness Means, Standard Errors, and 95% Confidence Intervals for the Si ppm content of *Lobaria oregana* per year.

Si ppm				**95% CI**	
Year	**Plot Type**	**Mean**	**Std. Error**	**Lower**	**Upper**
2004	Wilderness	332.41	96.8681	95.3837	569.4390
2005	Non-Wilderness	567.28	NA	NA	NA
2005	Wilderness	117.7676	60.9940	NA	311.8777

No t-tests were performed on these data. The mean values for Si are baseline in *Lobaria oregana.*

Relationships are not strong in Si content for Lobore after accounting for latitude, longitude, elevation, year (Figures XXVII-5, XXVII-6 for year) and precipitation (see Brenner, 2006 for all graphed results).

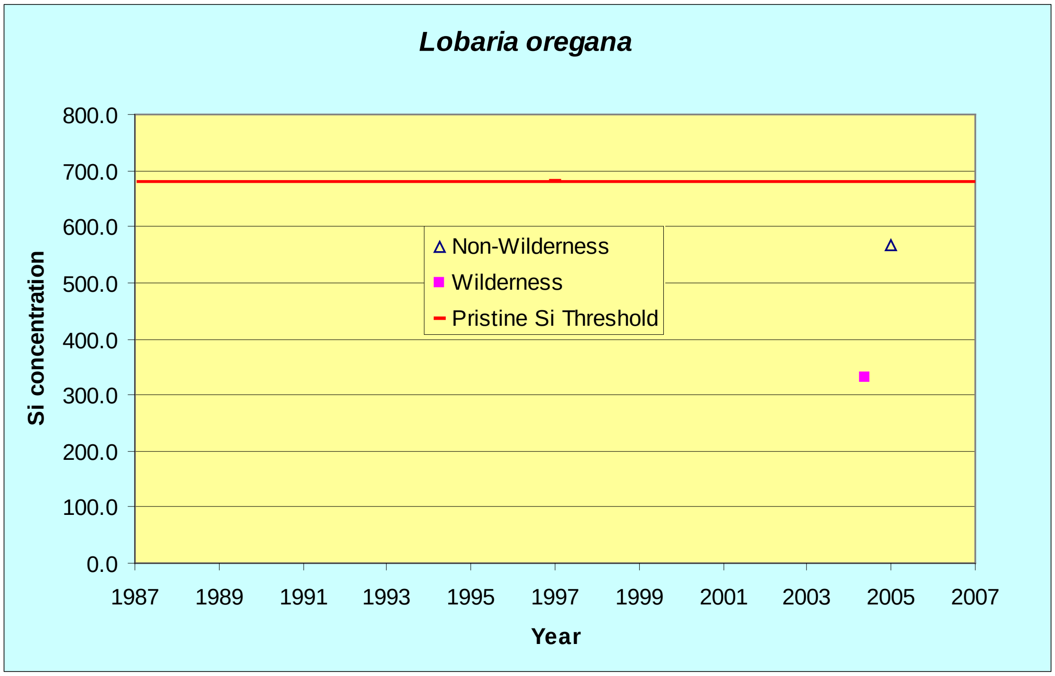

Figure XXVII-7. Wilderness and Non-Wilderness yearly means of Si ppm in *Lobaria oregana* per year.

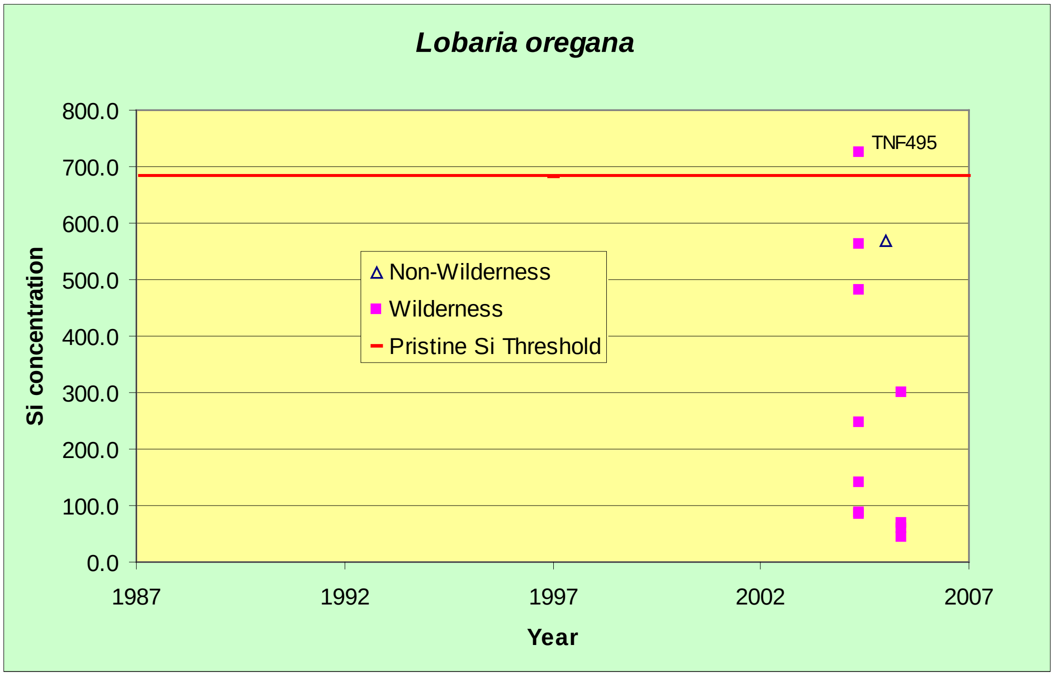

Figure XXVII-8. Wilderness and Non-Wilderness plot means of Si ppm in *Lobaria oregana* per year.

Platismatia glauca

Table XXVII-4. Wilderness and Non-Wilderness Means, Standard Errors, and 95% Confidence Intervals for the Si ppm content of *Platismatia glauca* per year.

Si ppm				**95% CI**	
Year	**Plot Type**	**Mean**	**Std. Error**	**Lower**	**Upper**
2004	Wilderness	389.73	63.0716	247.0559	532.4114
2005	Non-Wilderness	524.88	22.3015	474.4295	575.3285
2005	Wilderness	352.75	58.0100	215.5789	489.9224

No t-tests were performed on these data. The mean values for Si are baseline in *Platismatia glauca*

Relationships are not strong in Si content for Plagla after accounting for latitude, longitude, elevation, year (Figures XXVIII-9, XXVII-10 for year) and precipitation (see Brenner, 2006 for all graphed results).

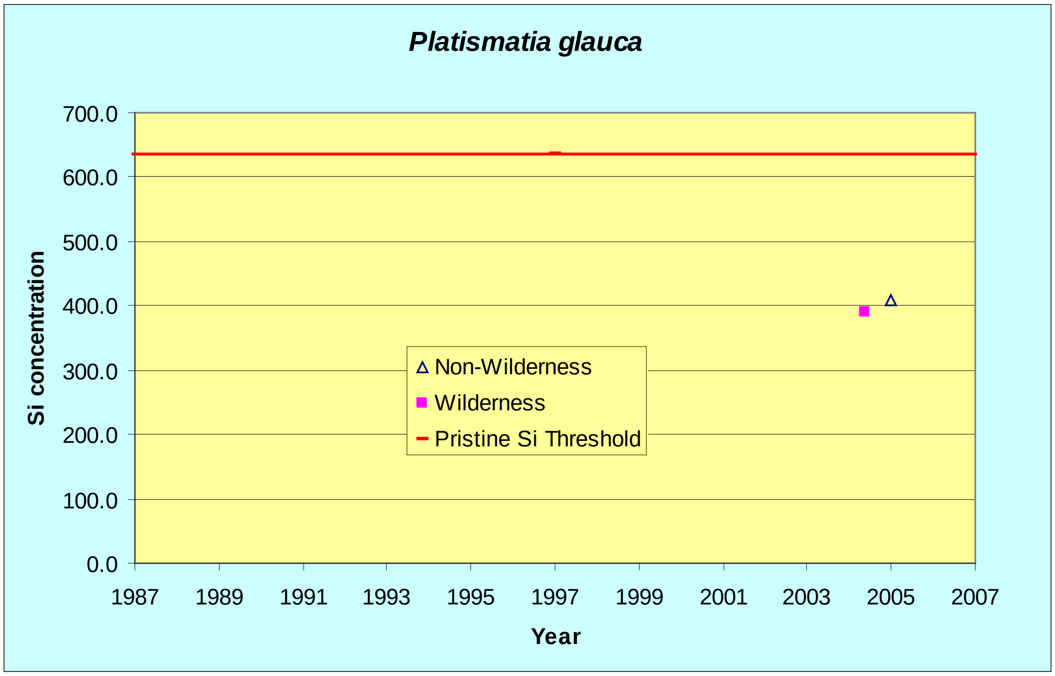

Figure XXVII-9. Wilderness and Non-Wilderness yearly means of Si ppm in *Platismatia glauca* per year.

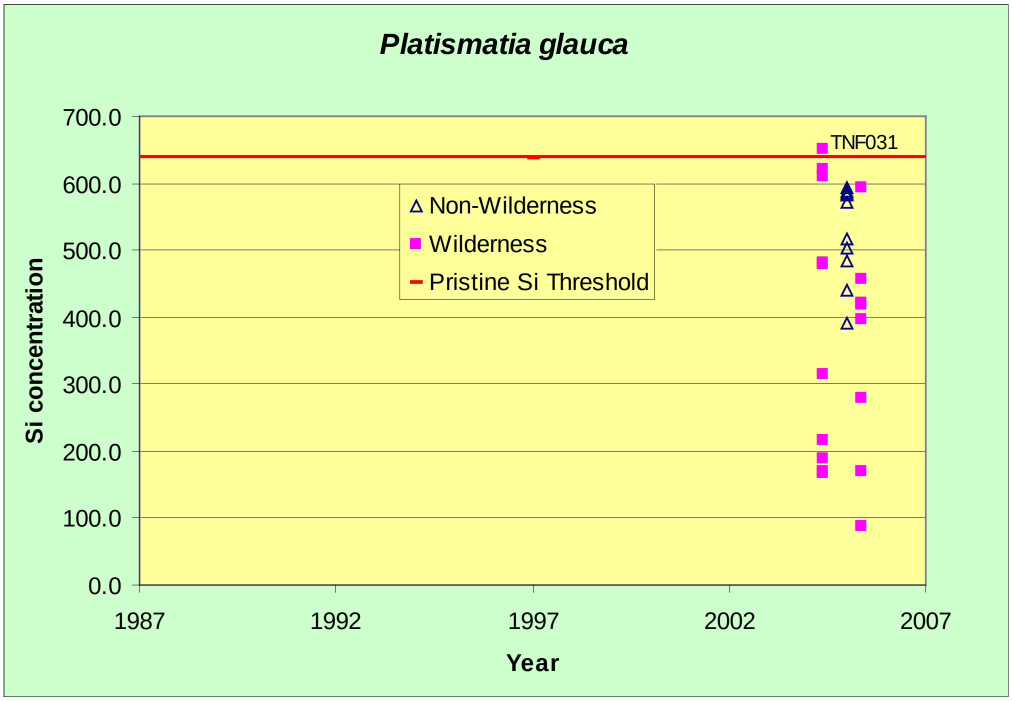

Figure XXVII-10. Wilderness and Non-Wilderness plot means of Si ppm in *Platismatia glauca* per year.

Conclusions: for Silicon (Si) and all lichen species
Background levels of Si are not available for lichens from the Pacific Northwest. Locations on the Tongass with elevated Si may be due to windblown soils and dust from interior regions.

Alectoria sarmentosa

Lichens from plot 508 from Endicott River are elevated in Si and is most likely associated with windblown soils and dusts from the glaciers and other geological features of the Chilkat Peninsula. Plot 512 from Greens Creek may be elevated due to the proximity to the tailings pile that contains siliceous rocks.

Hypogymnia

Similar to Alesar above, *Hypogymnia* in plot 512 at Greens Creek must be elevated due to the proximity to the open tailings pile. Lichens from plot 62 from Russell Fiords are probably influenced by the windblown dusts from the Yukon, and from the nearby road and airstrip.

Lobaria oregana

The Stikine River plot 495 from Flemer cabin is most likely elevated in Si due to windblown soils on the river from the interior.

Platismatia glauca

Stikine River plot 31 from the main river near the ADFG cabin is most likely elevated due to the windblown soils and sands on the river.

.

XXVIII. Summary of results for Strontium (Sr) from all species on the Tongass National Forest

Strontium is an alkaline earth metal that occurs naturally as a non-radioactive element. In nature, it is present in igneous rocks of the earth's crust and in seawater (ATSDR 2004). The stable forms of commercial interest are found in the minerals celestite and strontianite. It is also a minor component of other mineral deposits such as in veins associated with limestone or dolomite, or in or near sedimentary rocks associated with beds of gypsum, anhydrite, and rock salt. Strontium compounds are used in making ceramics and glass products, pyrotechnics, paint pigments, fluorescent lights, and medicines.

Strontium was not analyzed in lichens during the first monitoring period. Thresholds are established from the 2003 to 2005 data. Thresholds in lichens from the Tongass are the following: *Alectoria sarmentosa* (33.56 ppm); *Hypogymnia* (61.26 ppm); *Lobaria oregana* (6.30 ppm) and *Platismatia glauca* (28.91 ppm).

Only a few plots have lichens elevated above threshold for Sr: Alesar plot 513 (Coronation Island Egg harbor)(Figure XXVIII-4); *Hypogymnia* (Coronation Island Egg harbor)(Figure XXVIII-6); Lobore plot 62 is just at threshold (Russell Fiords)(Figure XXVIII-8) and Plagla plot 510 (Warren Island)(Figure XXVIII-10).

XXVIII. SUMMARY OF Sr PPM DATA ANALYSIS

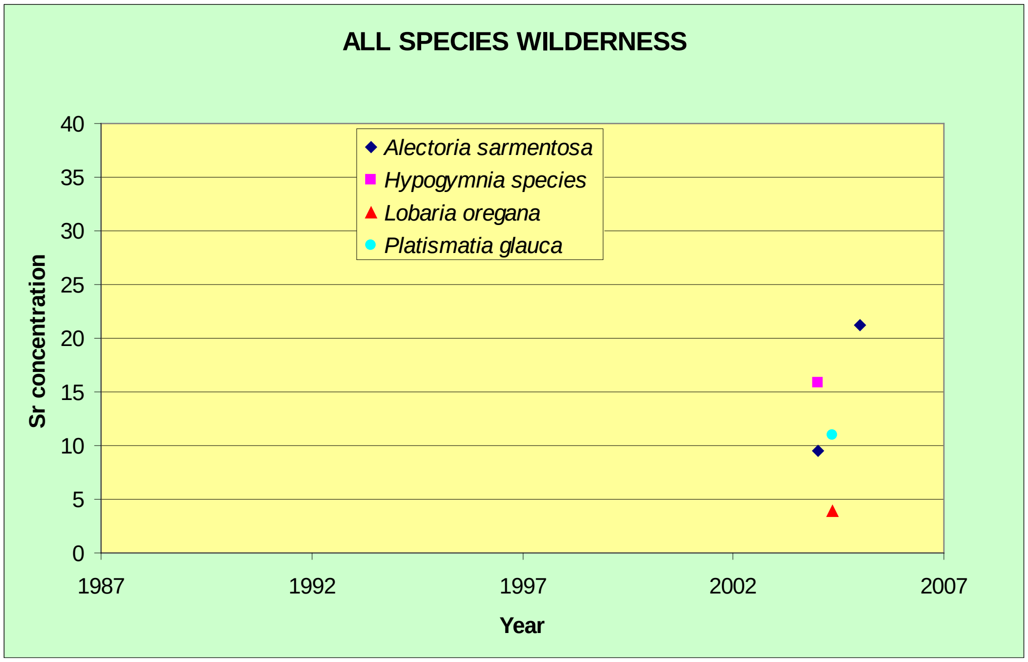

Figure XXVIII-1. Wilderness plot means of Sr ppm in *All Species* per year.

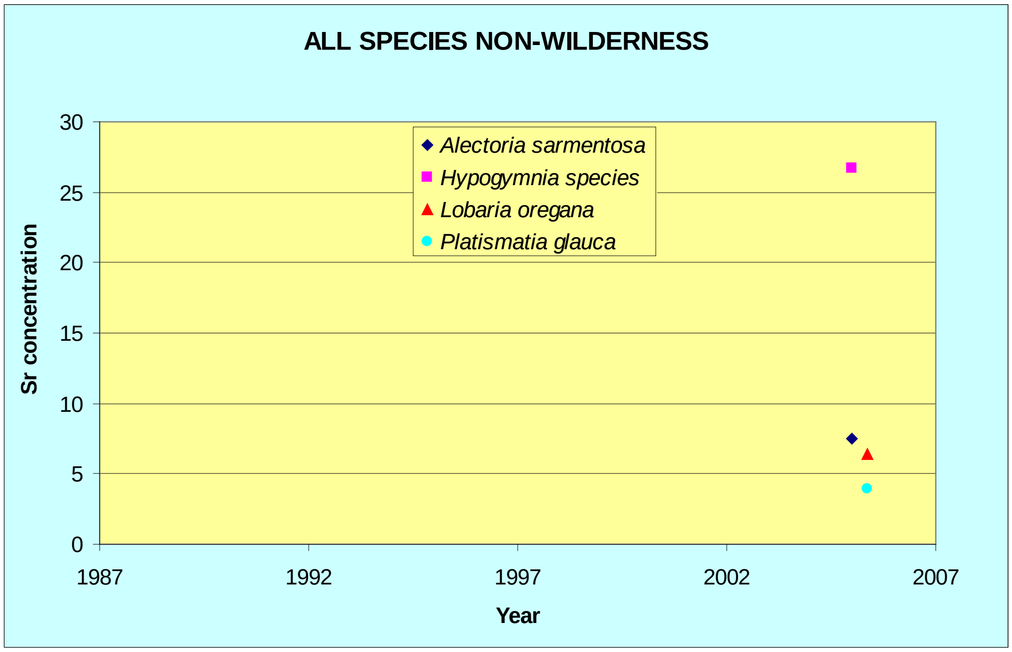

Figure XXVIII-2. Non-Wilderness plot means of Sr ppm in *All Species* per year.

Alectoria sarmentosa

Table XXVIII-1. Wilderness and Non-Wilderness Means, Standard Errors, and 95% Confidence Intervals for the Sr ppm content of *Alectoria sarmentosa* per year.

Sr ppm				95% CI	
Year	**Plot Type**	**Mean**	**Std. Error**	**Lower**	**Upper**
2004	Wilderness	9.46	1.3757	6.6153	12.3071
2005	Non-Wilderness	7.50	1.7813	2.9224	12.0803
2005	Wilderness	21.26	2.8934	14.7117	27.8023

No t-tests were performed on these data. The mean values for Sr are baseline in *Alectoria sarmentosa.*

Relationships are not strong in Sr content for Alesar after accounting for latitude, longitude, elevation, year (Figures XXVII-3, XXVII-4 for year) and precipitation (see Brenner, 2006 for all graphed results)

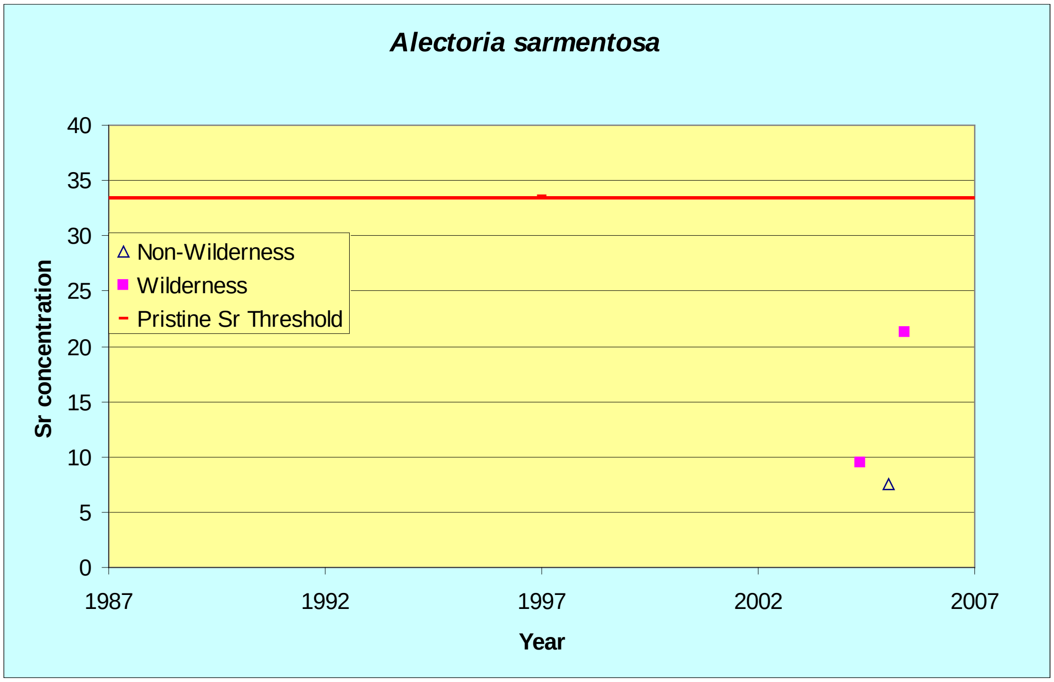

Figure XXVIII-3. Wilderness and Non-Wilderness yearly means of Sr ppm in *Alectoria sarmentosa* per year.

