National Park Service
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Natural Resource Stewardship and Science

Monitoring Air Quality in the Southeast Alaska Network

Linking Atmospheric Pollutants with Ecological Effects

Natural Resource Technical Report NPS/SEAN/NRTR—2014/839

ON THE COVER
Passive ion exchange resin tube deposition sampler (behind) and passive samplers for monitoring ambient air pollutants in Dyea, Klondike Gold Rush NHP, Alaska
NPS photo.

Monitoring Air Quality in Southeast Alaska's National Parks and Forests

Linking Atmospheric Pollutants with Ecological Effects

Natural Resource Technical Report NPS/SEAN/NRTR—2014/839

David Schirokauer

Klondike Gold Rush National Historical Park
PO Box 517
Skagway, Alaska 99840

Linda Geiser

USDA Forest Service
Pacific Northwest Region Air Resource Management Program
PO Box 1148
Corvallis, Oregon 97339

Andrzej Bytnerowicz, Mark Fenn

USDA Forest Service
Pacific Southwest Research Station
4955 Canyon Crest Drive
Riverside, California 92507

Karen Dillman

USDA Forest Service
Tongass National Forest
123 Scow Bay Loop Road
Petersburg, Alaska 99833

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Contents

Contents (continued)

Page

Contents (continued)

Contents (continued)

Page

Figures

Figures (continued)

Page

Tables

Page

Appendices

Abstract

Air quality and air quality related values are important resources to the National Park Service (NPS) units and Wilderness areas in northern Southeast Alaska. Air quality monitoring was prioritized as a high-priority Vital Sign at the Southeast Alaska Network's (SEAN) Inventory and Monitoring Program's terrestrial scoping workshop (Derr and Fastie 2006). Air quality monitoring of fossil fuel combustion emission products and heavy metals was conducted at several sites in the Southeast Alaska Network (SEAN) parks, the Tongass National Forest's Tracy Arm-Fords Terror Wilderness, and in the Skagway Borough from the May through September tourist seasons in 2008 and 2009. Passive samplers were deployed to measure average weekly ambient atmospheric concentrations of nitrogenous and sulfurous gaseous pollutants, and ion exchange resin tube samplers were deployed to measure seasonal bulk and throughfall deposition of nitrogen and sulfur compounds. Elemental concentrations of nitrogen, sulfur, and toxic metals in lichen samples were assessed at sites in all SEAN parks and reassessed at sites that were sampled in 1999 in and near Klondike Gold Rush NHP (KLGO). Epiphytic lichen communities were compared to reference sites in the Tongass National Forest. Lichen assemblages near the Skagway cruise ship terminal displayed shifts towards species favoring enhanced nitrogen and sulfur deposition while other sites in the study area hosted lichen communities indicative of clean sites. Atmospheric concentrations of air pollutants, deposition, and concentration of some elements, including sulfur, lead, zinc, and vanadium, in lichen samples near Skagway's ship docks were considerably elevated above background levels. Occasionally, weekly average ambient concentrations of nitrogen and sulfur containing compounds were elevated in Dyea and Sitka, probably due to atmospheric conditions during those weeks. Unusual very high spikes in ammonia were detected at several sites, and an especially high, difficult to explain, spike was detected at the Dewey 1700 site. Presence of lichen species indicative of excessive nutrient nitrogen deposition occurred at Sawyer Island in Tracy Arm-Fords Terror Wilderness, Dyea, and the Upper Dewey Lake Trail at 1480 ft. In general, as the distance increased from human activity centers, levels of pollutants declined. Most sites exhibited pristine or global background condition as expected for rural Southeast Alaska.

Although greater trans-Pacific emissions associated with industrial expansion and energy production in Asia and more wildfires emissions from northern Alaska/Canada contribute to background regional nitrogen oxide levels, nitrogen levels in epiphytic lichens did not increase significantly since 1999 except near local, seasonal sources of pollution. This study demonstrated that local emission sources have a greater impact on air quality impacts than distant sources.

Acknowledgments

Elaine Furbish set the stage in the mid-1990s by assessing elemental concentrations in lichen samples from the KLGO-Skagway area, without which the comparisons between time periods would not have been possible. Sarah Jovan and Heather Root provided the effort to add several more lichen plots to the study. Rick Graw and Albert Faure contributed their expertise on emissions from large diesel engines and completed the emissions inventory for Skagway that was an important component of this study. We thank Diane Alexander, the senior chemist at the USDA Forest Service Pacific Southwest Research Station, for her efficiency and patience in managing the membrane filters deployed and collected at multiple locations in logistically complex sampling scheme. Lewis Sharman in Glacier Bay National Park and Geoffrey Smith in Sitka National Historical Park diligently conducted the sampling at their respective parks. Mavis Irene Hendrickson, a citizen of Skagway, was instrumental in encouraging Skagway Borough officials to study the local air quality. Her efforts resulted in the Borough of Skagway joining this study by providing funding for additional plots. Thanks to the Southeast Coastal Cluster and Scott Gende for funding the Skagway emission inventory. The majority of funding for this work was provided by the SEAN Inventory and Monitoring Program and National Park Service's Air Resources Division, thanks to Brendan Moynahan and Tamara Blett. Thanks to Christopher Sergeant for his careful review and constructive comments on this report and to Dawn Adams for her meticulous editing and formatting. Finally, this study was only possible due to the fortitude, perseverance, and attention to detail of the many dedicated field staff in the parks that conducted the fieldwork.

List of Acronyms and Abbreviations

AKDEC	Alaska Department of Environmental Conservation
FIA	Forest Inventory Analysis
GLBA	Glacier Bay National Park and Preserve
HFO	Heavy fuel oil
KLGO	Klondike Gold Rush National Historical Park
MDN	Mercury Deposition Network
NADP	National Atmospheric Deposition Network
NPS	Tracy Arm-Fords Terror Wilderness
NTN	National Trends Network
OD	Open deposition sampler
PSW	Pacific Southwest Research Station
SEAN	Southeast Alaska I&M Network
SITK	Sitka National Historical Park
SOCs	Semi-volatile organic pollutants
SOP	Standard Operating Procedure
TAFT	Tracy Arm-Fords Terror Wilderness
TD	Throughfall deposition sampler
TNF	Tongass National Forest
USDA	US Department of Agriculture
US EPA	US Environmental Protection Agency
USPHS	US Public Health Service
WACAP	Western Airborne Contaminants Assessment Project
wOR/WA	Western Oregon and Washington
H_2SO_4	Sulfuric acid
Hg	Mercury
HNO_3	Nitric acid
NH_3	Ammonia gas
NH_4^+	Ammonium ion
NO	Nitric oxide, nitrogen monoxide
NO_2	Nitrogen dioxide
NO_3^-	Nitrate ion
NO_x	Nitrogen oxides
O_3	Ozone
PAN	Peroxyacetyl nitrate
Pb	Lead
SO_2	Sulfur dioxide
SO_4^{2}	Sulphate ion

Introduction

Increased cruise-ship tourism in SE Alaska and rapid industrialization in Asia, has heightened concerns among National Park and Forest Service land managers regarding the effects of local and global air pollution on visitor experience, human health, and ecosystem structure and function (Moynahan et al. 2008). Due to the lack of major local industrial development, relatively low human population density, and close proximity to the Pacific Ocean, it is not surprising that broad-scale air quality in SE Alaska is among the best in the world (Dillman et al. 2007). However, in areas with relatively pristine air quality, even small amounts of pollution can seriously impact visibility and sensitive ecosystem components, air quality-related values that are important to National Park and Wilderness area managers (Malm 1999, National Park Service 2006). While emissions at higher concentrations can affect human health, lower concentrations can result in deposition of sulfate and bio-available nitrogenous compounds that impact sensitive biota that form key components of Alaskan ecosystems such as diatom, bryophyte, mycorrhizal fungus, and lichen communities (Pardo et al. 2011).

The combustion of low-grade marine fuels by the marine transportation sector releases nitrogen and sulfur oxides, poly-cyclic aromatic hydrocarbons, and toxic metals (American Bureau of Shipping 1984, US EPA Office of Transportation and Air Quality 2009, Graw et al. 2011). In Skagway and portions of upper Glacier Bay, frequent summer-time stagnation and inversion events prevent dispersal of emissions while ships are mobile or in port operating diesel and bunker fuel generators. These emissions result in noticeable haze in view-sheds and in odors throughout downtown Skagway and Klondike Gold Rush National Historical Park's (KLGO) Skagway Historic District (Figure 1). Ships transiting the narrow fjords of Glacier Bay National Park (GLBA) and Tracy Arm-Fords Terror Wilderness (TAFT) of the Tongass National Forest (TNF) also produce visible plumes and lingering layers of anthropogenic haze (USDA Forest Service 2010). The KLGO-Skagway area has additional emissions sources that include the White Pass and Yukon Route Railway, dozens of buses, and a municipal incinerator that runs daily during that summer (Graw and Faure 2010). Significant summertime increases in the emission products of heavy fuel oil (HFO) from marine transportation sources have been modeled and verified for the coastal portion of south central Alaska, especially in areas with steep topography that limits air movement (Mölders et al. 2010). In other areas of SE Alaska addressed in this study, on-shore winds dominate the summertime weather pattern and similar morning inversions are common.

Another important legacy of airborne contaminants in the Skagway KLGO area is fugitive dust derived from lead-zinc ore concentrate that was transported through, and shipped out of the Port-of Skagway. Beginning in the 1960s and continuing through 1993, ore concentrate was transported in rail cars or open truck beds and loaded onto barges with an open conveyer belt system (Elder 1990). The fugitive dust generated due to this transportation method in conjunction with Skagway's famous strong winds was eventually recognized and remedied. Ore transport methods were modernized and the town cleaned up considerably in the late 1980s and the ore terminal's environmental controls were upgraded in the early 1990's (Akre 1989, Andrews 2008) but heavy metal concentrations in the environment around the Port-of Skagway remain high (Furbish et al. 2000). KLGO Skagway Historic District is within the area impacted by fugitive ore dust.

Elemental analysis of lichens has a long history of use as an integrator of contamination and was used to set reference conditions for the KLGO-Skagway area and nearby TNF (Geiser et al. 1994, Furbish et al. 2000, Geiser 2004, Derr et al. 2007, Dillman et al. 2007). In addition to being used as a tool to monitor legacy metal levels in Skagway, lichen tissue analysis is emerging as a method to monitor total mercury deposition (Mitchell et al. 2000, Balarama Krishna et al. 2003, Guevara et al. 2004), which is a growing concern worldwide due to increased emissions and its long atmospheric residence time. Currently, lichen elemental analysis and the mercury deposition network (MDN) station in GLBA at Bartlett Cove are the only method being used to assess levels of toxic metals deposited by atmospheric transport in the study area.

The deposition and acidification associated with air pollutants has many well documented effects on natural ecosystems (Matson et al. 2002, Fenn et al. 2003a, Galloway et al. 2003, Porter et al. 2005, Pardo et al. 2011). These effects can shift the structure and function of biotic communities in temperate forests, alpine habitats, and recently de-glaciated areas by increasing susceptibility to forest pathogens and tree mortality, reducing biodiversity, and increasing cover of invasive plants. Aquatic systems can experience acidification, loss of diatom species, and depressed fish populations. In SE Alaska, the Pacific Northwest and other temperate areas, with comparatively low rates of anthropogenic nitrogen deposition, sensitive lichen species have been suggested as an important sentinel of ecosystem change (Geiser 2004, Geiser and Neitlich 2007, Otnyukova and Sekretenko 2008, Sutton et al. 2009, Wolseley et al. 2009). Lichen biodiversity and community composition shifts as sensitive species are replaced by previously nitrogen limited, pollution-tolerant species. Emissions also result in acidic deposition that alters lichen communities, and soil chemistry (Wieder et al. 2010).

This study represents a collaboration of researchers and managers of the NPS Air Resources Division, the SE Alaska Inventory and Monitoring Program, the Tongass National Forest (TNF), The Municipality of Skagway (MOS), and the national parks of SE Alaska which include GLBA, KLGO, and Sitka National Historical Park (SITK) (Figure 2). This effort was also inspired by the results of the Western Airborne Contaminants Assessment Project which demonstrated that the most remote NPS lands accumulate anthropogenic pollutants originating thousands of miles away and that parks with regional sources had the highest contaminant levels. Multi-stakeholder interest and resources allowed the establishment of multi-sensor monitoring sites designed to assess the status of local ambient air quality, the deposition of airborne contaminants, and to detect ecological effects on sensitive epiphytic vegetation due to air pollution (Landers et al. 2008). Marine transportation emissions are currently the dominant local pollution sources at all sites, but an increase in Eurasian emissions and their potential transport to SE Alaska during spring, monsoon driven outflows (Lin et al. 2012) is also of concern.

This investigation addressed a subset of needs prioritized by the SEAN Vital Signs Monitoring Plan (Moynahan et al. 2008) and Alaska Natural Resources Advisory Committee. The objectives were to:

1. revisit monitoring plots in the KLGO-Skagway area established by Furbish et al. (2000) to track nitrogen, sulfur and metal levels in lichens;

2. assess passive methods (no electrical power) for collecting data on nitrogen and sulfur deposition and ambient atmospheric concentrations of nitrogenous and sulfuric combustion products (emissions and their secondary atmospheric products);

3. collect reference data on nitrogen, sulfur and metal levels in lichens for GLBA and SITK;

4. create an emission inventory for the Skagway area; and

5. establish lichen community monitoring plots following USDA Forest Service methods.

This study facilitated the establishment of baseline methods and data from which the SEAN Inventory & Monitoring program can refine objectives and develop an airborne contaminants monitoring protocol. It is envisioned that an airborne contaminants monitoring protocol would be repeated once per decade (Moynahan et al. 2008). This protocol may include methods from this study and may add additional air quality indicators such as visibility. Administrative details of this study (e.g., schedule, expenditures) are included in Appendix I. Monitoring of marine and freshwater contaminants such as mercury and semi-volatile organic compounds (SOCs) in biota are addressed by other vital signs (Moynahan et al. 2008;Nagorski et al. 2011, Tallmon 2012).

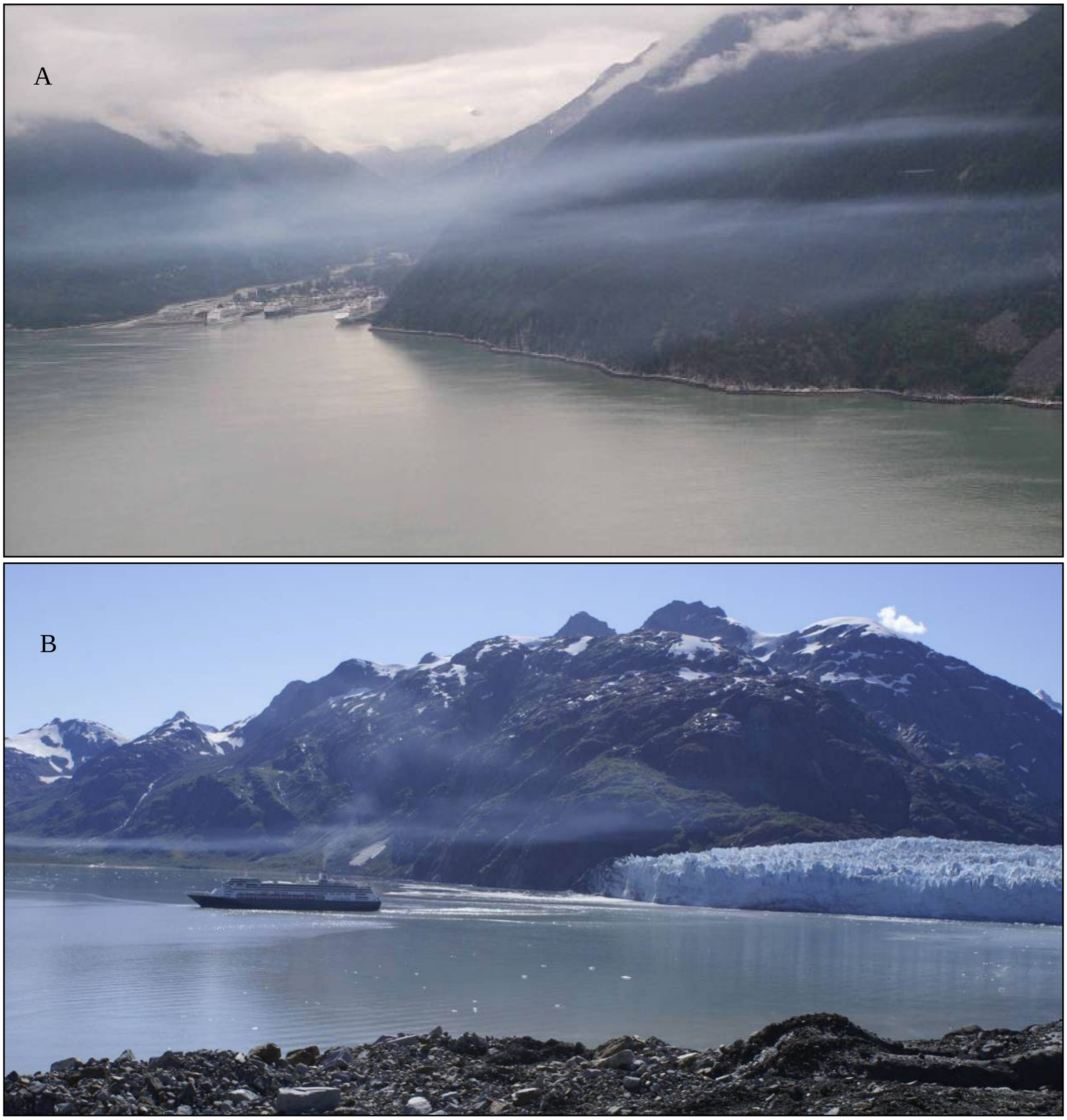


Figure 1. (A) Visible emissions from cruise ships docked in Skagway harbor cause extensive haze and odors in Klondike Gold Rush National Historical Park and the Municipality of Skagway. (B) A cruise ship leaves a visible plume of emissions at in Glacier Bay National Park. Photo credit: Alaska Department of Environmental Conservation and NPS.

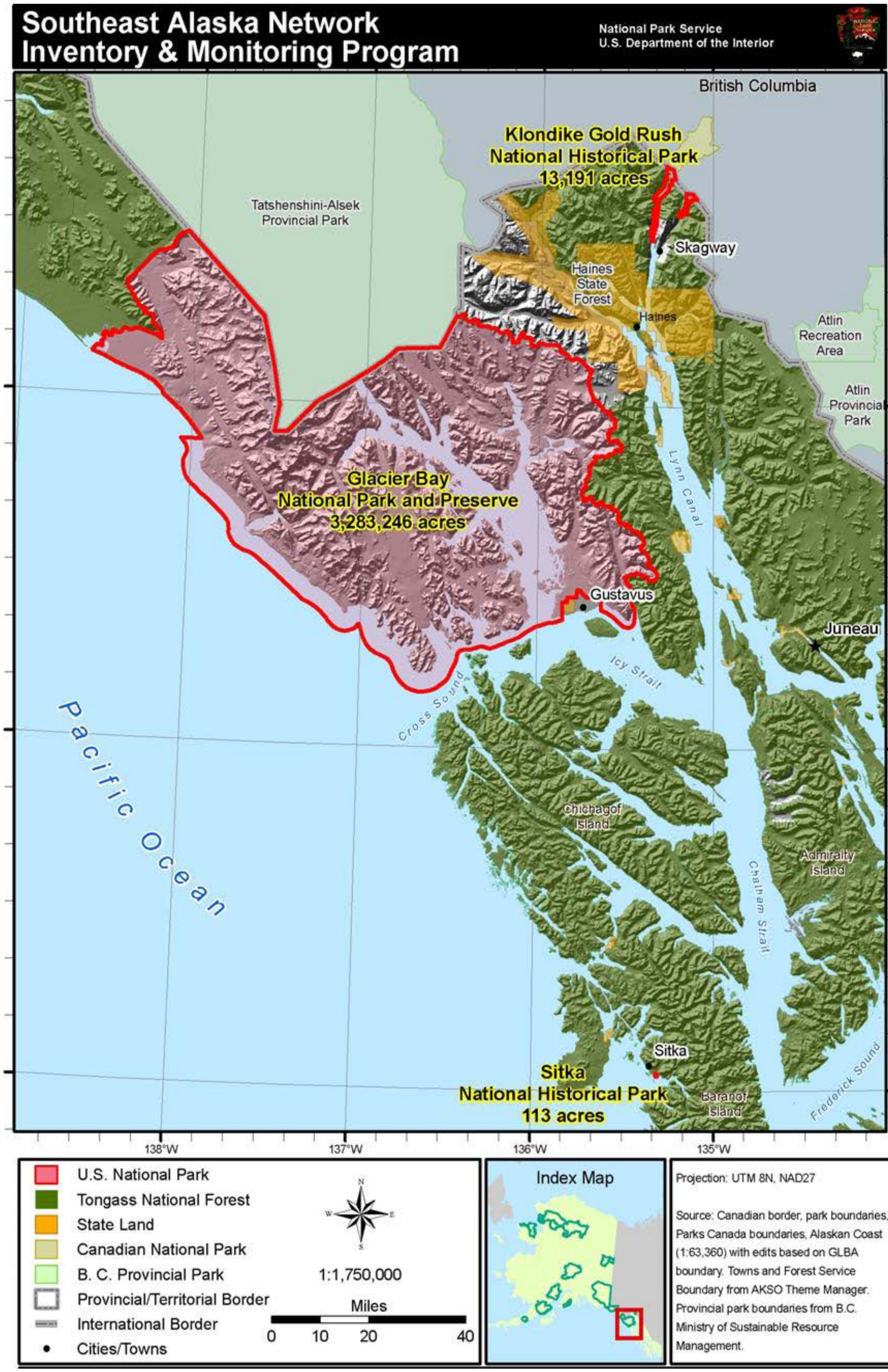


Figure 2. The Alexander Archipelago and the Southeast Alaska Network parks.

Methods

Monitoring sites in each SEAN park were established to host several different passive sensors and were co-located with lichen community and collection plots. The site locations were primarily selected for access in specific areas of interest to demonstrate impacts from marine transportation emission sources. A random spatial sampling design was not used to choose the site locations, thus inference to broader scales must be made with caution

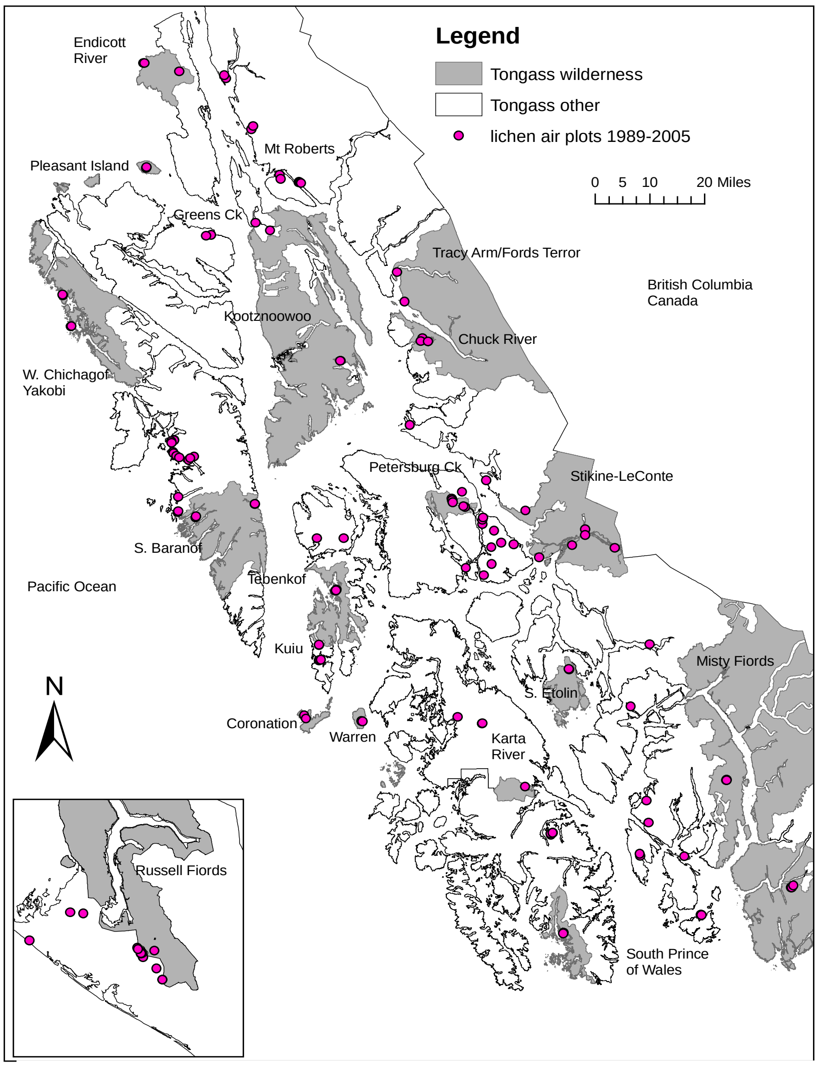


Figure 3. Lichen tissue collection biomonitoring plots on the Tongass National Forest as of 2007 (from Dillman et al. 2007).

The lichen community and tissue sample collection plots are part of a much broader network of over 286 sites on the Tongass National Forest (Figure 3). The number of plots and their broad geographic distribution may allow for a continuous surface extrapolation in the future.

Passive samplers (cover photo) were used to measure weekly average ambient concentrations of nitrogen oxide(s), nitric acid, ammonia, and sulfur dioxide gases. Open site (bulk deposition) and canopy through-fall resin tube samplers were used to measure the concentrations of nitrate, ammonium, and sulfate ions in precipitation and to calculate bulk or through-fall deposition. Air pollution exposure was also characterized from elemental analysis of epiphytic lichens, which can be compared to clean site ranges and thresholds established by TNF for nitrogen, sulfur, and metals. Elemental analysis data were compared to TNF baselines (Dillman et al. 2007); TNF managers have created a network of about 286 air quality biomonitoring plots since 1989 (Geiser et al. 1994). Community surveys of epiphytic lichens were conducted as a reference condition for future change detection analysis.

