Monitoring air quality in the Southeast Alaska Network: linking ambient and depositional pollutants with ecological effects

Assessment of current conditions, trends, and refinement of passive sampling and lichen bio-monitoring protocols

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Klondike Gold Rush National Historical Park
POB 517
Skagway AK 99840

US Forest Service, Pacific Northwest Region Air Resource Management Program
POB 1148
Corvallis, OR 97339

David Schirokauer - Co Investigator and NPS Lead
Klondike Gold Rush National Historical Park

Linda Geiser, Ph.D. - Co Investigator, Senior Advisor
US Forest Service -Pacific Northwest Region

Ellen Porter - Project Coordinator
NPS Air Quality Division, Natural Resources Program Center

Brendan Moynahan
SEAN Inventory and Monitoring Coordinator

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Abstract

Results of a 1998-99 pilot study in Klondike Gold Rush National Historical Park (KLGO) revealed that local lichens had higher levels of heavy metals and sulfur in lichen tissues than baseline values established at over 120 sites on the surrounding Tongass National Forest (Furbish et al. 2000). In 1998-99 the KLGO-Skagway area exceeded lichen tissue air pollution indicator thresholds set by the USDA-Forest Service Pacific Northwest and Alaska Regions for heavy metals, sulfur and other elements. Since then, visitation and the associated transportation needs (busses, trains, and cruise ships) have increased by 57% (NPS visitation statistics through 2006). This study will follow-up and refine the original methodology and expand the study area to include all NPS areas in Southeast Alaska in order to:

1. Track trends in air quality over time with biomonitoring at KLGO;
2. Contribute to the development of models linking ambient conditions to concentrations of pollutants in lichen thalli[1] by deploying passive air concentration samplers and passive bulk and through-fall samplers at lichen collection sites throughout the Southeast Alaska Network (SEAN);
3. Overcome the problem of determining the timing of heavy metal accumulation by collecting lichens from substrates of known age and by foliar lead analysis of deciduous or herbaceous vegetation.
4. Begin assessing the effects of air pollution on lichen community composition by comparing sites with different levels of air contaminants at lichen plots throughout the SEAN and greater Southeast Alaska on Tongass National Forest lands (TNF);
5. Collect reference data on lichen community composition for future trends analysis following the US Forest Service administered National Forest Inventory Analysis/Forest Health Monitoring (FIA/FHM) Lichen Indicator protocols;
6. Create a spatially explicit model of the Skagway Watersheds airshed and
7. Develop monitoring protocols for air quality as part of the SEAN Inventory and Monitoring Program following Oakley et al. (2003). Concurrently with this biomonitoring project, KLGO will be conducting a comprehensive lichen inventory (PMIS 119587), funded by KLGO, SEAN, and NRPP Small Parks.

Introduction

Problem Statement

The low population densities, lack of large-scale industrial development, proximity to Pacific Ocean, and vast stretches of wild-lands lead many people to believe the environmental quality of Southeast Alaska is among the most pristine in the world. However, the lichen-based air quality study completed in 1999 demonstrated that sulfur, nitrogen, and heavy metal concentrations in the KLGO-Skagway area exceeded thresholds established by the US Forest Service for the area (Furbish et al 2000). Reference data for elemental concentrations in lichen thalli also exists for four samples at one site, Beartrack Mountain, in Glacier Bay National Park (GLBA) from 2004, but does not exist for Sitka National Historical Park (SITK). However, SITK reference data does exist for nearby sites in Tongass National Forest (TNF) that can be used for comparative purposes (Geiser et al. 1994).

[1] The entire vegetative body of the lichen (plural).

The Klondike-Skagway area is exposed to a number of local and regional air pollution sources. Homes and businesses expel exhausts into the air from heating, cooking, cleaning and business operations. Residential and commercial open-air burning occurs in backyards and business lots. The city began operating an incinerator for trash disposal in 1999. Road transportation includes cars, buses, shuttles and large trucks. Ferries, barges and small boats operate year-round. Air traffic consists of small planes and helicopters. All of these sources increase dramatically during the summer tourist season when Skagway becomes the 16th busiest cruise ship port in the world (www.skagway.org). Up to six large cruise ships a day dock at Skagway from May to September. With the support facilities of a small town, Skagway power supplies are not adequate to offer dockside electrical plug-ins, therefore cruise ships continue operating on-board diesel generators while in port. Cruise ship generators produce exhausts that are usually visible to the naked eye as stack emissions. Diesel powered tourist trains also operate several times a day. Regional sources of air pollution include sooty fine particulates, nitrogen oxides, and other pollutants associated with forest fires and wind-blown dust and industrial emissions transported from Eurasia. Local and regional air pollutants are a concern because of the potential adverse effects to human health and to air pollution sensitive components of national park ecosystems from the air pollutants themselves and because of the impacts they have on visibility, an important air quality related value (NPS 2003). Cruise ships emit nitrogen oxides and sulfur dioxide, gaseous pollutants that are usually regulated under the Clean Air Act according to the National Ambient Air Quality Standards; however, mobile sources are not currently regulated by State or Federal entities. Visible haze from stack emissions is not rare in the KLGO-Skagway area.