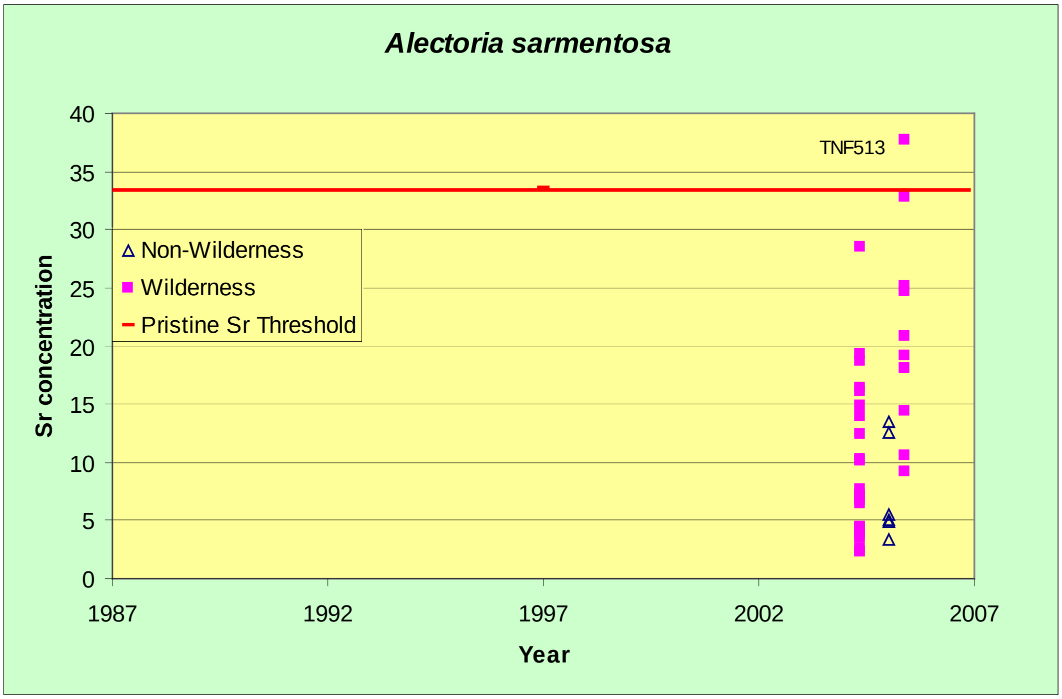

Figure XXVIII-4. Wilderness and Non-Wilderness plot means of Sr ppm in *Alectoria sarmentosa* per year.

Hypogymnia species

In this series, all of the *Hypogymnia* species were included as a group.

Table XXVIII-2. Wilderness and Non-Wilderness Means, Standard Errors, and 95% Confidence Intervals for the Sr ppm content of *Hypogymnia species* per year.

Sr ppm				**95% CI**	
Year	**Plot Type**	**Mean**	**Std. Error**	**Lower**	**Upper**
2004	Wilderness	15.90	3.3499	7.2877	24.5099
2005	Non-Wilderness	26.71	9.6389	14.7653	68.1803
2005	Wilderness	37.38	5.7698	24.0721	50.6823

No t-tests were performed on these data. The mean values for Sr are baseline in *Hypogymnia.*

Relationships are not strong in Sr content for *Hypogymnia* after accounting for latitude, longitude, elevation, year (Figures XXVIII-5, XXVIII-6 for year) and precipitation (see Brenner, 2006 for all graphed results)

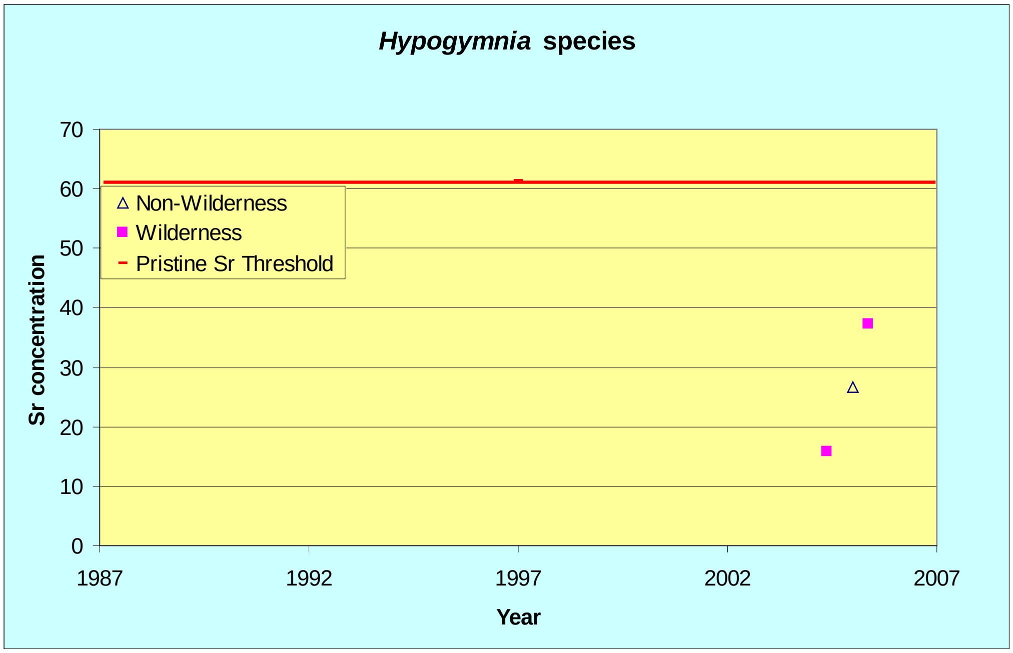

Figure XXVIII-5. Wilderness and Non-Wilderness yearly means of Sr ppm in *Hypogymnia species* per year.

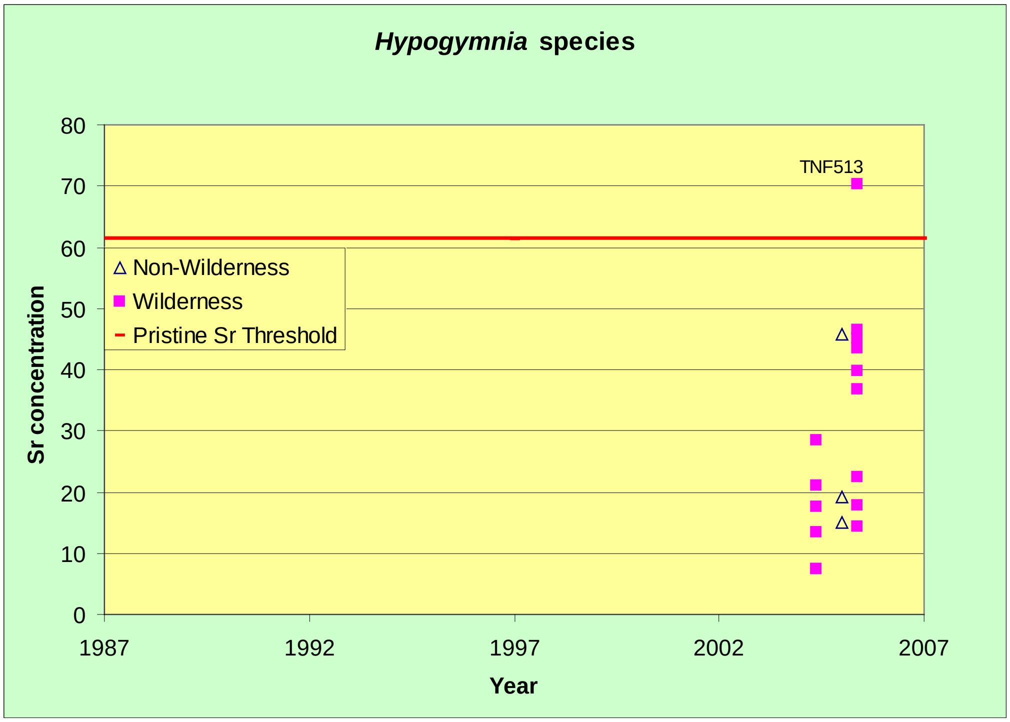

Figure XXVIII-6. Wilderness and Non-Wilderness plot means of Sr ppm in *Hypogymnia species* per year.

Lobaria oregana

Table XXVIII-3. Wilderness and Non-Wilderness Means, Standard Errors, and 95% Confidence Intervals for the Sr ppm content of *Lobaria oregana* per year.

Sr ppm				95% CI	
Year	**Plot Type**	**Mean**	**Std. Error**	**Lower**	**Upper**
2004	Wilderness	3.93	0.5206	2.6519	5.1995
2005	Non-Wilderness	6.37	NA	NA	NA
2005	Wilderness	3.1641	1.2125	-0.6946	7.0229

No t-tests or regression were performed on these data due to lack of repeated samples. The mean values for Sr are baseline in *Lobaria oregana*

Relationships are not strong in Sr content for Lobore after accounting for latitude, longitude, elevation, year (Figures XXVIII-7, XXVIII-8 for year) and precipitation (see Brenner, 2006 for all graphed results).

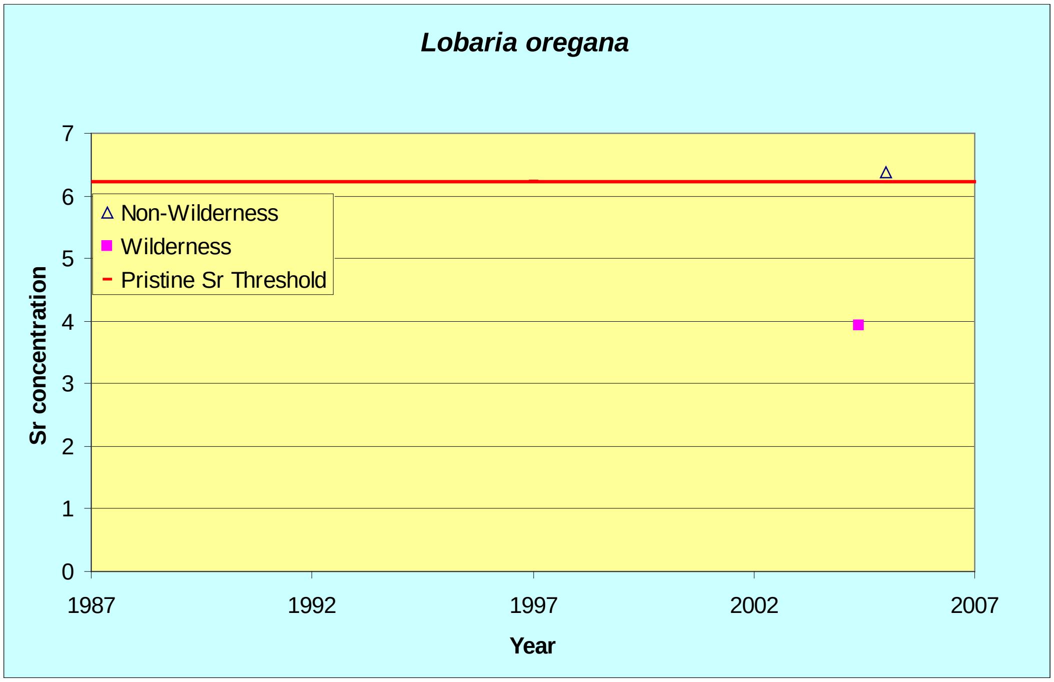

Figure XXVIII-7. Wilderness and Non-Wilderness yearly means of Sr ppm in *Lobaria oregana* per year.

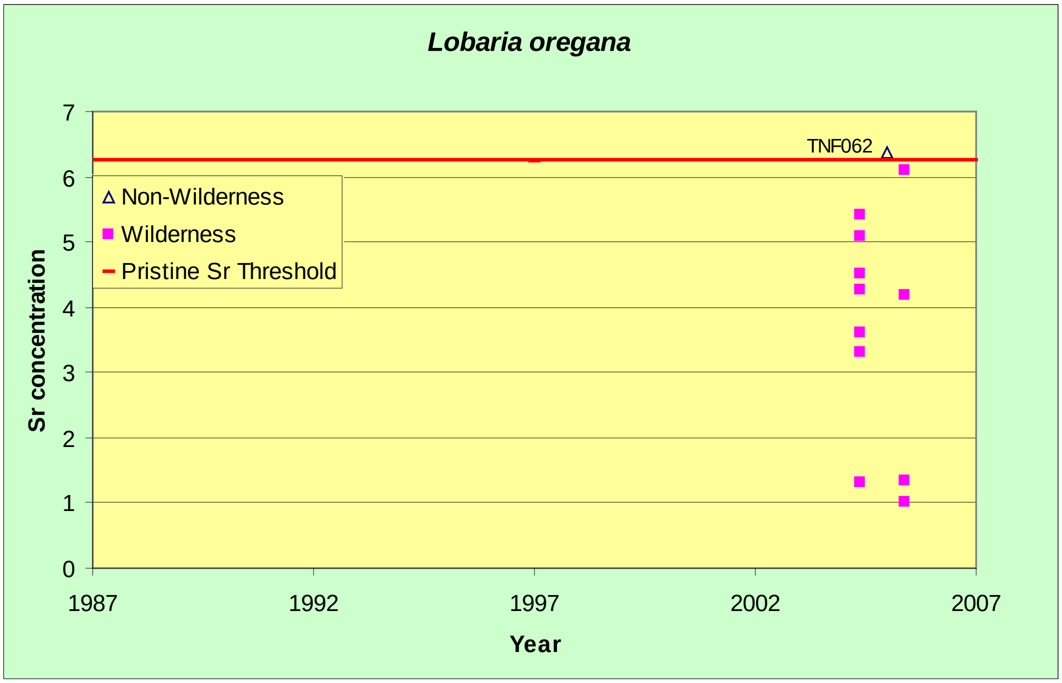

Figure XXVIII-8. Wilderness and Non-Wilderness plot means of Sr ppm in *Lobaria oregana* per year.

Platismatia glauca

Table XXVIII-4. Wilderness and Non-Wilderness Means, Standard Errors, and 95% Confidence Intervals for the Sr ppm content of *Platismatia glauca* per year.

Sr ppm				**95% CI**	
Year	**Plot Type**	**Mean**	**Std. Error**	**Lower**	**Upper**
2004	Wilderness	10.96	2.5239	5.2512	16.6700
2005	Non-Wilderness	12.36	1.4866	8.9956	15.7215
2005	Wilderness	19.93	2.3339	14.4071	25.4449

No t-tests were performed on these data. The mean values for Sr are baseline in *Platismatia glauca.*

Relationships are not strong in Sr content for Plagla after accounting for latitude, longitude, elevation, year (Figures XXVIII-9, XXVIII-10 for year) and precipitation (see Brenner, 2006 for all graphed results).

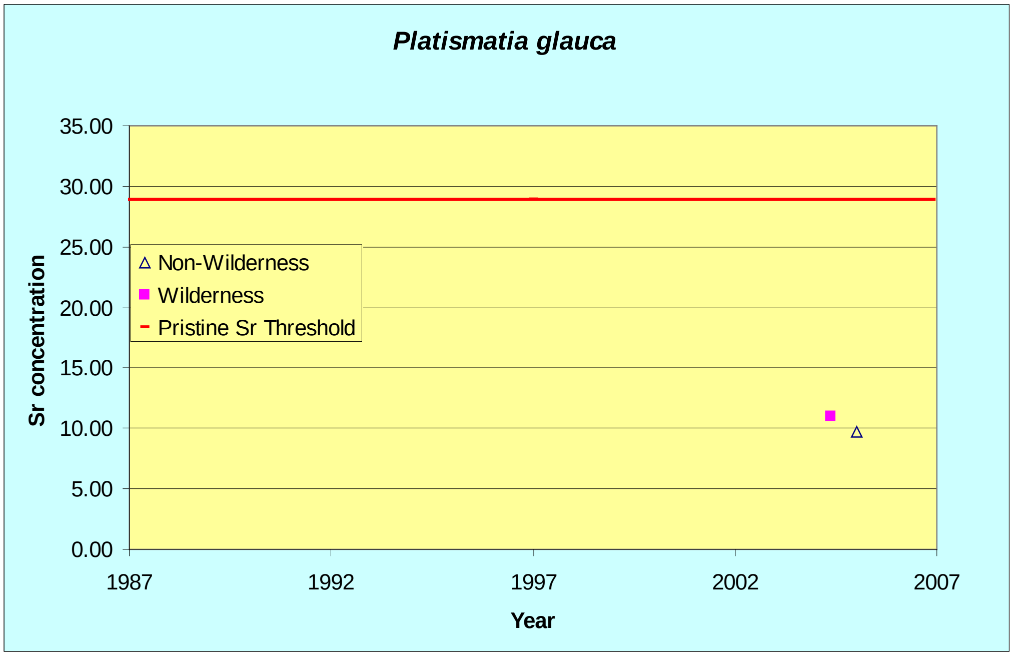

Figure XXVIII-9. Wilderness and Non-Wilderness yearly means of Sr ppm in *Platismatia glauca* per year.

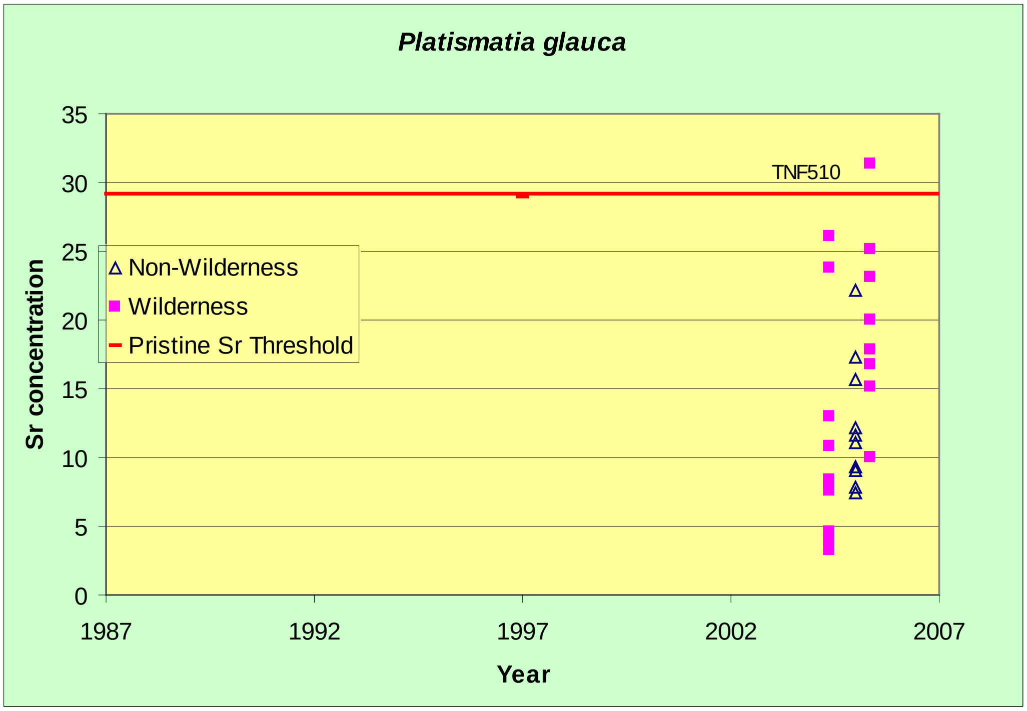

Figure XXVIII-10. Wilderness and Non-Wilderness plot means of Sr ppm in *Platismatia glauca* per year.

Conclusions: for Strontium (Sr) and all lichen species

Background Sr is not available for the Pacific Northwest. Strontium is not expected to be an anthropogenic pollutant on the Tongass, and elevated levels are most likely due to natural sources**.**

Alectoria sarmentosa

Plot 513 from Coronation Island is elevated above threshold (Figure XXIV-4). This may be party do the natural variation in Sr, or related to the close proximity to the ocean at Egg Harbor. This area is also of limestone geology, where Sr can be found associated.