Study Sites

One or more study plots were located in each SEAN park unit, on Skagway Borough lands, and in TNF's Tracy Arm. The four sites investigated during the 1998–1999 study in the KLGO-Skagway area (Dewey, Chilkoot, Sturgill's and Dyea) were revisited during this study. Descriptions of the previously visited sites in KLGO are reprinted below (Furbish et al. 2000) together with descriptions of new sites for the present study. In the KLGO-Skagway area, the Dewey and Chilkoot sites were selected to encompass the range of exposures to local sources of air pollution. Initial 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 similar in terrain, vegetative cover, slope, aspect and elevation, but the Chilkoot site is farther from marine waters than the Dewey site (Figure 4). The sites at GLBA were qualitatively selected to represent a reasonable geographic distribution with Glacier Bay proper, different levels of exposure to cruise ship emissions, and reasonable access (Figure 5). In SITK (Figure 6), the small size of the park provided only limited options for placing passive sensors where they would not interfere with visitor enjoyment of cultural and natural resources. The site in Tracy Arm (Figure 7) was selected to capture cruise ship impact at the head of a narrow fjord. All the sites are briefly described below.

Klondike Gold Rush National Historical Park – Skagway Area

Lower Dewey: This study plot 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 downtown Skagway, the small boat harbor, and cruise ship docks. 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 (*Tsuga heterophylla*) - lodgepole pine (*Pinus contorta*) - Sitka spruce (*Picea sitchensis*) - paper birch (*Betula papyrifera*) woodland in mid-seral stage. Burn scars remain from a fire 55+ years ago. Understory is sparse, composed of rusty menziesia (*Menziesia ferruginea*), feather and other mosses, and foliose and fruticose lichens. This site is located on land owned by the Municipality of Skagway.

Chilkoot Saintly Hill: This site is about 4.9 hectares (12.1 acres) in size. It sits above a small hill on the Chilkoot Trail 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. An open area above some small cliff bands allowed for the placement of the atmospheric samplers. Understory is sparse, composed of rusty menziesia, shag, feather and other mosses, and foliose and fruticose lichens.

Sturgill's: This site is 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's 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 menziesia, feather and other mosses, and foliose and fruticose lichens. This site is also located on land owned by the Municipality of Skagway.

Skagway Incinerator: This new site is on the west side of the Skagway valley near the US Customs Station in a Sitka spruce, western hemlock forest. It is placed to capture the effects of emissions from the Skagway municipal incinerator which is located about 400 meters south of this plot. During the summer, prevailing winds send the emission plumes from the incinerator to the area around this plot. The plot was only used as a lichen community and tissue collection site and was installed as part of another concurrent study investigating the lichen community climate gradient for SE Alaska (Root et al. in prep.). Because Root et al. followed the same lab and community assessment methods, it is presented in this study as well.

Dyea: This site is 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 1898 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 (*Populus balsamifera* ssp. *trichocarpa*) - western hemlock in mid-seral stage. Trees are 20–30 meters tall. Cottonwood and Sitka spruce dominate, with some paper birch, lodgepole pine, Scouler's willow (*Salix scouleriana*) and unusually large Sitka willows (*S. sitchensis*). 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.

Lost Lake Trail: This new site is above Dyea on the west side of the Taiya valley in a Sitka spruce - western hemlock forest. It was only used as a lichen community and tissue collection site. It was installed as part of the concurrent Root et al. (in prep.) study investigating a lichen climate gradient for SE Alaska and it is presented in this study as well.

Dewey 1700: This site near Skagway on Municipal land was not part of Furbish et al. 2000 and thus expanded the scope of the study within Skagway Borough lands. It is in a mountain hemlock (*T. mertensiana*) and Sitka spruce forest at 518 meters above Skagway. This site is estimated to be just below the elevation of an inversion cap that typically occurs during summer mornings in the Skagway valley. The site is about 30 meters north of Upper Dewey Creek Bridge on the trail to Upper Dewey Lake. The Skagway Borough funded the work at this site in 2008 and 2009.

Icy Junction: This new site above the mid-town section of Skagway, in a lodgepole pine forest, was only used temporarily at the beginning of the 2008 season while Upper Dewey was inaccessible due to snow and ice conditions. It is intended as a replicate of the similar elevation site at Lower Dewey, and not a substitution for Upper Dewey.

Icy Lake: This new site near Skagway in a lodgepole pine - Sitka spruce forest was only used as a lichen community and tissue collection site. It was installed as part of the Root et al. (in prep.) study investigating a lichen climate gradient for SE Alaska and it is presented in this study as well.

Upper Dewey: This alpine tundra site at Upper Dewey Lake sits at 975 meters in elevation and is just below the terminus of an alpine glacier. It was only used to site a bulk deposition sampler. It is intended to capture regional / global background levels of nitrogen and sulfur deposition rather than detect local effects. No epiphytic lichens are found at this location.

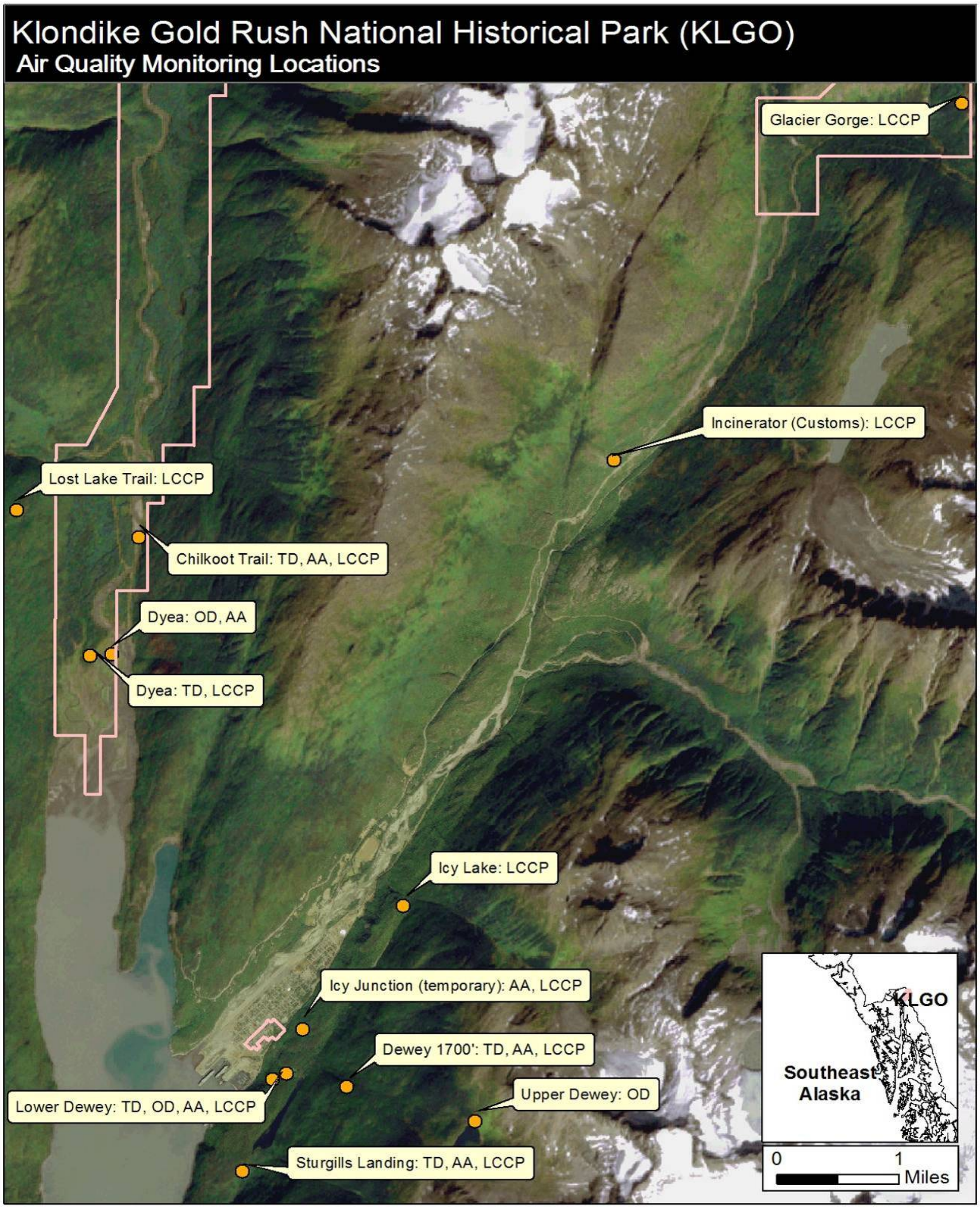


Figure 4. Air quality plots in the KLGO-Skagway area. LCCP-lichen Community and collection plots; AA-ambient atmospheric concentration samplers, OD-open deposition sampler; TD-throughfall deposition sampler..

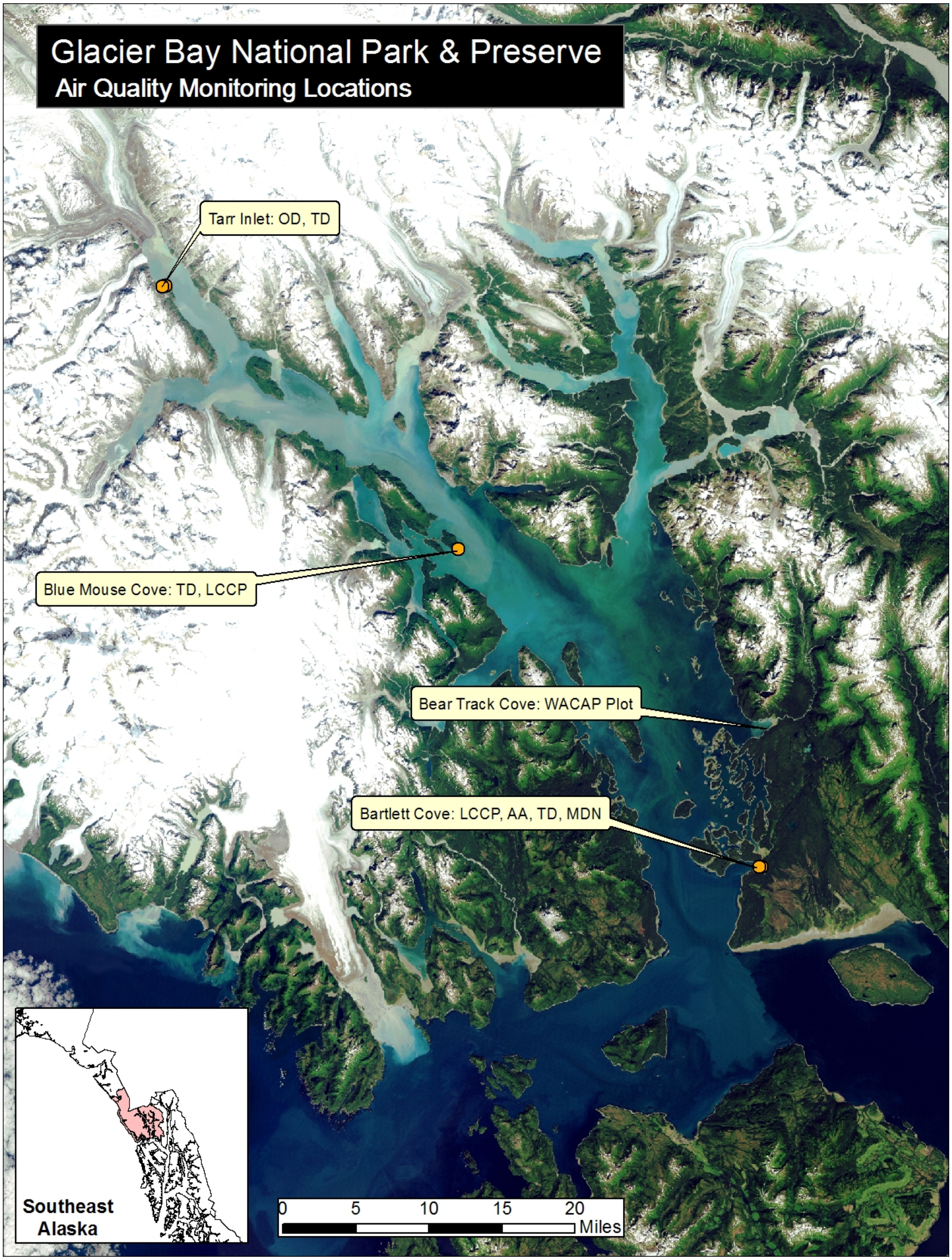


Figure 5. Air quality plots in GLBA. LCCP-lichen community and collection plots; AA-ambient atmospheric concentration samplers, OD-open deposition sampler; TD-throughfall deposition sampler, MDN-mercury wet deposition network.

Glacier Bay National Park and Preserve

Bartlett Cove: This site is adjacent to the only development in GLBA and is the only site where regular weekly access for passive ambient atmospheric sampler membrane swapping was possible. This site is at sea level in the lower portion of Glacier Bay and is also the only place within a dense Sitka spruce/western hemlock forest where a clearing large enough to deploy the passive atmospheric samplers occurred. The forest understory (throughfall site) is dominated by blueberry (*Vaccinium* spp.) shrubs, ferns, and mosses, along with conifer seedlings/saplings. The vegetation at the open canopy (bulk) deposition sampler site consists of beach grasses and forbs.

Blue Mouse Cove: This site is a medium-age developing forest dominated by a mixed cottonwood and Sitka spruce forest overstory at sea level is in the middle portion of Glacier Bay and is accessible only by boat. The diverse understory includes blueberry, salmonberry (*Rubus spectabilis*), elderberry (*Sambucus racemosa*), and various ferns and some mosses. Lichen community data and through-fall deposition samplers were deployed at this site.

Tarr Inlet: This recently de-glaciated site in upper Glacier Bay has little forest canopy and no lichens suitable for elemental analysis. Bulk and throughfall deposition samplers were deployed. The throughfall site is dominated by large shrubs (mostly *Salix* spp.) with scattered emergent cottonwood saplings to 5 m tall. The bulk site is a disturbed but relatively recently stabilized floodplain with scattered willow clumps and bare ground or mountain-avens (*Dryas drummondii*)/ground lichen/herbaceous groundcover. Cruise ships and tour vessels linger here for over an hour to observe wildlife and calving glaciers and then turn around, increasing the site’s exposure to pollutants. Other sites in GLBA do not have the additional effects due to stationary ship’s lingering.

Sitka National Historical Park – Sitka Area

Indian River: This is the only site away from centers of visitor activity available in SITK. This site is a mixed forest of Sitka spruce and red alder (*Alnus rubra*) with an understory of salmonberry. The intertidal meadow immediately adjacent to the forest housed open canopy (bulk) deposition samplers. Some of the deposition samplers at this site were vandalized during the 2008 season.

Sitka Magnetic Observatory: This site, outside the national historical park, was selected for the ambient atmospheric samplers for security reasons. The site is in a sedge and grass meadow adjacent to the Climate Reference Network site.

Tracy Arm-Fords Terror Wilderness, Tongass National Forest

Sawyer Island: Sawyer Island is a small rocky island (approximately 10 hectares) with little soil formation in a glacier fiord in view of two large glaciers. Dominant vegetation includes scattered alder (*Alnus* spp.) Sitka spruce and salmonberry were growing where thin soils have formed. Other alpine habitat plants and lichens grow in the rock crevices and small depressions, and on rock surfaces. Common ravens (*Corvus corvax*) and bald eagles (*Haliaeetus leucocephalus*) frequent the few larger Sitka spruce trees on the island. Epiphytic lichen communities are abundant on the older Sitka spruce. Lichen community data and through-fall deposition samplers were deployed at this site. The first year data from the tree samplers were not valid due to the proximity of the samplers to birds' nests in the trees. The second year the samplers were moved to different trees about one month into the cruise ship season. The samplers in the open areas were not impacted by birds. In 2012, the site was revisited and tissue was collected but the lichens were not analyzed in time for this publication.

North of Williams Cove: This site is on the west side of Tracy Arm north of Williams Cove about 200 meters from the beach on a forested bench. It was selected from the Tongass National Forest baseline dataset because the site is along the path of cruise ships venturing up Tracy Arm to the terminal glacier, about half way between the entrance to the Arm and Sawyer Island. The lichen community survey was conducted in 2003 in a western hemlock and Sitka spruce forest with a blueberry/huckleberry (*Vaccinium* spp.) and devil's club (*Ophlopanax horridum*) understory. In 2012, the site was revisited and tissue was collected but the lichens were not analyzed in time for this publication. No other monitoring data were collected for this site.

Salmon Creek: This site is on the east side of Endicott Arm near the junction with Tracy Arm representing the main entrance to the Wilderness. The fjord is very wide at this point and well vented. This is the point at which ship traffic divides into Tracy Arm or Endicott Arm. The lichen community was surveyed in 2003 and samples were collected for elemental analysis in a mixed conifer-peatland about 200 meters from the beach along Salmon Creek a small creek about 1km west of Power's Creek. The tree species at the site were western hemlock, Sitka spruce, and shore pine; the understory was heath-dominated with some skunk cabbage (*Lysichiton americanus*), sedges, and salmonberry. In 2012, the site was revisited and tissue was collected but the lichens were not analyzed in time for this publication.

Sanford Cove: This site was on the east side of Endicott Arm in Sanford Cove, in a large, circular peatland (approximately 200 hectares) about 100 meters from the beach, southeast of some cabin ruins. The survey took place at the edge of the peatland in a mixed conifer forest of mountain hemlock, western hemlock, and Sitka spruce. This site was selected to capture baseline conditions because cruise ships are now beginning to tour the Endicott Arm as well as Tracy Arm. It is technically in Chuck River Wilderness, which borders the east side of Endicott Arm. A lichen community survey and elemental analysis samples were collected in 2011 but are not reported on in this document.

Bushy Islands: This site was on the western shore of Endicott Arm across from the Bushy Islands in a large foreland meadow with scattered patches of Sitka spruce. Like the Sanford Cove site, it was selected to gather baseline data for the anticipated development of cruise ship routes through Endicott Arm. The lichen community was surveyed and samples for elemental analysis were collected in 2011 in an isolated riparian forest on a glacial foreland and estuary, approximately 200 meters from a large river. There is one large Sitka spruce and multiple smaller spruce surrounded by alder and meadow vegetation in the plot. The elemental analyses for this site are not presented in this report.

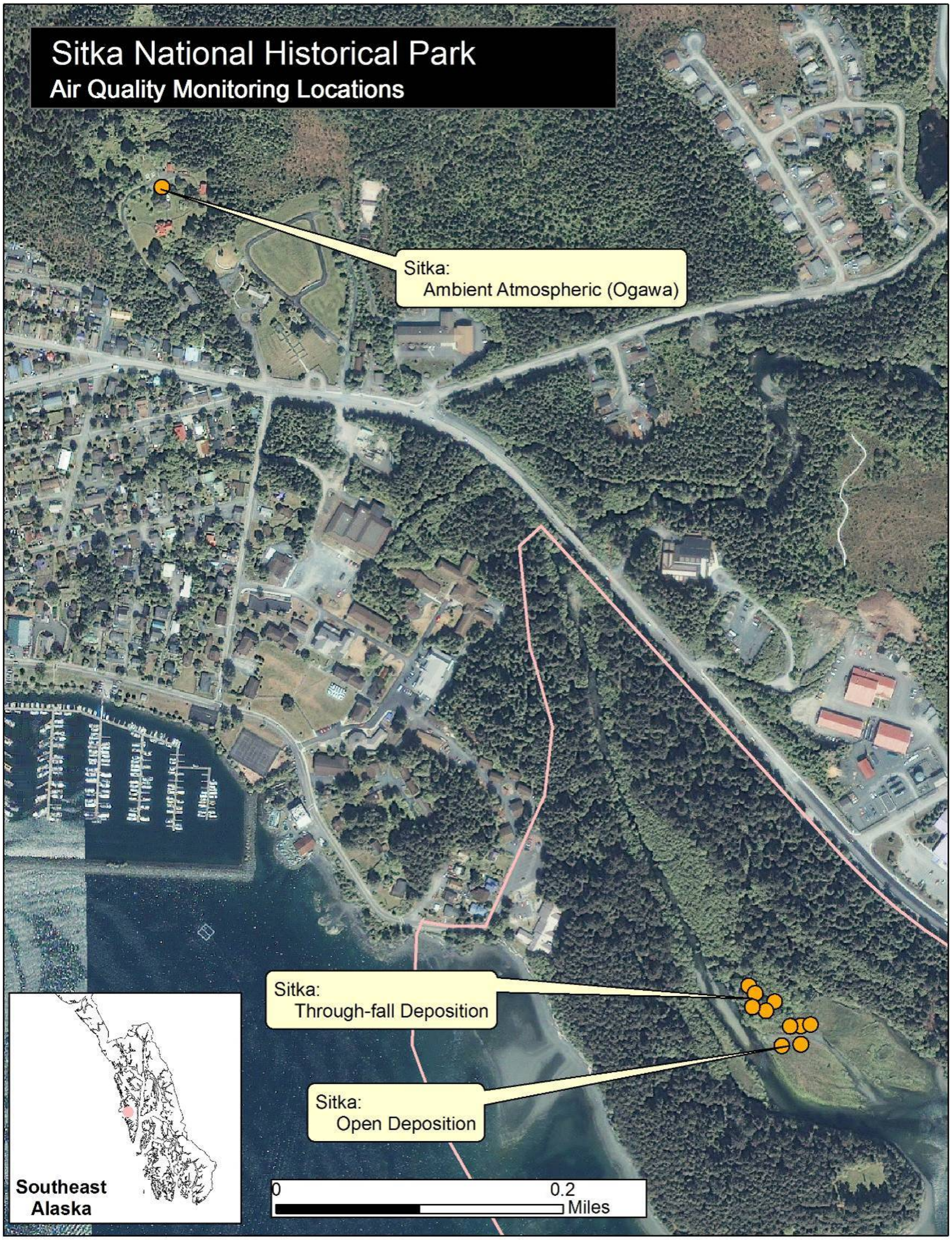


Figure 6. Air quality plots in SITK and vicinity.

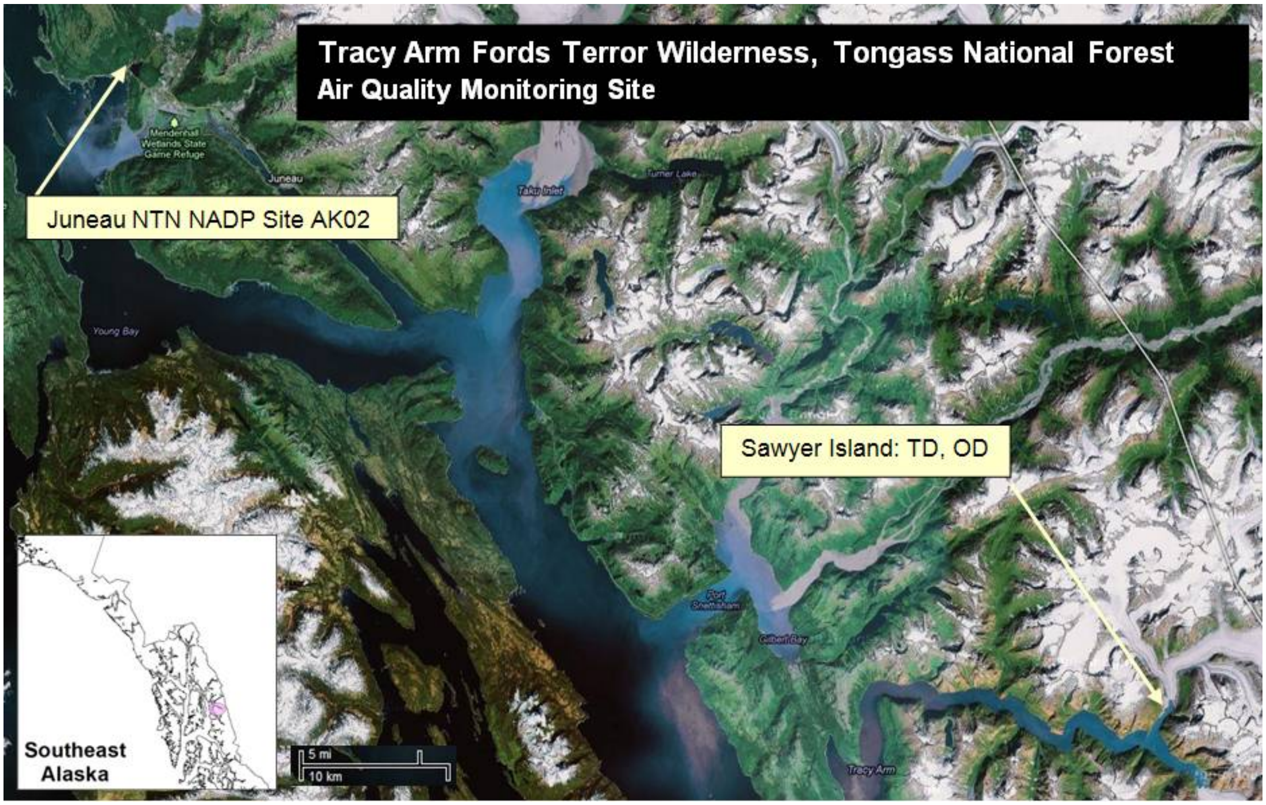


Figure 7. Air quality plot in Tracy Arm and the Juneau NTN-NADP site. OD-open deposition sampler; TD-throughfall deposition sampler.