Currently air quality is not being monitored on the KLGO-Skagway area, GLBA, or SITK. Other than the previous lichen study, Furbish et al. 2000, and one and a half summers' worth of PM2.5 monitoring in 2004-05, no data on air quality exists for the area. Klondike Gold Rush National Historical Park is the most visited NPS site in Alaska and maintaining air quality is essential to the NPS mission. With this study we will be initiating a long-term air quality monitoring program by collecting the second temporal reference point for our biomonitoring program, and refining protocols. Furthermore, long-term air quality monitoring has been selected as a vital sign by SEAN and will be among the first set of vital signs to be funded. The Tongass National Forest has been conducting lichen-based biomonitoring of air quality in Southeast Alaska since the late 1980's (Geiser et al 1994) and a rich reference dataset exists for dry weight element concentrations of select arboreal lichens. We will use these reference data, as well as the standards and thresholds set by the Forest Service for the nitrogen, sulfur, and heavy metals concentrations in lichen tissues as air quality indictors.

The NPS in KLGO hopes to use the results of long-term air quality monitoring in partnership with the Municipality of Skagway**,** the Taiya Inlet Watershed Council, and The Skagway Traditional Council to work with local power providers to develop and implement technology to allow cruise ships to shut down their generators and run on clean, shore based hydro-power during their 12-14 hour stays in Skagway. We also anticipate that results from this study may inspire local operators to deploy cleaner technology when replacing aging transportation equipment. For example, in the absence of adequate shore based hydro-power, we hope to inspire cruise ships to burn cleaner fuels when running generators while docked.

Background

Lichens are ideal long-term integrators of atmospheric deposition due to their longevity and lack of inter-seasonal morphological variation. Lichens lack roots, get their mineral nutrients directly from the air, and their tissue structure traps airborne particulates and soluble metal ions. Because of this, they are more susceptible to the harmful effects of nitrogen, sulfur, and some metal-containing air pollutants compared to plants and animals that have better protective coverings and selectively obtain their nutrients from the soil or from eating other organisms. Some lichens are particularly sensitive to certain air pollutants, and they decline or die when exposed to low levels of those pollutants. The presence or absence of these lichens in an area can be used to indicate incipient adverse effects of air pollution to the ecosystem and will be assessed by establishing permanent lichen community assessment plots following US Forest Service methodology (Geiser 2004). Lichen community studies are one type of lichen-air quality research that examines the composition of lichens in areas exposed to different levels of air pollution (Blett et al. 2003).

Lichens that grow on trees get their nutrients primarily from atmospheric sources; i.e., from precipitation, dry deposition of fine particulates, direct absorption of gases, and from leachates in canopy throughfall. As a result, many chemical elements in air and water are absorbed and accumulated by lichens. Mobile elements like nitrogen, sulfur, and potassium are easily absorbed and also easily leached, maintaining a dynamic equilibrium with seasonal changes in the availability of these nutrients. Chemical properties of other elements, (e.g., lead and cadmium), may cause them to bond more strongly to lichen surfaces and biomolecules and these elements may take years to decrease in concentration after the source has been removed. Accumulated pollutants may adversely affect lichens by interfering with important physiological processes like photosynthesis, they may cause changes in morphology, decline or death, or they may simply bioaccumulate without harming the lichen. Studies that examine the concentrations of chemicals in lichen thalli may reveal signs of air pollution before more overt signs, such as lichen death and changes in the species composition of lichens in an area, become apparent (Stolte et al. 1993).

Determining the actual levels of pollutants in the air requires expensive instruments and laboratory analyses. Lichen tissue analysis is an indirect method for gathering information about air pollutants. Although this method does not produce the rigorous level of information that direct measurements provide, it is relatively inexpensive and has the advantage of giving a summary picture of air quality over time, rather than at a particular moment. In 1998-99, KLGO completed a pilot study using selected lichen species to assess local air quality. The primary objectives of this study were to provide KLGO and the city of Skagway with some preliminary information about air quality, current air quality impacts on lichens, and the feasibility of using lichens as air quality indicators. This study found that KLGO-Skagway lichens had higher levels of heavy metals and sulfur in lichen thalli than baseline values established at over 120 sites on the surrounding Tongass National Forest. In fact, the KLGO-Skagway area exceeded air pollution indication thresholds for the US Forest Service Pacific Northwest and Alaska Regions for heavy metals, sulfur and other elements. All of the study sites sampled in both the Skagway and the Taiya valleys showed signs of air pollution, but the site closest to the Skagway city center and cruise ship docks had the highest levels of pollutants in lichen tissues (Furbish et al. 2000). The thresholds that we used in KLGO were the 97.5% quantiles for the distribution of element concentrations in each lichen species from all remote sites where the species was collected on national forests in southeast Alaska, Oregon and Washington, excluding sites within 100 m of a highway, sites in or adjoining

campgrounds, the Mt St Helens ash deposit zone in the northern half of the Gifford Pinchot NF, sites within 40 miles of a major city (Portland/Vancouver and Seattle), and sites in the Columbia River Gorge National Scenic Area. Lichen communities at sites where nitrogen is under the threshold are unimpacted by air pollution.