Hypogymnia

Plot 513 from Coronation Island is above Sr threshold for *Hypogymnia* for the same explanations with Alesar.

Lobaria oregana

Plot 62 from Russell Fiords Harlequin Lake area is just at threshold level for Sr in Lobore (Figure XXIV-8). This area reportedly receives a lot of windblown dusts from the Yukon, and surrounding geology, which could be an explanation for being the highest in Sr on the Tongass.

Platismatia glauca

Plot 510 from Warren Island is elevated in Sr for Plagla (Figure XXIV-10). Similar to Coronation Island, Warren is exposed to the open Pacific and extreme salt spray. Lichens may be elevated due to seashore enhancement.

XXIX. Summary of results for Titanium (Ti) from all species on the Tongass National Forest

Titanium is a white metal present in the earth's crust, meteorites, and the sun. It is always found in igneous rocks and the sediments derived by them (Weast et al 1987). Titanium is also present in iron ores, ash of coal, plants, natural bodies of water, and the human body. It is an important alloying agent with metals such as aluminum, molybdenum, manganese, and iron. Titanium metal is lightweight and has resistance to saltwater. It is used in the rigging, shafts and propellers of ocean vessels. Titanium dioxide is used in artists and house paints, accounting for the largest use of this element.

Titanium was not analyzed during the first monitoring period. Provisional Tongass thresholds for Ti are from the 2004 and 2005 data and are the following: *Alectoria sarmentosa* (4.93 ppm); *Hypogymnia* (62.42 ppm); *Lobaria oregana* (45.30 ppm); and *Platismatia glauca* (76.86 ppm).

Plots with lichens elevated above threshold for Ti are: Alesar plot 512 (Greens Creek tailings pile), plot 1000 (Mt Roberts 175 ft elevation), and plot 508 (Endicott River)(Figure XXIX-4) ; *Hypogymnia* plot 512 (Greens Creek tailings), and plot 62 (Russell Fiords-Harlequin Lake) (Figure XXIX-6); Lobore plot 62 is on the edge of threshold (Russell Fiords) (Figure XXIX-8); and Plagla plot 512 (Greens Creek), plot 62 (Russell Fiord), and plot 1000 (Mt Roberts) is at threshold (Figure XXIX-10).

XXXIX. SUMMARY OF Ti PPM DATA ANALYSIS

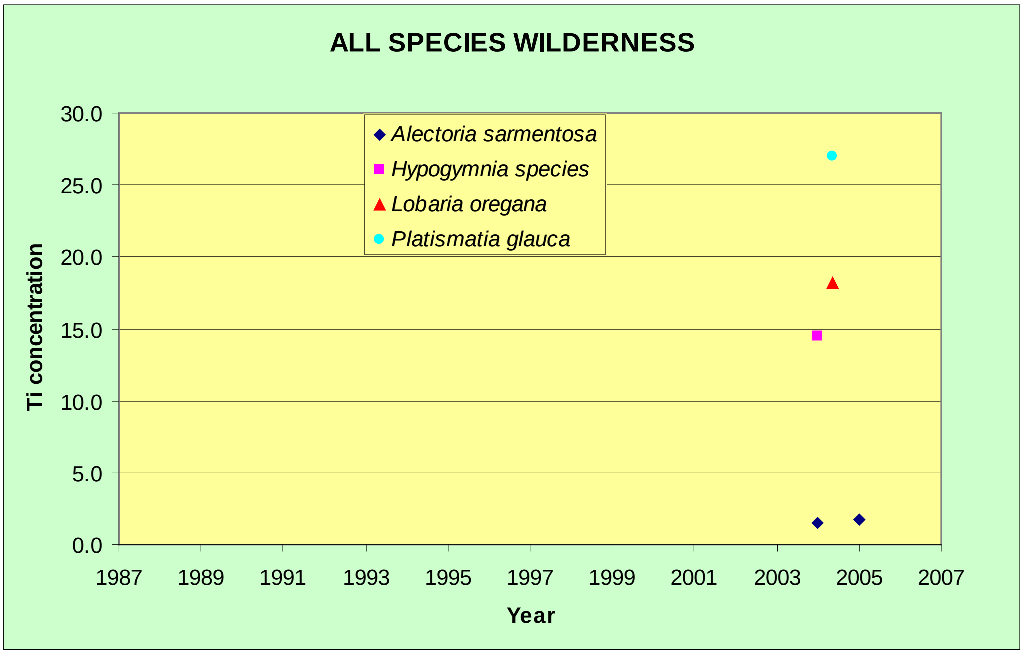

Figure XXIX-1. Wilderness plot means of Ti ppm in *All Species* per year.

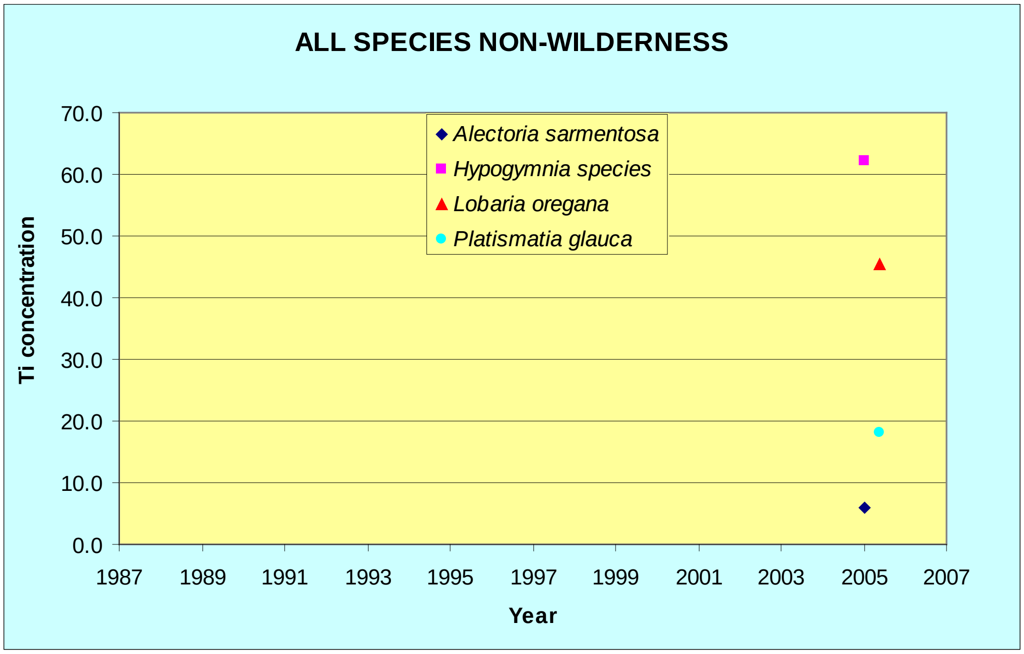

Figure XXIX-2. Non-Wilderness plot means of Ti ppm in *All Species* per year.

Alectoria sarmentosa

Table XXIX-1. Wilderness and Non-Wilderness Means, Standard Errors, and 95% Confidence Intervals for the Ti ppm content of *Alectoria sarmentosa* per year.

Ti ppm				**95% CI**	
Year	**Plot Type**	**Mean**	**Std. Error**	**Lower**	**Upper**
2004	Wilderness	1.54	0.1631	1.2042	1.8790
2005	Non-Wilderness	5.92	2.0308	0.7029	11.1438
2005	Wilderness	1.73	0.5346	0.5238	2.9426

No t-tests were performed on these data. The mean values for Ti are baseline in *Alectoria sarmentosa.*

Relationships are not strong in Ti content for Alesar after accounting for latitude, longitude, elevation, year (Figures XXIX-3, XXIX-4 for year) and precipitation (see Brenner, 2006 for all graphed results).

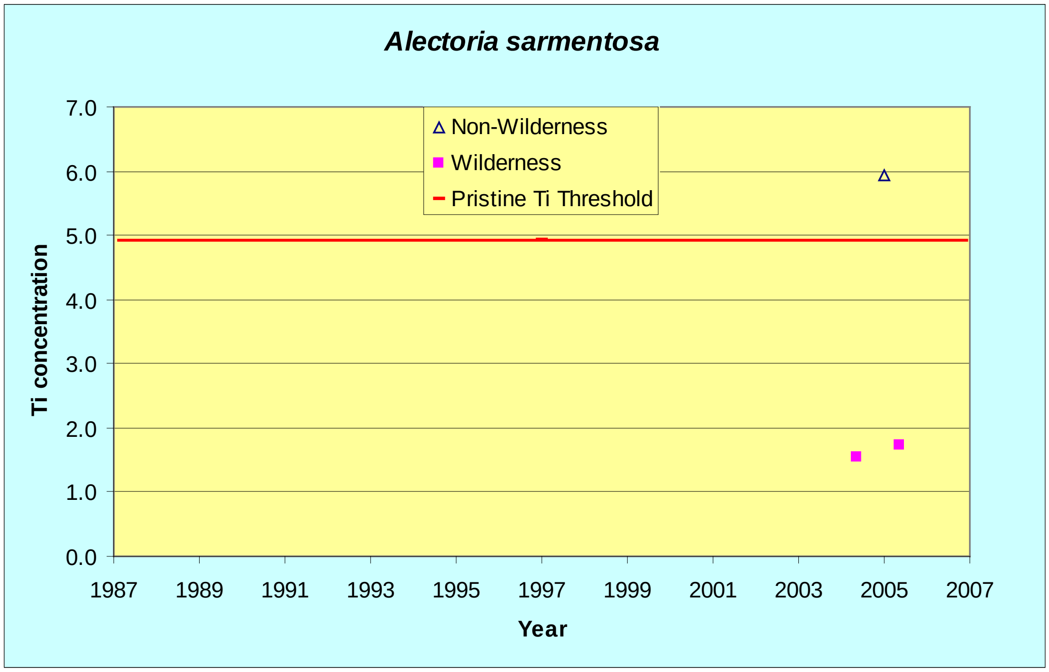

Figure XXIX-3. Wilderness and Non-Wilderness yearly means of Ti ppm in *Alectoria sarmentosa* per year.

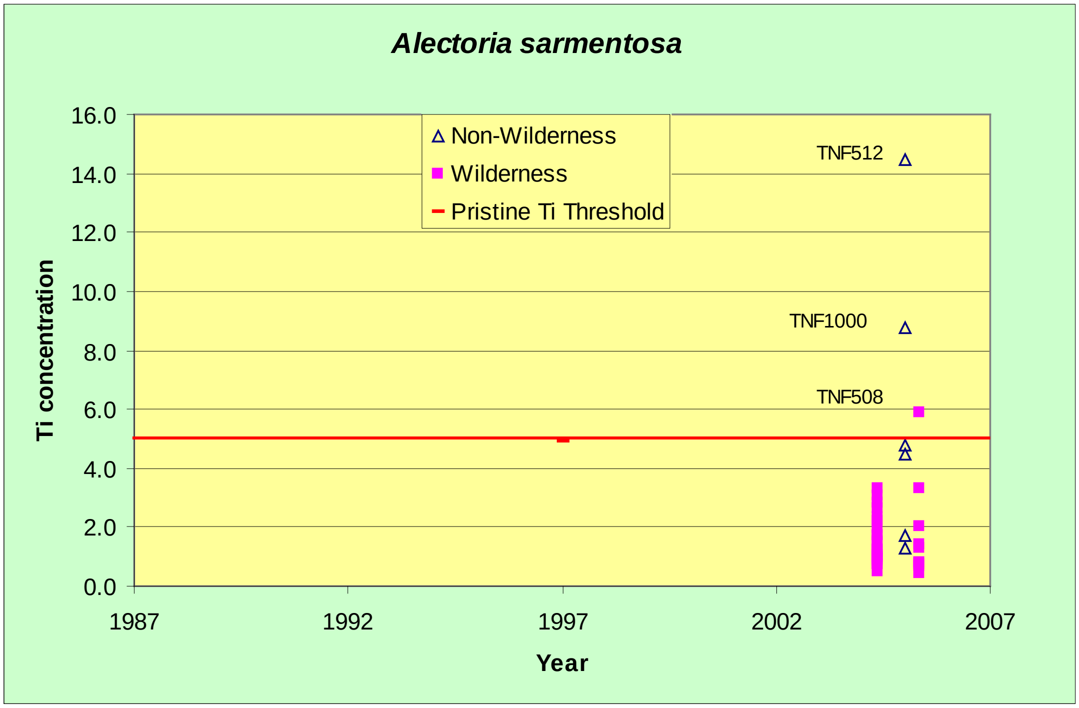

Figure XXIX-4. Wilderness and Non-Wilderness plot means of Ti ppm in *Alectoria sarmentosa* per year.

Hypogymnia species

In this series, all of the *Hypogymnia* species were included as a group.

Table XXIX-2. Wilderness and Non-Wilderness Means, Standard Errors, and 95% Confidence Intervals for the Ti ppm content of *Hypogymnia species* per year.

Ti ppm				95% CI	
Year	**Plot Type**	**Mean**	**Std. Error**	**Lower**	**Upper**
2004	Wilderness	14.52	5.0042	1.6582	27.3855
2005	Non-Wilderness	62.14	20.9610	28.0471	152.3288
2005	Wilderness	18.86	5.2284	6.8037	30.9170

No t-tests were performed on these data. The mean values for Ti are baseline in *Hypogymnia.*

Relationships are not strong in Ti content for *Hypogymnia* after accounting for latitude, longitude, elevation, year (Figures XXIX-5, XXIX-6 for year) and precipitation (see Brenner, 2006 for all graphed results).

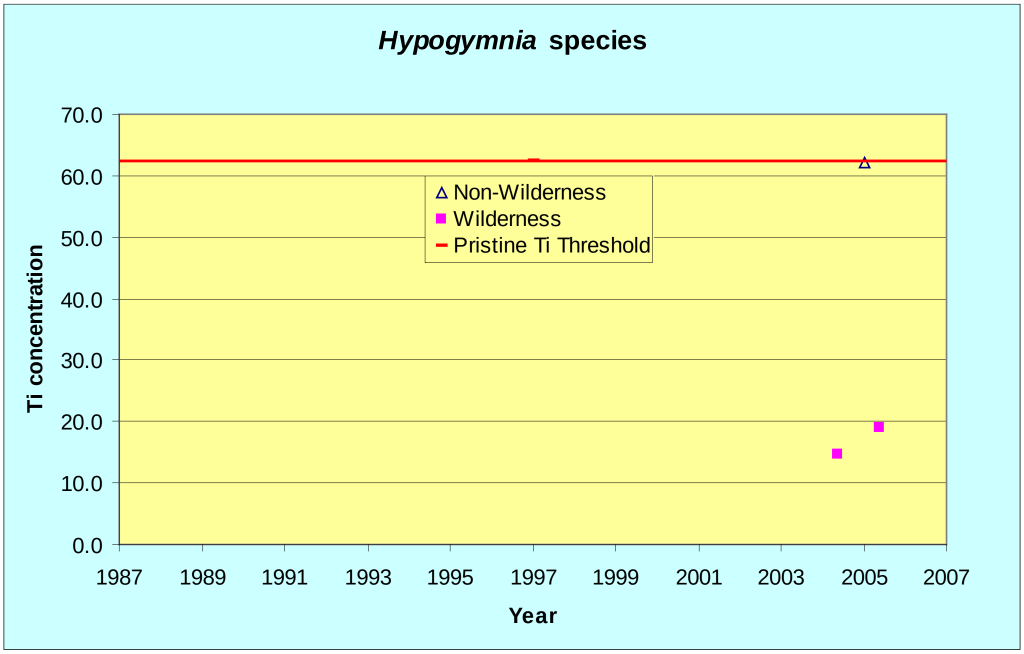

Figure XXIX-5. Wilderness and Non-Wilderness yearly means of Ti ppm in *Hypogymnia species* per year.

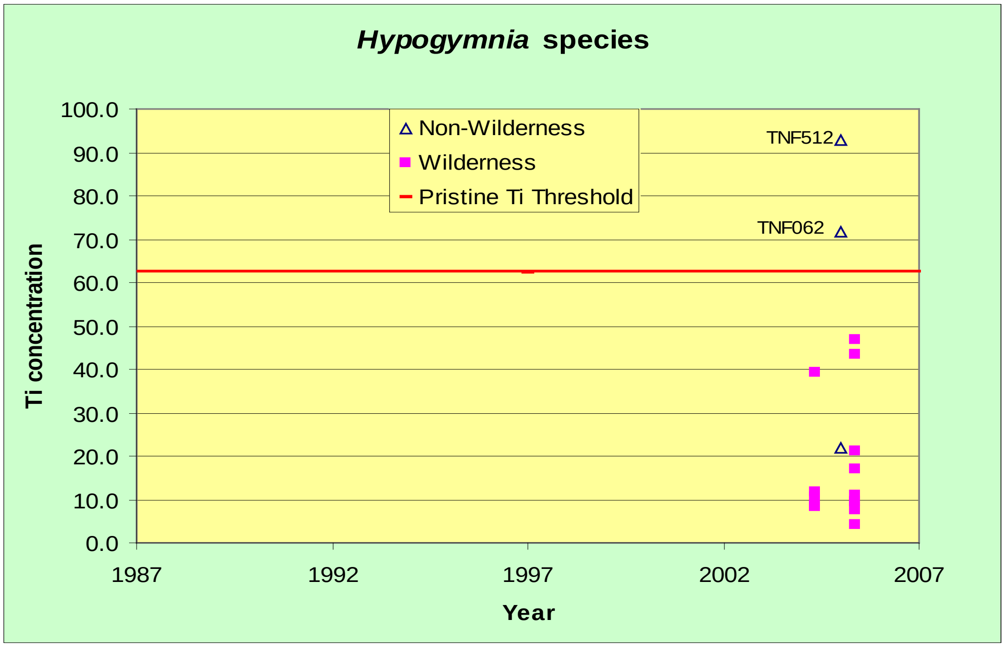

Figure XXIX-6. Wilderness and Non-Wilderness plot means of Ti ppm in *Hypogymnia species* per year.

Lobaria oregana

Table XXIX-3. Wilderness and Non-Wilderness Means, Standard Errors, and 95% Confidence Intervals for the Ti ppm content of *Lobaria oregana* per year.

Ti ppm				**95% CI**	
Year	**Plot Type**	**Mean**	**Std. Error**	**Lower**	**Upper**
2004	Wilderness	18.14	6.0711	3.2848	32.9958
2005	Non-Wilderness	45.49	NA	NA	NA
2005	Wilderness	5.19	2.1008	-1.4908	11.8807

No t-tests were performed on these data. The mean values for Ti are baseline in *Lobaria oregana.*

Relationships are not strong in Ti content for Lobore after accounting for latitude, longitude, elevation, year (Figures XXIX-7, XXIX-8 for year) and precipitation (see Brenner, 2006 for all graphed results).

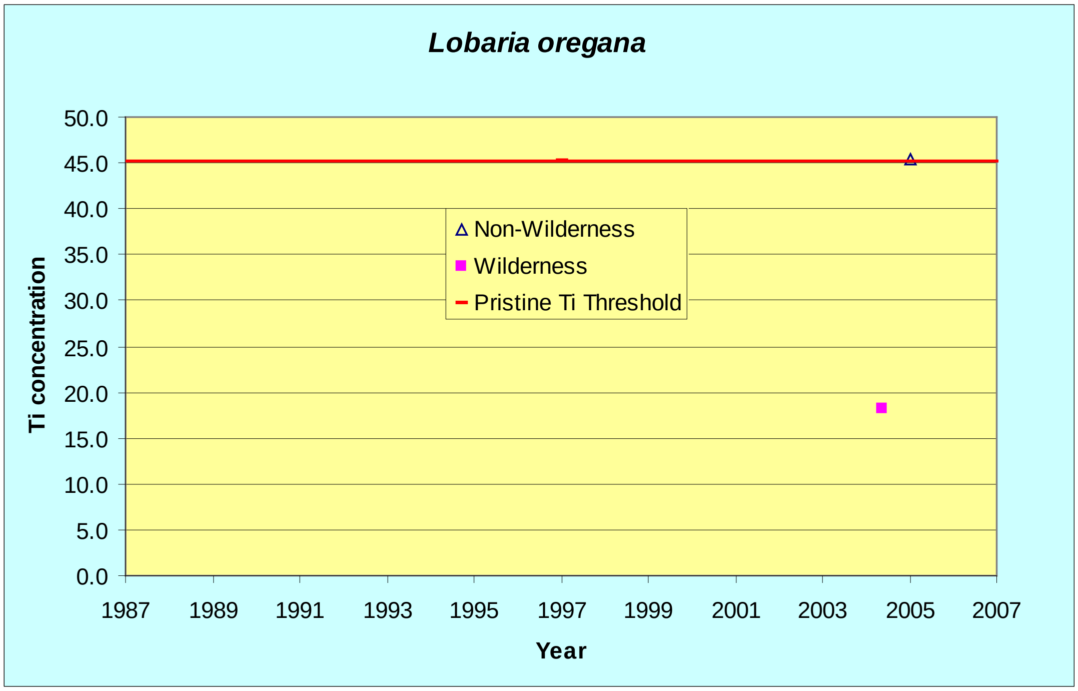

Figure XXIX-7. Wilderness and Non-Wilderness yearly means of Ti ppm in *Lobaria oregana* per year.