Ambient Atmospheric Pollution Samplers

Average weekly atmospheric concentrations of NO_2, NOx, NH_3, SO_2, and HNO_3 were measured with passive atmospheric samplers (cover photo). Ogawa (http://www.ogawausa.com), Nylasorb™, and Zeflour™ (www.pall.com/lab) membrane discs were deployed in custom housings at five sites in the KLGO-Skagway area, one site in GLBA, and one site in SITK during the 2008 and 2009 seasons (Figures 4, 5, and 6). An addition site at KLGO, Icy Junction, was temporally deployed during the first part of the 2008 season while the site at Upper Dewey was inaccessible due to snow conditions. Detailed instruction (SOPs) on placing, sighting, and swapping samplers are in Appendix A. Samplers were generally collected weekly from late April though early October and shipped to the USDA Forest Service Pacific Southwest Research Station (PSW) in Riverside, CA for analysis. Staff at PSW would extract and reload the membrane discs into sampler housings and return them to the parks for future deployments. Ogawa membrane discs for NO_2, NO_x, SO_2 were analyzed following methods described in (Ogawa Corporation 2006). Ogawa membrane discs for NH_3 were analyzed following methods described in (Roadman et al. 2003) and (Ogawa Corporation 2010) and Nylasorb™ and Zeflour™ membrane discs were analyzed for HNO_3 following Bytnerowicz et al. (2005).

Deposition Samplers

Seasonal totals for bulk and throughfall deposition of nitrogen (from NO_3^- and NH_4^+), and sulfur (from SO_4^{2-}) were assessed in open and closed canopy sites (which were also lichen collection plots) with passive ion exchange resin tube precipitation collector arrays (Figure 8). Collectors were generally deployed in early May and retrieved in October during 2008 and 2009 at eight sites in the KLGO-Skagway area (3 open, 5 closed canopy), three sites in GLBA (1 open, 2 closed canopy), two sites in SITK (one open, once closed canopy), one site in Tracy Arm, and at the Juneau National Atmospheric Deposition Program (NADP)-National Trends Network (NTN) site, AK02 (Figures 4-7). The USFS participated in this portion of the study by funding and deploying one open and one closed canopy site at Tracy Arm within TAFT during the 2008 and 2009 seasons. In addition, resin tube collectors were co-located at the NADP-NTN monitoring station near Juneau (Station AK02), which is operated by the USDA Forest Service Pacific Northwest Research Station in conjunction with the University of Alaska Southeast, in order to calibrate the resin tubes with the NTN data. Throughfall samplers yield data on atmospheric wet and dry deposition of target compounds including sulfate, nitrate, and ammonium calculated in kg/ha for the sampling period. Ten throughfall sampling tubes were deployed in forested portions of each lichen collection plot. Five sampling tube arrays were deployed in canopy gaps and non-forested sites. Detailed instruction (SOPs) on placing, sighting, and swapping samplers are in Appendix B. Resin tubes were produced and analyzed at the PSW laboratory following methods described in Fenn and Poth (2004).

Figure 8. A) Open (or bulk) resin tube deposition sampling array at Upper Dewey, and B) closed canopy (or throughfall) resin tube deposition sampler arrays at Lower Dewey. Open sites had five samplers and one blank while closed sites had ten samplers and one blank.

Lichen Samples for Elemental Analysis

The arboreal (a.k.a. epiphytic) lichens, *Platismatia glauca*, *Hypogymnia enteromorpha*, and *Hypogymnia inactiva* (Figure 9) were collected for elemental analysis at eight sites in KLGO, two sites in GLBA, one site in SITK and four sites in TAFT (Table 1) following methods used by the USDA Forest Service (Geiser 2004). Field crews were trained to identify target species and look-a-likes by lichenologist Dr. Toby Spribille (University of Montana), and a custom field guide to the target species was created for field crews. Complete instructions on identifying species and collecting lichen tissue are available in Appendix C. Dry lichen tissue samples (10 grams) were sent to the University of Minnesota Research Analytical Lab where they were ground and analyzed for: 1) total nitrogen following (Simone et al. 1994, Matejovic 1995); 2) total sulfur using a LECO S-144DR (LECO Corporation. 3000 Lakeview Dr. St Joseph, MI 49085); 3) P, K, Ca, Mg, Na, Al, Fe, Mn, Zn, Cu, B, Pb, Ni, Cr, Cd, Co, Mo, Si, Ti, Be, Sr, Rb, Li, V, and Ba following (Dahlquist and Knoll 1978, Munter and Grande 1981, Munter et al. 1984). Many of the samples were also analyzed for total elemental mercury following methods posted on the University of Minnesota lab website.

Table 1. Lichen samples collected for elemental analysis, 1998–2009. Abbreviations: Alesar = *Alectoria sarmentosa*; Hypapi = *Hypogymnia apinnata*; Hypent = *H. enteromorpha*; Hypina = *H. inactiva*; Plagla = *Platismatia glauca*.

Area	Locale	Plot Name	Year	Alesar	Hypapi	Hypent	Hypina	Plagla	*Totals*
GLBA	Bartlett Cove	BC	2008	.	.	3	.	2	5
			2009	2	.	.	.	2	4
	Blue Mouse Cove	BM	2008	.	.	4	.	2	6
			2009	.	.	2	.	2	4
	TOTALS			2	0	9	0	8	19
KLGO	Chilkoot Trail Saintly Hill	CH	1998	.	.	2	4	.	6
			1999	.	.	3	.	3	3
			2008	.	.	3	2	2	2
			2009	.	.	3	3	3	3
	Dyea	DY	1998	.	.	.	2	3	3
			2008	.	.	3	2	2	2
			2009	.	.	3	3	4	4
	Glacier Gorge	GG	2009	2	1	.	.	2	2
	TOTALS			2	1	17	16	19	25
Skagway	Incinerator	HR10	2009	1	.	.	.	2	3
	Ice Lake	HR11	2009	.	.	.	.	2	2
	Lost Lake	HR12	2009	3	.	.	.	1	4
	Icy Junction	IJ	2008	.	.	3	3	3	9
			2009	.	.	3	3	3	9
	Lower Dewey	LD	1998	.	.	3	3	2	8
			1999	.	.	3	.	3	6
			2008	.	.	3	4	4	11
			2009	.	.	3	3	3	9
	Sturgills	ST	1998	.	.	2	2	2	6
			2008	.	.	4	3	4	11
			2009	.	.	3	3	3	9
	Dewey 1700	UD	2008	.	.	3	.	4	7
			2009	.	.	3	.	3	6
	TOTALS			4	0	33	24	39	100
SITK	Indian River	IR	2008	.	.	.	.	3	3
			2009	.	.	.	.	2	2
	TOTALS			0	0	0	0	5	5
TAFT	Salmon Creekk	TNF504	2003	3	.	2	.	3	8
	Sawyer Island	TNF547	2009	.	.	.	.	2	2
	TOTALS			3	0	2	0	5	10
GRAND TOTALS				11	1	61	40	76	159

To repeat a previous KLGO study assessing elemental composition of lichen tissue (Furbish et al. 2000), and compare results, the methods regarding collecting and analyzing lichen samples followed Geiser et al. (1994) and Furbish et al. (2000). The four sites investigated during the 1998–1999 study (Dewey, Chilkoot, Sturgill’s, and Dyea) were revisited during this study.

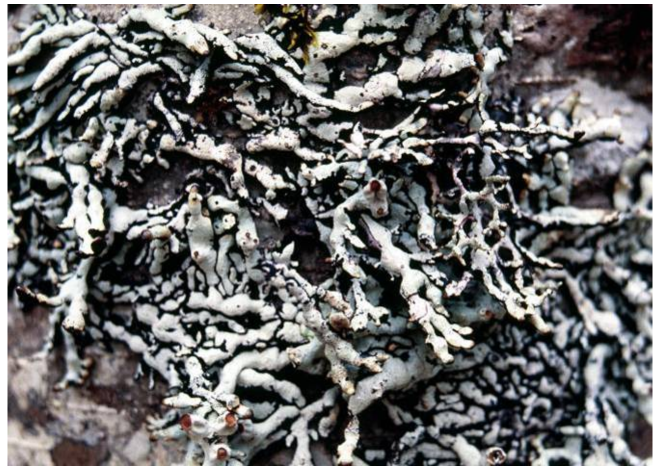


Figure 9. Arboreal lichens collected for elemental analysis: *Hypogymnia enteromorpha* (left; Jim Riley, OSU), *Hypogymnia inactiva* (upper right; Jim Riley, OSU), and *Platismatia glauca* (lower right; Karen Dillman, USFS). OSU photos from OSU Lichen Group 1999.

Lichen Community Assessments

Survey Sites

Surveys of epiphytic macrolichens (non-crustose lichens on trees and shrubs) were conducted at all sites where lichen tissue was collected and most sites where passive samplers were deployed. The exceptions were Upper Dewey and Tarr Inlet, alpine sites where surveys could not be conducted because no forest was present. Seven permanent epiphytic lichen community plots were installed in KLGO, twelve in the city of Skagway, four in GLBA, two sites at SITK, and five in TAFT (see Table 2). Lichen plots were purposely located close to each other and to any passive samplers deployed (within 100 m) to assure equivalent ambient air quality conditions among all plots and samplers within a site.

Table 2. Number of epiphytic macrolichen surveys at air quality monitoring sites.

Area	Site	Plot Names	1998	2003	2008	2009	2011	Totals
Skagway	Dewey 1360	UD13	-	-	1	-	-	1
	Dewey 1480	UD11	-	-	1	-	-	1
	Dewey 1700	UD10	-	-	1	-	-	1
	Icy Junction	IJ9, IJ12	-	-	2	-	-	2
	Lower Dewey	LD3, LD4	-	-	2	-	-	2
	Sturgill's	ST1, ST2	-	-	2	-	-	2
	Incinerator	HR10	-	-	-	1	-	1
	Ice Lake	HR11	-	-	-	1	-	1
	Lost Lake	HR12	-	-	-	1	-	1
	TOTAL		0	0	9	3	0	12
KLGO	Glacier Gorge	GG	-	-	-	1	-	1
	Dyea	DYB, DY7, DY8	1	-	2	-	-	3
	Chilkoot Trail Saintly Hill	CHC, CH5, CH6	1	-	2	-	-	3
	TOTAL		2	0	4	1	0	7
GLBA	Bartlett Cove	BC1, BC2	-	-	2	-	-	2
	Blue Mouse	BM1, BM2	-	-	2	-	-	2
	TOTAL		0	0	4	0	0	4
SITK	Indian River 1	IR1	-	-	1	-	-	1
	Indian River 2	HR20	-	-	-	1	-	1
	TOTAL		0	0	1	1	0	2
TAFT	Salmon Creek	TNF504	-	1	-	-	-	1
	Williams Cove	TNF505	-	1	-	-	-	1
	Sawyer Island	TNF547	-	-	-	1	-	1
	Sanford Cove	TNF571	-	-	-	-	1	1
	Bushy Islands	TNF570	-	-	-	-	1	1
	TOTAL		0	2	0	1	2	5
GRAND TOTAL			2	2	18	6	2	30

Survey Methods

Surveys at all sites followed the USDA Forest Service Forest Inventory and Analysis (FIA) lichen indicator protocol, modified by decreasing the standard circular plot radius from 35 m to 13 m to give surveyors more time to search substrates in rough terrain and to permit comparison to regional lichen survey sites maintained by the TNF (Dillman et al. 2007). Detailed survey methods and data forms are available at (http://fia.fs.fed.us/library/field-guides-methods-proc/). Briefly, a certified surveyor walks in a circuitous manner around the plot, collecting a voucher of each epiphytic macrolichen (i.e., non-crustose) species while searching among the variety of woody substrates and microhabitats on the site. Lichens within reach may be collected from live or standing dead trees, fallen trees, snags, shrubs, fallen branches, and litterfall. Soils, rock, stump and log substrates are excluded to avoid including the more protected ground flora. Surveyors must be able to distinguish, but not necessarily identify, separate species. Surveyors must spend at least 30 minutes searching for lichens, and may stop if no new species are detected for 10 minutes, or in 2 hours, whichever comes first. Before leaving the plot the surveyor assigns an abundance rating to each voucher reflecting the number of times that species was observed on the plot: 1 (1-3 individuals detected), 2 (4-10 individuals detected), 3 (> 10 individuals detected to individuals found on half of available substrates), 4 (individuals could be found on > half of available substrates). All vouchered specimens were identified by an expert lichenologist, primarily Dr. Toby Spribille, with some identifications by Karen Dillman and Doug Glavich.

Data Analysis Methods

Nutrient N

To detect effects of enhanced inorganic (nutrient) nitrogen on lichen community composition we employed a model developed for this purpose in western Oregon and Washington (wOR/WA; Geiser and Neitlich 2007). To create the wOR/WA model, an iterative multivariate technique, non-metric multidimensional scaling (PC-Ord, v. 5), was used to ordinate a calibration set of survey sites in two dimensions (i.e., an x, y coordinate grid) based on lichen species abundances at each site. Vector overlays of climate and air pollution variables permitted identification of an ordination axis (x) corresponding to an air pollution gradient, and a perpendicular axis (y) corresponding to a climate gradient. The ‘air score’ is the distance of the survey site along the air pollution axis (x); the ‘climate score’ is the distance of the survey site along the climate axis (y). Air scores positively correlated with increasing nitrogen and sulfur in lichens, increasing total deposition of N modeled by the US EPA Community Multi-scale Air Quality Model, and increasing concentrations of ammonium ions in wet deposition measured by the NADP network (Geiser and Neitlich 2007, Geiser et al. 2010). Climate scores were positively correlated with cooling mean minimum December temperatures, increasing summer and winter temperature differences, and decreasing relative humidity. New sites or repeat surveys can be fitted to the ordination and scored using the nonmetric multidimensional scaling scores routine in Pc-Ord. The main advantage of this technique is that it effectively separates lichen community responses to air pollution from those due to climate and other environmental variables. A potential criticism is that it was developed for an area that does not overlap geographically with SE Alaska.

The wOR/WA model was tested here to see if it could help explain variation in community composition related to air pollution among the SE Alaska study sites. We further discuss suitability of the model later. The initial justifications for extrapolating the study area to SE Alaska were as follows:

1. Both study areas are part of the US EPA Level I ecoregion, Marine West Coast Forests, which includes the temperate rainforest zone from coastal northern California, western Oregon and Washington, the coast ranges of British Columbia, and southeastern and south central Alaska.

2. Species overlap between the two study areas was high. Of the 83 species occurring 15 or more times in the wOR/WA calibration dataset, i.e., in >5% of plots, 90% also occurred in the SE Alaska dataset. Of the 76 species occurring 25 times or more in the SE Alaska dataset, i.e., on >5% of plots), 78% also occurred in the PNW calibration dataset. The primary

differences were that the SE Alaska dataset had a greater diversity of rare cyanolichens and additional species of horsehair lichens (*Bryoria spp.*). The high Cascades portion of the wOR/WA dataset had some lichens typical of cold AND dry climates that were absent from SE Alaska, specifically *Ahtiana pallidula*, *Esslingeriana idahoensis*, *Hypogymnia imshaugii* and *Letharia vulpina.* Several lichens also reach the northern extent of their range in OR/WA*: Platismatia stenophylla, Usnea glabrata, Usnea glabrescens.* Lichens occurring in >5% of plots in SE Alaska but absent from the wOR/WA flora were *Bryocaulon pseudosatoanum, B. bicolor, B. carlottae, B. cervinula, B. tenuis, Fuscopannaria laceratula, Hypogymnia vittata, Nephroma isidiosum.* It should be noted that 100% overlap is neither a necessary nor a realistic goal as rare species and extremely common species have little indicator value. For example of 227 species in wOR/WA sites scored by Geiser and Neitlich (2007) using the model, 98 (43%) did not occur in the calibration dataset, i.e., the dataset of indicator species. Of 173 species in the SE Alaska dataset, 73 (42%) did not occur in the calibration dataset.

3. It was the best tool available.

Each of the 30 plots in the SE Alaska study area and 372 historical reference plots (82 FIA-sized, 290 TNF-size) from SE Alaska were scored (data accessible at http://gis.nacse.org/lichenair). Scoring of the SE Alaska data followed the same procedures used to score wOR/WA sites (Geiser and Neitlich 2007). Sites with fewer than four species were not scored. Species that did not occur in the calibration dataset were left in the database to see if they would cause the site to be flagged. Sorensen's distance measure was used to fit each plot to the position of least stress relative to the calibration sites; the flag for poor fit was set at two standard deviations greater than the mean stress with an extrapolation limit of 10% of the axis length.

Resulting air scores were compared to air scores for background sites among

1) **wOR/WA lichen plots**. Lichen community composition at sites with scores below the range 0.02 to 0.21 is considered to be within the normal variability for clean sites within wOR/WA; community composition at plots with scores at or exceeding the threshold range could be considered to contain species indicative of enhanced nitrogen and sulfur deposition. Typically the ratio of eutrophic: oligotrophic species increases with increasing air scores and increasing availability of nitrogen and sulfur (Geiser et al. 2010). The primary limitation of this comparison is that the thresholds were created for a non-overlapping geographical area.

2) **SE Alaska FIA lichen plots**. Comparison of air scores to on-frame SE Alaska FIA plots was considered advantageous because FIA plots are remote from local point sources (i.e., could be considered clean sites) and the systematic sampling design yields data inferential for all (clean) SE Alaska forests. One plot near Haines was excluded because of its proximity to a highway, a potential pollution source. A disadvantage of referencing the FIA air scores is that plot size is larger—increasing the number of trees inspected and potentially species abundances and richness. To assess the effect of the larger FIA plot size on air score, air scores at 20 overlapping TNF and FIA plots were compared; FIA sites scored on average 2%

cleaner than TNF plots, or about 0.05 air score units. Because this value is smaller than the measurement error (typically within 8%; Geiser and Neitlich 2007), we did not further account for plot size. To compare air scores from the 30 current study sites to the FIA sites, we used the distribution quantiles for the FIA scores. Air scores that were poorer than 97.5% of FIA plots were considered ‘probably impacted’. Air scores poorer than 90 to 97.5% of FIA plots were considered ‘possibly impacted’. All others were considered ‘not impacted’

3) **TNF lichen plots**. Historical TNF sites were screened to include only sites that followed standard survey protocols on national forest land and remote from local emissions sources. Survey sites in SE Alaska cities and close to mines, incinerators, or local industries were excluded. This dataset, while not an inferential dataset for SE Alaska, has the advantage of encompassing many more sites, including more low elevation, hyper-maritime sites close to salt water similar to the habitats surveyed in the current study. Like the FIA sites it is a local dataset. To compare air scores from the 30 current study sites to the TNF sites, we used the distribution quantiles for the TNF scores. Air scores that were poorer than 97.5% of TNF plots were considered “probably impacted.” Air scores poorer than 90 to 97.5% of TNF plots were considered “possibly impacted.” All others were considered “not impacted.”

Hardwood influence on air scores. An initial analysis of the SE Alaska TNF and FIA air scores showed that the presence of hardwoods increased air scores by about 0.5 air score units or 21% of the wOR/WA gradient length. (In wOR/WA the effect of hardwoods on air scores was substantially smaller, shifting scores about 0.2 units [Geiser and Neitlich 2007]). To account for this, plots with any amount of hardwood trees present were compared only to the air scores quantiles for hardwood FIA and TNF sites, plots that had all conifers were compared only to air score quantiles for all conifer FIA and TNF plots.

SO_2/acidity

We used a simpler method to detect lichen community responses to SO_2 and throughfall sulfate deposition (a proxy for acidic deposition).

1. Each species detected within each of the 30 plots in the study area was assigned a sensitivity rating: “sensitive,” “intermediate,” “tolerant,” or not rated. The sensitivity ratings followed a literature search of fumigation and field studies compiled by McCune and Geiser (2009; Table 2), primarily based on Wetmore (1973). Sensitive species tolerate mean annual SO_2 levels under 50 μg/m^3, intermediate species tolerate 50-100 μg/m^3, and tolerant species tolerate >100 μg/m^3.

2. Study area plots were scored as the percentage of the rated species that were sensitive (100 x [no of sensitive species]/ [no of sensitive + intermediate+ tolerant species]).

3. FIA and TNF reference sites were also scored. Criteria for inclusion as reference sites were: must be either an on-frame FIA plot in SE Alaska or a standard survey TNF plot, must be presumed clean, and must have at least 9 species detected that have an S sensitivity rating. (All 30 study area plots had 9 or more rated species). This generated 92 conifer plots (35

FIA, 57 TNF) and 55 hardwood plots (4 FIA, 51 TNF). Because the scores are calculated from percentages rather than absolute numbers of sensitive species, biases due to plot size, after excluding plots with fewer than 9 rated species, were not expected. The larger TNF database contained some plots with both a higher and a lower percentage of sensitive species than the FIA plots. Although the mean difference was statistically different (60% for FIA vs. 65% for TNF; t-test, p>|t|=0.04), the 25 and 75% quantiles were very similar. Therefore to increase the size of the reference database, TNF and FIA data were combined. Because values for sensitive species percentages were higher in hardwood than conifer plots in every quantile, and because the means (61% conifers vs. 68% hardwoods) were also significantly different (t-test, p>|t|=0.0004), hardwood and conifer plots were compared separately.

4. Site scores at the 30 study area plots were evaluated by comparing them to the distribution of site scores among the TNF and FIA (hardwood or conifer) reference plots. Study sites with fewer sensitive species than 97.5% of the reference plots were interpreted as "probably impacted by SO_2 and/or acidity." Study sites with fewer sensitive species that 90% of the reference plots were interpreted as "possibly impacted;" all other scores were considered "not impacted."

Skagway Emission Inventory

An emission inventory in the City of Skagway for the week of July 20–26, 2008 was conducted in partnership with the USDA Forest Service and the Alaska Department of Environmental Conservation (AKDEC). Detailed emission factors from cruise ships, Alaska Marine Highway ships, diesel electric locomotives, steam locomotives (running on #4 fuel oil), diesel busses, and the municipal incinerator were collected using questionnaires sent to the cruise lines, interviews with personnel from the White Pass and Yukon Route railway and Municipality of Skagway incinerator, visual surveys of bus parking areas, and data available from engine manufactures were included in the inventory data. The full report on the Skagway emissions inventory (Graw and Faure 2010) including methods is available from AKDEC: http://www.dec.state.ak.us/water/cruise_ships/cruise_air.htm

Results

Ambient Atmospheric Pollution

Weekly monitoring commenced at the end of April, about one week prior to the cruise ship season and terminated in mid-October, about 2 weeks after the end of the tourist season during 2008 and 2009. The date-on and date-off for each sites' weekly exposure vary slightly due to staff schedules, but generally overlapped for at least 5 days of each exposure period. The actual dates for each exposure period are available in Appendix D. The results from the passive samplers yield data for weekly average ambient air concentrations of the selected compound (Appendix H). Sub-weekly sampling was considered but not attempted at any of the sites, as the low levels of pollutant were expected to be close to the samplers' detection limits.

Nitrogenous Compounds

NO_2

The weekly means of NO_2 levels ranged from a low of 0 ppb at Bartlett Cove to a high of 22.25 ppb at Icy Junction in 2008 and from a low of 0.12 ppb at Bartlett Cove to a high of 22.38 ppb Lower Dewey in 2009 (Figure 10). Seasonal means showed a similar pattern ranging from a low of 1.59 ppb at Bartlett Cove to a high of 13.60 ppb at Lower Dewey in 2008 and a low of 1.38 ppb at Bartlett Cove to a high of 13.24 ppb at Lower Dewey in 2009 (Table 3).

NO_x

The weekly means of NO_x levels ranged from a low of 1.80 ppb at Chilkoot Saintly Hill to a high of 111.93 ppb at Lower Dewey in 2008 and from a low of 0 ppb at Bartlett Cove to a high of 108.96 ppb at Lower Dewey in 2009 (Figure 11). Seasonal means showed a similar pattern ranging from a low of 10.17 ppb at Bartlett Cove to a high of 58.46 ppb at Lower Dewey in 2008 and a low of 6.39 ppb at Bartlett Cove to a high of 51.48 ppb at Lower Dewey in 2009 (Table 3).

NH_3

The weekly means of NH_3 levels ranged from a low of 0.0 $\mu g/m^3$ at Bartlett Cove to a high of 11.81 $\mu g/m^3$ at Sitka in 2008 and from a low of 0.0 $\mu g/m^3$ at Bartlett Cove to a high of 181.10 $\mu g/m^3$ at Dewey 1700 in 2009 (Figure 12). Seasonal means showed a similar pattern ranging from a low of 3.02 $\mu g/m^3$ at Dyea to a high of 4.14 $\mu g/m^3$ at Lower Dewey in 2008 and a low of 3.43 $\mu g/m^3$ at Sitka to a high of 16.59 $\mu g/m^3$b at Dewey 1700 in 2009 (Table 3).

HNO_3

The weekly means of HNO_3 levels ranged from a low of 0.07 $\mu g/m^3$ at Bartlett Cove to a high of 20.71 $\mu g/m^3$at Lower Dewey in 2008 and from a low of 0.06 $\mu g/m^3$ at Bartlett Cove to a high of 44.87 $\mu g/m^3$ at Lower Dewey in 2009 (Figure 13). Seasonal means showed a similar pattern ranging from a low of 0.24 $\mu g/m^3$ at Bartlett Cove to a high of 2.17 $\mu g/m^3$ at Lower Dewey in 2008 and a low of 2.71 $\mu g/m^3$ at Dewey 1700 to a high of 6.60 $\mu g/m^3$ at Lower Dewey in 2009 (Table 3).

Table 3. Mean seasonal ambient atmospheric concentrations of primary and secondary combustion products.