Nitrogen and sulfur are non-metals that form compounds in the air which are major contributors to acid rain and visibility degradation. These compounds are quickly absorbed by lichens, but also quickly leach out of lichens if air quality improves. High nitrogen and sulfur concentrations in lichens are strong indicators of current air pollution (Stolte et al. 1993). Heavy metals, such as lead and zinc, are not easily leached from lichen tissues and may persist for 10 years or more making it difficult to evaluate when the pollutant was absorbed by the lichen. Elevated levels of heavy metals are rarely found naturally, and are usually strong indicators of human caused air pollution. Although the pilot study methodology did not allow the park to determine when the heavy metal contamination had occurred, investigators concluded that lichen tissue analysis is an effective passive air pollution monitor for the KLGO-Skagway area. This study also recommended the use of active air quality monitoring equipment at the 'hot spots' identified in the study in order to determine ambient air concentrations and sources of target pollutants. Such equipment is very expensive to acquire and operate, and KLGO has been unable to establish an active air quality monitoring station. However, as part of this study we plan to deploy Ogawa passive air samplers to estimate ambient concentrations of sulfur dioxide (SO_2), nitrogen dioxide (NO_2), nitrogen monoxide (NO), ammonium (NH_3), ammonium nitrate (HNO_3) and nitrogen oxides (NO_x) in conjunction with conducting a second lichen assessment duplicating and enhancing the earlier methodology in order to track trends in air quality over time (Furbish et al. 2000). In addition, we seek to deploy passive deposition monitors at all sites to measure ammonium, nitrates, sulfates and hydrogen ion concentrations in bulk precipitation and canopy throughfall. The deposition monitoring technology uses a resin-filled tube attached to a large funnel to capture ions in precipitation. Deposition measurements will quantify the burden of nitrogen and sulfur containing pollutants deposited to the forest floor in kg/ha during the high emissions season. Deposition measurements will be compared to other western North American sites for potential exceedance of critical loads, likelihood of harmful ecological effects, and will be essential information in any future attempt to develop lichen-based critical loads for the temperate rainforests of southeastern Alaska. Simultaneous measurement of ambient gases, deposition, lichen element concentrations and lichen communities at the same sites, will make possible an integrated assessment of air quality and link ecological effects with specific levels of pollutants.

Because most sources of airborne pollution in the region are currently unregulated mobile sources (marine traffic) or are transported into the region from long distances, and funding is limited, this protocol focuses on easily obtainable measures of air quality and ecological effects rather than the much more costly air quality parameters that are currently used in the regulatory arena. However, elemental concentrations in lichens and their ecological effect on lichen communities may enter the regulatory arena in the near future in determining critical loads (Porter et al. 2004, Leith et al. 2006). A long-term, 5 - 10 year revisit cycle is warranted due to rapidly increasing levels of tourism, low levels of industrial development, and slow population growth in the region. One to two data points per decade will provide managers and researchers with a broad picture of trends in air quality and how park conditions compare to other sites conducting comparable monitoring across the region (Tongass National Forest) and in the Pacific Northwest.

Specific Monitoring Questions and Objectives Addressed by the Protocol

A) How are concentrations of contaminants in the air changing on a decadal cycle as manifested in concentrations in lichen tissue?

1) Determine the concentrations of selected chemical elements in tissue of three lichen species (*Hypogymnia heteromorphy, H. inactive, Platismatia glauca*) from 8 - 10 sites / collection plots across the network (four that were previously used in KLGO (Furbish et al. 2000) plus one or two additional sites, two or three in GLBA and one in SITK). These data will be the site specific reference conditions against which future samples will be compared.

   Sample size & frequency: Each lichen collection macro-plot consists of a relatively homogenous land-cover patch of about 2 hectares. During years when sampling occurs, three 10-20 gram samples (dry weight) of each of three lichen species (currently know as good integrator of airborne contaminants) are collected at the end of the summer season. Sample collection occurs once per year for two consecutive years, followed by a nine year break for a decadal sampling regime.

   Metrics include dry weight concentrations (µg/g) in target lichen species for a suite of elements including nitrogen, sulfur, phosphorus, potassium, calcium, magnesium, sodium, aluminum, iron, manganese, copper, boron, mercury, lead, nickel, chromium, cadmium, cobalt, molybdenum, silicon, titanium, beryllium, strontium, rubidium, lithium, vanadium and barium..

2) Spatial differences: Test for significant differences (H_o = no difference exists) in elemental concentrations between sites across the network.

3) Compare elemental concentration results with reference data from the greater Southeast Alaska area and the Pacific Northwest.

4) **As part of protocol development** measure actual concentration (µg m^{-3}) of SO_4, NO_2, NO_x in ambient air with Ogawa passive air samplers. Also, measure deposition (total wet and dry in kg/ha) by deploying passive through-fall samplers. Then use these data to create model(s) tying pollutant concentrations in ambient air with elemental concentration in lichens and lichen community effects. This will expand on active work in this area (Blum and Tjutjunnik 1992, L. Geiser pers. com.).