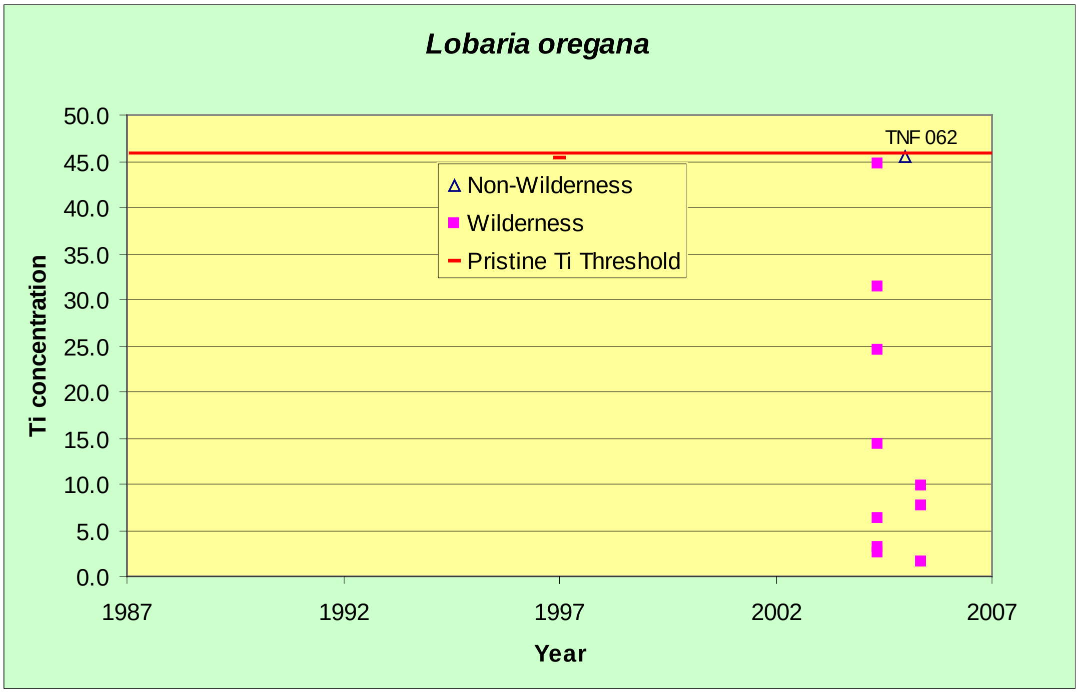

Figure XXIX-8. Wilderness and Non-Wilderness plot means of Ti ppm in *Lobaria oregana* per year.

Platismatia glauca

Table XXIX-4. Wilderness and Non-Wilderness Means, Standard Errors, and 95% Confidence Intervals for the Ti ppm content of *Platismatia glauca* per year.

Ti ppm				**95% CI**	
Year	**Plot Type**	**Mean**	**Std. Error**	**Lower**	**Upper**
2004	Wilderness	26.94	6.2880	12.7109	41.1599
2005	Non-Wilderness	59.38	10.1738	36.3656	82.3953
2005	Wilderness	24.28	6.6642	8.5198	40.0363

No t-tests were performed on these data. The mean values for Ti are baseline in *Platismatia glauca.*

Relationships are not strong in Ti content for Plagla after accounting for latitude, longitude, elevation, year (Figures XXIX-9, XXIX-10 for year) and precipitation (see Brenner, 2006 for all graphed results).

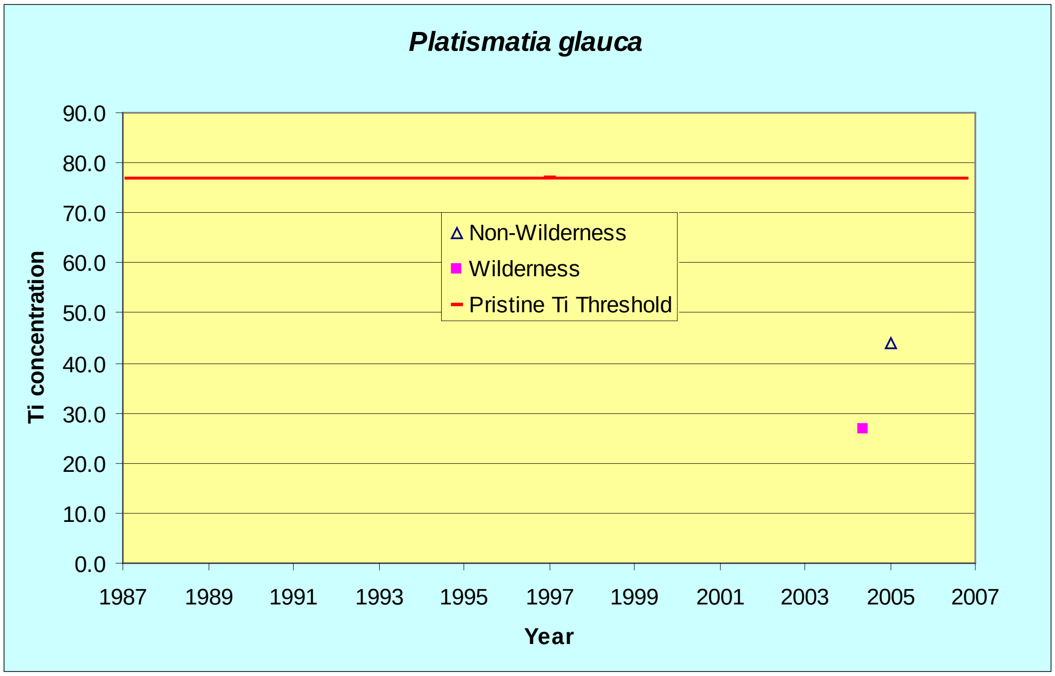

Figure XXIX-9. Wilderness and Non-Wilderness yearly means of Ti ppm in *Platismatia glauca* per year.

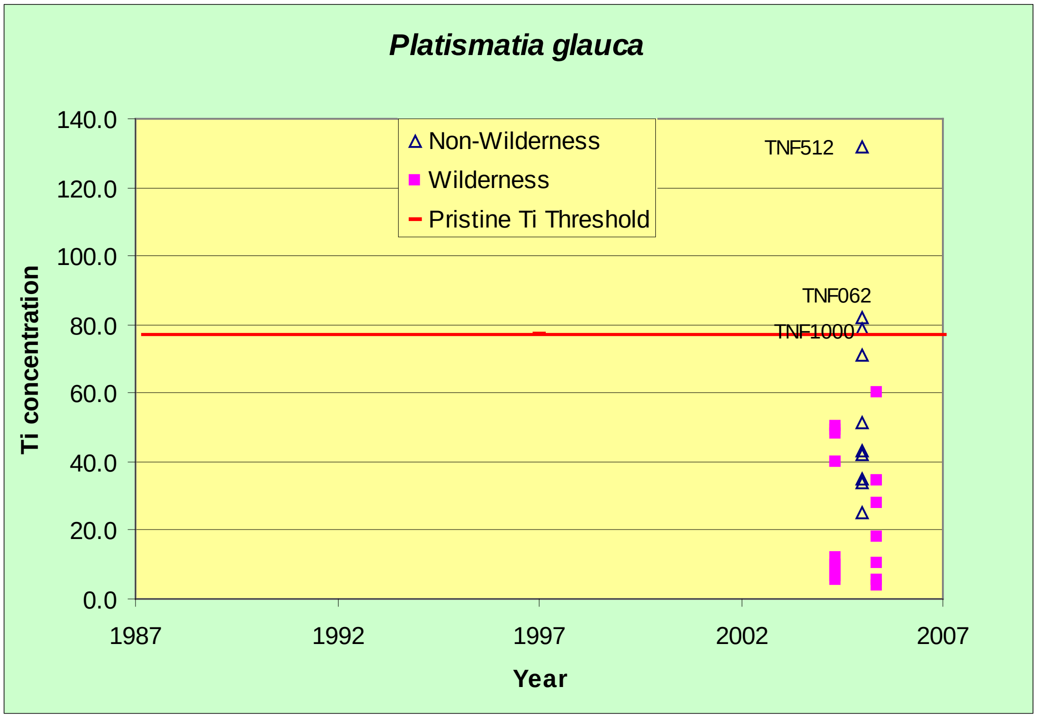

Figure XXIX-10. Wilderness and Non-Wilderness plot means of Ti ppm in *Platismatia glauca* per year.

Conclusions: for Titanium (Ti) and all lichen species

Background Ti in lichens from the Pacific Northwest or worldwide is not available. Threshold for Ti was developed using the 2004 and 2005 ICP analysis data from pristine locations. Elevated levels of Ti above threshold on the Tongass are probably due to natural variation or direct exposure to windblown soils or exposed rock containing titantium.

Alectoria sarmentosa

Plot 512 from Greens Creek tailings area has the highest mean Ti in Alesar, most likely due to the proximity to the tailings pile of exposed rocks and soils from the mining process (Figure XXIX-4). Higher than Ti threshold on Mt Roberts (175 level plot 1000) may be due to the extinct mine nearby, or other industial sources in the downtown Juneau area. Titanium is part of metal alloys used in many industries. Plot 508 from Endicott River is in an extremely exposed location on Chikat Peninsula, and receives windblown soils from the Yukon and local geologic features.

Hypogymnia

Plot 512 from Greens Creek is elevated in Ti probably due to the reasons stated under Alesar (Figure XXIX-6). Plot 62 from Russell Fiords is similar to plot 508 from Endicott in that it receives strong winds containing soils and sands.

Lobaria oregana

Plot 62 is just at Ti threshold in Lobore, probably due to the explanations under *Hypogymnia* (Figure XXIX-8).

Platismatia glauca

Mean Ti in Plagla is similar to other lichens for the same locations on the Tongass. Plot 512 from Greens Creek is elevated due to explanations above under Alesar. Plot 62 from Russell Fiords shows similar elevated levels of Ti in Plagla as in other lichens from the same natural sources. On the edge of threshold is plot 1000 from Mt Roberts, and is probably explained by the proximity to the extinct mine or downtown Juneau.

XXX. Summary of results for Vanadium (V) from all species on the Tongass National Forest

Vanadium (V) occurs in nature as a metal. It usually combines with other elements such as oxygen, sodium, sulfur and chloride (USPHS 1992). Vanadium can be found pure (in crystal form) or with other compounds in the earth's crust and rocks, some iron ores, and crude petroleum deposits. It is combined with other metals to make alloys. It is a component in special steels used in automobile parts, springs and ball bearings. Small amounts are used in making rubber, plastics, ceramics and other chemicals (USPHS 1992). Vanadium enters the environment from natural sources and from the burning of fossil fuels. It remains in the air, water, and soil for long periods of time. No studies are available as to the carcinogenicity of vanadium.

Vanadium was not analyzed during the first monitoring period. Provisional thresholds for vanadium in lichens on the Tongass are from the 2004 and 2005 data and are as follows: *Alectoria sarmentosa* (0.37 ppm), *Hypogymnia* (2.99 ppm), *Lobaria oregana* (2.42 ppm) and *Platismatia glauca* (3.08 ppm).

Levels of vanadium are elevated in lichens from the following locations and species: Alesar plots 1000 (Juneau Mt Roberts) plot 512 (Greens Creek tailings) and plot 100 is at threshold (West Chichagof wilderness)(Figure XXX-4); *Hypogymnia* plot 512 (Greens Creek tailings) and plot 62 is at threshold (Russell Fiord-Harlequin Lake)(Figure XXX-6); Lobore plot 495 (Stikine River-Flemer cabin)(Figure XXX-8); Plagla plots 512 and 511b (Greens Creek), plots 1000 and 1001 (Juneau Mt Roberts) and just at threshold is plot 508 (Endicott River)(Figure XXX-10).

XXX. SUMMARY OF V PPM DATA ANALYSIS

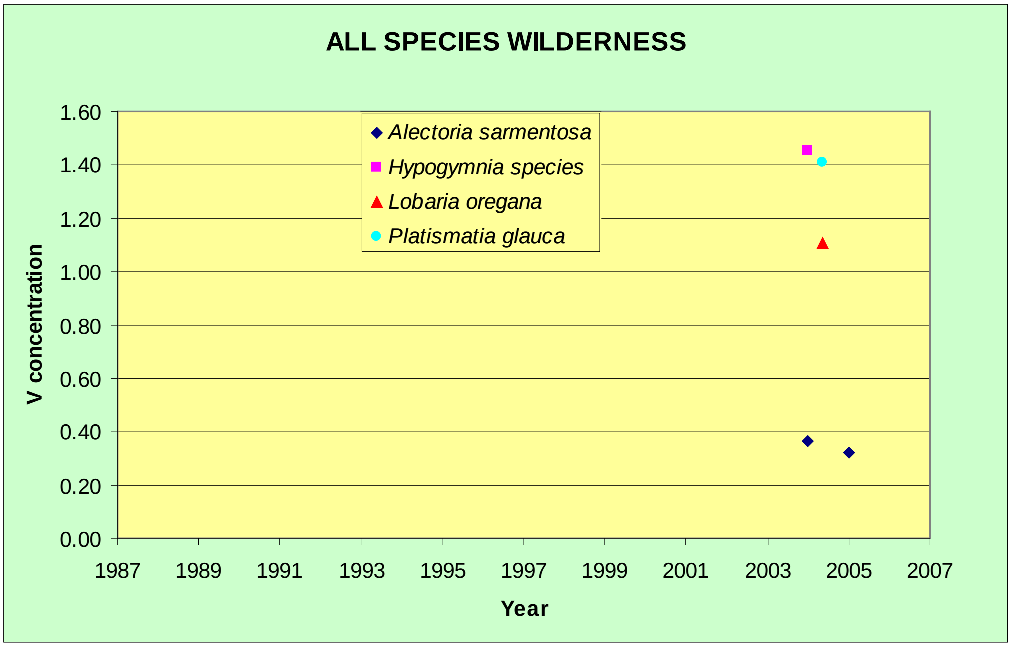

Figure XXX-1. Wilderness plot means of V ppm in *All Species* per year.

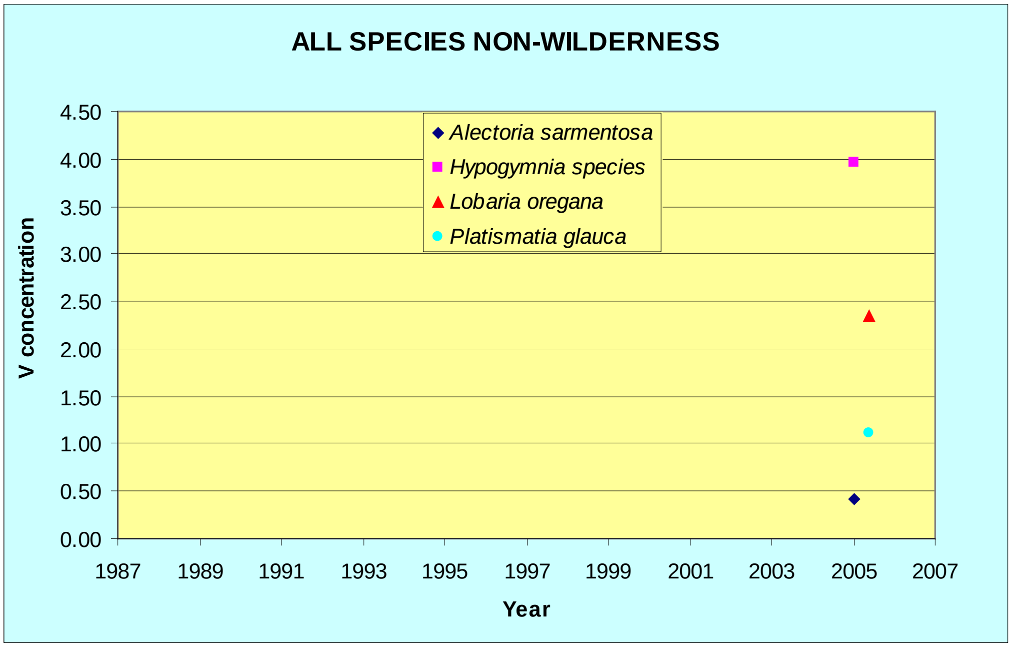

Figure XXX-2. Non-Wilderness plot means of V ppm in *All Species* per year.

Alectoria sarmentosa

Table XXX-1. Wilderness and Non-Wilderness Means, Standard Errors, and 95% Confidence Intervals for the V ppm content of *Alectoria sarmentosa* per year.

V ppm				**95% CI**	
Year	**Plot Type**	**Mean**	**Std. Error**	**Lower**	**Upper**
2004	Wilderness	0.36	0.0010	0.3597	0.3639
2005	Non-Wilderness	0.42	0.0653	0.2522	0.5879
2005	Wilderness	0.32	0.0000	0.3200	0.3200

No t-tests were performed on these data. The mean values for V are baseline in *Alectoria sarmentosa.*

Relationships are not strong in V content for Alesar after accounting for latitude, longitude, elevation, year (Figures XXX-3, XXX-4 for year) and precipitation (see Brenner, 2006 for all graphed results).

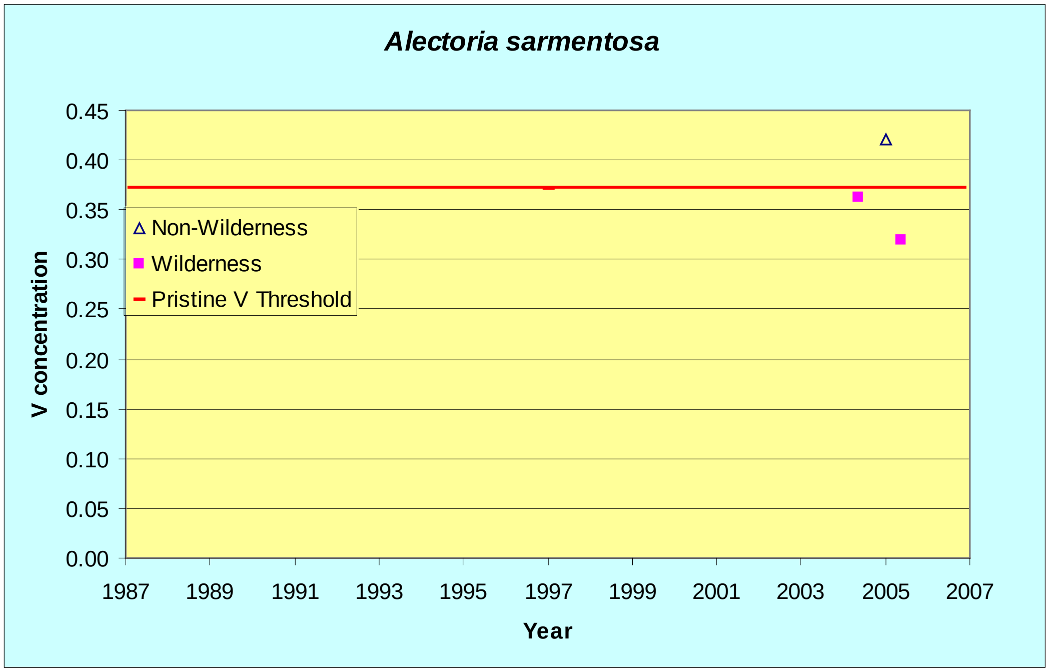

Figure XXX-3. Wilderness and Non-Wilderness yearly means of V ppm in *Alectoria sarmentosa* per year.