		GLBA	SITK	KLGO	SKAGWAY			
Analyte	**Year**	**Bartlett Cove**	**Sitka**	**Chilkoot Saintly Hill**	**Dewey 1700**	**Dyea**	**Lower Dewey**	**Sturgills**
NO_2 (ppb)	2008	1.59	2.73	2.58	3.29	3.26	13.60	4.24
	2009	1.38	2.18	2.55	3.80	2.68	13.24	4.43
NO_x (ppb)	2008	10.17	11.10	10.55	17.14	13.23	58.46	17.16
	2009	6.39	8.02	8.98	11.30	11.09	51.48	14.95
NH_3 (µg/m^3)	2008	3.67	3.28	3.66	4.14	3.02	3.29	3.45
	2009	7.41	3.43	5.69	16.59	7.40	8.92	6.51
HNO_3 (µg/m^3)	2008	1.50	1.01	1.31	0.24	2.05	2.17	1.72
	2009	2.85	3.60	4.38	2.71	6.02	6.60	3.45
SO_2 (µg/m^3)	2008	0.33	0.40	0.83	1.62	1.39	8.96	2.79
	2009	0.36	0.45	0.97	2.07	1.43	7.07	2.87

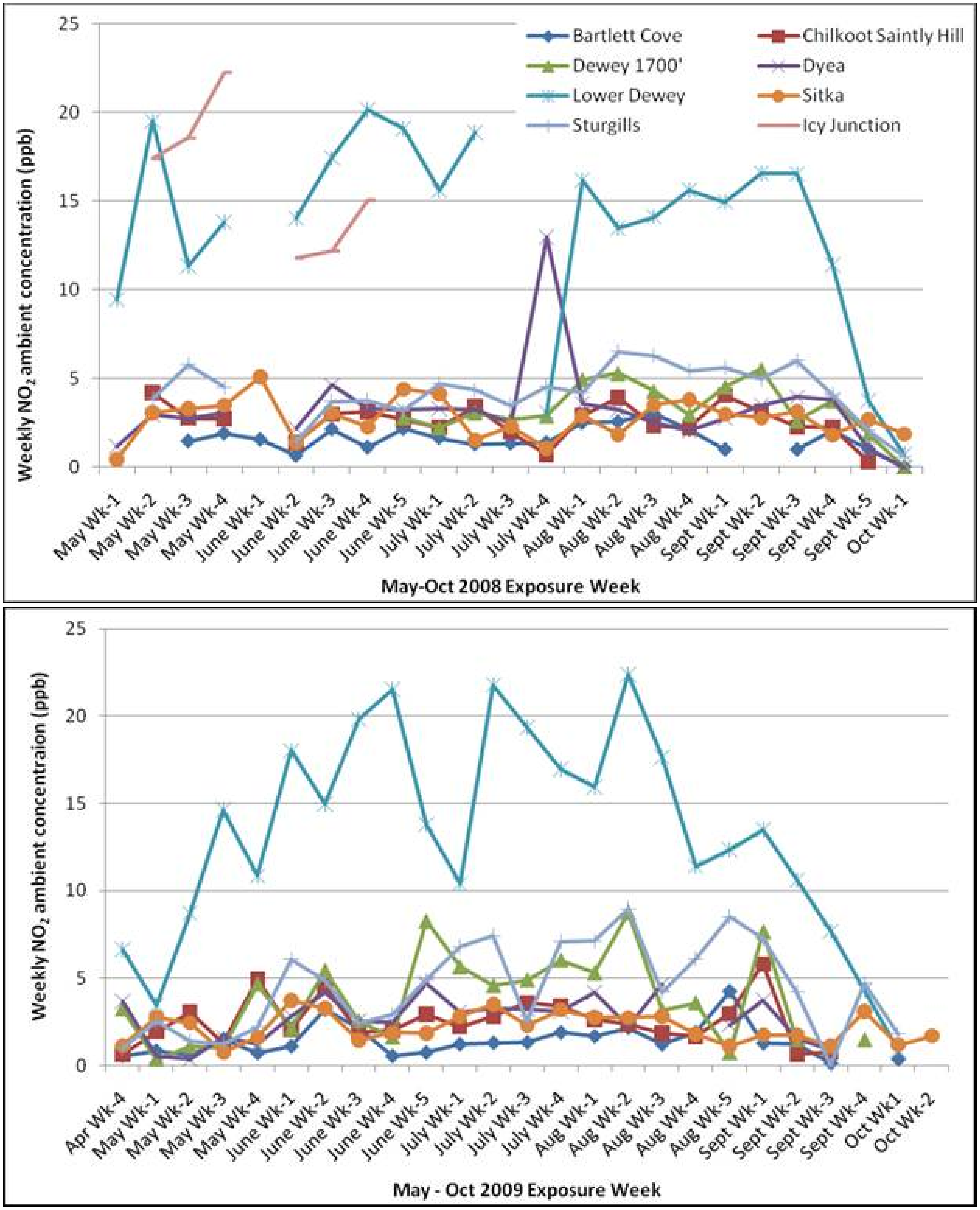


Figure 10. Weekly NO_2 ambient concentrations during May-Oct sampler exposure weeks in (a) 2008 and (b) 2009 for Glacier Bay NPP, Sitka NHP, and Klondike Gold Rush NHP study sites.

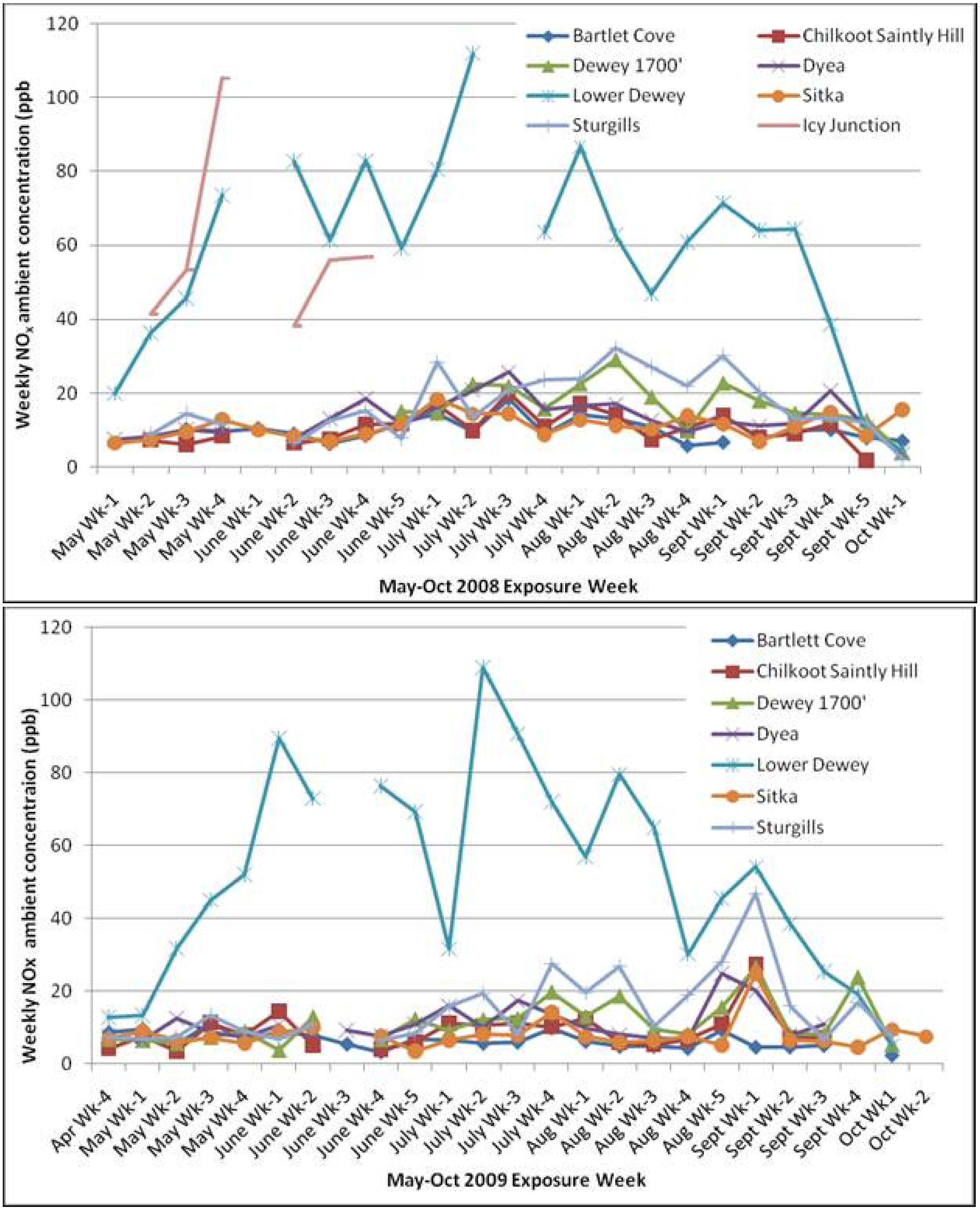


Figure 11. Weekly NO_x ambient concentrations during May-Oct sampler exposure weeks in (a) 2008 and (b) 2009 for Glacier Bay NPP, Sitka NHP, and Klondike Gold Rush NHP study sites.

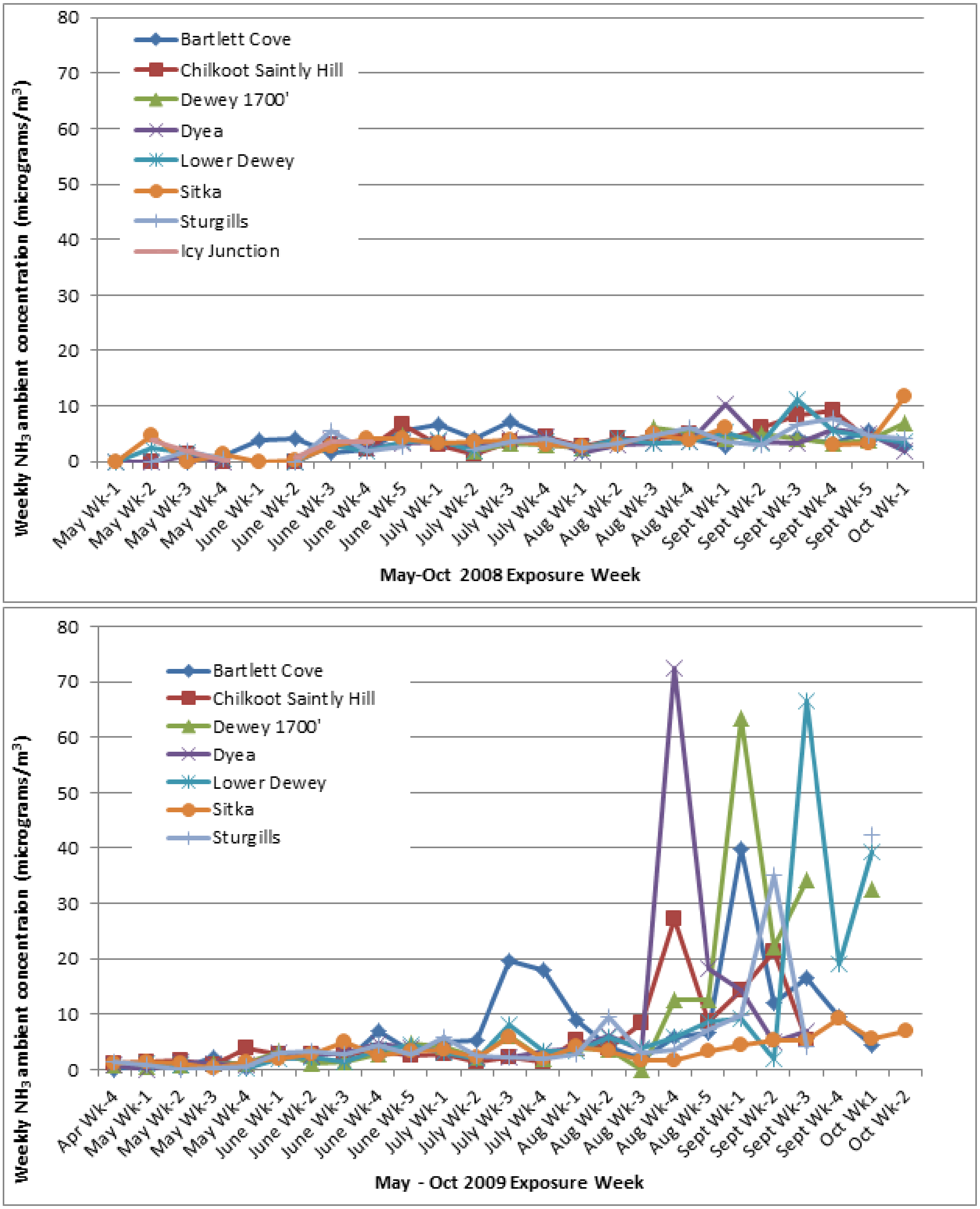


Figure 12. Weekly NH_3 ambient concentrations during May-Oct sampler exposure weeks in (a) 2008 and (b) 2009 for Glacier Bay NPP, Sitka NHP, and Klondike Gold Rush NHP study sites. Note: Dewey 1700' value of 181.10 on September Week 4 2009 removed for graph comparison purposes.

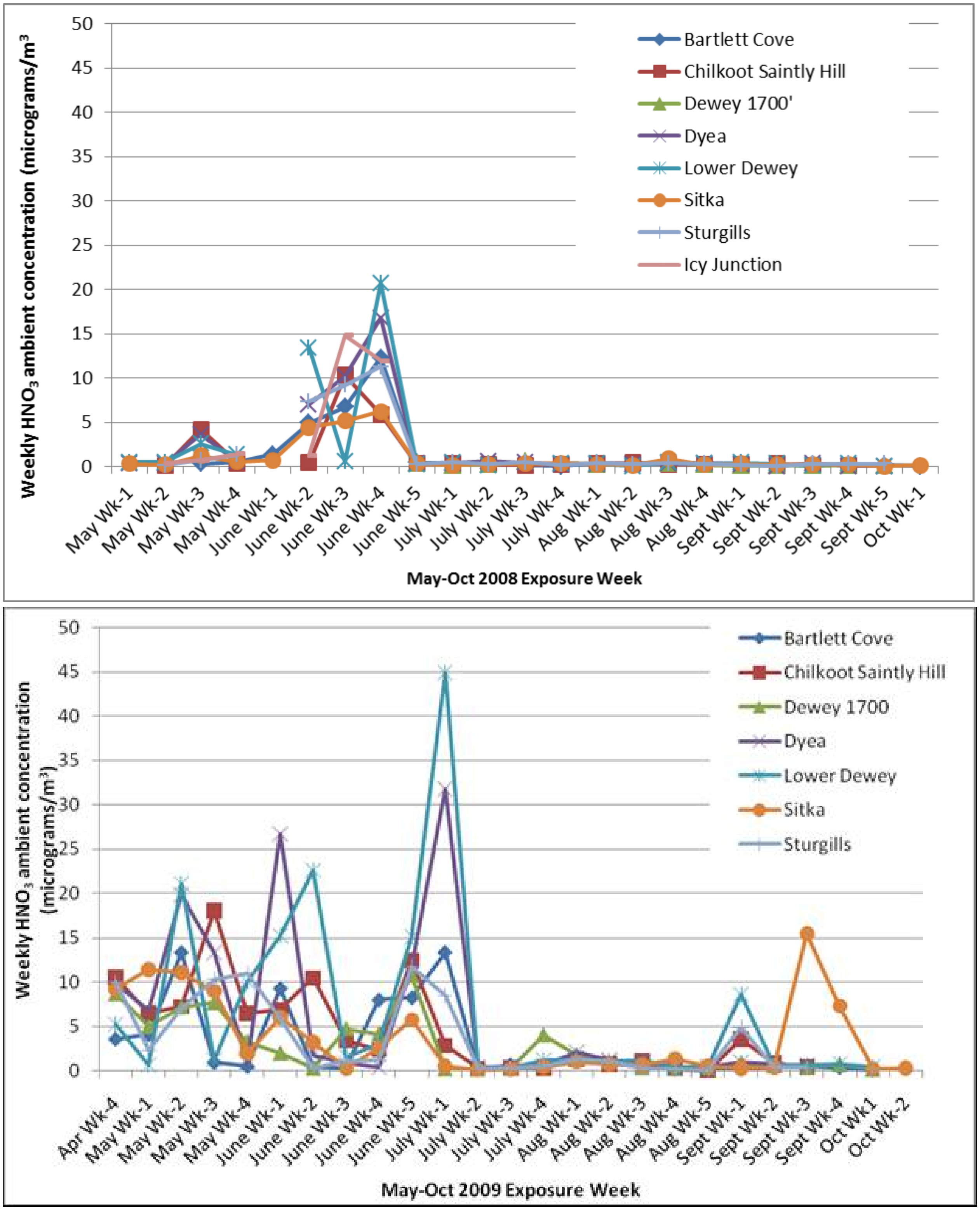
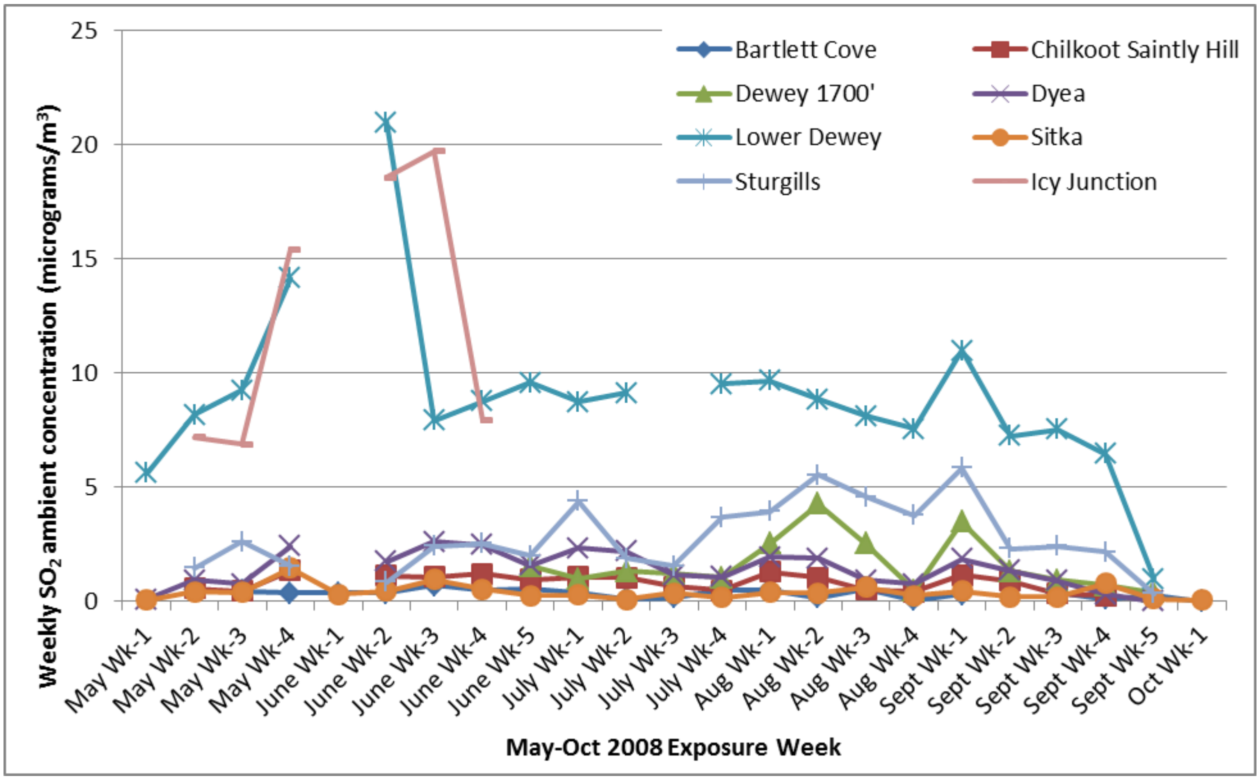


Figure 13. Weekly HNO_3 ambient concentrations during May-Oct sampler exposure weeks in (a) 2008 and (b) 2009 for Glacier Bay NPP, Sitka NHP, and Klondike Gold Rush NHP study sites.



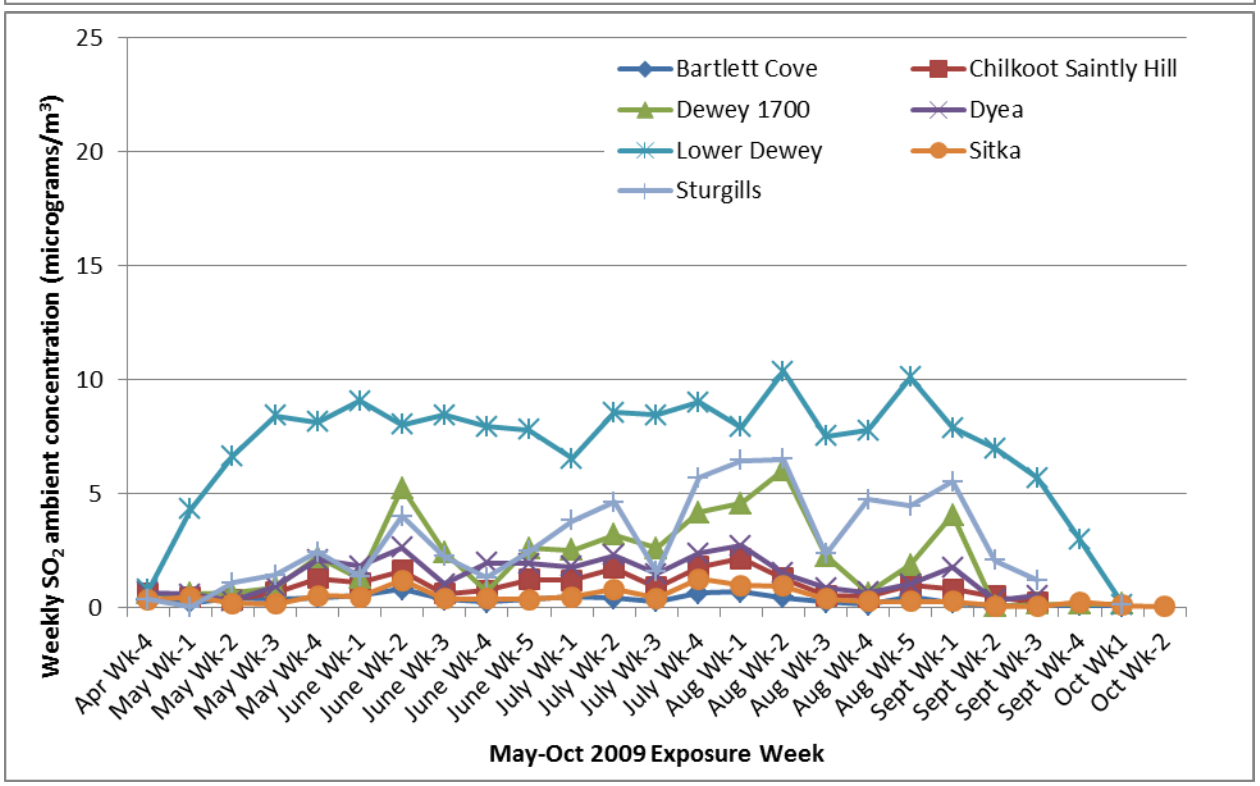


Figure 14. Weekly SO_2 ambient concentrations during May-Oct sampler exposure weeks in (a) 2008 and (b) 2009 for Glacier Bay NPP, Sitka NHP, and Klondike Gold Rush NHP study sites.

Sulfur Dioxide

The weekly means of SO_2 levels ranged from a low of 0 µg/m^3 at Bartlett Cove to a high of 20.97 µg/m^{3}at Lower Dewey in 2008 and from a low of 0.09 µg/m^3 at Bartlett Cove to a high of 10.37 µg/m^3 at Lower Dewey in 2009 (Figure 14). Seasonal means showed a similar pattern ranging from a low of 0.33 µg/m^3 at Bartlett Cove to a high of 8.96 µg/m^{3}at Lower Dewey in 2008 and a low of 0.36 µg/m^3 at Bartlett Cove to a high of 7.07 µg/m^3 at Lower Dewey in 2009 (Table 3).

Atmospheric Deposition

Resin tube deposition samplers measure bulk deposition (defined as wet deposition plus inadvertent dry deposition to continually open samplers), or canopy throughfall deposition of select nitrogenous and sulfurous compounds in kilograms per hectare for the period of exposure. During this study the period of exposure was concurrent with the period of high visitation and associated cruise ship traffic and with weeks that the passive membrane samplers were deployed, generally from late April to early October. Results are displayed in Figures 15-18 for nitrogen and Figure 19 for sulfur. The 2008 data from Tracy Arm was adjusted to account for bird feces contamination and two low outliers were removed from the 2009 data for Lower Dewey.

NH_4^+

For open site (canopy gaps or alpine habitats) N contributed by NH_4^+ ranged from a low of 0.06 kg/ha at Upper Dewey to a high of 0.35 kg/ha at Lower Dewey in 2008 and a low of 0.02 kg/ha at Upper Dewey to a high of 0.29 kg/ha at Tracy Arm in 2009. The largest interannual difference was a change from 0.35 kg/ha in 2008 to 0.11 kg/ha in 2009 at Lower Dewey (Figure 15).

For closed canopy sites, N contributed by NH_4^+ ranged from a low of 0.04 kg/ha at Dewey 1700 to a high of 1.02 kg/ha at Tracy Arm in 2008 and a low of 0.03 kg/ha at Dewey 1700 to a high of 0.85 kg/ha at Tracy Arm in 2009. The largest interannual difference was a change from 1.46 kg/ha in 2008 to 0.85 kg/ha in 2009 at Tracy Arm (Figure 15).

NO_3^-

Nitrogen contributed by NO_3^- at open sites ranged from a low of 0.09 kg/ha at Upper Dewey to a high of 0.25 kg/ha at Tarr Inlet in 2008 and a low of 0.04 kg/ha at Upper Dewey and Tarr Inlet to a high of 0.12 kg/ha at Juneau in 2009. The largest interannual difference was a change from 0.47 kg/ha in 2008 to 0.12 kg/ha in 2009 at Juneau (Figure 16).

Nitrogen contributed by NO_3^- at closed sites ranged from a low of 0.03 kg/ha at several sites to a high of 0.05 kg/ha at Tarr Inlet in 2008 and a low of 0 kg/ha at Lower Dewey to a high of 0.05 kg/ha at Tarr Inlet in 2009. The largest interannual difference was a change from 0 kg/ha in 2008 to 0.17 kg/ha in 2009 at Tarr Inlet (Figure 16).

Total Inorganic Nitrogen

Among the field sites, total inorganic nitrogen (NH_4^+-N plus NO_3^--N) in open sites ranged from a low of 0.15 kg/ha at Upper Dewey to a high of 0.55 kg/ha at Lower Dewey in 2008 and ranged from a low of 0.06 kg/ha at Upper Dewey to a high of 0.41 kg/ha at Tracy Arm in 2009. At the Juneau NADP station, bulk (open site) resin tube deposition samplers recorded total inorganic nitrogen as 0.64 kg/ha in 2008 and 0.18 kg/ha in 2009 (Figure 17).