5) Lichen air quality sites conducted in KLGO in 1998-99 will be revisited during the development and testing phase of this protocol. Test for significant changes (H_o = no difference exists) in elemental concentrations between the 1998/99 and the 2008/09 sampling period at each KLGO site.

B) How are lichen communities changing over time in response to changes in air quality?

1) Establish lichen community plots following methods used in the Tongass National Forest and National Forests in the Pacific Northwest (Geiser et al 1994, Geiser 2004). Use data from these studies as reference data for inter site comparisons and future intra-site trend

analysis and comparisons. These sites will be immediately adjacent to the lichen collection areas in objective A-1.

Sample size & frequency: Two lichen community plots per collection macro-plot are read once per five year or ten year sampling cycle.

Metrics: Standard site information (percent cover of dominant species by strata, abiotic data, etc.), abundance categories per lichen species, species richness and other diversity metrics for lichens, compositional gradient score. A voucher of each species is collected at each plot (Geiser 2004).

Area of inference: These lichen plots will be part of a region wide monitoring program run by the US Forest Service. By leveraging the 73 (Dillman 2007) plots already in place on Forest Service Land, coarse spatial resolution inferences can be made throughout Southeast Alaska. Fine-scale, park-wide inferences would require additional intra-park sample sites.

2) Re-read lichen community plots at next sampling cycle in 5 to 10 years.

3) Develop models of the relationship between lichen community plot data and metrics (diversity indices), and elemental concentrations in lichen thalli using inter site comparisons metrics. Expand on and test the modeling methods described in Geiser and Neitlich (2007).

Note: In addition to air quality, climate change may affect the lichen community parameters being investigated. This will be controlled for by the existence of several plots sites within the SEAN and the Tongass National Forest, the assumption being that climate effects may manifest at broader scales than local pollution effects. Methods to tease apart climate and pollution effects are presented in Geiser and Neitlich (2007).

C) Develop a protocol (Oakley et al. 2003) for long-term monitoring of air quality trends with lichens as 1) air quality sensors for elemental analysis and 2) bioindicators as expressed through community monitoring plots for the SEAN I&M program.

Environmental Compliance

This project will be entered into the PEPC program following an initial review of this implementation plan by NRPC staff. Although small samples of common lichen species will be destroyed during elemental analysis, this de minimis removal is a negligible impact and qualifies as a Categorical Exclusion under DO-12 section 3.4 - E(6).

Principle Project Managers

Dave Schirokauer, Biologist and Natural Resource Program Manager, Klondike Gold Rush National Historical Park, Skagway, AK. Dave has worked as a biologist for the NPS and USGS since 1996, in Denali, and Glacier National Parks and Point Reyes National Park Seashore. As the Natural Resource Program Manager for Klondike Gold Rush National Historical Park, Dave is responsible for managing and preserving the extensive natural resources of this 13,000 acre historical park. Dave brings to this project his knowledge of the park, field surveying skills, supervisory abilities, and experience as a project manager. These skills will be important for his role as facilitator, implementer, manager, and report writer for this project.

Dr. Linda H. Geiser, Ecologist and Air Quality Specialist, US Forest Service Pacific Northwest Region Air Program, Corvallis, OR. Dr. Geiser has extensive experience as a lichenologist and air quality specialist in the Pacific Northwest and Alaska. Her professional experience has been focused in the area of air quality biomonitoring methods development, implementation, and analysis for the USFS regional air program. She has also integrated biomonitoring data with data from passive filters, active ozone monitors, and existing instrumented networks. In addition, she authored a regional field guide to the lichens and provided regional training in lichen taxonomy and monitoring. She has been involved in the design and implemention of air pollution assessment studies using lichen communities and tissue analysis of lichens and mosses in Oregon, Washington, Alaska (Arctic National Parks, Denali NPP, Klondike Gold Rush Historic NP), Colorado (Mt. Zirkel Wilderness), Vancouver City--British Columbia, and the Alberta Athabasca Oil Sands . Additionally, Dr. Geiser has conducted assessments of organochlorines and metals in lichens and mosses of federally managed lands in the Pacific Rim (Oregon, Alaska, and the Kamchatsky and Primorski Oblasts) and for the NPS sponsored Western Airborne Contaminants Assessment Project. Dr. Geiser's knowledge of air quality biomonitoring techniques, species identification and monitoring protocol development will be integral to this project.

Potential Project Co investigators

Dr. Mark Fenn, Plant Pathologist, US Forest Service Pacific Southwest Research Station, Riverside, CA.

Dr. Andrzej Bytnerowicz, Atmospheric Chemist, US Forest Service Pacific Southwest Research Station, Riverside, CA.

Dr. Rick Graw, Air Resource Management Specialist, USDA Forest Service, Pacific Northwest Region, Portland, OR.

Karen Dillman, Lichenologist, Tongass National Forest, Petersburg, AK.

Dr. Sarah Jovan, Forest Ecologist, National Coordinator Forest Health Monitoring Program, US Forest Service Region 10, Portland, OR.