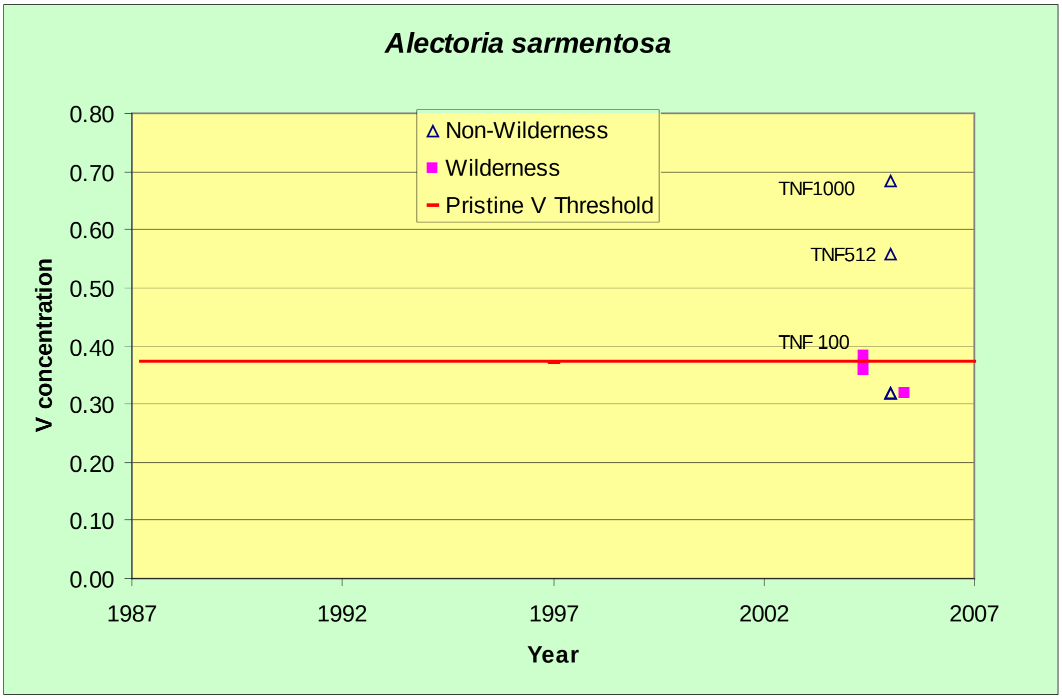

Figure XXX-4. Wilderness and Non-Wilderness plot means of V ppm in *Alectoria sarmentosa* per year.

Hypogymnia species

In this series, all of the *Hypogymnia* species were included as a group.

Table XXX-2. Wilderness and Non-Wilderness Means, Standard Errors, and 95% Confidence Intervals for the V ppm content of *Hypogymnia species* per year.

V ppm				95% CI	
Year	**Plot Type**	**Mean**	**Std. Error**	**Lower**	**Upper**
2004	Wilderness	1.45	0.1356	1.1056	1.8029
2005	Non-Wilderness	3.95	1.1721	1.0898	8.9962
2005	Wilderness	1.35	0.2744	0.7167	1.9821

No t-tests were performed on these data. The mean values for V are baseline in *Hypogymnia.*

Relationships are not strong in V content for *Hypogymnia* after accounting for latitude, longitude, elevation, year (Figures XXX-5, XXX-6 for year) and precipitation (see Brenner, 2006 for all graphed results).

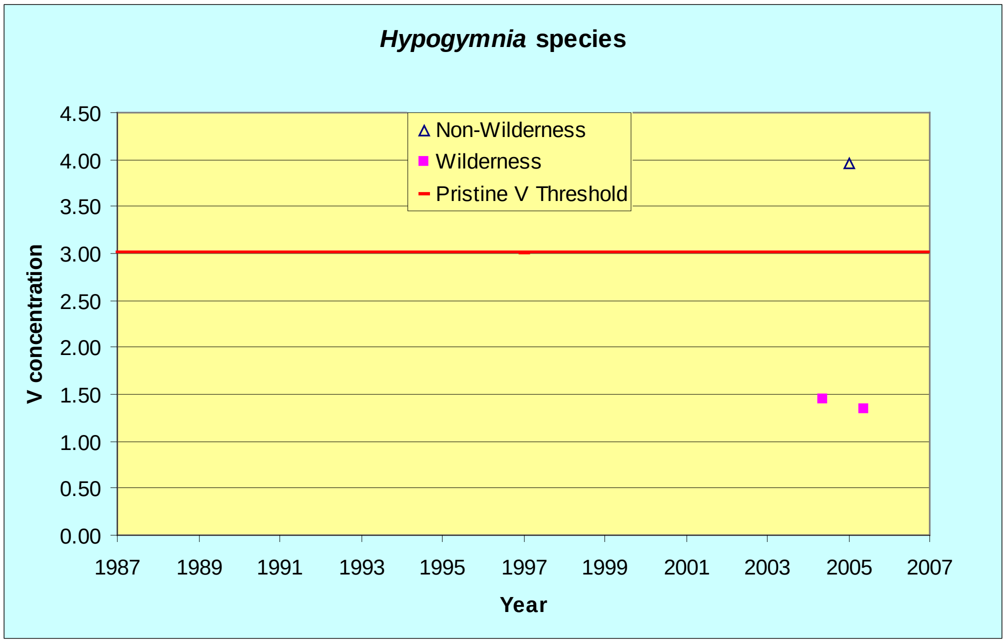

Figure XXX-5. Wilderness and Non-Wilderness yearly means of V ppm in *Hypogymnia* species per year.

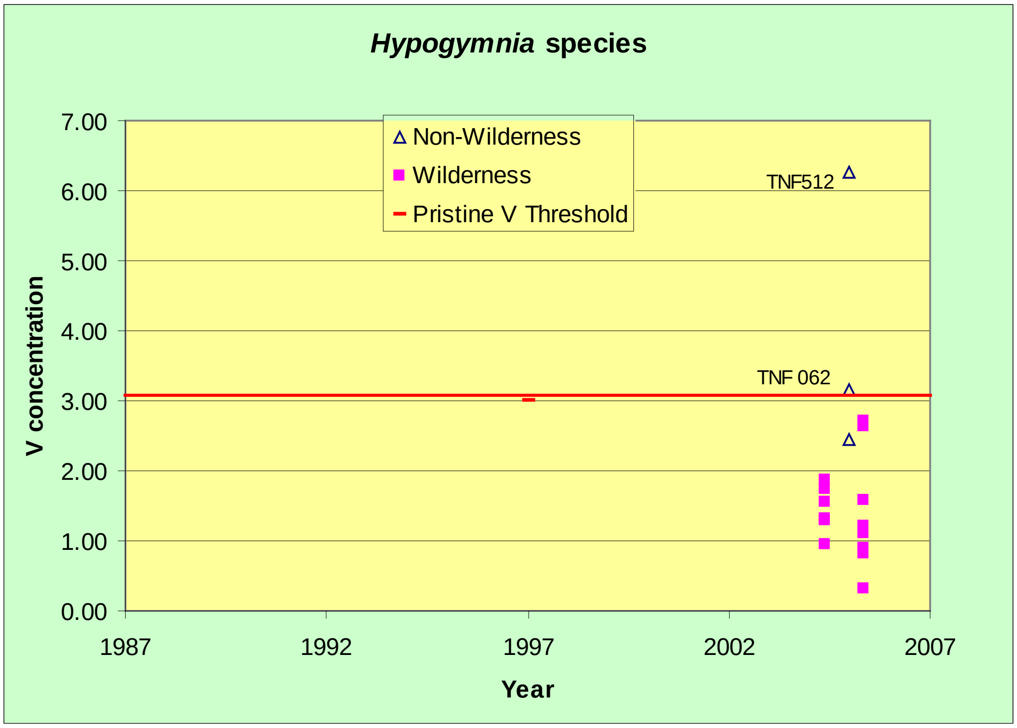

Figure XXX-6. Wilderness and Non-Wilderness plot means of V ppm in *Hypogymnia* species per year.

Lobaria oregana

Table XXX-3. Wilderness and Non-Wilderness Means, Standard Errors, and 95% Confidence Intervals for the V ppm content of *Lobaria oregana* per year.

V ppm				**95% CI**	
Year	**Plot Type**	**Mean**	**Std. Error**	**Lower**	**Upper**
2004	Wilderness	1.11	0.3151	0.3360	1.8779
2005	Non-Wilderness	2.34	NA	NA	NA
2005	Wilderness	0.51	0.1711	-0.0302	1.0587

No t-tests were performed on these data. The mean values for V are baseline in *Lobaria oregana.*

Relationships are not strong in V content for Lobore after accounting for latitude, longitude, elevation, year (Figures XXX-7, XXX-8 for year) and precipitation (see Brenner, 2006 for all graphed results).

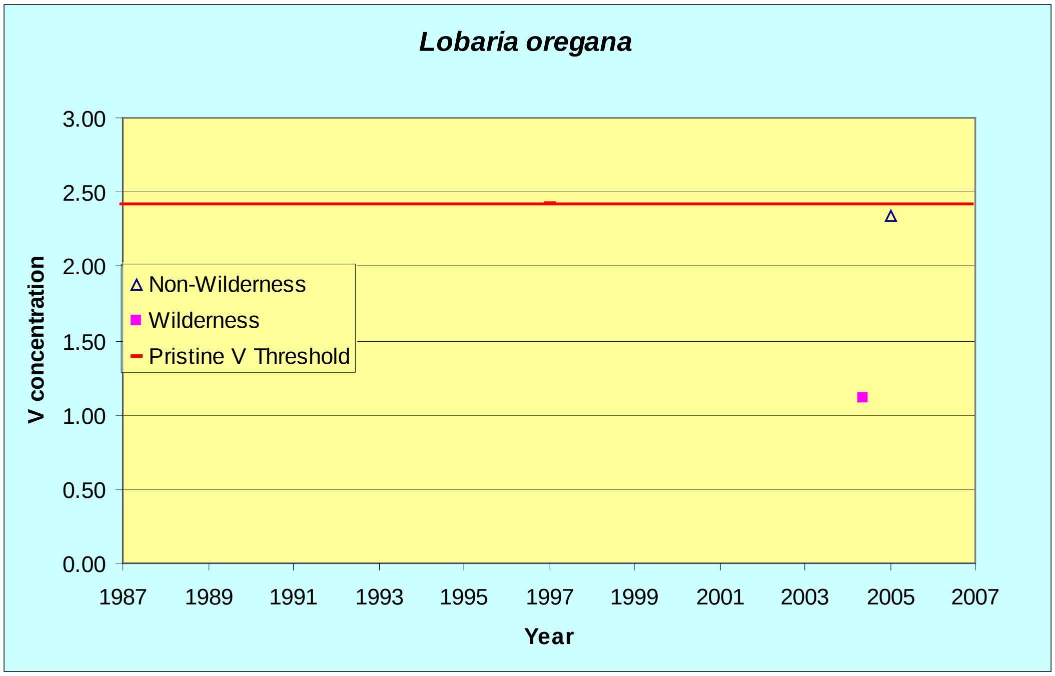

Figure XXX-7. Wilderness and Non-Wilderness yearly means of V ppm in *Lobaria oregana* per year.

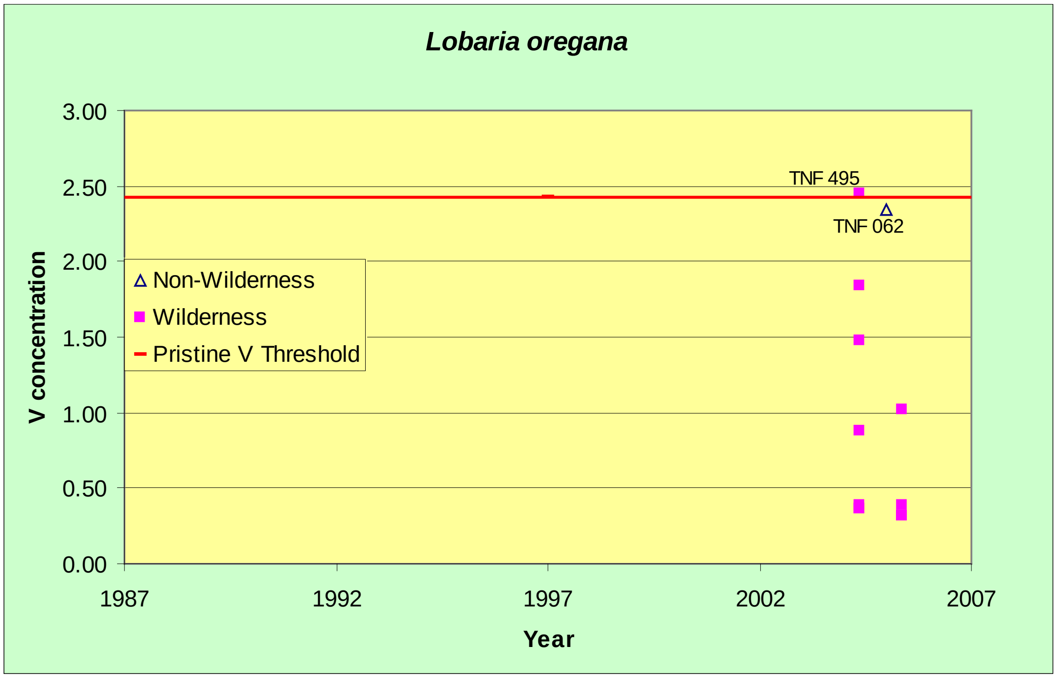

Figure XXX-8. Wilderness and Non-Wilderness plot means of V ppm in *Lobaria oregana* per year.

Platismatia glauca

Table XXX-4. Wilderness and Non-Wilderness Means, Standard Errors, and 95% Confidence Intervals for the V ppm content of *Platismatia glauca* per year.

V ppm				95% CI	
Year	**Plot Type**	**Mean**	**Std. Error**	**Lower**	**Upper**
2004	Wilderness	1.41	0.2856	0.7614	2.0535
2005	Non-Wilderness	3.55	0.4823	2.4584	4.6403
2005	Wilderness	1.45	0.3682	0.5794	2.3206

No t-tests were performed on these data. The mean values for V are baseline in *Platismatia glauca.*

Relationships are not strong in V content for Plagla after accounting for latitude, longitude, elevation, year (Figures XXX-9, XXX-10 for year) and precipitation (see Brenner, 2006 for all graphed results).

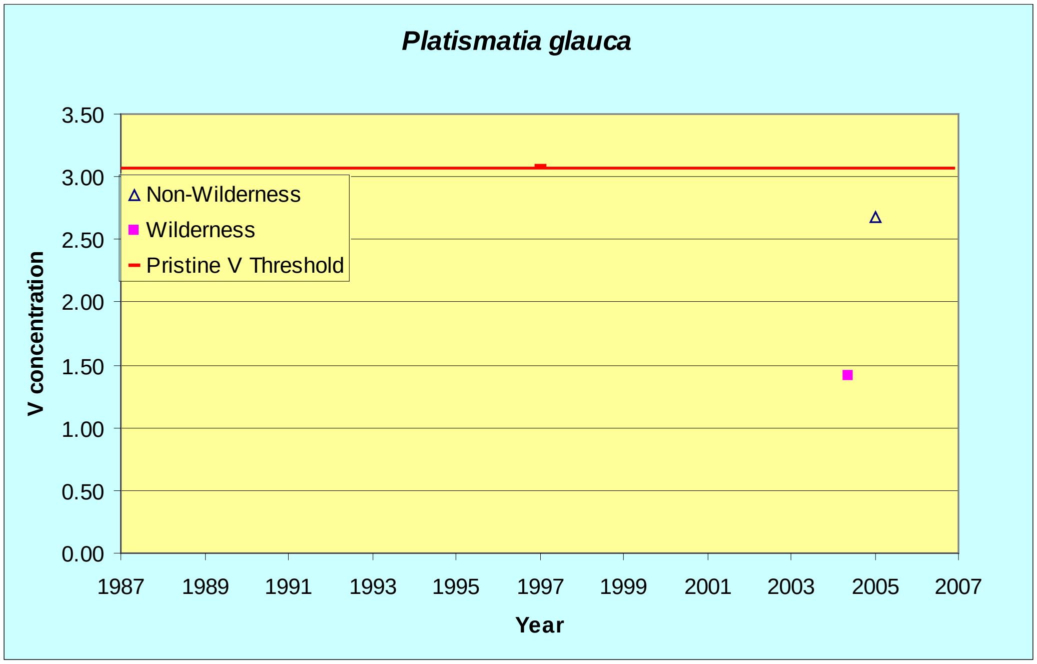

Figure XXX-9. Wilderness and Non-Wilderness yearly means of V ppm in *Platismatia glauca* per year.

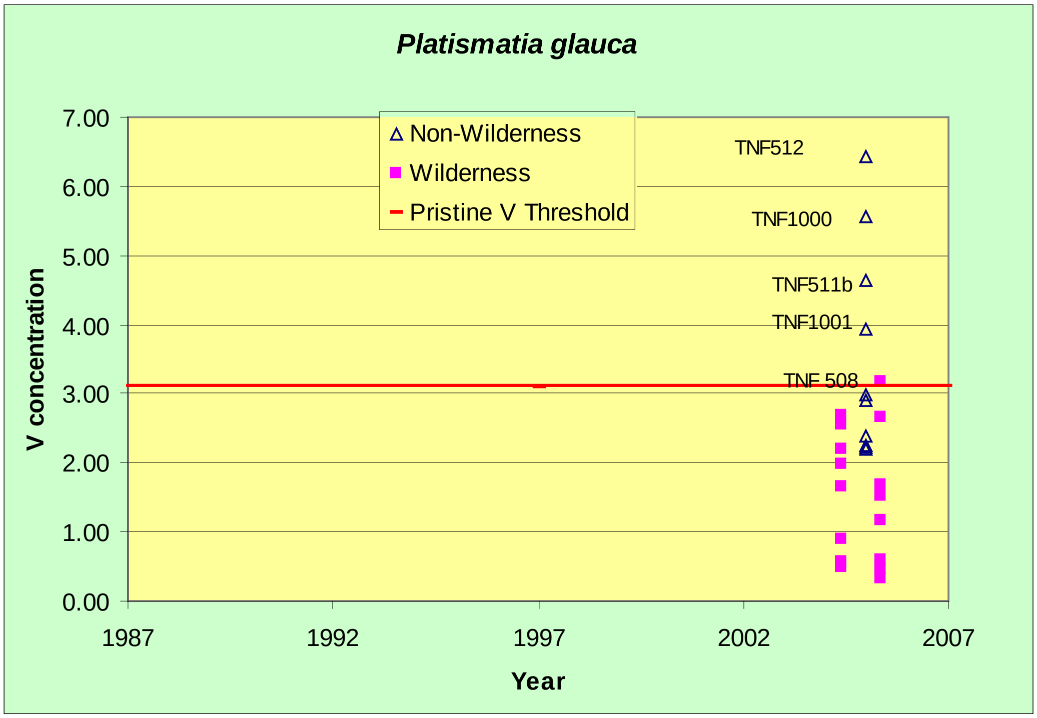

Figure XXX-10. Wilderness and Non-Wilderness plot means of V ppm in *Platismatia glauca* per year.

Conclusions: for Vanadium (V) and all lichen species

Background V from the Pacific Northwest and worldwide in lichens is not available. Thresholds for V were generated with 2004 and 2005 ICP analysis data. Elevated levels of V in lichens are probably due to industrial and natural sources, depending upon the plot location.

Alectoria sarmentosa

Plot 1000 from Mt Roberts is elevated in V likely due to the close proximity to the burning of fossil flues in the downtown Juneau area (Figure XXX-4). Similarly plot 512 from Greens Creek may be enhanced due to the burning of fossil fuels from the mining industry and the windblown soils from the tailings pile. Lichens in plot 100 from West Chichagof wilderness with V at threshold may be partof the natural variation as no industrial sources exists in the area

Hypogymnia

Mean V is above threshold in plot 512 from Greens Creek most likely due to the reasons stated above under Alesar (Figure XXX-6). Plot 62 from Russell Fiord is exposed to windblown soils and sands, as well as the airstrip and unpaved road nearby. All of these could play a role in the enhanced level of V in the lichens.

Lobaria oregana

Plot 495 from the Stikine River Flemer cabin area is just at threshold for V (Figure XXX-8). This could be part of the natural variation of V due to the windblown soils and sands from the interior.

Platismatia glauca

Plots from Greens Creek (512 and 511b) are most likely elevated above threshold for V due to the industrial sources and exposed rock and soils at the mine (Figure XXX-10). Plots 1000 (175 ft elevation) and 1001 (600 ft elevation) from Mt Roberts may be elevated due to the fossil fuels burning in downtown Juneau, and the extinct mine in the area. Plot 508 from Endicott River is right at threshold and is probably part of the natural variation of V in areas with exposure to windblown soils and sands

XXXI. Summary of results for Zinc (Zn) from all species on the Tongass National Forest

Zinc is one of the most common elements on earth. It is found in the air, soil, and water and is present in all foods. Zinc has many uses in industry. It is used to coat iron or other metals to impede corrosion or rust. It is also used to make alloys such as bronze and brass. Zinc compounds can be found at hazardous waste sites such as zinc chloride, zinc oxide, zinc sulfate and zinc sulfide (USPHS 1994). Zinc oxide is used to make white paints, ceramics and rubber. Zinc compounds are also used to make wood preservatives, and in manufacturing fabrics, sun block, ointments, and other cosmetics.

Zinc enters the air water and soils naturally and though human activities. Activities that introduce zinc into the environment are mining, purifying of zinc, lead and cadmium ores, steel production, coal burning, and burning of wastes (USPHS 1994).