Among the closed canopy field sites, total inorganic nitrogen ranged from a low of 0.05 kg/ha at Dewey 1700 to a high of 1.05 kg/ha at Tracy Arm in 2008 and from a low of 0.05 kg/ha at Dewey 1700 to a high of 0.86 kg/ha in Tracy Arm in 2009 (Figure18).

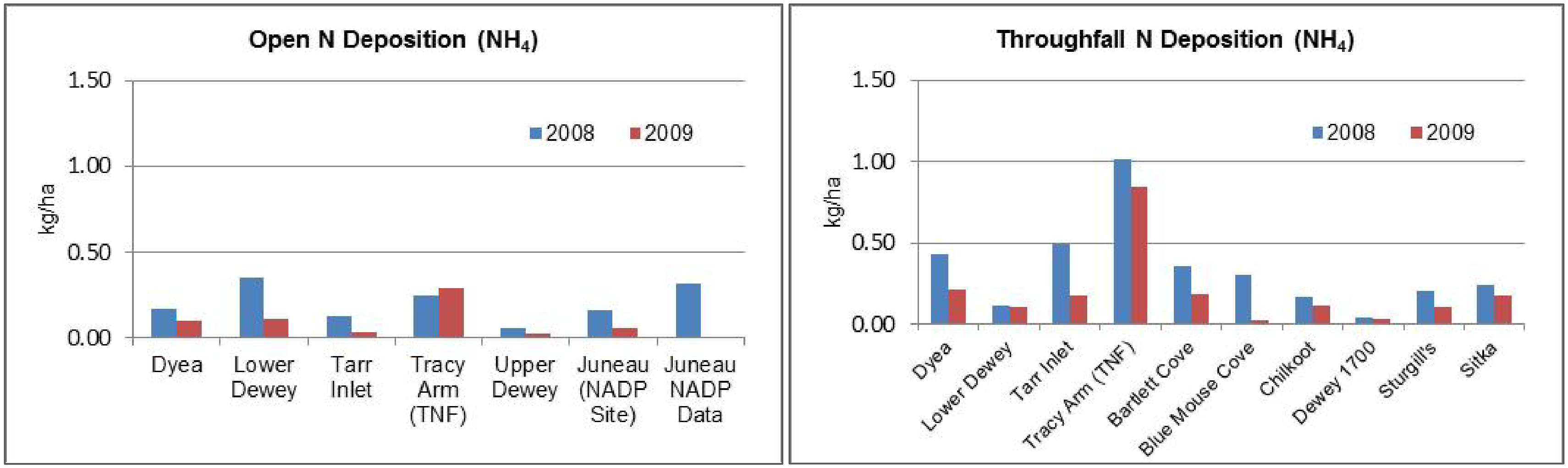


Figure 15. Open and throughfall deposition of NH_4^+in 2008 and 2009.Note the Tracy Arm site's throughfall sampler was probably contaminated by bird droppings during the 2008 season.

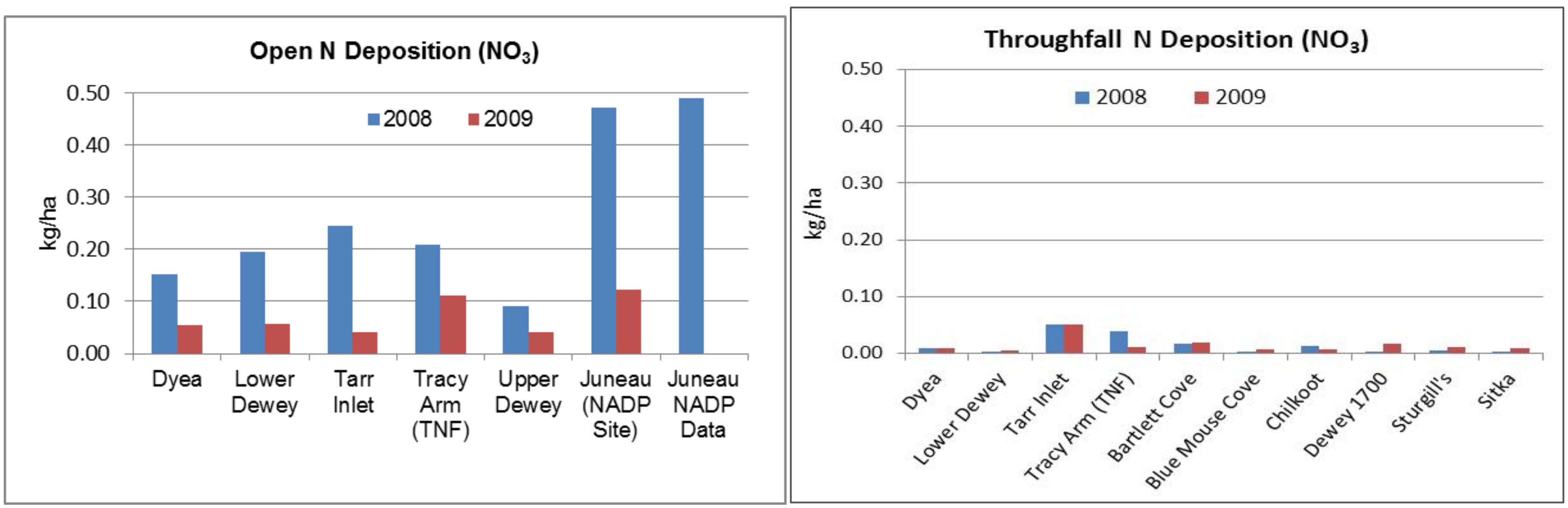


Figure 16. Open and canopy throughfall deposition of NO_3^- in 2008 and 2009.

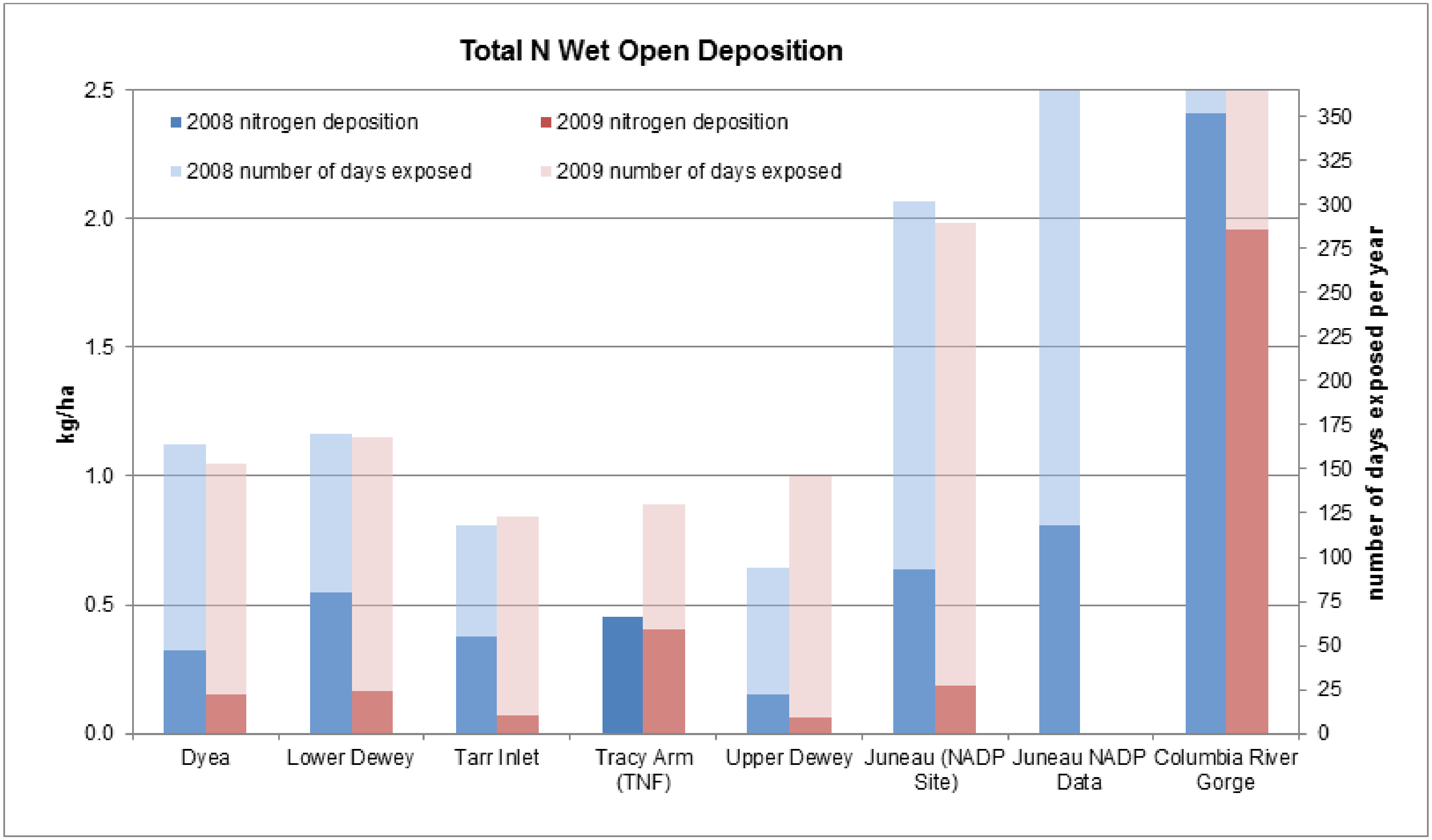


Figure 17. Total N wet open deposition values in 2008 and 2009 with number of annual exposure days shown in shaded bars. Number of exposure days for 2008 Tracy Arm (TNF) deposition sampler was not available but was similar to other sites.

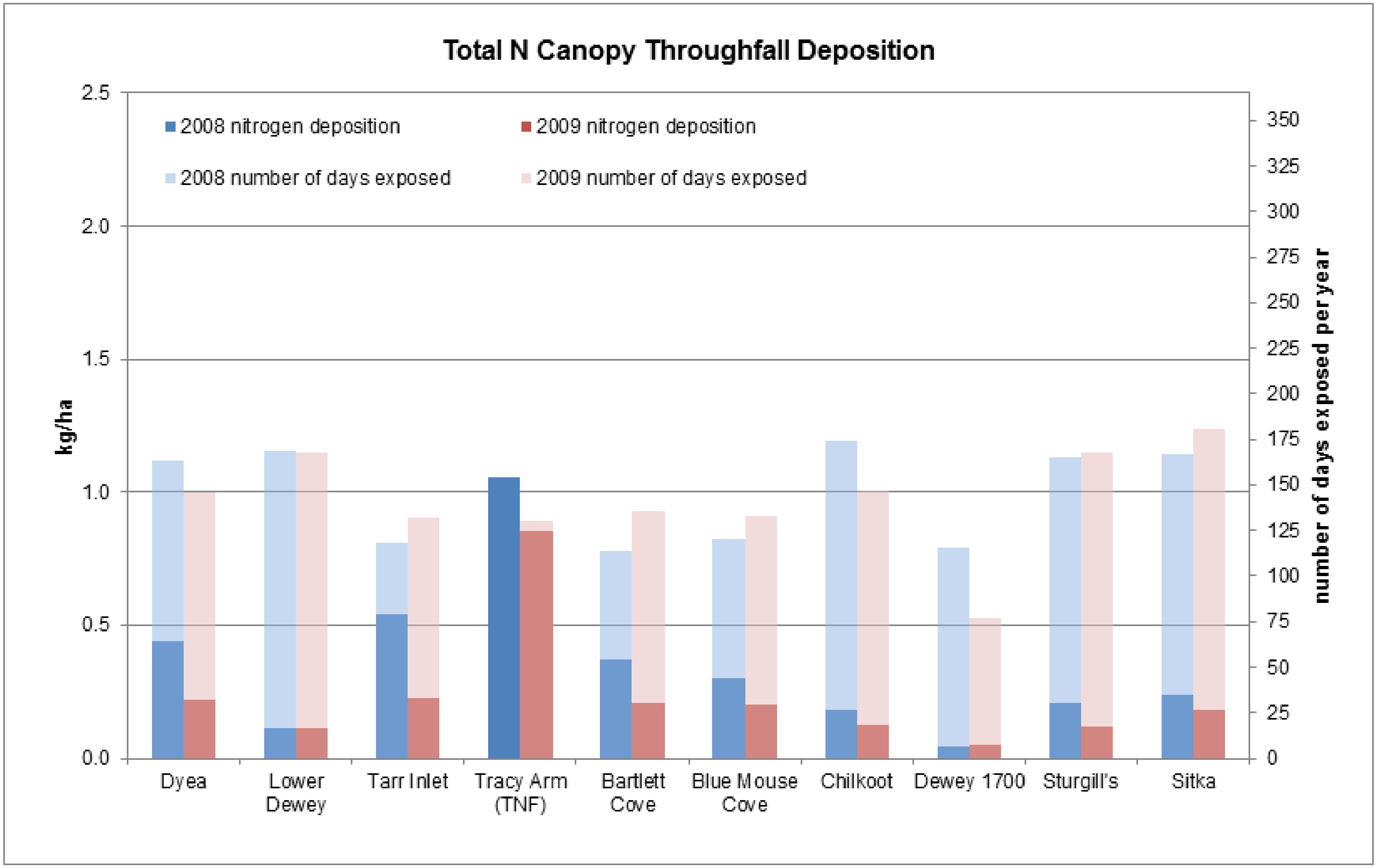


Figure 18. Total N throughfall deposition values in 2008 and 2009 with number of annual exposure days shown in shaded bars. Number of exposure days for 2008. Note that Tracy Arm's (TNF) deposition may have been influenced by bird droppings in 2008. Other than Dewey 1700, exposure days between years are similar enough that data are not normalized.

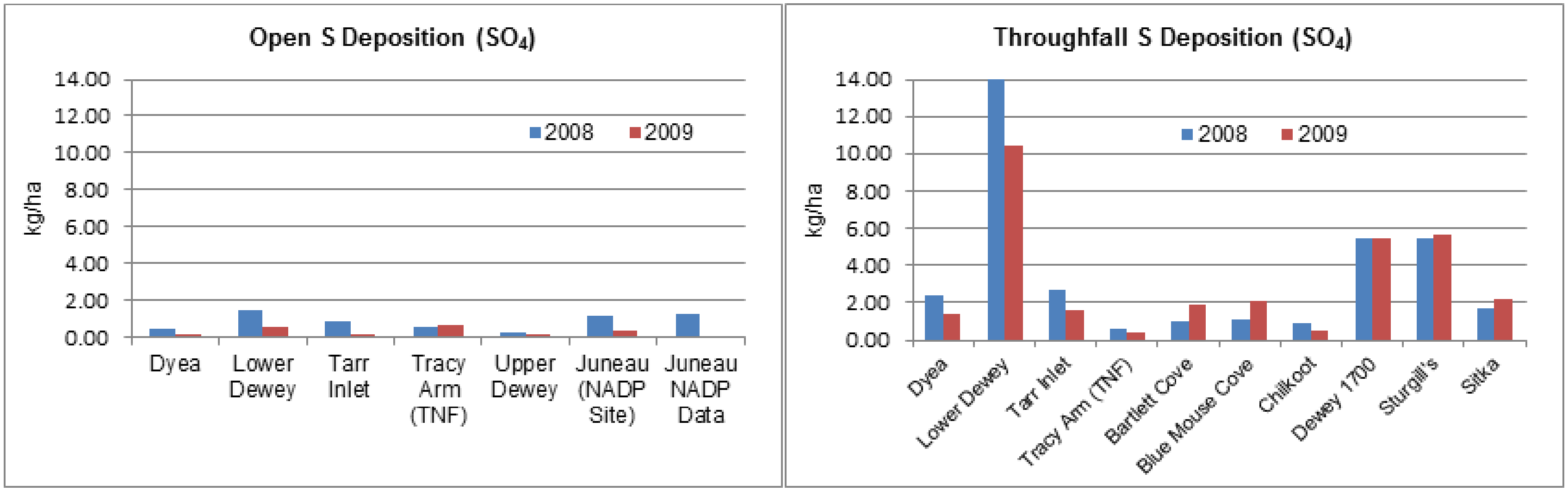


Figure 19. Open and throughfall deposition of S from SO_4^{2-} in 2008 and 2009.

SO_4^{2-}

Sulfur contributed by SO_4^{2-} in open area (bulk deposition) collectors ranged from a low of 0.28 kg/ha at Upper Dewey to a high of 1.49 kg/ha at Lower Dewey in 2008 and a low of 0.12 kg/ha at Tarr Inlet to a high of 0.67 kg/ha at Tracy Arm in 2009. The largest interannual difference was for Lower Dewey with 1.49 kg/ha in 2008 and 0.52 kg/ha in 2009 (Figure 19).

Sulfur contributed by SO_4^{2-} at closed canopy sites ranged from a low of 0.87 kg/ha at Chilkoot to a high of 14.23 kg/ha at Lower Dewey in 2008 and a low of 0.47 kg/ha at Tracy Arm to a high of 10.46 kg/ha at Lower Dewey in 2009. The largest interannual difference was for Lower Dewey with 14.23 kg/ha in 2008 and 10.46 kg/ha in 2009 (Figure 19).

Lichen Tissue Samples

Elemental concentration data from lichen samples from 3 species at 7 sites in the Skagway Borough, 3 sites in KLGO, 2 sites in GLBA, 1 site in SITK, and 1 site in TAFT were determined from lichen samples collected in 2008 and 2009. Data from samples of the same species collected at the same site but in the two different years (2008 and 09) were combined, after confirming no significant interannual differences, to create box plots that are displayed with thresholds established for the TNF (Dillman et al. 2007) in Appendix E (raw data in Appendix F). The thresholds represent the upper limit for dry weight concentration of an element expected for sites with no local anthropogenic source (i.e., clean sites). Specifically, they are the 97.5% quantiles for the distribution of each element for *Alectoria sarmentosa*, *Hypogymnia* species (*H. enteromorpha* and *H. imshaugii*), and *Platismatia glauca* collected from clean sites on the TNF. Generally levels of N above thresholds are associated with shifts in lichen community composition away from natural conditions (fewer sensitive species, fewer oligotrophs). Metal thresholds have not been associated with lichen community effects but are useful for identifying sites with elevated deposition relative to known clean site ranges. Concentrations of Hg were determined for most samples but thresholds have not been established. Several sites exceeded TNF thresholds for one or more elements (Table 4). Results from TAFT were not included in data presented in Appendixes E and F as samples for elemental analysis were collected only in 2009, and only two elements, nitrogen and sulfur, were analyzed.

Table 4. Sites exceeding TNF thresholds (Dillman et al. 2007) for specific elements. Some elements were analyzed but not found to exceed TNF thresholds at any site (Be, Bo, B, Ca, Co, Fe, Mg, Mn, Hg, Na). No threshold currently exists for mercury. Samples from Sawyer Island were analyzed for nitrogen and sulfur only. See Appendix F for results.

Area	**Site**	**Element**																	
		Al	**Ba**	**Cd**	**Cr**	**Cu**	**Pb**	**Li**	**Mo**	**N**	**Ni**	**K**	**Rb**	**Si**	**Sr**	**S**	**Ti**	**V**	**Zn**
GLBA	Bartlett Cove											X							
	Blue Mouse Cove							X		X		X		X					
KLGO	Chilkoot Saintly Hill 1999					X						X							X
	Chilkoot Saintly Hill 2009																		
	Dyea 1999					X	X				X	X							X
	Dyea 2009		X				X				X	X		X	X		X		X
	Glacier Gorge						X				X	X	X					X	X
	Icy Junction						X				X	X				X		X	X
	Icy Lake						X												X
	Lost Lake Trail																		
	Lower Dewey 1999	X		X	X	X	X				X	X				X			X
	Lower Dewey 2009						X		X		X	X		X		X	X	X	X
Skagway	Skagway Incinerator						X						X						X
	Sturgill's 1999						X									X			X
	Sturgill's 2009						X									X		X	X
	Dewey 1700						X												
SITK	Sitka									X		X							
TAFT	Sawyer Island									X						X			

Glacier Bay National Park and Preserve

In Bartlett Cove a few samples of *P. glauca* slightly exceeded thresholds for K. In Blue Mouse Cove, a few samples of *P. glauca* and *H. enteromorpha* exceeded thresholds for K, Li, N, and Si.

Klondike Gold Rush National Historical Park

The Chilkoot Saintly Hill site had threshold exceedances for Cu (*H. enteromorpha* and *H. inactiva*), K (*P. glauca*), and Zn (*H. enteromorpha*, *H. inactiva*, *P. glauca*) in 1999. Levels of Cu declined dramatically and fell below threshold values with the 2008-09 samples. Values for K dropped slightly for all species and *P. glauca* dropped to threshold values with the 2008-09 samples. Values for Zn dropped slightly to below threshold values for *H. enteromorpha* and *H. inactiva*, and *P. glauca* dropped to threshold values with the 2008-09 samples.

Dyea had threshold exceedances for Cu, Pb, K, and Zn in 1999. Levels of Cu (*H. enteromorpha* and *H. inactiva*) dropped well below thresholds between 1999 and 2009. Levels of Pb in all species remain well above thresholds but declined slightly over the intervening decade. Levels of K were stable between sampling and remained above threshold in *P. glauca*. Levels of Zn fell in all species between 1999 and 2009, but remain above threshold in *P. glauca* and *H. enteromorpha*. Ba was above threshold in *P. glauca* and *H. enteromorpha*, Si was above threshold in *H. enteromorpha*, Sr was above threshold in *H. enteromorpha* and Ti in *H. inactiva* in 2009. Chemical analysis for Ba, Si, Sr, and Ti was not conducted in 1999 so comparisons are not available.

Skagway

Lower Dewey is the most impacted site in the study area; however, several elements dropped below thresholds during the intervening decade. Al in *H. enteromorpha* and *H. inactiva* dropped well below threshold and declined in *P. glauca* which was below threshold for both time periods. Cd and Cu dropped from above to below threshold values for all species, Cr was elevated in 1999 for *H. enteromorpha* but dropped below threshold in 2009. Pb remained well above threshold for all species for both time periods, but displayed a declining trend. S remained above threshold for all species for both time periods and may be displaying an increasing trend. K remained above threshold for *P. glauca* for both time periods but is below threshold for the other species. Zn declined in all species; however, only in the case of *H. inactiva* did concentrations drop below threshold values. Mo, Si, Ti, and V were not assessed in 1999. In the TNF, Mo was below detection levels at all sites, therefore the threshold values were set at the methods detection limit. Lower Dewey in 2009, is the only site where Mo was detected and above threshold. Si is above threshold for *H. enteromorpha*, Ti is above threshold for *H. enteromorpha* and *H. inactiva*, and V is well above threshold for all species at Lower Dewey in 2009.

Conditions at Sturgill's remained somewhat stable between 1999 and 2009. Pb remained above threshold but shows a declining trend for all species. S declined to below the threshold for *H. inactiva*, remained at threshold for *H. enteromorpha*, and remained below threshold for *P. glauca*. Zn shows a declining trend at all sites, dropping below threshold in *H. enteromorpha*, remaining just above threshold values in *P. glauca*, and remaining below threshold in *H. inactiva*. V which is just above threshold for all species in 2009 was not assessed in 1999.

Among sites not visited in 1999, Icy Junction had elevated levels of Pb, K, V, and Zn in *P. glauca*, and elevated levels of S in all species. The Skagway incinerator site had elevated levels of Pb, Rb, and Zn in *P. glauca*. Icy Lake had elevated levels of Pb and Zn in *P. glauca*. Lost Lake Trail was below threshold for all analytes. Dewey 1700 had elevated levels of Pb in *P. glauca* and *H. enteromorpha.*

Sitka

Sitka had fewer lichen collections, as part of this study, than other sites due to logistical constraints and the absence of *H. enteromorpha* and *H. inactiva*. The TNF has several sites in Sitka near SITK that are presented in Dillman et al. 2007. The *P. glauca* collected in 2008 showed elevated levels of N and K.

Tracy Arm-Fords Terror Wilderness, Tongass National Forest

No elements were above TNF thresholds in the 2003 samples of *A. sarmentosa*, *H. enteromorpha,* and *P. glauca* from Salmon Creek. In contrast, at Sawyer Island, samples of *P. glauca* were at or above both nitrogen and sulfur thresholds (the only elements analyzed).

Lichen Community Plots

Nutrient N

Lichen-community based air scores are presented in Tables 5 and 6. Thirteen plots in the TNF reference dataset and one plot in the study area (HR20 in SITK) received a low end-of-axis flag (air score<-1.364). A low end-of-axis flag means the air scores were lower (‘cleaner’) than scores observed in the Oregon and Washington calibration dataset. None of the plots were flagged for surpassing the upper end of axis cut-off (air score>1.504; ‘more polluted’) and none were flagged for poor fit (stress>18.287) or for exceeding climate axis cut-offs. Air scores exceeded wOR/WA air score thresholds at only 2 sites in the study area, Sawyer Island in TAFT, and Dyea in KLGO. In general, sites that had any amount of hardwood substrates scored about 0.5 units higher than sites where conifers were the only substrates. For a visual comparison of ordination results for the wOR/WA and SE Alaska air scores see Figure 20.

Table 5. Distribution quantiles and statistics for air scores among 369 reference hardwood and conifer FIA and TNF plots in SE Alaska. These distributions were used to interpret air scores at study sites. Air scores exceeding 97.5% quantiles for the larger, more representative TNF dataset were considered 'probably impacted' and represent a threshold lichen community response to N deposition in SEAK (highlighted). Air scores in the TNF 90-97.5% quantile ranges were considered possibly impacted to allow for measurement error. See also Table 6.