Study Plan

Approaches and Methods

In order to repeat the previous KLGO study and compare results, the general methods regarding collecting and analyzing lichen will follow Geiser et al. (1994), and Furbish (2000) and collection sites will follow Furbish et al. (2000). However, we will be collecting additional air chemistry data by deploying passive air and through-fall samplers, which were not part of the 1998-99 study in KLGO. This study will also be enhanced by the addition of lichen community composition plots at each site following the methods used by the US Forest Service (Geiser et al. 1994 and Geiser 2004). Also, the size of each plot may be expanded in size to accommodate the higher number of samples being proposed for collection during this study. An additional two sites in the KLGO–Skagway area and two or three sites in GLBA and one additional site in SITK will be added. The

US Forest Service is also likely to join in this study by adding sites in the nearby Tracy Arm Wilderness.

Study Sites

The four sites investigated during the 1998-99 study (Dewey, Chilkoot, Sturgill's and Dyea) will be revisited during this study. The descriptions of the previously visited sites are taken from Furbish et al. (2000). The Dewey and Chilkoot sites were selected to encompass the range of exposures to local sources of air pollution. The results (Furbish et al. 2000) revealed that the greatest exposure was near the town of Skagway and the harbor, and the least exposure was near the beginning of the Chilkoot Trail. The two sites are positioned to be similar in terrain, vegetative cover, slope, aspect and elevation. But they are not identical; the Chilkoot site is farther from marine waters than the Dewey site. The additional sites in the KLGO – Skagway areas are proposed for Upper Reid Falls, Goat Lake, and/or Sturgill's Landing. The sites in GLBA and SITK have not yet been identified.

Dewey (most exposed) - This site is about 4.4 hectares (10.9 acres) in size. It is situated on a low bench along the lower edge of the 1500 meter high ridge that is the east wall of the Skagway River valley, overlooking the Skagway small boat harbor. The plot elevation ranges from about 50 to 175 meters. The plot slope ranges from about 10 to 45 degrees, facing west-northwest (295 degrees). Vegetative cover is a western hemlock - lodgepole pine - Sitka spruce - paper birch woodland in mid-seral stage. Burn scars remain from a fire 55+ years ago. Understory is sparse, composed of rusty menziesie, feather and other mosses, and foliose and fruticose lichens. This site is located on land owned by the Municipality of Skagway**.** (Note: The Skagway Borough Assembly is providing a letter of support authorizing this project on municipal land)

Chilkoot (least exposed) – This site is about 4.9 hectares (12.1 acres) in size. It sits on a small hill known locally as "Saintly Hill" which is a low section of the AB Mountain ridge that forms the east wall of the Taiya River valley. The plot elevation ranges from 85 to 110 meters. The plot slopes to the west-northwest (280 degrees) at 20 to 40 degrees. Vegetative cover is a western hemlock - lodgepole pine - Sitka spruce - paper birch woodland in mid-seral stage. Burn scars remain from a fire 15+ years ago. Understory is sparse, composed of rusty menziesie, shag, feather and other mosses, and foliose and fruticose lichens.

Sturgill's

This site was about 4.0 hectares (8.6 acres) in size. It sits on a 150 meter high bench at the base of a 1500 meter ridge that is the east wall of the Skagway River valley, approximately 1 kilometer south of the Dewey site. The Sturgill site is on the southeast side of a low ridge, and on the south side of the depression that forms Dewey Lake. Elevation is 150 to 175 meters, with a gentle slope (4-15 degrees) facing south-southeast (140 degrees). Vegetative cover is a western hemlock - lodgepole pine - Sitka spruce - paper birch woodland in mid-seral stage. Understory is sparse, composed of rusty menziesie, feather and other mosses, and foliose and fruticose lichens. This site is also located on land owned by the Municipality of Skagway**.**

Dyea

This site was about 4.2 hectares (10.3 acres) in size. It is located on the terminal delta of the Taiya River floodplain. Elevation is 3-18 meters, with near level slope. The site is located on a low bench

above tidal grass/sedge meadows. Site of the historic 1989 gold rush town of Dyea, the area was cleared for agriculture during the decades after the gold rush. Soils are very sandy and well drained. Vegetative cover is coastal Sitka spruce - black cottonwood - western hemlock in mid-seral stage. Trees are 20-30 meters tall. Cottonwood and Sitka spruce dominate, with some paper birch, lodgepole pine, Scoulers willow and unusually large Sitka willows. Many of the dead, lower limbs of trees are covered with lush foliose lichens, such as *Hypogymnia inactiva*. Undisturbed ground is covered with a deep bed of mosses and, in season, mushrooms.

Upper Reid Falls – new KLGO – Skagway site
The site, on USFS land, will be described during the study.

Goat Lake – potential new KLGO – Skagway site
The site, on USFS land, will be described during the study.

Upper Dewey Lake– potential new KLGO – Skagway site
The site, on USFS land, will be described during the study.