Provisional thresholds for zinc on the Tongass are the following: *Alectoria sarmentosa* (38.06 ppm), Hypogymnia (70.20 ppm), Lobaria oregana (82.93 ppm) and Platismatia glauca (52.85 ppm).

Locations with lichens elevated above threshold for Zn include: Alesar plots 1000, 1002 and 1004 (Mt Roberts-Juneau), 512 (Greens Creek tailings pile), and 108 and 240 from Sitka road system and closed pulp mill area (Figure XXXI-4); *Hypogymnia* plots 511b, 512 (Greens Creek), 506 (lower Endicott River), and 242 (Sitka pulp mill area) (Figure XXXI-6); Lobore plots 64 (Yakutat road system), 62 (Russell Fiords) and 506 (lower Endicott River)(Figure XXXI-8); Plagla plots 511a, 511b, 512 (Greens Creek), and 1004 (Mt Roberts 1745 ft elevation) (Figure XXXI-10).

XXXI. SUMMARY OF Zn PPM DATA ANALYSIS

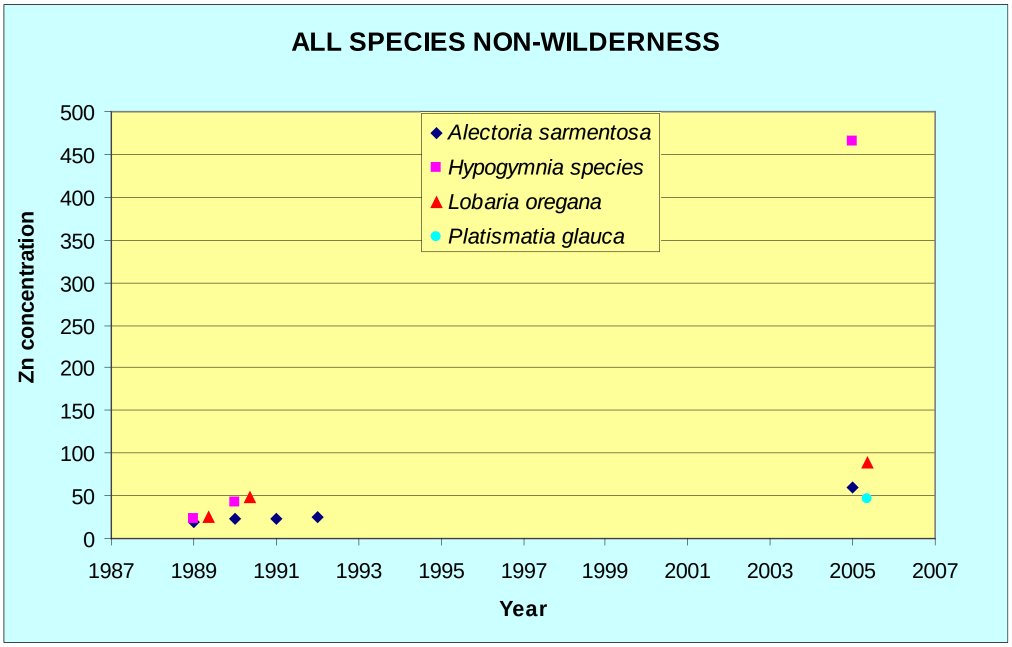

Figure XXXI-1. Wilderness plot means of Zn ppm in *All Species* per year.

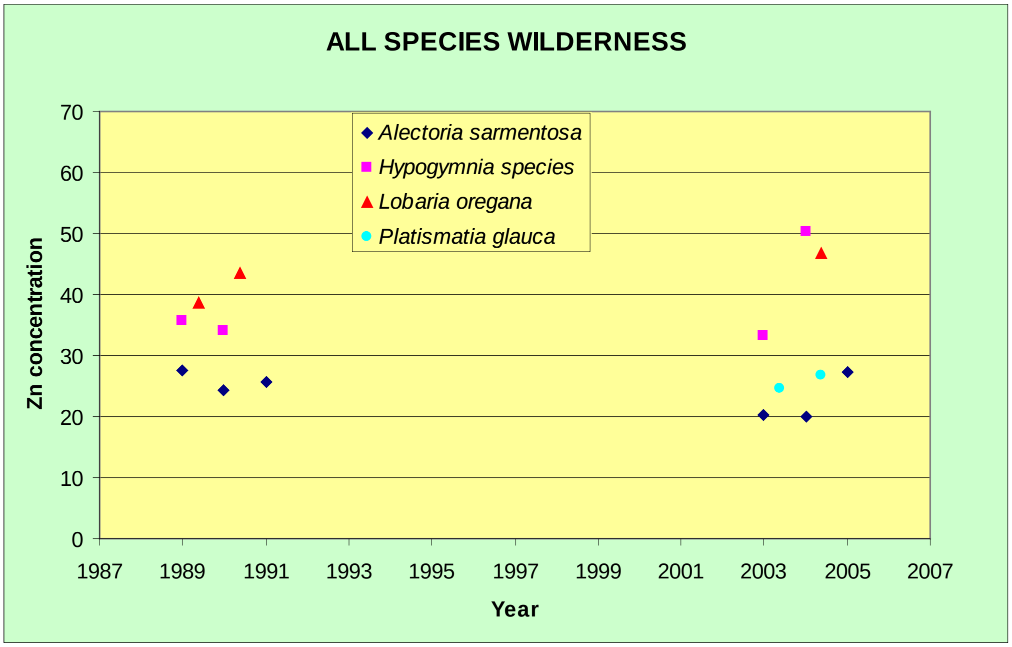

Figure XXXI-2. Non-Wilderness plot means of Zn ppm in *All Species* per year.

Alectoria sarmentosa

Table XXXI-1. Wilderness and Non-Wilderness Means, Standard Errors, and 95% Confidence Intervals for the Zn ppm content of *Alectoria sarmentosa* per year.

Zn ppm				**95% CI**	
Year	**Plot Type**	**Mean**	**Std. Error**	**Lower**	**Upper**
1989	Non-Wilderness	19.23	1.4279	15.2625	23.1915
1989	Wilderness	27.70	2.1087	22.2788	33.1200
1990	Non-Wilderness	22.61	1.7568	19.0031	26.2253
1990	Wilderness	24.43	2.4163	18.5126	30.3374
1991	Non-Wilderness	22.3505	0.7525	20.7696	23.9314
1991	Wilderness	25.74	2.1710	19.7112	31.7663
1992	Non-Wilderness	26.01	2.7419	19.5289	32.4961
2003	Wilderness	20.21	7.9278	80.5194	120.9439
2004	Wilderness	20.04	1.1782	17.6020	22.4764
2005	Non-Wilderness	60.43	10.7321	32.8410	88.0166
2005	Wilderness	27.16	1.9577	22.7344	31.5919

Summary of Statistical Tests:

t = -0.048, df = 8, p-value = 0.9629

There is no evidence of a difference in Zn content in *Alectoria sarmentosa* from pre-2000 and post 2000 samples (p-value = 0.9629). Plots with repeated samples for Zn in Alesar are: Karta River (#159), Pleasant Island (#145, 146), Pikes Lake RNA (# 69), Kootznoowoo (# 189, 190), Petersburg Creek (#116), Stikine-LeConte (#30, 31), Yakobi (#101), Tebenkof (#33) and Misty Fiords (#85, 86).

Relationships are not strong in the Zn content in *Alectoria sarmentosa* after accounting for latitude, longitude, elevation, year (Figures XXXI-3, XXXI-4 for year) and precipitation (see Brenner, 2006 for all graphed results).

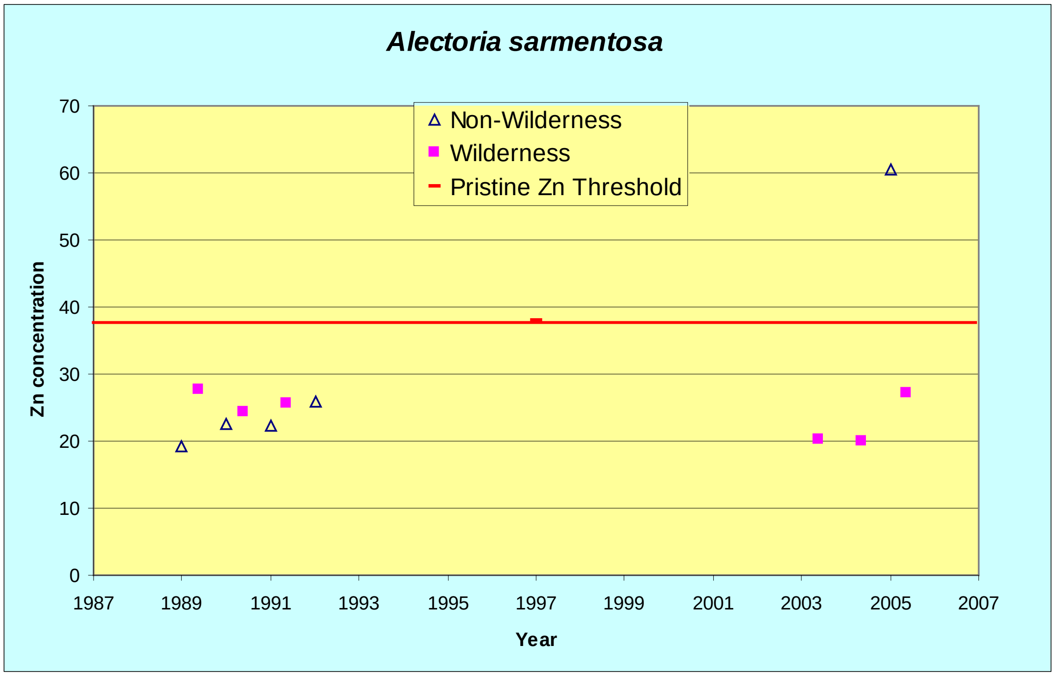

Figure XXXI-3. Wilderness and Non-Wilderness yearly means of Zn ppm in *Alectoria sarmentosa* per year.

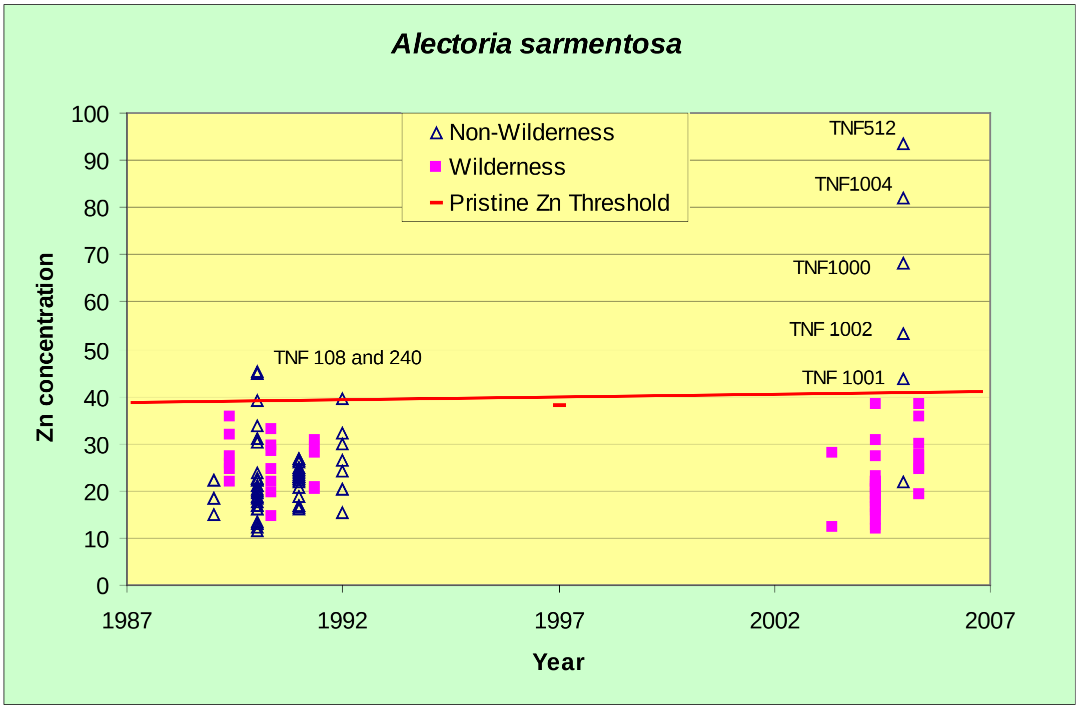

Figure XXXI-4. Wilderness and Non-Wilderness plot means of Zn ppm in *Alectoria sarmentosa* per year.

Hypogymnia species

In this series, all of the *Hypogymnia* species were included as a group.

Table XXXI-2. Wilderness and Non-Wilderness Means, Standard Errors, and 95% Confidence Intervals for the Zn ppm content of *Hypogymnia species* per year.

Zn ppm				**95% CI**	
Year	**Plot Type**	**Mean**	**Std. Error**	**Lower**	**Upper**
1989	Non-Wilderness	24.05	2.2500	4.5390	52.6390
1989	Wilderness	35.66	4.5948	22.8977	48.4123
1990	Non-Wilderness	43.21	4.2690	34.2443	52.1820
1990	Wilderness	33.94	2.8097	27.0677	40.8180
2003	Wilderness	33.15	NA	NA	NA
2004	Wilderness	50.18	5.1319	36.9903	63.3743
2005	Non-Wilderness	465.56	227.7318	514.2949	1445.4066
2005	Wilderness	58.42	4.7799	47.3967	69.4416

No t-tests were performed on these data. The mean values for Zn are baseline in *Hypogymnia.*

Relationships are not strong in Zn content for *Hypogymnia* after accounting for latitude, longitude, elevation, year (Figures XXXI-5, XXXI-6 for year) and precipitation (see Brenner, 2006 for all graphed results).

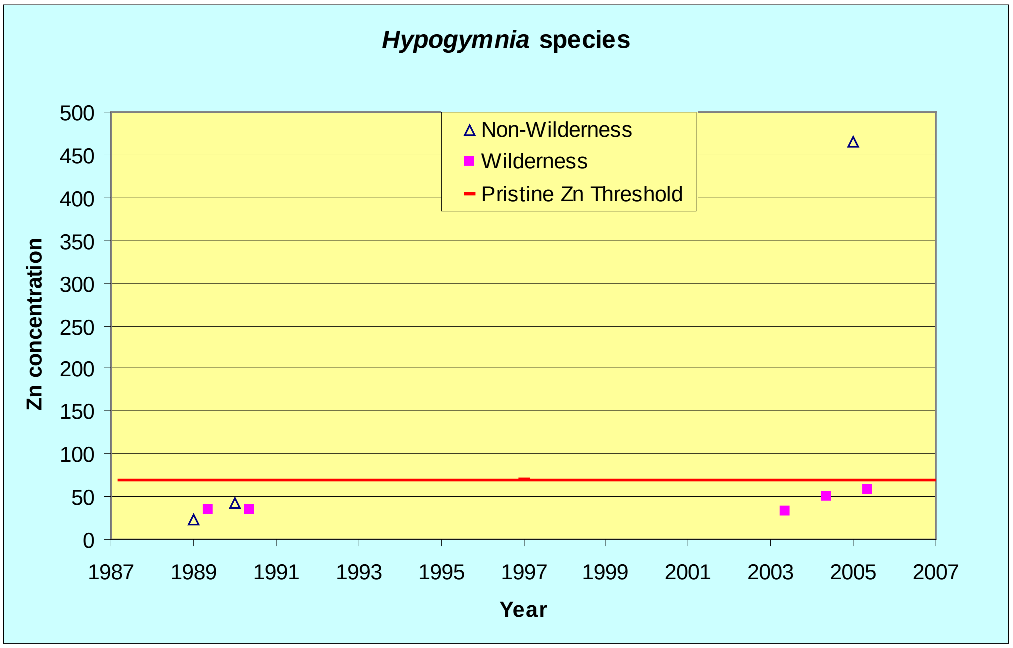

Figure XXXI-5. Wilderness and Non-Wilderness yearly means of Zn ppm in *Hypogymnia species* per year.

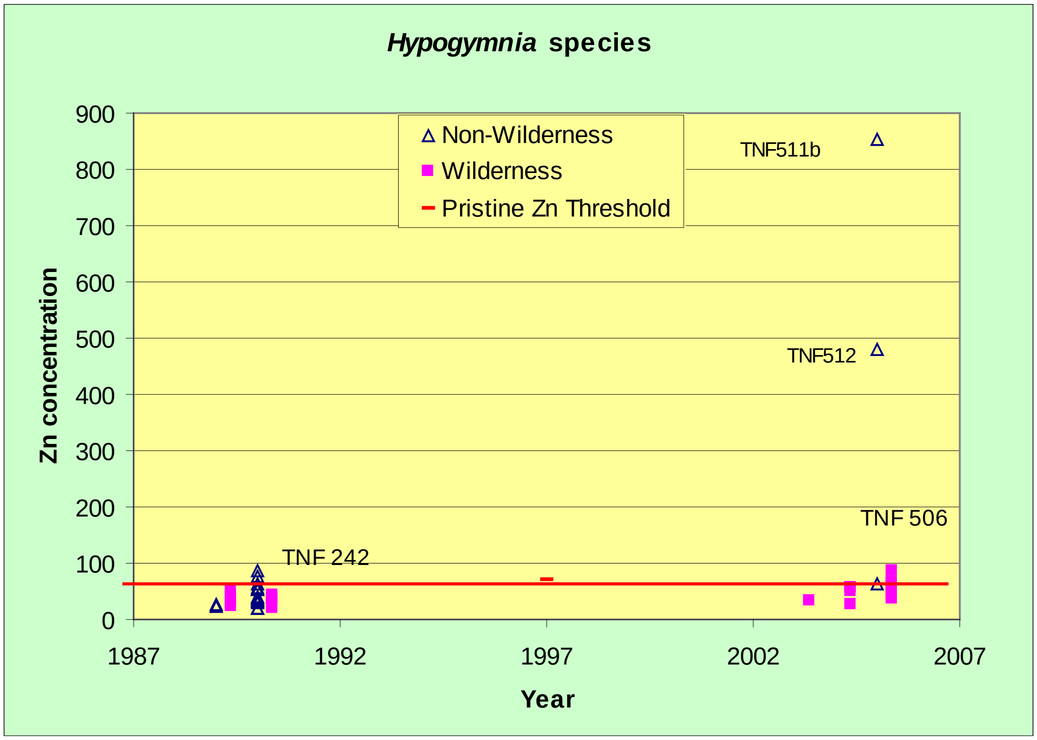

Figure XXXI-6. Wilderness and Non-Wilderness plot means of Zn ppm in *Hypogymnia species* per year.

Lobaria oregana

Table XXXI-3. Wilderness and Non-Wilderness Means, Standard Errors, and 95% Confidence Intervals for the Zn ppm content of *Lobaria oregana* per year.

Zn ppm				**95% CI**	
Year	**Plot Type**	**Mean**	**Std. Error**	**Lower**	**Upper**
1989	Non-Wilderness	24.95	6.2151	5.1709	44.7291
1989	Wilderness	38.52	5.9265	22.0631	54.9723
1990	Non-Wilderness	48.98	5.5963	36.7844	61.1708
1990	Wilderness	43.61	2.7187	36.6252	50.6026
2004	Wilderness	46.80	6.0877	31.9051	61.6971
2005	Non-Wilderness	88.41	NA	NA	NA
2005	Wilderness	46.39	12.1530	7.7157	85.0684

Summary of Statistical Tests:

t = -0.7491, df = 4, p-value = 0.4955

There is no evidence of a difference in Zn content in *Lobaria oregana* from pre-2000 and post 2000 samples (p-value = 0.4955). This analysis was for wilderness areas that had repeated values for Zn in *Lobaria oregana:* Russell Fiords (plot 62 near Harlequin Lake), Tebenkof (33) and Misty Fiords (86, 88).

Relationships are not strong in the Zn content in *Lobaria oregana* after accounting for latitude, longitude, elevation, year (Figures XXXI-7, XXXI-8 for year) and precipitation (see Brenner, 2006 for all graphed results).