		Air Score			
Quantile	**Statistic**	**FIA con n=71**	**TNF con n=216**	**FIA hwd n=11**	**TNF hwd n=71**
100.00%	maximum	0.213	0.704	-0.306	0.571
99.50%		0.213	0.698	-0.306	0.571
97.50%		0.034	0.265	-0.306	0.514
90.00%		-0.523	-0.197	-0.326	0.218
75.00%	quartile	-0.849	-0.574	-0.411	-0.092
50.00%	median	-1.025	-0.882	-0.692	-0.301
25.00%	quartile	-1.140	-1.096	-0.911	-0.520
10.00%		-1.348	-1.232	-1.300	-0.760
2.50%		-1.437	-1.401	-1.378	-1.211
0.50%		-1.445	-1.538	-1.378	-1.249
0.00%	minimum	-1.445	-1.545	-1.378	-1.249
	Mean	-0.960	-0.798	-0.708	-0.283
	Std Dev	0.323	0.406	0.318	0.375
	Std Err Mean	0.038	0.028	0.096	0.045
	Upper 95% Mean	-0.883	-0.744	-0.494	-0.194
	Lower 95% Mean	-1.036	-0.853	-0.922	-0.372

Table 6. Lichen community based air scores for nutrient N deposition at study sites, sorted from lowest to highest. Ratings are compared to wOR/WA thresholds and to air score distributions of reference FIA and TNF hardwood and conifer plots in SE Alaska (Table 5). Potentially impacted sites are highlighted.

Area	**Site**	**Year**	**Hwd?**	**Spp**	**Fit**	**Flag**	**Air Score**	**OR/WA TH**	**FIA quantile**	**TNF quantile**	**Impact**
near SITK	Indian River HR20	2009	yes	22	18.0	2	-1.47	below	< 0	< 0	none
TAFT	Sanford Cove	2011	no	19	18.0	0	-1.29	below	10-25	2.5-10	none
TAFT	Bushy Island	2011	no	20	18.0	0	-1.24	below	10-25	2.5-10	none
Skagway	Sturgills	2008	yes	19	18.1	0	-1.11	below	10-25	2.5-10	none
TAFT	Salmon Creek	2003	no	23	18.0	0	-1.08	below	25-50	10-25	none
GLBA	Bartlett Cove	2008	no	18	18.0	0	-1.03	below	25-50	10-25	none
TAFT	Williams Cove	2003	no	14	18.0	0	-0.96	below	50-75	25-50	none
GLBA	Bartlett Cove	2008	no	20	18.1	0	-0.92	below	50-75	25-50	none
Skagway	Icy Junction	2008	no	17	18.1	0	-0.78	below	75-90	50-75	None
Skagway	Dewey 1700	2008	yes	20	18.1	0	-0.73	below	25-50	10-25	none
Skagway	Sturgills	2008	yes	24	18.1	0	-0.70	below	25-50	10-25	none
Skagway	Ice Lake	2009	no	30	18.0	0	-0.69	below	75-90	50-75	none

Table 6. Lichen community based air scores for nutrient N deposition at study sites, sorted from lowest to highest. Ratings are compared to wOR/WA thresholds and to air score distributions of reference FIA and TNF hardwood and conifer plots in SE Alaska (Table 5). Potentially impacted sites are highlighted (cont.).

Area	Site	Year	Hwd?	Spp	Fit	Flag	Air Score	OR/WA TH	FIA quantile	TNF quantile	Impact
GLBA	Bartlett Cove	2009	no	34	18.0	0	-0.68	below	75-90	50-75	none
KLGO	Chilkoot Trail	2000	yes	21	18.1	0	-0.67	below	50-75	10-25	none
Skagway	Lower Dewey	2008	no	28	18.0	0	-0.61	below	75-90	50-75	none
KLGO	Glacier Gorge	2009	no	19	18.1	0	-0.57	below	75-90	75-90	none
Skagway	Dewey 1360	2008	yes	24	17.8	0	-0.55	below	50-75	25-50	none
Skagway	Icy Junction	2008	yes	30	18.0	0	-0.55	below	50-75	25-50	none
KLGO	Chilkoot Trail	2008	yes	32	18.0	0	-0.51	below	50-75	25-50	none
GLBA	Blue Mouse	2008	yes	27	18.0	0	-0.45	below	50-75	25-50	none
Skagway	Incinerator	2009	yes	34	18.0	0	-0.43	below	50-75	25-50	none
GLBA	Blue Mouse	2008	yes	27	17.8	0	-0.38	below	75-90	25-50	none
KLGO	Chilkoot Trail	2008	no	29	18.0	0	-0.34	below	90-97.5	75-90	none
Skagway	Lost Lake	2009	yes	30	17.9	0	-0.32	below	90-97.5	25-50	none
KLGO	Dyea	1999	no	27	18.0	0	-0.25	below	90-97.5	75-90	none
GLBA	Blue Mouse	2009	yes	34	17.9	0	-0.20	below	>100	50-75	none
Skagway	Lower Dewey	2008	yes	28	17.9	0	-0.17	below	>100	50-75	none
SITK	Indian River	2008	yes	19	18.2	0	-0.16	below	>100	50-75	none
KLGO	Dyea	2008	no	33	18.0	0	-0.05	below	90-97.5	90-97.5	possible
Skagway	Dewey 1480	2008	yes	28	17.9	0	-0.01	below	>100	75-90	none
KLGO	Dyea	2008	yes	38	17.7	0	0.26	above	>100	90-97.5	possible
TAFT	Sawyer Island	2009	yes	13	18.1	0	0.52	above	>100	97.5-100	probable

Abbreviations: **Hwd?** = Were hardwood trees present on the plot?; **Spp** = total species count; **Fit** = NMS scores fit; **Flag**: 0 = plot fits within 2 SD of calibration dataset scores, 2 = plot exceeds 2 SD, and is cleaner than plots in the calibration dataset; **Air Score** = NMS Scores air score rating, values in the wOR/WA calibration dataset increased with increasing N deposition; **OR/WA rating**= below or above the threshold range of 0.02 to 0.21 for w OR/WA calibration plots; **FIA quantile** = matching quantile for relevant hardwood or conifer reference plots, the higher the quantile the more nutrient enriched the site; **TNF quantile** = same as FIA quantile but for TNF plots; **Impact** = best estimate of presence or absence of an anthropogenic effect. 'None' fits within TNF reference ranges, 'possible' fits within the 90 to 97.5 % TNF quantile and allows for measurement error, 'probable' means all evidence points to the site exceeding values observed for OR/WA, FIA and TNF reference sites.

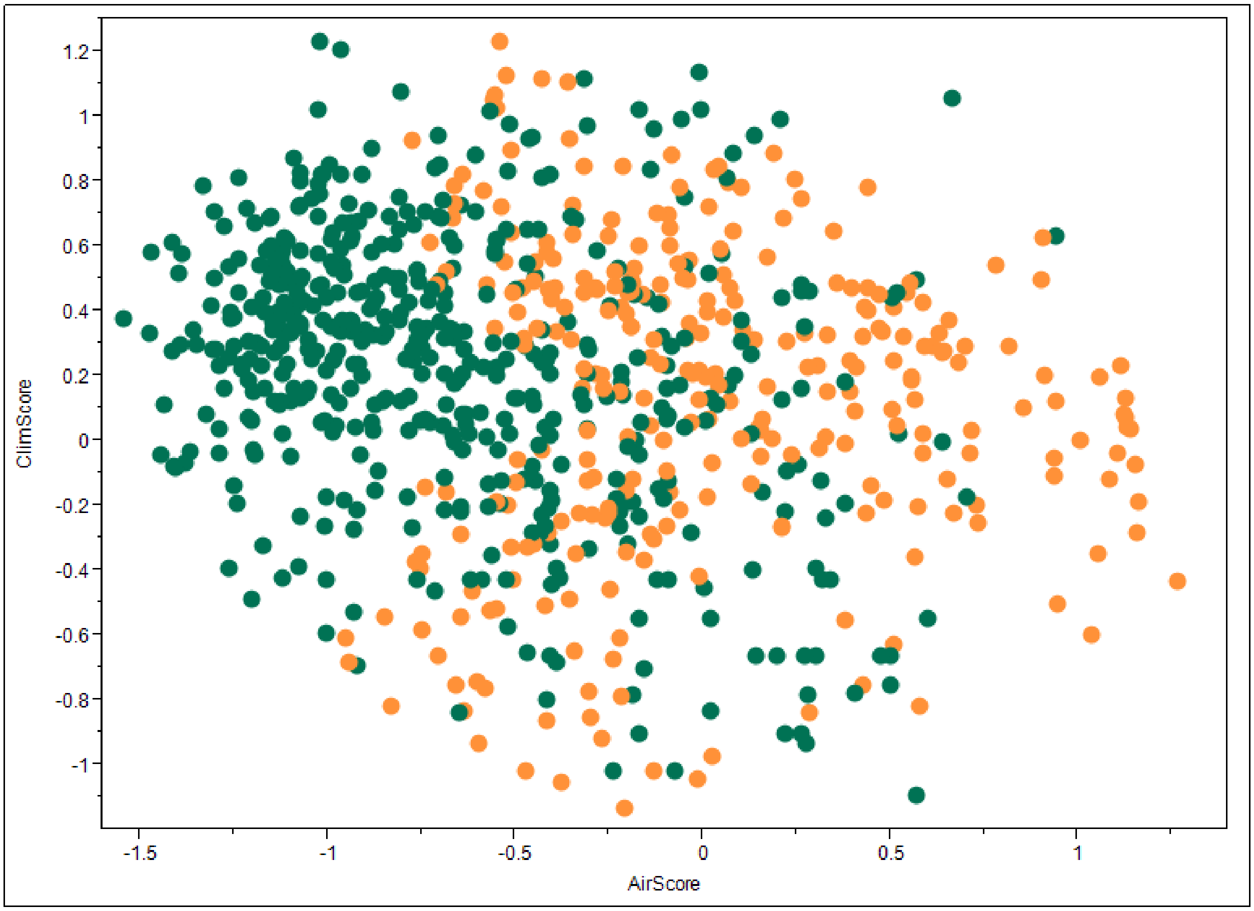


Figure 20. Position of SE Alaska air and climate scores (green) calculated using the PC-Ord NMS Scores routine, compared to scores for the wOR/WA calibration dataset (orange) used to build the gradient model. Most SE Alaska sites fell in the coolest, cleanest quadrant of the ordination.

SO2/acidity

Lichen community based responses to SO_2/acidity, i.e., calculated from a comparison of the percentage of SO_2 sensitive species at the study sites to ranges observed among TNF and FIA reference sites in SE Alaska, are reported in Tables 7 and 8. SO_2-sensitive lichens comprised 44 to 92% of the lichen community at all 147 reference sites, with the exception of 4 conifer sites with 20 to 30% sensitive species. Of these, Camp Polk inlet on Prince of Wales Island and Woodpecker Cove on Mitkof Island may not be background sites due to boat traffic. The other two, at Dry Pass on Chichagof Island and Old Tom's Creek on Prince of Wales Island had no observable local emissions sources. All Skagway sites except the site near the city incinerator and the site at Icy Lake, were rated either possibly or probably impacted. Of these, at least one site at Icy Junction, Upper Dewey, Dewey 1360, Lower Dewy, and Sturgill's were rated as probably impacted. Within KLGO, one of the Dyea sites and the Glacier Gorge site were rated as possibly impacted. Outside of the Skagway/KLGO area, only two sites were flagged as possibly impacted: Indian River in SITK and Salmon Creek in TAFT. Unlike air scores for N deposition, there were no published comparison data from wOR/WA.

Table 7. Distribution quantiles and statistics for the percentage of SO_2-sensitive species among 369 reference hardwood and conifer FIA and TNF plots in SE Alaska. These distributions were used to assess percentages observed at study sites. Percentages below 2.5% quantiles were considered 'probably impacted' and represent a threshold lichen community response to sulfur deposition in SEAK (highlighted). Percentages in the 2.5-10% quantile ranges were considered 'possibly impacted' to allow for measurement error. See also Table 8.

		Percentage of Rated Species that are SO_2 Sensitive	
Quantile	**Statistic**	**Conifer Plots (n = 92)**	**Hardwood Plots (n = 55)**
100.00%	maximum	90.9	92.3
99.50%		90.9	92.3
97.50%		87.5	92.1
90.00%		78.4	81.3
75.00%	quartile	70.0	77.8
50.00%	median	60.0	70.0
25.00%	quartile	54.5	61.1
10.00%		45.9	54.0
2.50%		23.2	45.2
0.50%		20.0	44.4
0.00%	minimum	20.0	44.4
	Mean	61.4	69.2
	Std Dev	13.5	11.1
	Std Err Mean	1.4	1.5
	Upper 95% Mean	64.2	72.1
	Lower 95% Mean	58.6	66.2

Table 8. Percentages of species that are SO_2-sensitive at study sites, sorted from highest to lowest. Percentages at study sites were compared to distributions of the percentage of SO_2-sensitive species among reference hardwood and conifer plots in SE Alaska from the FIA and TNF datasets (Table 5). Potentially impacted sites are highlighted.

Area	Site	year	HW?	number of rated species	Pct Rated Spp that are sensitive	reference plots quantile	Interpretation
SITK	Indian River HR20	2009	1	10	80	75 to 90	No impact
GLBA	Bartlett Cove	2008	0	10	80	90 to 97.5	No impact
TAFT	Sanford Cove	2011	0	9	77.8	75 to 90	No impact
GLBA	Bartlett Cove	2008	0	9	77.8	75 to 90	No impact
GLBA	Bartlett Cove	2009	0	15	66.7	50 to 75	No impact
GLBA	Blue Mouse Cove	2008	1	14	64.3	25 to 50	No impact
KLGO	Chilkoot Trail 1999	2000	1	11	63.6	25 to 50	No impact
KLGO	Chilkoot Trail 2008	2008	0	18	61.1	50 to 75	No impact
GLBA	Blue Mouse Cove	2009	1	18	61.1	25 to 50	No impact
KLGO	Dyea 1999	2000	0	15	60	50 to 75	No impact
KLGO	Dyea 2008	2008	0	17	58.8	25 to 50	No impact
GLBA	Blue Mouse Cove	2008	1	17	58.8	10 to 25	No impact
KLGO	Chilkoot Trail 2008	2008	1	14	57.1	10 to 25	No impact
Skagway	Incinerator	2009	1	20	55	10 to 25	No impact
Skagway	Ice Lake	2009	0	15	53.3	10 to 25	No impact
Skagway	Lost Lake	2009	1	19	52.6	2.5 to 10	Possible impact
Skagway	Dewey 1480	2008	1	17	47.1	2.5 to 10	Possible impact
Skagway	Icy Junction	2008	0	9	44.4	2.5 to 10	Possible impact
KLGO	Dyea 2008	2008	1	18	44.4	0 to 2.5	Probable impact
Skagway	Sturgill's	2008	1	12	41.7	<0	Probable impact
Skagway	Lower Dewey	2008	1	17	41.2	<0	Probable impact
Skagway	Sturgill's	2008	1	10	40	<0	Probable impact
Skagway	Dewey 1360	2008	1	16	37.5	<0	Probable impact
TAFT	Salmon Creek	2003	0	11	36.4	2.5 to 10	Possible impact
SITK	Indian River	2008	1	11	36.4	<0	Probable impact
Skagway	Dewey 1700	2008	1	9	33.3	<0	Probable impact
Skagway	Lower Dewey	2008	0	15	33.3	2.5 to 10	Possible impact
Skagway	Icy Junction	2008	1	16	25	<0	Probable impact
KLGO	Glacier Gorge	2009	0	12	25	2.5 to 10	Possible impact

TNF and FIA Reference Sites

Nutrient N. The mean air score for TNF hardwood reference sites was -0.35 (SD=0.39); for conifer reference sites it was -0.84 (SD=0.39). See also Table 7. Air scores are unitless, being the relative distance along the pollution axis in the NMS ordination for the wOR/WA calibration dataset. Only 24 of the 372 SE Alaska sites scored at or above the threshold range (0.02 to 0.21) established for wOR/WA. Of these, 14 were beach fringe plots with a strong hardwood component subject to nutrient rich sea spray, four were in Aeolian glacial dust affected sites along the Stikine or Unuk rivers, three had no associated habitat data, and three had high scores with no apparent explanation. These results provide a reminder that nutrient enrichment can originate from natural as well as anthropogenic sources. Both FIA and TNF air score distributions are provided in Table 7. Because the TNF dataset is larger, included more plots close to salt water in habitats similar to many of the study sites, and had a wider range of high and low air scores, it was considered more representative of reference sites in SE Alaska. Air scores at study sites exceeding TNF 90 and 97.5% quantiles, were flagged as ‘possibly’ or ‘probably’ impacted, respectively. The TNF 97.5% quantile air scores, i.e., 0.265 for conifer plots and 0.514 for hardwood plots, could be considered threshold lichen community responses for calculations of nutrient nitrogen deposition critical loads in Southeast Alaska.

SO_2/acidity. The mean percentage of species rated SO_2-sensitive for all hardwood reference sites (combining FIA and TNF plots) was 69.1 (SD=11.0). The mean for conifer plots was 61.4 (SD=13.5). Distribution statistics are presented in Table 8. Ranges observed in this 147-plot reference dataset were considered to be representative of expected ranges among clean sites for SE Alaska. Study sites with fewer sensitive species than 97.5% or more of reference sites were considered likely to be adversely affected by SO_2 or acidic deposition, those with fewer sensitive species than 90% of reference plots were considered ‘possibly impacted’, to allow for measurement error. Thus lichen communities consisting of fewer than 23.2% and 45.2% SO2-sensitive species for conifer plots for hardwood plots, respectively, could be considered threshold lichen community responses for calculations of SO_2 critical levels or sulfur-related acidity critical loads in Southeast Alaska.

Glacier Bay National Park and Preserve

Nutrient N. Air scores at GLBA were very close to mean scores for the TNF plots (compared to the relevant hardwood or conifer reference set). Both Blue Mouse Cove plots had a hardwood component and mean air score was -0.34 (SD=0.13). Both Bartlett Cove plots were in conifer stands, mean air score was -0.88 (SD=0.18). Thus there was no evidence of any detrimental effect of N-based air pollutants at these sites.

SO_2/acidity. The percentage of SO_2-sensitive species at all GLBA sites fell within ranges observed in the cleanest 90% of TNF reference sites. Thus there was no evidence of any detrimental effect of SO_2 or acidity at these sites.

Klondike Gold Rush National Historical Park

Nutrient N. Air scores at KLGO differed among sites. Air scores at Chilkoot Trail and Glacier Gorge ranged between -0.67 and -0.34 for both hardwood and conifer sites, below the wOR/WA response threshold range, and within ranges observed among TNF reference sites. Air scores at the Dyea hardwood plot in 2008 was 0.26, exceeding the 0.02 to 0.21 air score threshold range established for wOR/WA, and the air score for the conifer plot was -0.05, very close to the 0.02 threshold. Air scores at these plots fell in the 90 to 97.5% quantiles for the reference TNF sites, which generated a rating of 'possibly impacted'. Therefore community composition at both Dyea sites appears to indicate some degree of nutrient enrichment. The 1999 Dyea plot was in a conifer stand and scored -0.25, which is below the wOR/WA threshold response and within the 75 to 90% quantile range for TNF conifer plots. In general a 10% change along the gradient length is needed to see an effect beyond that attributable to observer error (Geiser and Neitlich 2007). Ten percent of the distance would be (1.504 minus -1.364)/10 or 0.29 units. The difference between the 1998 and 2009 conifer plot air scores at Dyea was 0.20 units. So there is no evidence that Dyea has become more polluted from N-containing deposition since 1999 based on lichen community composition trends.

SO_2/acidity. At the 2008 hardwood Dyea site, 44% of the rated species were SO_2 sensitive. This score falls in the 0 to 2.5% range (probably impacted) for TNF reference hardwood sites. Glacier Gorge, with 25% SO_2-sensitive species fell in the 2.5 to 10% quantile (possibly impacted) for the TNF reference conifer sites. There was no evidence of detrimental SO_2 effects on the other two Dyea nor any of the Chilkoot Trail sites. Regarding trends, in 1999, the percentage of SO_2-sensitive species at the Chilkoot Trail hardwood site was 64%, and in 2008 it was 57%. In 1999 the percentage of SO_2-sensitive species at the Dyea conifer site was 60%, and in 2008 it was 59%. Because the within-site differences and the total number of measurements (n=4) were small, there is insufficient statistical power to demonstrate an improvement (matched pairs t-test; p<t=0.19), however it is quite unlikely that a decline has occurred (p>t=0.81).

Skagway

Nutrient N. Air scores at Skagway also varied among sites. All plots along the Dewey Lake Trail at 1360, 1480 and 1700 feet had a hardwood component and scored -0.73, -0.01 and -0.73, respectively. The middle elevation score is close but did not exceed the lower end of the threshold range (0.02). This site was more exposed than the other two, having a clear view of the harbor below. The smell of diesel exhaust was also noted here by the field observers. Air scores at hardwood plots at Icy Junction, Icy Lake, the incinerator, and Lost Lake ranged from -0.69 to -0.32, on the clean side of the TNF hardwood reference plots mean. There was one conifer plot in this group, at Icy Junction; the air score there was -0.78, close to the TNF conifer reference plots mean. Sturgill's Landing was evidently supporting the fewest eutrophic lichens among the Skagway sites, with hardwood plot air scores of -1.1 to -0.70, well below one standard deviation of the TNF hardwood plot mean. The Lower Dewey conifer site scored -0.61 and the hardwood site -0.17, also below the threshold response range and within one standard deviation above mean scores for TNF conifer and hardwood reference sites, respectively. Therefore, with the possible exception of Dewey Lake trail at 1480 feet, there is no evidence among the Skagway sites to suggest that lichen community composition has shifted to favor eutrophic lichens that are usually associated with nutrient enriched environments.

SO_2/acidity. Results for this analysis were much different than those for nutrient N. All sites were flagged for possible or probable SO_2/acidity impact except Icy Lake and the incinerator site (See

Table 7). Conifer sites at Lower Dewey, and Icy Junction, as well as hardwood sites at Dewey 1480, and Lost Lake, fell in the 2.5 to 10% quantiles for TNF reference sites, flagging them as possibly impacted. Of the 55 reference TNF hardwood sites, none had fewer than 45% sensitive species, therefore hardwood sites at Lower Dewey, Dewey 1700, Dewey1360, Sturgill's sites, and Icy Junction, all with only 25 to 42% sensitive species, supported fewer sensitive species than all of the hardwood reference sites and were flagged as probably impacted.

Sitka National Historical Park

Nutrient N. The air score at the Indian River Trail hardwood plot surveyed by Heather Root (HR20) was the best among all 30 sites in the study area, and beyond the 10% interpolation at the low end of the gradient used as a cut-off for non-flagged sites. It is about 1.5 km north of SITK. The other Indian River area plot (IR) lies in a forest inside SITK, bordering saltwater just outside Sitka's Crescent Bay boat harbor. It also had a hardwood component but received an air score of -0.16, below the PNW threshold range and well within TNF reference site ranges. In sum, there is no evidence of air pollution impacts from enhanced nutrient deposition on lichen communities at either study site in or near SITK.

SO_2/acidity. A similar dichotomy in scores as observed in Skagway was noticed with regard to the percentage of SO_2-sensitive species comprising lichen communities. The HR20 site, with 80% sensitive species, fell in the 75 to 90% quantile for TNF reference sites, i.e., among the 'cleanest' 25% of plots. At the IR plot, only 36% of species were rated sensitive (fewer than any of the reference TNF hardwood sites) flagging it as probably impacted.

Tracy Arm-Fords Terror Wilderness

Nutrient N. Air scores at the Bushy Island, Salmon Creek, Sanford Cove, and Williams Cove (all conifer) plots in TAFT received among the best air scores in the study area, ranging from -0.96 to -1.29. These scores range to about one standard deviation below the mean for TNF conifer reference plots. Therefore there is no evidence of air pollution impacts from enhanced nutrient deposition on lichen communities at these sites. In contrast, the air score at Sawyer Island was 0.52, the highest score among the 30 plots in the study area. The lichen community had a significant component of eutrophic (or nitrogen-loving) species including *Candelaria concolor*, *Parmelia sulcata*, *Xanthoria polycarpa*, and a second *Xanthoria* species. The air score exceeded both wOR/WA thresholds and 97.5% quantiles for TNF reference sites and therefore was rated "probably impacted."

SO_2/acidity. There were enough rated species to score two TAFT sites: Salmon Creek and Sanford Cove. Of these, Sanford Cove, with 78% SO_2 sensitive species, was well within the TNF reference site range. Salmon Creek, a conifer plot at the entranceway to Tracy Arm, with 36% SO_2-sensitive species, fell within the 2.5 to 10% quantile for reference TNF conifer sites, and therefore was flagged as possibly impacted.

Correlations between Lichen Community Results and other Measures of Deposition

Nitrogen-containing Air Pollutants

Lichen community based air scores correlated best with wet deposition of nitrogen compounds at open and throughfall sites, excluding throughfall nitrate; r >0.70 (Table 9). As discussed later, significant amounts of nitrate in low N deposition areas like SE Alaska can be absorbed by the tree canopy. Elemental N concentrations in lichens were most strongly correlated with open-site wet deposition of nitrogen compounds and with N concentrations in other lichen species; r>0.93). Neither of the lichen-based measurements correlated very well with ambient air concentrations of NO_x, NH_3 or HNO_3, which was not surprising given the interaction of these pollutants with seasonal climates. Air scores were only poorly correlated with lichen N concentrations, as lichen N concentrations increased with N deposition regardless of S deposition, but air scores did not increase at sites that had both high N and high S deposition or high SO_2 concentrations. The variable most strongly correlated with all other variables was open deposition of inorganic N (mean |r|=0.85).

Table 9. Pearson's product-moment correlations for pair-wise comparisons of measures of N-containing pollutants. Strongest correlations (|r|>0.7) are highlighted.