Lichen Species and Collections

The three species used by Furbish et al. (2000) and currently used as biomonitors in the region are *Hypogymnia enteromorpha, Hypogymnia inactivea* and *Platismatia glauca*. These locally abundant species were selected from a list of species that are used for biomonitoring of air quality in Southeast Alaska. At each site, three samples of each species will be collected at the end of the summer season. A sample consists of 10 - 20 grams of clean, dry lichens. For non-forested plots in upper GLBA a different set of lichen species may be used because the arboreal lichens listed above may not be present. For non-forested sites, *Cladina rangeriferina* is the most suitable candidate because reference data on elemental concentrations exists for it elsewhere in Southeast Alaska. It is also a possibility that lichen collections may not occur at these non-forested sites if suitable lichen species are not abundant enough for collection. However, even in the absence of collections at these sites, the two passive sampling methods described below will provide valuable reference information on the local air chemistry.

Training in lichen identification will be accomplished by using vouchers in KLGO's herbarium and instruction from an accomplished lichenologist working in the park on the concurrent lichen inventory. Three replicate samples will be obtained per site for each species during each of the two years of the project for a total of 90 samples for the KLGO-Skagway area, and an additional 90 samples for GLBA and SITK combined. Past studies on elemental concentrations in lichen have shown that within-site variation is low (Bennett 1995); therefore, three replicates per site, per species is the current sampling standard used by the US Forest Service. Cores from a subset of trees at each site will be collected to age the stands in which lichens are collected. Samples will be collected during the late summer near the end of the tourist season because bioaccumulation of contaminant is likely to be highest at this time. Lichens will be collected from tree trunks and branches and sealed in airtight, metalized polyester samples bags that have been approved for this purpose (Ampak Corporation).

Samples will be cleaned and air-dried in a secured room free from smoking, cleaning supplies, automobile emissions and unnecessary personnel. Samples will be sent for analyses in Ampak bags that have been sealed with tape to prevent contamination during transit.

Passive Air Samplers

Ogawa passive air samplers with collection pads for SO_2, NHO_3, NH_3, NO_2 and NO_x will be deployed at the lichen collection sites when possible. Because some potential sites in GLBA may not be accessible on a weekly or biweekly basis, only throughfall samplers (see below) will be deployed at these sites if selected. The results from the Ogawa samplers yield data for ambient air concentrations for selected compounds measured in ppm or ppb. Nitrogen monoxide (NO) is calculated by subtracting NO_2 from NO_x. Weekly monitoring will commence on April 15th (3 weeks prior to the beginning of the tourist season) and terminate on Oct 15th (3 weeks after the end of the tourist season). For the Dewey Lake site, between June and August, during the second week of each month we will shift to a daily sampling frequency. This information will be used to examine the relationship between daily and weekly variation in air chemistry, together with weather conditions and number and types of cruise ships in port. Overall, results from the passive samplers will be used to develop models **(**e.g., Fenn et al. 2007**)** linking elemental concentrations in lichen tissue with concentrations detected in ambient air during the study. Dr. Andrjez Bytnerowicz is the project collaborator for the passive air samplers.

Passive Throughfall and Bulk Samplers

Passive throughfall samplers following the methods of Fenn and Poth (2004) will be deployed at each lichen plot. These devices will be left in place from mid-April through mid-October. Throughfall samplers yield data on atmospheric wet and dry deposition of target compounds including sulfates, nitrates, ammonium and hydrogen ions calculated in kg/ha for the sampling period. Ten throughfall sampling tubes will be deployed in forested portions of each 4-5 acre lichen collection plot along with an additional five sampling tubes in canopy gaps. For non-forested plots in upper GLBA, only five throughfall sampling tubes are required (M. Fenn pers. comm. 2007). Results from the passive throughfall samplers will be used to develop models (e.g. Fenn et al. 2007) linking elemental concentrations in lichen tissue and lichen community data with deposition rates detected during the study. Tying deposition rates of key anthropogenic components of air, with measurable effects on lichen community structure and diversity can be used to determine critical loads for specific pollutants. In some parts of the United States and Europe, critical loads have been used to set limits on industrial emissions (Porter et al. 2005). Dr. Mark Fenn is the project's collaborator for throughfall sampling.

Air Dispersion Model

An airshed model conducted with AERMOD (EPA 2008) will be used to assist with quantification of the concentration and depositional impact of nitrogen and sulfur from cruise ships, ferries, harbor vessels, the railroad, and the municipal incinerator near KLGO. The modeling will complement the larger ecological indicator study by (1) demonstrating areas of maximum impact from these sources, (2) quantifying the attribution to the total depositional impacts, and (3) potentially be used to simulate the difference in impacts from emission reduction strategies.

AERMOD is a steady-state plume model that incorporates air dispersion based on planetary boundary layer turbulence structure and scaling concepts, including treatment of both surface and

elevated sources, and both simple and complex terrain. It is the U.S. Environmental Protection Agency's preferred air quality dispersion model for regulatory applications for source-receptor distances less than 50 km.

The model requires a digital simulation of the location of emission sources, terrain, and meteorology to transport and disperse pollutants. These data are all available from the GIS system at KLGO. The model also requires detailed data on the location and chemistry of emission sources. Emission inventories will be developed for these sources for the 2008 tourist season in Skagway which begins May 1st and ends September 30th. Emissions from these sources will be estimated by using site-specific activity information and established emissions factors. An emissions factor is a representative value that attempts to relate the quantity of a pollutant released to the atmosphere with an activity associated with the release of that pollutant. These factors are usually expressed as the weight of pollutant divided by a unit weight, volume, distance, or duration of the activity emitting the pollutant (e.g., kilograms of particulate emitted per megagram of coal burned). In most cases, these factors are simply averages of all available data of acceptable quality, and are generally assumed to be representative of long-term averages for all facilities in the source category (i.e., a population average).