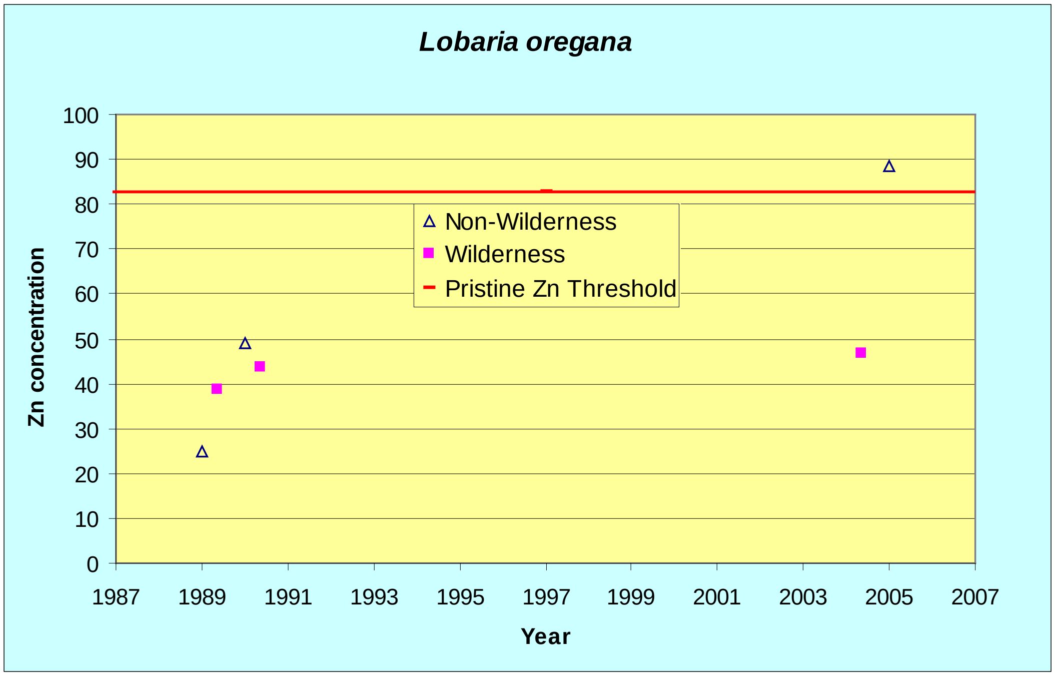

Figure XXXI-7. Wilderness and Non-Wilderness yearly means of Zn ppm in *Lobaria oregana* per year.

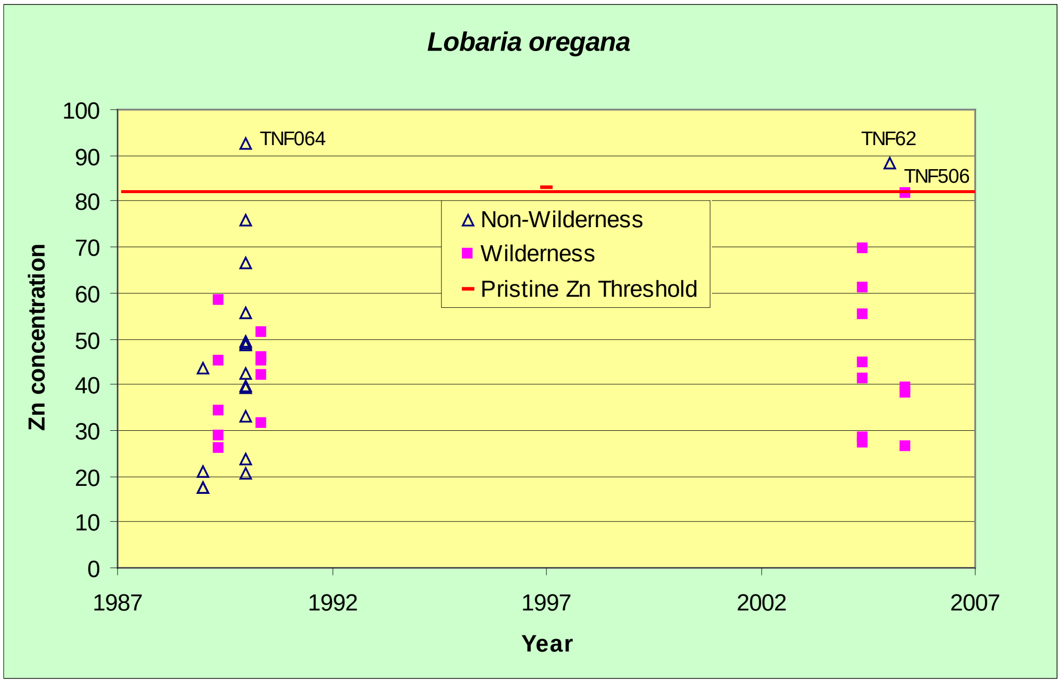

Figure XXXI-8. Wilderness and Non-Wilderness plot means of Zn ppm in *Lobaria oregana* per year.

Platismatia glauca

Table XXXI-4. Wilderness and Non-Wilderness Means, Standard Errors, and 95% Confidence Intervals for the Zn ppm content of *Platismatia glauca* per year.

Zn ppm				95% CI	
Year	**Plot Type**	**Mean**	**Std. Error**	**Lower**	**Upper**
2003	Wilderness	24.65	NA	NA	NA
2004	Wilderness	26.81	2.2295	21.7695	31.8566
2005	Non-Wilderness	317.57	164.4844	54.5146	689.6646
2005	Wilderness	33.70	5.2992	21.1646	46.2260

No t-tests were performed on these data. The mean values for Zn are baseline in *Platismatia glauca.*

Relationships are not strong in Zn content for Plagla after accounting for latitude, longitude, elevation, year (Figures XXI-9, XXI-10 for year) and precipitation (see Brenner, 2006 for all graphed results).

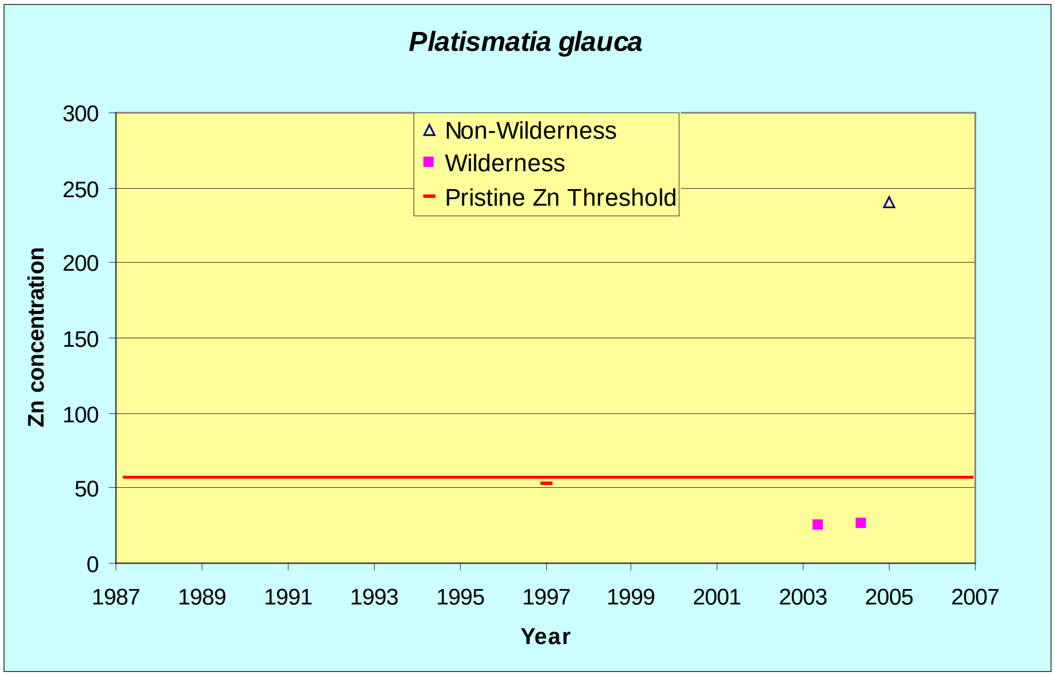

Figure XXXI-9. Wilderness and Non-Wilderness yearly means of Zn ppm in *Platismatia glauca* per year.

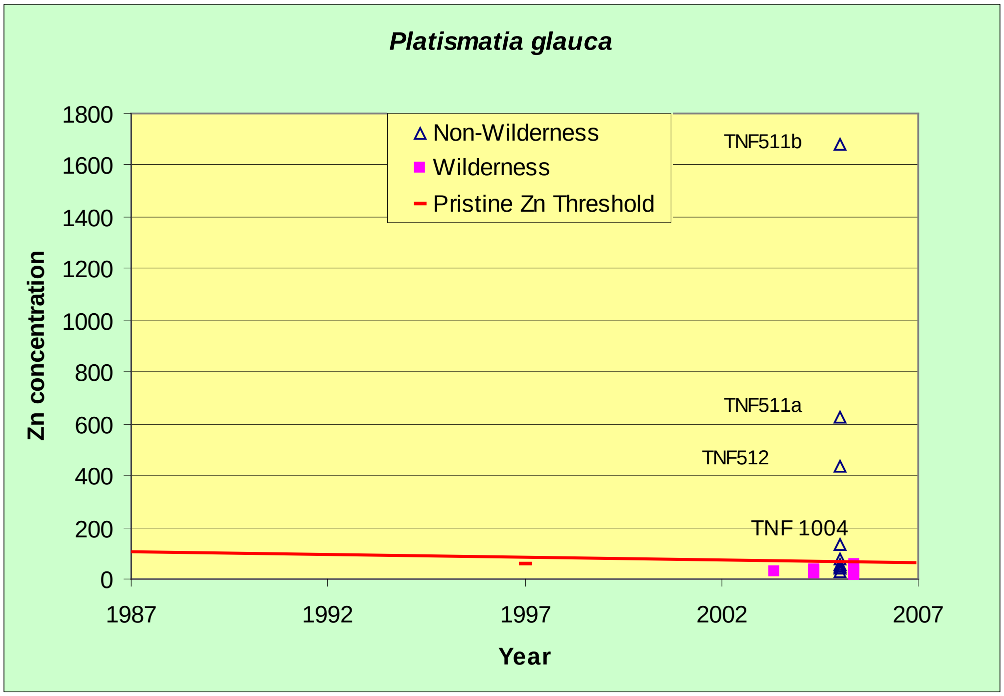

Figure XXXI-10. Wilderness and Non-Wilderness plot means of Zn ppm in *Platismatia glauca* per year.

Conclusions: for Zinc (Zn) and all lichen species

Zinc in lichens can be enhanced due to many factors including automobile exhaust, urban and industrial areas, and areas of marine influence (USDA 1999; Davidson at al 1985). All thresholds are slightly higher than the background Zn in the Pacific Northwest, indicating that lichens may be regionally enhanced due to natural sources of Zn on the Tongass. Neiboer and others (1978) suggested that enhanced Zn levels in lichens are above 500 ppm, but depending on the location, lichens may be enhanced with as low as 30 ppm (Neiboer and Richardson 1981).

Alectoria sarmentosa

Background Zn for Alesar in the Pacific Northwest are slightly lower than threshold for Zn on the Tongass (25 ppm and 38.06 ppm respectively) (USDA 1999). Lichens may be regioanlly enhanced due to the geology and hypermaritime region. Lichens from Greens Creek plot 512 are elevated due to the close proximity to the tailings pile where exposed ore is stored. Plots from the Mt Roberts area in Juneau (1000, 1002, and 1004) are most likely elevated above threshold due to the nearby urban setting of the hillside where the lichens were collected, and possibly due to the extinct mine in the vicinity (Figure XXXI-4). Plots from the Sitka road system and closed pulp mill (plots 108 and 240) are elevated due to the proximity to industry and automobile exhaust. These plots have not been remonitored.

Hypogymnia

Background Zn in *Hypogymnia* from the Pacific Northwest are between 35 and 60 ppm (USDA 1999). Tongass threshold is slightly higher at 70.20 ppm. Plots from Greens Creek are expected to be high in Zn due to the ore mining industry (511b and 512) and associated roads and vehicle exhaust (Figure XXXI-6). Plot 506 from the lower Endicott River is slightly above threshold, and may be part of the natural variation due to the close proximity to the ocean or exposed geology of the Chilkat Peninsula. Plot 242 from Sitka is slightly elevated above threshold due to reasons stated above for other plots near Sitka.

Lobaria oregana

Background Zn for Lobore in the Pacific Northwest are lower than the threshold established for Zn on the Tongass (50 ppm and 82.93 ppm respectively) (USDA 1999). The Yakutat plot 64 from the road system is probably elevated above threshold due to the proximity to automobile exhaust and the unpaved road. Plot 62 from Russell Fiords may be elevated due to the close proximity to unpaved roads, the airstrip and windblown soils. Lichens from both plots on the Yakutat District may also be elevated as a function of the natural variation in Zn, as levels are not much higher in magnitude above threshold (Figure XXXI-8). Similarly, Zn from plot 506 on Endicott River is just at threshold, indicating part of the natural variation.

Platismatia glauca

Background Zn from the Pacific Northwest is below the threshold for the Tongass in Plagla (30 ppm and 52.85 ppm respectively) (USDA 1999). At over 1600 ppm, Greens Creek Plagla (plot 511b) is within what is considered enhanced due to urban and industrial sources (between 1000 and 13000 ppm) (USDA 1999) (Figure XXXI-10). What is considered enhanced due to mine and smelter activities worldwide is between 2000 and 25000 ppm (USDA 1999). The high precipitation in the region may account for lower Zn levels than what is assumed enhanced due to mining activities worldwide. The next lowest mean Zn in Plagla is from the plot 51la upstream from the portal about 200 ft, indicating that Zn is airborne in the road dust and settling some distances from the unpaved road and portal. The Plagla at the tailings pile is lower still at 400 ppm, indicating that less Zn is being released into the environment from the tailings pile than what is released at or near the portal. Plot 1004 from the 1745 ft level on Mt Roberts is curiously higher in Zn than the lower elevations that are closer to Juneau. Plot 1004 was also the highest in Zn for Alesar. It is possible that the tram and restaurant at the top of the hill may emit Zn in the mechanisms of this tourism industry.

XXXII. THRESHOLDS

Species	S	N	Al	B	Ba	Be
Alesar	0.06	0.56	56.78	9.33	15.84	0.04
Hypog	0.09	0.88	1126.44	9.47	76.62	0.04
Lobore	0.13	NA	580.03	4.06	16.46	0.04
Plagla	0.08	0.80	1063.57	6.05	53.80	0.04

Species	Ca	Cd	Co	Cr	Cu	Fe
Alesar	9689.25	0.40	0.78	0.73	1.86	55.64
Hypog	24671.17	0.61	1.25	2.38	31.31	1990.78
Lobore	1158.10	0.55	0.83	1.51	10.18	1010.97
Plagla	4104.48	0.32	1.14	3.29	7.55	1773.56

Species	K	Li	Mg	Mn	Mo	Na
Alesar	2413.25	0.40	740.83	188.24	0.54	893.16
Hypog	3284.34	0.71	2127.70	860.85	0.54	929.13
Lobore	8001.57	0.59	735.79	168.00	0.54	394.30
Plagla	2523.88	0.60	1717.08	483.70	0.54	693.21

Species	Ni	P	Pb	Rb	Si	Sr
Alesar	0.96	913.75	5.00	53.00	134.75	33.56
Hypog	4.26	1597.23	10.13	53.00	563.82	61.26
Lobore	1.65	2532.49	3.52	53.00	681.18	6.30
Plagla	2.65	1115.00	3.52	53.00	635.83	28.91

Species	Ti	V	Zn
Alesar	4.93	0.37	38.06
Hypog	62.42	2.99	70.20
Lobore	45.30	2.42	82.93
Plagla	76.86	3.08	52.85

XXXIII Conclusions

Air quality of the Tongass National Forest is relatively good. Of the 127 monitoring sites, 67 exhibit no elemental enhancement above provisional thresholds. Of these 67 sites, 31 are in wilderness where air quality is also assumed to be very good. The remaining 65 sites have one or more elements at or above provisional threshold; 21 of these sites are in wilderness (Table XXXIII-1). Most of the contaminents elevated in lichens from non-wilderness sites are attributed to unpaved roads, nearby industrial sources, or natural sources such as the geology of the site. There were no relationships among the elemental content in lichens and physiographic characteristics such as elevation, latitude, longitude, and precipitation. Therefore, elevated levels of certain contaminenets are most likely due to what occurs in the local environment near the monitoring site and are not influenced by the physiographic factors measured at a site.

An objective of this recent biomonitoring initiative was to establish provisional elemental thresholds for target lichen species that can be used in future air quality biomonitoring work on the Tongass and in the Alaska Region. As shown in Table XXXII-1 and throughout this report, provisional thresholds were established for 27 elements on the Tongass National Forest. Provisional thresholds can be used as a comparison to determine if levels are enhanced beyond what is considered clean or background for a species on the Tongass. The Tongass generally has higher thresholds in many elements than the average background levels in the Pacific Northwest. This is most likely due to the hypermaritime influence and active geologic processes of the region.

Most of the wilderness areas that contain lichens elevated above threshold are in locations with exposure to the open ocean or to the interior climates of the mainland (i.e. Tebenkof, Endicott River, Stikine River, Russell Fiords, Coronation, Warren). Mainland areas tend to be drier and contain windblown sands and soils that are continual sources for dry and wet deposition on the lichen thallus. Lichens quickly hydrate during humid conditions and elements are then absorbed into the tissues where they remain until they are leached out over time into the environment. Exposed locations on the beaches are susceptible to incessant salt spray containing naturally occurring elements in sea water (i.e. Ca, S, Mn, and Na). Elements are deposited on lichens from the salt spray and absorbed into the thallus. The use of some bays as anchorages by marine vessels such as Coronation and Warren Islands may also enhance certain contaminants in the beach lichens due to burning of fossil fuels.

Another objective of the recent biomonitoring initiative was to determine patterns of contaminant accumulation in relation to the industrialization of Greens Creek mine and downtown Juneau. Both of these areas contain large machinery and/or vehicles that burn fossil fuels which produce NO_x. Elevated sulfur in these areas is most likely anthropogenic from diesel power and other machinery. Greens Creek and Juneau are not in exposed locations subjected to continual salt spray as are the more pristine places that were elevated in sulfur (ie. Tebenkof, Coronation).

The three Greens Creek sites contained between 7 and 17 different contaminents elevated above threshold. The most common were cadmium, copper, iron, sulfur, lead, zinc, vanadium, and nickel. Several of these contaminants were at the highest levels reported in lichens on the Tongass. Some contaminants were also within ranges considered enhanced due to smelters and mining from worldwide studies. Therefore, the levels of some contaminants from Greens Creek are similar to other sites in industrial locations worldwide with heavy metal air pollution. The tailings pile site contained the most elements above threshold, followed by the site near the entrance to the portal. This indicates that the open tailings pile releases contaminants into the air and surrounding environs through weathering of the exposed ore. These contaminants are mainly from the ore dusts extracted in the mining process.

The five monitoring sites on Mt Roberts in Juneau had at least three elements above threshold from each of the five sites. The 175 ft elevation site sampled near the downtown tram contained 13 elements at or above threshold level (Table XXXIII-1). The most common elements elevated were nitrogen, potassium, phosphorus, sulfur, and zinc. Additionally, Mt Roberts's sampling sites are above the cruise ship docking area where ships use diesel power when in port. Along with this industry, automobile traffic and wood burning stoves play a role in contributing air pollutants in the downtown area.

From the data presented in this report, it is probable that contaminant enhancement in lichens from the Juneau and Greens Creek area are attributed to industrial and urban sources. However, the distance beyond the monitoring sites that the elements have dispersed into the forest or surrounding habitats is unknown. Land managers concerned with air quality in Juneau and Greens Creek should consider implementing a gradient of collection locations radiating from the pollution sources to determine where the levels of certain elements drop below threshold.

Elemental air data can also be compared and contrasted to water quality data to determine if airborne contaminants are eventually leaching into soils and freshwater sources. Air pollution is directly tied to forest health. Deposition of certain pollutants may harm vegetation and soil resources due to changes in pH of the soil water, thus increasing the solubility of certain ions and promoting leaching. These mobilized ions can damage roots and soil biota (CARB 1989).

Due to time constraints, lichen community data were collected at Greens Creek, but not on Mt Roberts. Lichen species diversity or the presence of nitrophilous lichens can also be an indicator of elemental enhancement. Similary, the abundance and overall health of the lichens at a particular site can be useful in determining enhancement impacts.

Table XXXIII-1. Summary of air biomonitoring data on the Tongass National Forest. Plots with elemental values above provisional threshold levels are in bold type for an element. *Alectoria sarmentosa* = Alesar; *Lobaria oregana* = Lobore; *Platismatia glauca* = Plagla. All other elements not in bold were at threshold level.