	Open N:NH_4	TF N:NH_4	Open N:NO_3	TF N:NO_3	Open Inorg N	TF Inorg N	NO_2	NO_x	NH_3	HNO_3	Air Score	Hypo N	Plagla N
Open N:NH_4		0.90	0.89	0.94	0.99	0.90	0.81	0.82	-0.89	0.97	0.71	0.98	0.99
TF N:NH_4	0.90		0.98	0.17	0.94	0.99	-0.59	-0.54	0.09	-0.20	0.71	-0.36	0.35
Open N:NO_3	0.89	0.98		0.99	0.94	0.98	0.97	0.97	-0.67	0.81	0.73	0.98	0.93
TF N:NO_3	0.94	0.17	0.99		0.97	0.30	-0.55	-0.50	0.23	-0.54	0.33	0.77	0.51
Open Inorg N	0.99	0.94	0.94	0.97		0.94	0.83	0.83	-0.88	0.96	0.73	0.99	0.99
TF Inorg N	0.90	0.99	0.98	0.30	0.94		-0.60	-0.55	0.10	-0.22	0.74	0.14	0.41
NO_2	0.81	-0.59	0.97	-0.55	0.83	-0.60		1.00	0.02	0.59	0.15	0.62	-0.04
NO_x	0.82	-0.54	0.97	-0.50	0.83	-0.55	1.00		0.02	0.60	0.15	0.67	-0.01
NH_3	-0.89	0.09	-0.67	0.23	-0.88	0.10	0.02	0.02		-0.60	0.23	-0.19	-0.49
HNO_3	0.97	-0.20	0.81	-0.54	0.96	-0.22	0.59	0.60	-0.60		0.35	0.56	-0.07
Air Score	0.71	0.71	0.73	0.33	0.73	0.74	0.15	0.15	0.23	0.35		0.23	0.21
Hypo N	0.98	-0.36	0.98	0.77	0.99	0.14	0.62	0.67	-0.19	0.56	0.23		0.93
Plagla N	0.99	0.35	0.93	0.51	0.99	0.41	-0.04	-0.01	-0.49	-0.07	0.21	0.93	
mean |r|	0.83	0.52	0.83	0.52	0.85	0.53	0.52	0.51	0.34	0.50	0.40	0.57	0.46

Abbreviations: Open and throughfall (TF) measurements are 2008-2009 means in kg N/ha/100 days; **NO_2, NO_x** = 2008-2009 seasonal averages in ppb; **NH_3, HNO_3** = 2008-2009 seasonal averages in µg/m3; Air score = lichen community based air score; **Hypo N** = mean dry weight concentrations (%) of N in *Hypogymnia enteromorpha* and *H. imshaugii* calculated by averaging lab replicates, then field replicates, then years (2008-2009), and finally species. Data from *Hypogymnia* species were combined because prior analysis of TNF data showed no difference in elemental profiles between these species (Dillman et al. 2007); **Plagla N** = mean dry weight concentrations (%) of N in *Platismatia glauca*, calculated as for *Hypogymnia*.

Sulfur-containing Air Pollutants

The percentage of the lichen community comprised by SO_2-sensitive species was moderately to strongly negatively correlated (|r| >0.55) with nearly all measures of sulfur-containing air pollutants: ambient air concentrations of sulfur dioxide, total deposition of sulfur in open and canopy throughfall, and concentrations of sulfur in *Hypogymnia* species (Table 10). *Platismatia glauca* was moderately to strongly correlated (|r| >0. 50) with all other measures of S-containing pollutants except the percentage of SO_2-sensitive species. Overall, the variables most strongly correlated to all other variables (mean |r| > 0.90) were ambient seasonal SO_2 concentrations and sulfur concentration in *Hypogymnia* species. A critical level of sulfur dioxide can be estimated by quantifying the relationship between summer SO_2 concentrations and lichen community response (Figure 21; equation 1).

Equation 1:

$$y = 61.779x^{-0.279}$$

where x = mean summertime SO_2 in ug/3 and y =the lichen community response. For this CL, the lichen community response is the percentage of the rated species on the plot that are rated sensitive to SO_2 (adversely affected by SO_2 levels between 5-15 ppb, see McCune and Geiser 2009, Table 2) and at least nine rated species are present.

At the threshold for hardwood plots (y = 45.2%) the critical level would be 33.5 ug/m3 (12.5 ppb at standard temperature and pressure (STP); at the threshold for conifer plots (y =23.2%), the critical level would be about 3.1 ug/m3 (~ 1.1 ppb at STP). This range is similar to the 5-15 ppb range for sensitive species in McCune and Geiser 2009. Although the hardwood critical level of 1.1 ppb is rather low, this value is still about ten times higher than background levels of SO_2. Because the fit to the datapoints is strongly influenced by the lone anchor point at 8 ug/m3, the fitting equation strongly influences the conifer CL. For example a natural log transformation of y = -15.82ln(x) + 64.031, yields the same regression coefficient for the fit (r^2=0.91) but produces a CL of 1.2 ppb for stands with a hardwood component and 13.3 ppb for conifer only stands. Thus we consider 1.1 to 13.3 ppb to be a reasonable range for critical levels of SO_2 in southeastern Alaska.

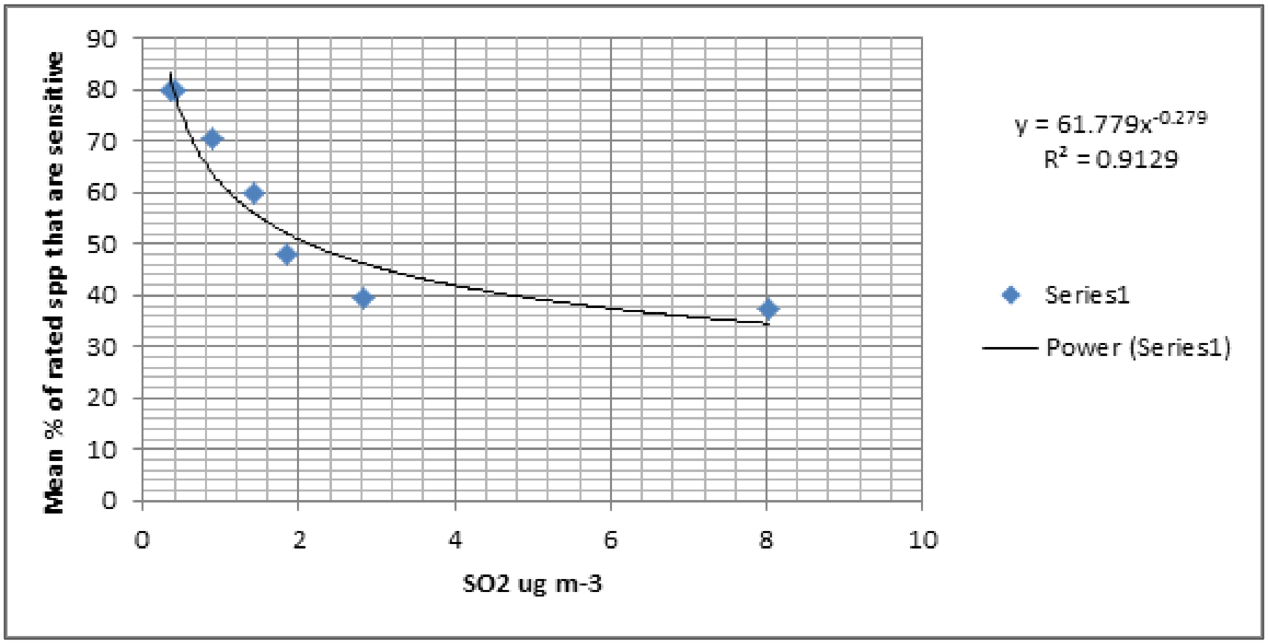


Figure 21. The relationship between summertime SO2 concentrations in SEAK and lichen community response as the mean percentage SO_2 sensitive species comprising the lichen community. The regression equation can be used to estimate the critical level of SO2 at any threshold for community response.

Table 10. Pearson's product-moment correlations for pair-wise comparisons of measures of S-containing pollutants. Strongest correlations (|r| >0.7) are highlighted.

	Open S:SO_4	**TF S:SO_4**	**SO_2**	**Hypo S**	**Plagla S**	**SO_2-sensitive spp**
Open S:SO_4		0.62	1.00	0.99	0.99	-0.56
TF S:SO_4	0.62		0.98	0.98	0.50	-0.77
SO_2	1.00	0.98		0.99	0.70	-0.66
Hypo S	0.99	0.98	0.99		0.85	-0.71
Plagla S	0.99	0.50	0.70	0.85		-0.24
SO_2-sensitive spp	-0.56	-0.77	-0.66	-0.71	-0.24	
mean |r|	0.79	0.84	0.91	0.92	0.66	0.59

Abbreviations: **S:SO_4** = mean summertime sulfur deposition in kg S /ha/100 days for 2008- 2009 at open and throughfall (TF) sites; **SO_2** = mean summertime average of sulfur dioxide in (µg/m3) for 2008-2009; **Hypo S** = mean dry weight %S in *Hypogymnia enterormorpha* and *H. imshaugii* after averaging lab replicates, then field replicates, then years (2008-2009), and finally species. Data from *Hypogymnia* species were combined because prior analysis of TNF data showed no difference in elemental profiles between these species (Dillman et al. 2007); **Plagla S**: Mean dry-weight % S in *Platismatia glauca*, mean calculated as for *Hypogymnia*. **SO_2-sensitive spp**: mean percentage of rated species that were SO_2-sensitive in 2008-2009; **mean |r|:** the mean of the absolute values of the Pearson's correlation coefficients across all measures of S-containing pollutants.

Comparison of Measures of Nitrogen- and Sulfur-containing Air Pollutants with Lichen Community Effects across Study Sites.

Nitrogen-containing Air Pollutants

Study sites with data for open total inorganic N deposition (the variable with strongest correlations to other measures of N-containing pollutants) were sorted by increasing deposition (Table 11). From this table, it is possible to see how the different measures of N-containing pollutants can be integrated to evaluate air quality at a site. For example, the highest levels of deposition, lichen N and poorest air scores all occurred at Sawyer Island, providing a weight of evidence of nutrient N-enrichment at this site. Similarly elevated levels of NO_2 and NO_x at Lower Dewey relative to Dyea and Dewey 1700 were accompanied by a moderate increase in N deposition, HNO_3 concentrations, and lichen N, though these latter measurements were not considered elevated relative to reference regions or sites. Highest levels of HNO_3, SO_2, SO_4^{2-} (see Table 12), all measures correlated with acidity also occurred at Lower Dewey, but Lower Dewey air scores were not elevated, consistent with the known sensitivity of eutrophs to acidic deposition.

Table 11. Comparison of 2008-2009 means for N measures at open sites with measurements of N deposition in bulk precipitation, sorted by increasing deposition. Elevated values are highlighted.

Site	Open Inorg N	Open N:NH_4	Open N:NO_3	NO_2	NO_x	NH_3	HNO_3	Plagla N	Hypo N	Air Score
Dewey 1700	0.10	0.04	0.06	3.5	14.2	10.4	1.5	0.59	0.68	-0.43
Dyea 2008	0.15	0.09	0.06	3.0	12.2	5.2	4.0	0.62	0.72	0.11
Lower Dewey	0.19	0.12	0.07	13.4	55.0	6.1	4.4	0.69	0.78	-0.39
Sawyer Island	0.32	0.20	0.13					0.82		0.52

Abbreviations: **Open** Inorg **N, N:NH_4, N:NO_3** = mean deposition of N compounds in summers in kg N/ha/100 days. **NO_2, NO_x** = mean seasonal concentrations in ppb; **NH_3, HNO_3** = mean seasonal concentrations in µg/m3; **Plagla N** = mean dry weight concentration (%) of elemental N in the lichen *Platismatia glauca* (averaging lab replicates, followed by field replicates, then year); **Hypo N** = mean dry weight concentration (%) of elemental S in the lichens *Hypogymnia enteromorpha* and *H. imshaugii*, calculated as for Pl glauca, averaging species last. **Air Score** = lichen community based air score indicating nutrient N deposition. Air scores from hardwood and conifer plots were averaged because separating them did not alter air score order or the plots flagged for elevated scores. **Bold-faced** values exceeded clean site ranges for rural California (NO_2, NO_x), TNF elemental analysis thresholds (Plagla N) or wOR/WA/ TNF ranges associated with no detrimental effect to lichen community composition (Air Score).

Sulfur-containing Air Pollutants

All study sites with SO_2 measurements (the variable, together with %S in *Hypogymnia*, which had the strongest correlations to other measures of S-containing pollutants) were sorted by increasing SO_2 concentrations (Table 12). As SO_2 increased from Bartlett Cove to Lower Dewey, other measures of S also increased and the percentage of SO_2-sensitive species decreased. At Lower Dewey, all six measures exceeded expected ranges for references areas/sites, providing convincing evidence of enhanced SO_2 and S deposition accompanied by an adverse biological effect (absence of SO_2 sensitive lichens) at this site. Multiple measures exceeding reference levels were also detected at Dewey 1700 and Sturgill's, lending a weight of evidence for enhanced deposition and adverse lichen community effects at these sites as well.

Table 12. Comparison of S measures of 2008-2009 means at sites where SO_2 was measured, sorted by increasing SO2. Elevated values are highlighted.

Site	# con plots	# hdw plots	SO_2	TF S:SO_4	Plagla S	Hypo S	SO_2-sensitive spp CON	SO_2-sensitive spp HWD
Bartlett Cove	3		0.35	1.14	0.077	0.070	74.8	
Indian River		2	0.43	1.12	0.076			58.2
Chilkoot Trail	1	1	0.90	0.43	0.063	0.068	61.1	57.1
Dyea 2008	1	1	1.41	1.23	0.065	0.070	58.8	44.4
Dewey 1700		1	1.85		0.069	0.076		39.3
Sturgills		2	2.83	3.34	0.059	0.082		40.85
Lower Dewey	1	1	8.02	7.31	0.099	0.130	33.3	41.2

Abbreviations: **# con plots, # hwd plots =** number of conifer and hardwood plots, respectively with useable lichen survey data (i.e., at least 9 species with SO_2-sensitivity ratings; **SO_2**= mean seasonal concentrations in µg/m3; **Plagla S** = mean dry weight concentration (%) of elemental S in the lichen *Platismatia glauca* (averaging lab replicates, followed by field replicates, then year); **Hypo S** = mean dry weight concentration (%) of elemental S in the lichens *Hypogymnia enteromorpha* and *H. imshaugii*, calculated as for *P. glauca*, averaging species last. **SO_2-sensitive spp CON and HWD** = Percentage of rated species that are SO_2 sensitive, expected to decrease with increasing levels of SO_2 and acidic deposition, in conifer and hardwood plots, respectively. **Bold-faced** values exceeded clean site ranges for rural California (NO_2, NOx), TNF elemental analysis thresholds (Plagla N) and wOR/WA and TNF ranges associated with no detrimental effect to lichen community composition (Air Score).

Discussion

Ambient Atmospheric Concentrations

Nitrogen Oxides

Oxides of nitrogen (NO_x and NO_2) are primary products of fossil fuel combustion. Although petroleum fuels contain some nitrogen, most N oxides form when atmospheric nitrogen gas, N_2, is oxidized to NO (and some NO_2) inside a combustion chamber. NO is further oxidized into NO_2 in the atmosphere (Finlayson-Pitts and Pitts 2000). Nitrogen dioxide occurs naturally and non-anthropogenic background levels estimated at 0.1 to 0.3 ppb for North America (US EPA 2010). Elevated levels of NO_2, and the other nitrogenous compounds, described below, can case foliar damage or alter ecosystem structure by increasing the amount of bio-available nitrogen and altering pH (Fenn et al. 2003a, Galloway et al. 2003, Krupa 2003). Lichens and lichen communities are relatively insensitive to the gases NO and NO_2 due to their low deposition velocity. However NO and NO_2 contribute to the dry deposition loads of anthropogenic bio-available nitrogen, like NH_3, NH_4^+, NO_3^-, and HNO_3 that have higher deposition velocities (Zhang et al. 2003). These five primary and secondary nitrogenous combustion products have short atmospheric residence time, generally less than one day (Finlayson-Pitts and Pitts 2000). Therefore, their presence above background levels is typically the result of local or regional sources of pollution as long-distance atmospheric transport from Eurasian sources takes at least five days (Lin et al. 2012).

Peroxyacetyl nitrate (PAN), another secondary reactive nitrogenous product of combustion, has a longer atmospheric residence time and is stable under colder conditions present in the troposphere boundary layer where long-distance transport occurs (Jaffe et al. 1997, Finlayson-Pitt and Pitts 2000). When PAN settles out of the atmosphere and warms up, it can reconstitute into NOx and other components. PAN from Eurasian sources is transported to North America (Fischer et al. 2011, Lin et al. 2012), but the amount is likely to be small. Currently, there is no evidence pointing to Eurasian PAN as an important source of nitrogenous pollution in the Pacific Northwest (Fischer et al. 2011) or Alaska, but the potential exists for Eurasian anthropogenic nitrogen (transported as PAN) to affect nitrogen-limited ecosystems.

Background levels of NO_2 and NO_x for SE Alaska are unknown. However, concentrations measured at Barrow and Bethel, AK can be considered a reference for background levels at northern latitudes. Summertime NO_2 at Barrow ranged from 0-0.009 ppb with a median of <0.001 ppb (Emmons et al., 1997, after Finlayson - Pitts and Pitts, 2000) and NO_x levels at Bethel ranged from 0.005 -0.02 ppb with a median of 0.015 (Emmons et al. 1997). When compared to these values, levels of NO_2 and NO_x at sites measured during this study were orders of magnitude higher. However, other than the Lower Dewey site, levels of NO_2 and NO_x are similar to observations from rural California (Alonso et al. 2002). At sites near the Port of Skagway (the 16th busiest cruise ship port-of-call in the world), which is situated at the head of a narrow steep fjord, NO_2 and NOx were elevated well above background levels. Peak levels were up to10 times higher and mean levels were about 8 times higher at Lower Dewey and Icy Junction when compared to sites in GLBA and SITK (Figures 10 and 11), which are the most pristine sites in the study area. NO_x levels (NO+NO_2) were also up to 10 times higher at Lower Dewey when compared to more pristine areas in GLBA. Dyea, which is only 3.6 miles from the Skagway harbor, had low levels of NO_2 and NO_x because it is at the foot of the adjacent valley. However, during the late July exposure period in 2008, elevated values of 13.3 ppb were observed. This may have been due to a strong stagnation event on a busy cruise ship day, but it is somewhat surprising that no other peaks for Dyea were observed and no concurrent associated peak in SO_2 was observed. The sites above downtown Skagway were expected to have higher levels of pollutants than sites with less exposure to emissions sources because one to five cruise ships dock in Skagway harbor each day from early May to late September. Typically, ships arrive between 5 -7 AM and depart between 9 and 10 PM. Visible haze (Figure 1) often accumulates below inversion layers in the morning, beginning at the Skagway terminal and spreading uphill and northward above the narrow (<1 mile wide) Skagway River valley. Skagway lies at the head of the Taiya Inlet, a fjord that is only 1.2 miles wide. The odor of marine HFO or bunker fuel fumes can be detected by residents, hikers on the Dewey Lake trail systems and also by visitors exploring the historic buildings in town. All cruise ships plying the waters of SE Alaska stop in Skagway for 12 to 16 hours during the day. Ship calls to the Port of Skagway declined slightly during the study from 474 in 2008 to 426 in 2009. This 11% drop in cruise ship days was not evident in any of the air quality assessments. Cruise ships traveling through GLBA do not stop in the vicinity of Bartlett Cove and the fjord is 7.5 miles wide at this location; therefore, pollutant concentrations occur at very low levels. In Sitka, the cruise ship moorings are only one mile from the park. However fewer ship calls, and the open coast usually result in emission dispersal.

The atmospheric concentration levels detected are of local interest in Skagway; however, the site and exposure period with the highest concentration of NO_2, 22.4 ppb at Lower Dewey in August of 2009, was below the US EPA's regulatory limit of 53 ppb for an average annual concentration (http://www.epa.gov/air/criteria.html#2). The annual average for any of these sites is expected to be well below the weekly averages because local marine transportation emissions sources are greatly reduced during the non-visitor season. Recently, national air quality regulations were updated (US EPA 2010) to include a 1-hour average exposure maximum of 100 ppb; however, the weekly resolution of the passive sampler data does not allow a comparison with one hour data.

Sulfur Dioxide

Long distance transport of anthropogenic sulfur, in the form of SO_2 (a primary emission product) and more commonly SO_4^{2-} (sulfate, a secondary oxidization product), across the North Pacific to SE Alaskan latitudes have been reported; particularly, during atmospheric conditions and circulation patterns that occur most commonly in spring (Tu et al. 2004, Tran et al. 2011). Although, much of the time atmospheric SO_2 is oxidized and deposited prior to its arrival in coastal Alaska, model results suggest that long range transport of SO_4^{2-} from offshore international shipping lanes, and Canadian and Asian sources results in increases in SO_4^{2-} in SE Alaska (Tran et al. 2011). Volcanic activity in Southwest Alaska also has the potential to sporadically influence atmospheric sulfur in the study area; however, was not known to occur during the sample periods. Because this study deployed passive sensors only during the summer, winter and spring time SO_2 or SO_4^{2-} was not assessed.

In remote areas, background levels of SO_2 have been reported to range between 0.0026-0.130 µg/m^3 (Bandy et al. 1993). These levels are similar to many of the observations at the more pristine sites measured during this study. At impacted sites, sulfur dioxide showed very similar spatial and temporal patterns to NO_x and NO_2. It was elevated at Lower Dewey, Dewey 1700 and at Sturgill's but not at other sites. The highest average weekly concentrations measured during the study, 21 µg/m^3, occurred in mid-June of 2008 at the Lower Dewey site. The spatial and temporal patterns detected during this study are not unexpected given the sites' proximity and exposure to cruise ship emissions and the local topography. However, a highly impacted area in southern California had average concentrations of 104 µg/m^3 in 2009 (California Air Resources Board 2011). Even the highest concentration observed during this study were below the below US EPA's prior annual average limit of 30 ppb. The US EPA's annual limit was recently revoked in favor of a 75ppb 1-hour limit (http://www.epa.gov/oaqps001/sulfurdioxide/actions.html), but the SEAN weekly average data cannot be evaluated against an hourly standard.

Ammonia and Nitric Acid

Nitric acid (HNO_3) and ammonia (NH_4) levels were elevated at different times during the sampling periods. During both years, HNO_3 levels were much higher during the first third of the sampling than during the latter part of the season and elevated levels occurred at most sites. Nitric acid is not a primary product of fuel combustion. Rather, it is produced by a sunlight driven chemical reaction between NO_x and atmospheric hydroxyl radicals. Typically, May, June and early July are the sunniest months of the year in SE Alaska. This weather pattern may explain the higher HNO_3 levels that drop off quickly as the rainy season begins. HNO_3 can be an important contributor to bio-available N due to its high deposition velocities. Levels of HNO_3 at some sites during peak exposure periods reached over 40 µg/m^3, 2 orders of magnitude above the background levels of <0.5 µg/m^3 reported for Alberta (Legge and Krupa 1989). Many sites had several exposure periods well above background levels confirming atmospheric reactions of local emission products.

Ammonia levels were variable at all sites during the early part of the 2008 season and then rose to highly elevated levels of 6-10 µg/m^3 by the latter part of the sampling period. These levels are comparable to levels measured in the Athabasca oil sands region of Canada (Bytnerowicz et al. 2010) and the western slope of Sequoia Kings Canyon National Parks downwind of a major agricultural center (Bytnerowicz et al. 2002) and are elevated above background levels of 0.26 µg/m^3 suggested for Western Canada (Krupa 2003). In 2009, early season levels were at near background levels until July when extreme spikes began occurring at most sites; only SITK remained at steady low levels throughout the sampling period. The peak ammonia levels detected late in the 2009 season, 181 µg/m^3 at Dewey 1700, (and at the other sites near Skagway) (Figure 12) were well above ambient concentrations reported elsewhere and are high enough to cause foliar damage to trees. The cause of these spikes is unknown, but local residents and the ecologist for the TNF report smelling ammonia at the Dewey 1700 site and impacts to the foliage and trunks (conchs) of mountain hemlocks near the Dewey 1700 site were apparent. (K. Dillman, pers. comm. 2008).

Possible source for the temporary, very high ammonia levels include releases from municipal or cruise ship waste-water treatment, plants, dead animals near the site (unlikely), or vandalism (also unlikely). Nitric acid levels show an opposite pattern to ammonia with high levels occurring early in the season. HNO_3 can scavenge NH_3 out of the atmosphere (Finlayson-Pitt and Pitts. 2000), which can explain the timing of the increase in NH_3 being concurrent with a drop in HNO_3. More monitoring would be required to fully understand the high spikes in ammonia.

Ambient atmospheric ammonia is not regulated by the US EPA, but is regulated by OSHA for industrial settings. OSHA maximum 8-hour exposure limit is 35,000μg/m^3, which is many orders of magnitude above the levels detected at Dewey 1700 in 2009. However, NH_3 is an important source of deposited nitrogen and has high deposition velocity. NH_3 may contribute nitrogen to the environment proximal to the emission source in greater amounts than other nitrogenous emission compounds. Gaseous ammonia can decrease (acidify) the pH of tree bark and increase available nitrogen (Sutton et al. 2009). Ammonia mediated effects on lichen communities have been documented in Europe (Otnyukova and Sekretenko 2008, Rihm et al. 2009, Sutton et al. 2009, Wolseley et al. 2009), but has not been thoroughly investigated for North America. As air quality regulations' focus on SO_x and NO_x has reduced these pollutants, potential role of ammonia in ecological effects has increased (Sutton et al. 2009).

Although atmospheric concentrations of these aerosols is an important metric and high levels can have human and ecosystem health implications, most observations (with the exception of ammonia at Dewey 1700) are below critical values. However, these ambient concentration metrics do not quantify the true exposure of target ecosystems to nitrogen and sulfur deposition. Aerosols eventually fall out of the atmosphere as dry deposition or are scavenged by precipitation (wet deposition) and are deposited on terrestrial vegetation, fresh and marine waters, and soils. Wet deposition was quantified during this study and discussed below but dry and fog water (fog is not rare in SE Alaska) deposition is difficult to measure and often not fully quantified. Depending on weather patterns, dry deposition can contribute the majority of total deposition (Fenn et al. 2003b), especially in the arid areas. The contribution of the dry component to the total deposition is unknown for SE Alaska and is likely to vary widely within the study area and between years due to a strong precipitation gradient and annual variation (Davey et al. 2007). For example mean May-Sept precipitation varies from 9.8 inches in Skagway to 29.8 inches in Sitka, and for Gustavus, July total precipitation has ranged from 2.5 inches to 11.7 inches (Table 13). The atmospheric concentration data collected during this study could be used in conjunction with meteorological data to model and estimate dry deposition. Furthermore, the amount of wet deposition is proportional to the amount of precipitation during the exposure period. An analysis assessing combined wet and dry deposition is beyond the scope of this report but is recommended to receive attention in the near future. Currently, University of Alaska, Fairbanks investigator Nicole Mölders (2011) is investigating the impact of current and future marine transportation emissions on air quality, visibility, and contaminant deposition in SE Alaska national parks and Wilderness areas under a Cooperative Agreement with the NPS Southeast Alaska Coastal Cluster.