The general equation for emissions estimation is:

$$E = A \times EF \times (1-ER/100)$$

where:

- E = emissions;
- A = activity rate;
- EF = emission factor, and
- ER =overall emission reduction efficiency, %

Emissions from marine vessels will be quantified while in docked in port only. Similarly, emissions from locomotives will be calculated for the period and location when they are stationary.

Ideally, in creating an accurate emission inventory, one would need to quantify the number and type of marine vessels docked in port each hour of each day throughout the year. However, certain assumptions can be made which will simplify this task while maintaining meaningful representation for modeling purposes. These assumptions are as follows:

- Emissions only occur during the cruise ship operating season (May 1 – September 30).
- Emission generating activities are the same each day of the week during this period.
- The diurnal variation of emissions will be developed based upon local observations.

Mr. Albert Fauvre of the Alaska Department of Environmental Conservation (AK DEC) has developed the following list of information required to quantify emissions from marine vessels. KLGO and SEAN staff will work with AK DEC to develop and populate a database with the following information:

- Vessel Name
- Cruise Line Name
- Technical Hull particulars: Length; Beam; Height, and height from water line top exhaust (stack); stack pattern (fore / aft) (determination stack location, etc.)
- Stack type (e.g., round oval diameters) capped, bend, and estimated exhaust gas temperature
- Fuel type combusted while in port: 1) distillate (diesel) (MDO), 2) Residual fuel (IFO HFO). Fuel type and Sulfur content based on percent of fuel weight
- Operation mode while docked (e.g., engine / turbine selection auxiliary / boilers, incinerators, etc.)
- Description of the combustion source, RPM, Rating in relation to the generator output (kWe), engine cylinder displacement. Note that for diesel electric power generation the engine RPM is constant (frequency)
- Arrival time (time that dock operations mode starts)
- Departure time (time start up / commence maneuvering)

Vessel operators will be requested to provide the operation mode while docked in Skagway. Some operators choose to operate certain auxiliary engines, or gas turbines. Most of the vessels do have diesel electric propulsion, so in port the diesel electric generator(s) are used to provide the auxiliary power (hotel power). Also, boilers (for steam heating, etc.) are used onboard vessels and in port. Steam propulsion / steam power generation is not commonly used in Alaska.

The modeling will be conducted in the autumn of 2008, once all necessary model input data is available. This data includes the emission inventory, meteorological data, land use data, terrain elevations, and a plot plan of the emission source locations in a geo-referenced coordinate system.

Once the data is available, the model will be set up, run, and the output evaluated. Output products will include deposition isopleths of seasonal N and S deposition (kg/ha/season). Additionally, source contribution to the model-predicted deposition rates will also be provided. What-if scenarios may then be evaluated to determine the effects of potential changes. A final report will be delivered documenting the methodology and results.

Laboratory Analyses

Elemental analysis will be conducted at the University of Minnesota, Soil Science Department Research Analytical Lab. Analysis will determine the dry concentrations of aluminum, boron, cadmium, calcium, chromium, copper, iron, lead, magnesium, manganese, mercury, nickel, nitrogen, phosphorus, potassium, sodium, sulfur, and zinc. This lab was used during the previous study and has more than 20 years experience in analyzing lichens. Lab methodology is available at http://ral.coafes.umn.edu/plant.htm.

Passive air sampler filters and the throughfall samplers will be provided and analyzed by the USDA Forest Service Lab in Riverside, California (methodology available from the US Forest Service, Dr. Andrzej Bytnerowicz and Dr. Mark Fenn) or from Ogawa. http://www.ogawausa.com/about.html.

Lichen Community Plots

Lichen community composition plots provide quantitative information on the macro lichen species composition and relative abundance within fixed area permanent plots. Because some lichen species are more sensitive to changes in air chemistry than others (Farmer et al. 1992, Johnson 1979, Holopainen, T. and L. Kärenlampi 1985, and several others), these permanent plots will provide reference data for future change detection analysis in lichen communities. Lichen community plots have been installed throughout Southeast Alaska (Dillman 2007); therefore, future assessments could include not only temporal intra-site changes in lichen communities, but also spatial comparisons across reference sites throughout southeast Alaska. Lichen communities also respond to climatic changes which has the potential to make interpretation of temporal comparisons difficult. However, Geiser and Neitlich (2006) report on the phenomena and describe methods to tease apart air quality and climatic response signals. The extensive network of lichen community plots in southeast Alaska will allow refinement of this method in the future. Two lichen community plots will be installed at each assessment site, including the non-forested sites in upper GLBA, following methods established on the TNF (Geiser at al. 1994 and US Forest Service 2004). Karen Dillman, the lichenologist for the TNF, is the collaborator for this portion of the project.