Plot Number	**General location**	**Lichen species and elevated elements**	**Possible sources**
28	Petersburg Creek wilderness	none	
29	Petersburg Creek wilderness	Alesar: **Mn**, **Ni**	Natural variation, geology
57	Petersburg Creek wilderness	none	
82	Petersburg Creek wilderness	none	
116	Petersburg Creek wilderness	Alesar: Mn	Natural variation, geology
237	Petersburg Creek wilderness-not permanent plot	none	
145	Pleasant Island wilderness	none	
146	Pleasant Island wilderness	none	
189	Kootznoowoo wilderness-Gambier Bay	Alesar: **Cd** *Hypogymnia*: **Mn**	Natural variation, geology
190	Kootznoowoo wilderness-Gambier Bay	*Hypogymnia*: Mn	Natural variation, geology
30	Stikine River wilderness-Shakes	none	
31	Stikine River wilderness-main river	Plagla: **Mn, Si**	Windblown soils
195	Stikine River wilderness-Gut Island	Plagla: **B**	marine influence, windblown soils
494	Stikine River wilderness-Andrews Slough	none	
495	Stikine River-Flemer cabin	Lobore: **Ba**, **Si**, V	Windblown soils
503	Stikine wilderness-Thunder Mt	none	
496	South Etolin wilderness-alpine lake	none	
497	South Etolin wilderness-alpine lake	none	
199	Bradfield area-Harding River	none	
32	Tebenkof wilderness-beach	Alesar: **Mg** Lobore: **P**	Marine influence, marine vessels
33	Tebenkof wilderness-beach	Alesar: **S**, **Al**, **Cu**, **K**, **P** Lobore: **S**	Marine influence, marine vessels
500	Tebenkof wilderness-beach	none	
37	Cape Fanshaw	Lobore: Mn	Natural variation, geology
192	Point Agazii-PRD mainland	none	
43	Shrine of St Teresa-Juneau-temporary plot	*Hypogymnia*: **Al**	road dust
159	Karta River wilderness	none	
39	Mitkof Island Raven’s Roost	none	

Plot Number	General location	Lichen species and elevated elements	Possible sources
40	Mitkof Island, Raven's Roost	none	
42	Mitkof Island Raven's Roost	none	
44	Mitkof Island near Petersburg temporary plot	*Hypogymnia*: **Al**	road dust
91	Mitkof Island Crystal mountain- temporary plot	none	
118	Mitkof Island-Froot Rd	Alesar: **Cd**	Road dust, nearby rifle range
117	Mitkof-3 Lakes Loop Rd-temporary plot	none	
124	Mitkof Island-off 6227 Rd	none	
140	Mitkof Island, Twin Creeks	none	
167	Mitkof Island, Woodpecker	none	
121	Kupreanof Is, Sherman Pk	none	
152	Woewodski Is Harvey Lake-temporary plot	none	
60	Yakutat bunkhouse-temporary plot	none	
64	Yakutat road system-temporary plot	none	
65	Yakutat Pike lakes RNA	none	
66	Yakutat Greens Pond	Alesar:**Cr** *Hypogymnia*: **Cr** Lobore: **Cu**	road dust
67	Yakutat road 11 mile-temporary plot	*Hypogymnia*: **S** Lobore: **B**	Road dust
69	Yakutat Pikes Lakes RNA	Alesar: Al Plagla: **N**, **Al**	Road dust, windblown soils
208	Yakutat Pikes Lakes RNA	none	
209	Yakutat Pikes lake RNA	none	
210	Yakutat Pikes Lakes RNA	none	
211	Yakutat Pikes Lakes RNA	none	
212	Yakutat Pikes Lakes RNA	none	
62	Russell Fiords wilderness	*Hypogymnia* : **Al**, **Cr**, **Li**, **Si**, **Ti**, V Lobore: **Al**, **Co**, **Cr**, Cu, **Fe**, **Li**, **Ni**, Ti Plagla: **Cr**, **Li**, **Ni**, **Ti**	Road dust, bridge, airstrip, windblown soils from interior, and nearby glaciers
76	Dog Island, near Duke Is.-temporary plot	Alesar: **Cd**	Geology, natural variation
77	Dog Island near Duke Is.	none	
79	Kuiu Island-Kell Bay isthmus-temporary plot	*Hypogymnia*: **Ca**, **Mn** Lobore: **Mn**	Salt spray
80	Kuiu Island-Kell Bay isthmus-temporary plot	none	
81	Kuiu Island-Kell Bay isthmus	Alesar: Ca	Salt spray

Plot Number	General location	Lichen species and elevated elements	Possible sources
219	Kuiu Island- Rowan Ck	Alesar: **Al**, **Fe**	Road dust
220	Kuiu Island Crane Ck	none	
498	Kuiu wilderness-Malmsberry Lk	none	
499	Kuiu wilderness-Malmsberry Lk	none	
86	Misty Fiords-Hugh Smith	Lobore: **K**	Natural variation
88	Misty Fiords-Hugh Smith	none	
83	Misty Fiords Manzanita Lk	none	
84	Misty Fiords Manzanita Lk	none	
85	Misty Fiords Manzanita Lk	none	
164	Cleveland Pen.Lk McDonald	none	
98	Chichagof Is. Dry Pass, West Chichagof wilderness	none	
99	Chichagof Is. Dry Pass, West Chichagof wilderness	Alesar: **Na**	Marine influence
100	Myriad Island-West Chichagof wilderness	Alesar: **Mn**, V	Marine influence, geology, or natural variation
101	Myriad Island-West Chichagof wilderness	none	
110	Juneau Amalga Tr Yankee Basin	Lobore: **Cd**	Old mine site, geology or natural variation
111	Juneau Amalga Tr-Boulder Ck	Alesar: **Mn** *Hypogymnia*: K, P Lobore: **K**	Old mine site, geology or natural variation
102	Baranof Island-Big Bay	none	
105	Baranof Island-Kanga Bay	none	
221	Douglas Island-Eaglecrest Rd	Alesar: **Al**, **Cd**, **Pb**	Nearby road, old mining
112	Douglas Island-Eaglecrest Rd	none	
113	Berners Bay- Cove Pt	Alesar: **Co**, K, P *Hypogymnia*: **Al**	marine influence, old mine nearby, natural variation
114	Berners Bay-Cove Pt	none	
130	Revilla Island, Settlers Cove	Alesar: **Ca**	Ocean influence
125	Revilla Is. Ward Lake	none	
132	Gravina Is	none	
133	Gravina is	none	
135	Bold Is KMRD	none	
142	Whitestone-Hoonah	Alesar: **Na**	Natural variation
143	Whitestone-Hoonah	Alesar: **Al**, **Na**	Nearby road, natural variation
107	Sitka near Blue lk- temporary plot	Alesar: **Ca**, **Ni**, **P**	Road dust, industry, urban
108	Sitka near Thimbleberry Tr.-temporary plot	Alesar: **Al**, **B**, **Cd**, **Cu**, **Na**, **Zn** *Hypogymnia*: **B, Na**	Road dust, industry, urban

Plot Number	**General location**	**Lichen species and elevated elements**	**Possible sources**
236	Sitka Blue Lake rd- temporary plot	*Hypogymnia:* **Cr**, **Ni**, **P**	Road dust, industry, urban
239	Sitka Hwy- temporary plot	*Hypogymnia*: **S**, **Cr**, **Cu**, **K**, **Ni**, **Pb**	Road dust, industry, urban
241	Sitka Hwy- temporary plot	*Hypogymnia*: **K**, **P**, **Pb**	Road dust, industry, urban
240	Sitka Hwy temporary plot	Alesar: **S**, **Al**, **Cr**, **Cu**, **Fe**, **Ni**, **Zn**	Road dust, industry, urban
242	Sitka Hwy- temporary plot	*Hypogymnia:* **S**, **Cr**, **K**, **Pb**, **Zn**	Road dust, industry, urban
243	Sitka Hwy- temporary plot	*Hypogymnia*: **S**, **Al**, **B**, **Cr**, **Fe**, **K**, **Ni**, **P**, **Pb**	Road sust, industry, urban
244	Sitka Hwy- temporary plot	*Hypogymnia*: **S**, Al, **Cr**, **K**, **Ni**, **Pb**	Road sust, industry, urban
245	Sitka Hwy- temporary plot	*Hypogymnia*: **B**, **Cr**, Fe, **Ni**	Road dust, industry, urban
246	Sitka Hwy- temporary plot	Alesar: **Cr** *Hypogymnia*: **S**, **B**, **Cd**, **Mg** Lobore: **B**, **Cr**, **Cu**, **Mg**, **Mn**, **Pb**	Road dust, industry, urban
487	S. Baranof wilderness-West Crawfish	none	
488	S. Baranof wilderness -West Crawfish	none	
489	S. Baranof wilderness-Red Bluff Bay	none	
490	S. Baranof wilderness-Red Bluff Bay	none	
491	Chuck River-mouth of river	none	
492	Chuck River-Taylor Creek	none	
493	Chuck River-Taylor Lake	none	
504	Tracy Arm wilderness-muskeg	none	
505	Tracy Arm wilderness-forest	none	
506	Endicott River wilderness-lower river	*Hypogymnia*: **N**, Ca, Zn Lobore: **Ca**, Zn Plagla: N, **Co**	Marine influence, marine traffic, geology, natural variation
507	Endicott River wilderness-upper river	Alesar: Ba, Ca *Hypogymnia*: **S**	Unknown S source, geology, natural variation
508	Endicott River wilderness-upper river	Alesar: **Al**, **Ba**, **Fe**, K, **Si**, **Ti** *Hypogymnia*: **S**, **Ba**, **Co**, K. Plagla: **Ba**, **Co**, P, V	Geology, windblown soils from interior, unknown S source
509	Warren Island wilderness-muskeg	*Hypogymnia*: Mg	Natural variation or marine influence

Plot Number	**General location**	**Lichen species and elevated elements**	**Possible sources**
510	Warren Island wilderness-Warren Cove	Alesar: **S**, **N**, **Mg** Plagla: K, **Mg**	Exposed to ocean, marine anchorage
511a	Green Creek mine plot near stream	Plagla: **Ba**, **Cd**, **Cu**, **Ni**, **Pb**, **V**, **Zn**	Mining activities
511b	Greens Creek mine at portal-temporary plot	*Hypogymnia*: **S**, **Cd**, **Cu**, **K**, **Pb** Plagla: **S**, **Cd**, **Cr**, **Cu**, **Fe**, **K**, Li, **Ni**, **P**, **Pb**, **V, Zn**	Mining activities
512	Greens Creek mine-tailing pile	Alesar: **S**, **N**, **Al**, **Ba**, **Cd**, **Cu**, **Fe**, **Pb**, **Si**, **Ti**, **V**, **Zn** *Hypogymnia*: **S**, **Al**, **Cd**, **Co**, **Cu**, **Fe**, **Li**, **Ni**, **Pb**, **Si**, **Ti**, **V**, **Zn** Plagla: **S**, **Al**, **Ba**, **Cd**, **Co**, **Cr**, **Cu**, **Fe**, **K**, **Li**, **Ni**, **Pb**, **Si**, **Ti**, **V**, **Zn**	Mining activities
513	Coronation wilderness-Egg Harbor	Alesar: **N** *Hypogymnia*: **Mg** Plagla: **S**	Exposure to open ocean, marine vessel anchorage
513	Coronation wilderness-Windy Pass	Alesar: **Ca**	Natural variation, exposure to open ocean
71	POW Old Toms Ck RNA	none	
72	POW Old Toms Ck RNA	none	
73	POW Old Toms Ck RNA	none	
119	POW Coffman Cove	none	
120	POW Coffman Cove	none	
128	POW Naukati	none	
515	S Prince of Wales wilderness-muskeg	none	
516	S Prince of Wales wilderness-beach	Alesar: **S**, **Mg**	Marine influence
1000	Mt Roberts 175 ft	Alesar: **S**, **N**, **Al**, Ba**, Cu**, **Fe**, **Na**, **Ti**, **V** Plagla: **N**, **Cr**, **K**, **Ni**, **P**, Ti**, V**	urban Juneau, cruise ship dock, old mine
1001	Mt Roberts 600 ft	Plagla: **S**, **K**, **Ni**, **P**, **V**	urban Juneau, cruise ship dock, old mine
1002	Mt Roberts 910 ft	Alesar: P, **Zn** Plagla: **S**, **K**, **P**	urban Juneau, cruise ship dock, old mine
1003	Mt Roberts 1241 ft	Plagla: N, **K**, **P**	urban Juneau, cruise ship dock, old mine
1004	Mt Roberts 1750 ft	Alesar: **Zn** Plagla: N, **K**, **P**, **Zn**	urban Juneau, cruise ship dock, old mine, tourist tram station

Recommendations for future biomonitoring with lichens

1. Consider monitoring only certain elements such as sulfur, nitrogen and some heavy metals that have levels above threshold for Tongass biomonitoring plots. This will reduce the costs in the ICP analysis and the generation of results and subsequent reports.
2. Monitor wilderness plots every 5 years to determine trends in elemental deposition and changes in trans-pacific transport of nitrogen. In wilderness areas with elements elevated above threshold, gather more detailed information on the surrounding geology if available as well as the frequency of marine traffic (in the case of Coronation, Tebenkof and Warren).
3. Monitor non-wilderness plots of interest every 5 to10 years to help determine if pollutants are from nearby anthropogenic sources. Revisit the Sitka plots along the road and near the extinct pulp mill to determine if the elemental content of the lichens have changed since the mill has closed.
4. Analyze the lichen community data from all the biomonitoring plots, and include the FIA plots that contain with lichen community data. This will document trends in species composition and abundance across the Forest and serve as baseline for changes due to atmospheric depositions and climate change due to global warming.

XXXIII. LITERATURE CITED

Agency for Toxic Substances and Disease Registry (ATSDR). 2004. Toxicological Profile for Strontium. Atlanta, GA: U.S. Department of Health and Human Services, Public Health Service

Barbalace, Kenneth 2007 Periodic Table of Elements - Rubidium – Rb. EnvironmentalChemistry.com. 1995 - 2007. Accessed on-line: 9/19/2007 http://EnvironmentalChemistry.com/yogi/periodic/Rb.html

Boonpragob, K. and T.H. Nash III. 1990. Seasonal variation of elemental status in the lichen *Ramalina menziesii* Tayl. from two sites in southern California: evidence for dry deposition accumulation. *Environmental and Experimental Botany* **30**(4): 415-428.

California Air Resource Board (CARB) 1989. The Health and Welfare Effects of Acid Deposition in California: Technical Assessment: State of California Air Resource Board

Davidson, C.I., W.D. Goold, T.P. Mathison, G.B. Wiersoma, K.W. Brown, and M.T. Reilly. 1985. Airborne trace elements in Great Smoky Mountains, Olympic and Glacier National Parks. Environmental Science Technology. **19** (1):27-35.

Derr, C.C., B.McCune, and L.H. Geiser 2007. Epiphytic macrolichen communities in Pinus contorta peatlands in southeastern Alaska. Bryologist **110** (3) 521-532

________1997. Air Quality Biomonitoring on the Chugach National Forest: Methods and Baselines Using Lichens. Unpublished report. January 1997.

________1994. Elemental analysis of lichens from *Pinus contorta* peatlands in southeast Alaska. P.29-48. In: Lichen biomonitoring in southeast Alaska and western Oregon. MS thesis. Oregon State University, Corvallis. 98pp.

Farmer, A.M., J.W. Bates and J.N.B. Bell. 1991. Comparisons of three woodland sites in Northwest Britain differing in richness of the epiphytic Lobarion pulmonariae community and levels of wet acidic deposition. *Holarctic Ecology* **14**: 85-91.

Fields, R.F. 1988. Physiological responses of lichens to air pollutant fumigations. *In* Nash, T.H. III ed. *Lichens, Bryophytes and Air Quality*. Biblio. Lichenol. 30. J. Cramer, Berlin-Stuttgart.

Garty, J. 2001. Biomonitoring atmospheric heavy metals with lichens: Theory and application. *Critical Reviews in Plant Sciences* **20** (4): 309-371.

Geiser, L.H., C.C. Derr, K.L. Dillman. 1994a. Air Quality Monitoring on the Tongass National Forest. USDA Forest Service, Alaska Region Technical Report R10-TB-46. September 1994.

Geiser, L.H., K.L. Dillman, C.C. Derr, and M.C. Stensvold. 1998. Lichens and Allied Fungi of Southeast Alaska. Lichenographia Thomsoniana: North American Lichenology in Honor of John W. Thomson. *Eds*. M.G. Glenn, R.C. Harris, R. Dirig & M. S. Cole. Mycotaxon Ltd. Ithaca, NY.

Herzig, R., L. Liebendörfer, M. Urech, K. Ammann, M. Cuecheva and W. Landolt. 1989. Passive biomonitoring with lichens as a part of an integrated biological measuring system for monitoring air pollution in Switzerland. *International Journal of Environmental Analysis and Chemistry* **35**: 43-57.

IPCS 1998. International Program of Chemical Safety. http://www.inchem.org/

Kabata-Pendias , A.and H. Pendias 1984. Trace elements in soils and plants. CRC Press Inc. Boca Raton. 315 p.

Miller, R.E., D.P. Lavender, and C.C. Grier. 1976. Nutrient cycling in the Douglas-fir type –silvicultural implications. Proceedings of the Society of American Foresters. 1975. 359-390.

Nash T, and C. Gries 1991. In: Hutzinger, O (ed.) The Handbook of Environmental Chemistry Vol 4 Part C. Springer-Verlag: Berlin Heidelberg New York.

Neiboer, E. and D.H.S Richardson. 1981. Lichens as monitors of atmospheric deposition. In: S.J.Eisenreich, (ed.) Atmospheric pollutants in natural waters. Ann Arbor, MI: Ann Arbor Science Publishers: 339-388.

Neiboer, E., D.H.S. Richardson, and F.D. Tomassini 1978. Mineral uptake and release by lichens: an overview. Bryologist **81**: 226-246.

Nowacki, G., M. Shephard, P. Krosse, W. Pawuk, G. Fisher, J. Baichtal, D. Brew, E. Kissinger & T. Brock. 2001. Ecological subsections of Southeast Alaska and Neighboring Areas of Canada. USDA Forest Service, Alaska Region. Technical Publication No. R10-TP-75. October 2001

Ramsey F.L. and D.W. Schafer. 1997. The Statistical Sleuth, A Course in Methods of Data Analysis. Duxbury Press, London.

Rona, P.A. 2003. Resources of the Sea Floor. Science **31** Vol 299 No 5607 pp. 673-674.

Richardson, D.H.S 1988. Understanding the pollution sensitivity of lichens. Botanical. Journal. of the Linnean Society. **96**:31-43.
Seaward, M.R.D.1974. Some observations on heavy metal toxicity and tolerance in lichens. Lichenologist. **6**:158-164.

Sigal, L. L. and T.H. Nash III. 1983. Lichen communities on conifers in southern California mountains: An ecological survey relative to oxidant air pollution. Ecology **64** (6): 1343-1354.

S-Plus 2000. 1988-1999. Data Analysis Products Division, MathSoft, Seattle, WA.

USDA 2006. National Lichens and Air Quality Database and Clearinghouse. http://www.nacse.org/lichenair/ accessed September 2006.

USPHS 1990. Toxicology Profile for Copper. Agency for Toxic Substances and Disease Registry; United States Public Health Service http://www.eco-usa.net/toxics/copper.shtml

USPHS 1990. Toxicology Profile for Chromium. Agency for Toxic Substances and Disease Registry; United States Public Health Service
http://www.eco-usa.net/toxics/chromium.shtml

_______ 1992. Toxicology Profile for Manganese: Agency for Toxic Substances and Disease Registry: United States Public Health Service
http://www.eco-usa.net/toxics/mang.shtml

_______ 1992. Toxicology Profile for Barium: Agency for Toxic Substances and Disease Registry: United States Public Health Service
http://www.eco-usa.net/toxics/barium.shtml

_______ 1992 Toxicology Profile for Vanadium: Agency for Toxic Substances and Disease Registry: United States Public Health Service
http://www.eco-usa.net/toxics/vanadium.shtml

_______ 1993. Toxicological Profile for Cadmium. Agency for Toxic Substances and Disease Registry; United States Public Health Service http://www.eco-usa.net/toxics/cadmium.shtml

_______ 1993. Toxicological Profile for Cobalt. Agency for Toxic Substances and Disease Registry; United States Public Health Service http://www.eco-usa.net/toxics/cobalt.shtml

_______ 1994. Toxicological Profile for Zinc. Agency for Toxic Substances and Disease Registry; United States Public Health Service http://www.eco-usa.net/toxics/zinc.shtml

______ 1995 Toxicology Profile for Nickle August 1995 Draft Update. Agency for Toxic Substances and Disease Registry: United States Public Health Service http://www.eco-usa.net/toxics/nickel.shtml

Weast, R.C., J.A. Melvin, and W.H. Beyer (eds.) 1987. *CRC Handbook of Chemistry and Physics*. CRC Press, Inc., Bocan Raton, FL, pp.

See Geiser et al (1994) for a discussion on standards used and methods in the laboratory for ICP analysis.