Data Analyses

Several statistical tests will be conducted to look for difference in elemental concentrations between sites within parks, between parks, and with US Forest Service reference data sets from the Tongass and Chugach National Forests in southeastern Alaska, and from national forests in western Oregon and Washington. For normally distributed elemental concentrations data, paired *t*-tests will be conducted to test for significant differences between sites within the park. Additional ANOVA tests will be conducted to test for significant differences between the park data set and US Forest Service reference data sets. For non-normally distributed elemental concentration data, a Mann-Whitney U test will be employed to test for differences in elemental concentrations between collection sites in the park, and between park sites and reference datasets that are available for the Tongass National Forest.

Models relating elemental concentration in lichen tissue with data from the passive air samplers will be developed using methods described in Fenn et al. (2007) and Glavich & Geiser (in press). The SEAN I&M Coordinator and Data Manager will provide statistical assistance during the analysis phase of the project.

Tasks, Organization, and Schedule

Completion Date	FY 2008								FY 2009								FY 2010			
Task	11/9	3/14	4/11	4/21	6/27	7/15	9/1	9/29	10/9	2/10	3/14	4/11	4/21	6/27	9/1	9/29	2/1	3/1	4/1	5/1
Compliance project entry into PEPC and get signature on CE																				
Hire seasonal bio-techs																				
Complete set-up / conduct training in operating Ogawa and throughfall passive samplers																				
Initiate **weekly** (Monday) change cycle for passive air samplers																				
Compile emissions inventory for the KLGO area for (AERMOD)																				
Run AERMOD for KLGO – Skagway area																				
Read lichen community plots																				
Complete training lichen ID and collection methods																				
Initiate lichens collecting																				
Clean and dry lichens																				
Terminate passive air and throughfall sampling																				
Ship lichen samples to lab																				
I&M draft protocol submitted																				

Deliverables

Reporting
Annual accomplishment reports will be provided to the WASO program managers and input into PMIS by Oct. 30 following each funding year and a final accomplishment report will be input into PMIS by Oct. 30 following the end NRPP funding for this work.

Journal Submission
A manuscript describing new methods developed during this work and the results will be prepared and submitted to a scientific journal within six months of completion of the project. Authorship of the manuscript will be based on the quantity and quality of the contributions by team members working on this project.

Monitoring Protocols
Detailed monitoring protocols and associated standard procedures (SOPs) will be prepared following Oakley et al. (2003). The SEAN I&M coordinator will be the final editor and reviewer of the draft protocol and will orchestrate the document's peer review following NPS I&M standards within one year of completing the project. Following peer review and finalization, protocols will be made available on the NPS Air Quality Division and the SEAN I&M websites.

Database
The lichen elemental analysis data, data from the Ogawa passive samplers and bulk & throughfall passive samplers, and lichen community plots data will be made available to the public in an MS Access database following I&M data management guidelines. Data and associated metadata will be posted on the NPS DataStore within 6 months of completion of the project.

AERMOD Results
The airshed model will be set up, run, and output evaluated in the fall of 2008. Output products will include deposition isopleths of seasonal N and S deposition (kg/ha/season). Additionally, source contribution to the model-predicted deposition rates will also be provided. What-if scenarios may also be evaluated to determine the effects of potential emission reductions or increases. A final report will be delivered which will document the methodology and results by the spring of 2009.

Quality Assurance, Quality Control

Field Data Collection and Quality Assurance
We will provide rigorous field training and testing in lichen species identification. We are fortunate to have contract lichenologists, Toby Sprillbille and Tor Tønsberg, conducting a lichen inventory concurrently with this project. They will provide training and testing for field staff on identification of the three species used for elemental analysis in this project. Field crews will follow a rigorous standard operating procedure (to be developed prior to collections) for handling and tracking the Ogawa air samplers, the resin tubes from throughfall sampling, and collected lichens.

Data Management and Database Development

Data management will follow the general protocols prescribed by the NPS I&M program. Field data collection will consist of collecting basic site information at the locations of passive air samplers and lichen collection sites. The large bulk of data being generated for this project will come from the lichen elemental analysis and the passive air samplers' analyses. The SEAN I&M data manager will develop a database following I&M program standards and the NRDT database template that will hold collections site characteristics, lichen plot community data, as well as the tissue analysis and passive sampler lab results.

Laboratory Analysis

Quality Assurance (QA) procedures for elemental analysis lab work are available from the University of Minnesota http://ral.coafes.umn.edu/plant.htm. QA procedures for elemental analysis lab work for passive air samplers are available from Ogawa at http://www.ogawausa.com/protocol.html or from the US Forest Service's Air Chemistry Lab (Andrjez Bytnerowicz). QA procedures for throughfall sampler analysis is available from the US Forest Service's Air Chemistry Lab (Mark Fenn). We will provide several blanks to insure data from the passive samplers is accurate. At this time we are planning on using the Ogawa lab; however, we may switch to the USDA Forest Service Lab in Corvallis, OR, for this work.

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Appendix A- Plot Locations and Descriptions

Appendix B- 1989-1990 Elemental Analysis Data

Appendix C- 1991-1992 Sulfur and nitrogen data for *Alectoria sarmentosa* from shorepine muskeg plots.

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