Table 13. Monthly and seasonal mean precipitation (inches) for SEAN parks, 1949–2011. Western Regional Climate Data Center (accessed 12/27/2011).

Park Unit: Station Name		May	June	July	Aug.	Sept.	Seasonal Totals
GLBA: Gustavus 2SW	Mean (N=22)	2.81	2.50	3.79	4.86	7.12	21.08
	2008	2.63	1.66	7.43	4.14	8.98	24.84
	2009	1.77	1.50	1.87	9.28	6.23	20.65
	Min	0.40	0.78	1.05	0.68	2.48	NA
	Max	6.56	6.10	7.43	11.58	11.72	NA
SITK: FAA Japonski AP	Mean (N=52)	4.42	3.22	4.29	6.86	11.02	29.81
	2008	3.11	1.78	6.54	4.79	14.00	30.22
	2009	1.94	1.75	0.80	9.73	9.43	23.65
	Min	1.15	0.51	0.80	1.72	3.94	NA
	Max	10.04	8.12	12.27	19.51	20.75	NA
KLGO: Skagway 2	Mean (N=14)	1.30	1.11	1.19	2.19	4.04	9.83
	2008	1.66	0.82	2.33	2.51	3.90	11.22
	2009	0.41	0.22	0.12	4.29	5.34	10.38
	Min	0.24	0.22	0.12	0.65	0.58	NA
	Max	3.57	2.58	3.79	4.30	9.54	NA

Note that records were not available at all sites for the full time period 1949–2011.

Wet Deposition

Wet deposition of nitrogen as nitrate (NO_3^-) and ammonium (NH_4^+), and sulfur as sulfate (SO_4^{2-}) has been monitored by NADP/NTN since 1978. Initially, monitoring occurred at 21 sites located in urban areas as a means to monitor acidic precipitation and the effect of regulations designed to curb its anthropogenic precursors. The national network program has grown, as of 2010, 243 sites were operational with four sites in Alaska. The NTN site most relevant to this study (AK02) has been operating since 2004 and is located near Juneau in Auke Bay, on the University of Alaska Southeast Campus. The site is about 14 miles from the cruise ship docks in downtown Juneau. It is assumed the precipitation collected at the Auke Bay site is generally not impacted by local emission sources; it is far enough from the cruise ship docks in downtown Juneau that a cruise ship signal was not detected. The site operators have had challenges keeping the precipitation collector running during the winter and in 2010 moved the station to a site with commercial power. Although winter precipitation was not collected following full NTN protocols, it was collected in ‘bulk’ mode and analyzed. The raw precipitation chemistry data for the winters of 2008-2009 is available from the NTN program if specifically requested but is not served in the NADP website. Because an NADP style wet deposition collector is very labor intensive, requires commercial power, and expensive, weekly lab work, SEAN deployed resin tube deposition monitors during the cruise ship seasons of 2008 and 2009.

The wet deposition values for total inorganic N detected during this study are among the lowest in North America; Fenn et al. (2003b) present results from eight sites in the Pacific Northwest averaging 1.6 kg N/ha/yr and consider these as relatively low pollution sites compared to some other regions of the U.S. Bulk N deposition inputs reported in this study are 3 to 25 times lower than the reported wet deposition value of 1.6 kg N/ha/yr (Fenn et al. 2003b). For both NO_3^- and NH_4^+, higher rates of deposition were reported for 2008 compared to 2009 (Appendix G). The increase in nitrogen deposition does match the change in cruise ships visits which fell slightly in Skagway between 2008 and 2009 with 474 calls in 2008 and 426 calls in 2009, a drop of 11%. However, the differences in N deposition between the two years are more likely due to differences in the amount, timing and intensity of precipitation. Table 13 shows there was more precipitation in 2008 than 2009. For SITK there was 28%, Gustavus (up-bay precipitation at Blue Mouse Cove and Tarr Inlet are unknown) 20%, and Skagway 8% more precipitation in 2008 than in 2009. Thus the higher volume of precipitation in 2008 explains some of the difference in wet deposition between the two years. Although this difference between years is visible in the figures 15-19, these inter-annual fluctuations do not represent a categorical difference between years but show that inter-annual variation is a function of precipitation variability between years. (M. Fenn, pers. comm. 2011). Summer time precipitation is the driving co-variable for wet deposition, especially in southeast Alaska's wet maritime climate.

Critical loads are an important tool used by ecologists and increasingly by regulators to understand an ecosystem's resilience to various deposited pollutants. A critical load is the amount of a pollutant below which damaging effects on sensitive ecosystem components are not observed, according to present knowledge (Grennfelt et al. 2001). For terrestrial ecosystems, lichen communities are often the ecosystem component used to determine the critical load, particularly during the initial phases of N deposition effects. Setting the stage for monitoring lichen communities for changes in species composition was one of the objectives of this project. However, changes cannot be quantified until plots are revisited, a task tentatively scheduled for 2018 and 2019. Critical loads for nitrogen deposition in forests of the Pacific Northwest have been developed (Geiser et al. 2010). The level of nitrogen deposition lichen communities can tolerate is highly dependent on precipitation, thus critical loads for the Pacific Northwest forests vary from 2.7 kg N/ha/yr for dry forest types to 9.2 kg N/ha/yr for wet forest types. Wet deposition levels are well below both these levels for all the samplers deployed during this study. However, as discussed above, dry deposition has not been quantified and an untested assumption of this study's design is that most deposition of anthropogenic pollutants occurs during the cruise ship season. The potential for long-range transport of combustion products is higher during the spring (Tu et al. 2004, Lin et al. 2012), so this assumption needs to be tested. The lichen community response, quantified as air scores along a nutrient nitrogen gradient, was only convincingly elevated, relative to TNF reference sites at Sawyer Island. Because this site is also nesting habitat for bald eagles, ravens, and possibly seagulls, it is possible that some of the nutrient N related shift in lichen species can be explained by ammonia released from bird droppings. On the other hand, there was good evidence for enhanced lichen thallus concentrations and enhanced depositional S and N at Lower Dewey. The absence of an elevated air score at this site could be attributed to SO2 or acidic deposition as many eutrophs are sensitive to these pollutants.

Where possible, pairs of passive deposition monitoring arrays were deployed in open and closed canopy sites to account for the canopy's effect on atmospheric deposition fluxes. The results show the forest canopy removes much of the nitrate present in rainwater. Lichens get most of their nutrients from rainwater, and high lichen biomass may be absorbing this essential nutrient from precipitation before it reaches the collectors. This hypothesis is supported by comparison of the relationship between lichen elemental N and canopy throughfall inorganic nitrogen by Root et al. (2013; Figure 3 A,C,D), across 84 sampling locations in the western US and Canada, including the passive samplers in this study, showed that the SEAK lichens had more nitrogen than expected for the amount of canopy throughfall. A similar preference for efficient canopy uptake of nitrate compared to ammonium has also been observed in throughfall studies in three national parks in Washington state (Fenn et al. 2013) and in the Wind River Experimental Forest in the Gifford Pinchot National Forest in south central Washington (Klopatek et al. 2006). In the present study, ammonium was slightly higher in throughfall than in bulk deposition in most instances (Figure 15), suggesting that ammonium accumulates in the canopy and that a significant fraction is then washed out during rain events. Sulfate levels during this study were much higher at throughfall collectors than at open sites (Figure 19, Appendix G). Sulfate levels at the throughfall sampling sites near the Skagway marine terminal (Lower Dewey and Sturgill's) were also much higher than sites distant from stationary emission sources. Many studies have shown that sulfate deposited to canopies during fog events or as dry deposition is effectively washed from the canopy as throughfall, while 30-40% or more of atmospherically-deposited nitrate and ammonium are retained within the canopy and not removed by precipitation (Fenn et al. 1997). However in this study and the studies cited above from Washington, up to 90% of atmospheric nitrate can be retained in the canopy.

Elemental Concentrations in Lichen Tissue

Lichens have been used as integrators of environmental contaminants and sentinels of ecological change for several decades and at numerous sites around the world (Nimis et al. 2002). The USDA Forest Service has been using elemental concentration in lichen tissue on the TNF and in National Forest in the Pacific Northwest since the 1990s (Geiser 2004, Dillman et al. 2007). The NPS's WACAP project primarily assessed lichen tissue for SOCs, but nitrogen was also included and was elevated at Bear Track Cove, a sea level site in GLBA (Landers et al. 2008). Thresholds for elemental concentration in lichen tissue samples designed to distinguish between impacted and clean sites in the TNF (Dillman et al. 2007) were applied to samples collected for this study and to samples collected Skagway and KLGO in 1999 (Furbish et al. 2000). The species used for elemental assessments (*H. enteromorpha*, *H. inactiva* and *P. glauca*) (Nieboer et al. 1978, Garty 2001, Geiser 2004, Naeth and Wilkinson 2008) are highly pollution tolerant and have been used worldwide as proxies of atmospheric conditions. Most elemental concentrations levels in samples at most sites collected during this study were well below TNF threshold values and several elements are below the detection limits of the methods applied; however, a few general and site specific exceptions stand out.

Potassium (K) was slightly over threshold as several locations across all SEAN parks, most commonly at sites near saltwater. Because K is an important component of seawater, the observed concentrations may be due to marine influences. The only site without marine influence with near threshold levels of K was Glacier George, which is strongly affected by train emissions. Among the sites in the KLGO-Skagway area that have observations for two time periods, little change in levels of K was observed.

The sites with elevated concentrations of silicon (Si) did not follow an explainable geographical pattern with elevated levels in GLBA at Blue Mouse Cove and in KLGO at Lower Dewey and Dyea. Si is abundant as silica (in quartz) and variety of metallic ores. On the TNF elevated Si levels are associated with mine tailing and a windy glacial valley with granitic parent material (Dillman et al. 2007). Silicon was not assessed in 1999 so no inter-site comparison is possible.

Mercury was not previously assessed in lichen tissue is Southeast Alaska so no thresholds or comparisons are possible (Appendixes E and F). However, Hg was above detection limits at all sites and was approximately an order of magnitude higher than the levels detected in *Hylocomium splendens* arctic nationals parks (P. Neitlich pers. com 2011) and within ranges observed in Oregon and Washington for epiphytic lichens (http://gis.nacse.org/lichenair).

Lower Dewey, Icy Junction, and Sturgill's

Lower Dewey is the most impacted site in the study areas. The site, just above the Port of Skagway, is in direct line with cruise ship stacks. During morning stagnation events emissions accumulate in the vicinity and during summer afternoons when the south winds pick up, emission plumes cross the area. Historically, fugitive dust from ore loading operations in the port below was deposited in the area. The impacts of these industrial activities were apparent in 1999 (Furbish et al. 2000) and many of the analytes are still above TNF thresholds.

<u>Elements Associated with Fugitive Ore Dust</u>

Aluminum (Al) is a common component of lead-zinc ore concentrate, road dust, and fossil fuel emissions (Harte et al. 1991). Aluminum is also common in the dust of recently deglaciated valleys. Aluminum levels were above threshold for *H. enteromorpha* and *H. inactiva* in 1999 have declined well below threshold. Al levels declined significantly for *P. glauca* as well. The effect of installing a new ore terminal and ore transport methods with good dust control measures is apparent.

Lower Dewey was the only site within the study areas where cadmium (Cd) exceeded threshold in 1999 (Furbish et al. 2000); however, it dropped below threshold during the past 10 years. Atmospheric cadmium, typically the result of coal burning, and ore processing, can travel long-distances prior to deposition, and is then slow to leach out and disperse (USPHS 1993). The high Cd levels at Lower Dewey were likely due to fugitive dust from historical ore transport.

Lower Dewey was also the only site within the study areas where chromium levels exceeded thresholds in 1999; however, levels dropped below threshold for all lichen species used in this assessment. Some forms of chromium are a micronutrient while other forms are highly toxic. The ICP test used in this study does not distinguish between forms. Cr was detected at sites on the TNF associated with mining (Dillman et al. 2007) and the levels at Lower Dewey were likely due to fugitive dust from historical ore transport. However, atmospheric Cr is also produced from the combustion of coal and petroleum (USPHS 2010).

Copper (Cu) is also a metal associated with the type of ore being transported through the Port of Skagway and showed a similar pattern to analytes described above at Lower Dewey, dropping from just above threshold to below threshold for all species. Dillman et al. (2007) suggested that copper levels are naturally elevated in the TNF due to bedrock geology; however, most samples in the SEAN study areas were near the analysis method's detection limits.

Nickel levels at Lower Dewey remained above TNF thresholds but declined between the two sampling periods, and were above threshold at Icy Junction and Glacier George in 2009, an indication of the long residence time of heavy metals in the ecosystem.

Lead levels in Skagway became a major concern when extremely high levels were detected in soil near the shipping terminal in 1988. Lead occurs at background levels of 50 ppm in Skagway soils but tests conducted by the Alaska Department of Environmental Conservation (AKDEC) found levels up to 133,000 ppm (Akre 1989). Historically, lead based ores were transported by open rail cars and trucks and loaded onto barges using an open conveyor system. Mineral dust commonly became airborne because of these open transport methods and Skagway's almost constant high winds. Concerns about human exposure resulted in the removal of contaminated soils in 1989-1990 by the Alaska Dept. of Environmental Conservation. Ore is currently transported in closed truck beds and the ore terminal was replaced with modern equipment designed to capture fugitive dust in 2006. Therefore, the historical source of metallic dust no longer exists in Skagway. However, particles that were released prior to 1993 may still be present and could be redistributed in the air during dry, windy periods. In 2009, the elemental concentrations of lead in all 3 lichen species remains up to 150 times higher than TNF thresholds. Although levels have declined markedly during the intervening decade since the 1999 sampling, clearly, lead sulfide dust can remain in the ecosystem for decades. Lead levels were above threshold at other sites near Skagway (Icy Junction and Sturgill's) and at Glacier Gorge, a site adjacent to the White Pass and Yukon Route railway tracks about 12 miles north of Skagway with KLGO's White Pass Unit. Lead levels were below detection limits at all the sites outside of the Skagway area.

Molybdenum (Mo) and Titanium (Ti), a heavy metal byproduct of copper mining, was at or below detection limits at all sites in the study area except in *H. enteromorpha* at Lower Dewey in 2009, where it was slightly above detection limits. As with the other heavy metals, fugitive dust from historical ore transportation was the likely source.

Zinc (Zn) was a major component of the ore concentrate shipped out of Skagway. Levels at Lower Dewey declined between 1999 and 2009 but remain above TNF thresholds in *P. glauca* and *H. enteromorpha*. Levels at Sturgill's remained just above threshold in *P. glauca* and declined to below threshold in *H. enteromorpha* and *H. inactiva*. Elevated levels also occurred at Icy Junction, Icy Lake, and Glacier George in 2009 but these sites were not sampled in 1999.

<u>Elements Associated with Petroleum Combustion</u>

Nitrogen (N) levels at Lower Dewey increased markedly from 1999 to 2009; however, most samples were still below threshold levels. Only one 2009 sample of *H. enteromorpha* was at threshold. The increase in N may represent changes in cruises ship operations or fuel types at the Port of Skagway. Because the number of ship calls has remained stable during the intervening decade, another possible cause for increase in lichen tissue N is an increase in long distance transport of N from Eurasian sources. The fact that N increased at the Chilkoot Saintly Hill site (remote from ship operations) between 1999 and 2009 in a similar fashion suggests that local emissions are not the source of increasing N in the KLGO – Skagway area. Data from the TNF also shows an increase in the concentration of N in lichen tissue at sites not influenced by local sources suggesting a far-field trans-Pacific source (Dillman et al. 2007). However, an increase in mid-distance atmospheric transport due to increases in marine transportation sources may also be contributing to the N signal in lichen tissue (Tran et al. 2011). Another explanation is that the observed increases in lichen N are due to a change in the laboratory protocol after 2004, at which point the University of Minnesota Research Analytical Laboratory purchased a Leco total N analyzer to replace the micro-Kjeldhal method. Scrutiny of N concentrations in reference materials show that the lab attained improved recovery with the new method, about 18% better for a low N concentration lichen reference material (*Alectoria sarmentosa*) submitted every year by the USFS Pacific Northwest Region, and 5-7% better for plant-based SRMs with higher N concentrations (USFS, L. Geiser, lichenologist, personal observation). An 18% improvement in recovery could account for most if not all of the increases observed in lichens at SE Alaska study sites. On the other hand, the observation that N in lichen tissue remains at or below threshold, while the atmospheric concentration of nitrogenous aerosols at Lower Dewey are elevated suggests that deposition is not concentrated near the port, but rather emissions are disbursing somewhat prior to being deposited. Observations of low levels of wet N deposition from the passive resin tube samplers (Figure 17-18) along with the elevated atmospheric concentrations (Figures 10-13) suggests that dry deposition is an important contributor to N concentrations in lichen tissue.

Sulfur levels were above threshold concentration during both the 1999 and the 2009 samplings with little change at Lower Dewey and Sturgill's. This is not surprising given that cruise ship calls at the Port-of-Skagway and the sulfur content of HMO were relatively stable during the decade between samplings. The relatively high levels of wet deposition at Lower Dewey and Sturgill's described above corroborate the signal in lichens. Sulfur levels associated with adverse effects to sensitive plants (Glavich and Geiser 2008 and data presented here) were primarily observed in lichens within 2 km of Skagway at Lower Dewey and Icy Junction.

Although most other SEAN samples are below TNF thresholds, many sites that are remote from local sources show near threshold levels of sulfur. Long distance transport of sulfurous aerosols has also been demonstrated (Tu et al. 2004) and may contribute to the total sulfur deposition loads for SEAN parks. However, because there has been no significant change in sulfur between 1999 and 2009 at Lower Dewey, and a small decline in S was observed at Chilkoot Saintly Hill, the role of Eurasian sources is not clear. In general, lichen tissue samples from TNF plots that displayed elevated S levels were from sites with local anthropogenic influence, but sea-salt is a source of elemental sulfur in lichen tissue at sites proximal to salt water (Dillman et al. 2007).

Monitoring of sulfur atmospheric pollution levels is especially important because it is a major emission product with potential to acidify ecosystems (Glavich and Geiser 2008) and significantly impact visibility (Malm 1999). Repeated sampling will improve trend detection and help validate an ongoing (Mölders 2011) marine transportation emission modeling effort. Significant reductions in sulfur emissions have been demonstrated following the implementation of the Clean Air Act.

Reductions in marine transportation emissions may begin in 2015 with new regulations limiting sulfur content of marine fuels used along the US coast (US EPA 2009). Monitoring the effectiveness of these new regulations is another motivation for repeating ambient sulfur pollution assessments.

Vanadium is associated with crude oil deposits (American Bureau of Shipping 1984). Exceedances of threshold levels at Lower Dewey, Icy Junction, Sturgill's and Glacier Gorge are suspected to be a signature of fossil fuel combustion. It was not assessed during the 1999 sampling so a comparison is not possible. Vanadium was also elevated at TNF sites influenced by petroleum fuel combustions (Dillman et al. 2007).

Blue Mouse Cove and Bear Track Cove

Blue Mouse Cove, located in the middle of Glacier Bay, is a relatively pristine site. Although cruise ships and other marine traffic traverse nearby waters, they generally do not linger in the area and elevated levels of elements associated with fossil fuel combustion were not evident in lichen samples. Interestingly, Blue Mouse Cove was the only site where samples of *P. glauca* and *H. enteromorpha* were slightly above threshold for lithium. Lithium (Li) occurs at trace levels in seawater (Angino and Billings 1966) and is a component of pegmatite, a mineral found in types of granitic known to occur in Southeast Alaska (Sainsbury 1957). Further investigation would be required to determine the source of Li at Blue Mouse Cove; however, slightly elevated levels of Li were detected in the TNF at Russell Fjord, which is thought to be influence by local geology, and at a site near the Greens Creek mine (Dillman et al. 2007). The NPS's WACAP project primarily assessed lichen tissue for SOCs, but nitrogen was also included and was elevated at Bear Track Cove, a sea level site in GLBA (Landers et al. 2008).

Dyea and Chilkoot Saintly Hill

Barium (Ba) was elevated above provisional thresholds in *H. enteromorpha* and *P. glauca* in Dyea, but it was not included in the 1999 analysis so no comparison is available. Barium occurs naturally in ore and certain igneous bedrock types (USPHS 1992). Barium may be present in the dust and soil in the Dyea Flats, which is upwind of the sample site. Dyea Flats is an uplifted estuary, so Ba mobilized from marine and terrestrial sediments derived of igneous parent material is a possible explanation. Because Ba has not been an analyte until recently, more data are needed to understand variability across SE Alaska and establish more robust thresholds (Dillman et al. 2007). Elevated levels for Ba were found at a few sites in the TNF, one associated with a mine, the other with a glacial river valley (Dillman et al. 2007). It is surprising that Dyea was the only site in the study area that had elevated levels of Ba. A better understanding of its distribution will develop as Ba is included in more lichen tissue plots from across the region.

Copper dropped from slightly above to below thresholds for *H inactiva* and *P. glauca* during the decade between samplings in Dyea and at the Saintly Hill-Chilkoot Trail sites. The historical source of Cu in Dyea may also be fugitive dust; as levels of zinc, also associated with fugitive dust, were also above threshold in Dyea and the Saintly Hill-Chilkoot Trail sites during the 1999 sampling.

Nickel (Ni) is associated with metallic ores and is released during fossil fuel combustions. Nickel levels in *P. glauca* declined from above TNF thresholds to well below thresholds during the decade between sampling. Elevated levels of Ni were also detected at sites near mines and above the Juneau cruise ship docks (Dillman et al. 2007).

Strontium (Sr) levels in *H. enteromorpha* from Dyea exceeded TNF's provisional thresholds. It was not elevated at any other SEAN sites but Dillman (2007) reported a few sites exposed to windblown dust or marine influences with threshold values for Sr on the TNF. It was not included in the 1999 analysis so no comparison is available, but an anthropogenic source is not expected. A better understanding of its distribution will develop as Sr is included in more lichen samples from across the region.

The small decline in sulfur concentration between 1999 and 2009 at the Dyea and Chilkoot Saintly Hill sites is difficult to explain considering the site is somewhat remote from local emission sources, local source were stable during the decade (cruise ship numbers were relatively stable), and Eurasian source increased over the decade. The decline at these two sites is likely an insignificant artifact of natural variation or of the lab or sampling methods.

Lichen Community Plots

Methodology for Scoring Nutrient N Deposition

Unlike lichen indicators of SO_2 and acidity, no universal set of N indicators exists. Dry, warm climates are known to favor eutrophs in the absence of air pollution (Grenon et al. 2012). As winter temperatures become colder and continentality increases, species composition shifts to favor species better adapted to those climate conditions. Thus indicator species of N deposition are different in warm, dry places than in cool, wet places. Separation of climate from pollution effects is the primary reason that the wOR/WA gradient model was considered a better tool for analyzing community response to nutrient N deposition than eutroph to oligotroph ratios alone. The gradient model scores air quality along the relatively long pollution gradient (1-8 kg N/ha/yr) in wOR/WA, assigning scores that are independent of temperature, humidity and continentality.

The SE Alaska reference climate and air scores largely fit within the range of climate and air scores observed in wOR/WA. Only two sites exceeded the 2-standard deviation cut-off, falling off the clean end of the air quality axis. The majority of the sites, as expected, placed in the cleanest half of the wOR/WA gradient. Sites with highest air scores generally occurred in natural settings with higher nutrient availability, such as mixed conifer and hardwood forests along beach-forest ecotones. This phenomenon was also observed in OR/WA, but comparatively few sites lay close to salt water compared to the number of sites in urban and agricultural settings there.

Climate scores in SE Alaska generally fell in the cooler half of the wOR/WA climate gradient. Lowest climate scores were typically in hypermaritime localities close to bays and coves ; highest climate scores occurred at the most continental sites, i.e., in the Skagway vicinity. None were flagged as having colder maximum December temperatures or greater continentality than the wOR/WA dataset and none were flagged as warmer or more maritime than the wOR/WA dataset. Of course, climate in SE Alaska is not exactly the same as wOR/WA and one of the largest differences is in precipitation, which is generally much higher in SE Alaska. To separate precipitation from pollution effects, the wOR/WA calibration dataset was balanced with equal numbers of polluted sites from wet and dry parts of the region. However, there was still a weak correlation between precipitation and air scores (Pearson's r=-0.21) in the final model. Thus higher precipitation sites tend to receive somewhat cleaner air scores relative than drier sites. If anything, this would be expected to make the wOR/WA air scores conservative for SE Alaska.

A related unknown is how well wOR/WA thresholds apply to SE Alaska sites. What is an adverse effect in SE Alaska relative to wOR/WA? Lichen community composition shifts continuously along a nitrogen availability/deposition gradient in both regions, however community composition thresholds and associated N critical loads based on SE Alaska lichen data have not been established to date. Root et al. (in prep.) attempted to model lichen response to nitrogen deposition in SE and SC Alaska using the FIA dataset but did not find enough sites with substantial emissions sources to produce a convincing model. In this study we therefore compared air scores not only to community response thresholds for wOR/WA but also to reference sites in SE Alaska that could be assumed clean (remote from local anthropogenic sources). To be flagged as enhanced with regard to nutrient N, air scores at our study sites had to exceed both wOR/WA thresholds (air score of 0.1 to 0.21) and the more strict TNF thresholds (air score > 97.5% of TNF plots, i.e., 0.265 in conifer forests and 0.513 in forests with a hardwood component).

Effects of Nutrient N Deposition on Lichen Community Composition and Lichen N Levels in the Study Area

Using the above criteria, only two sites in the study area exceeded expected clean-site ranges for both wOR/WA and SE Alaska; these were Sawyer Island and Dyea. The presence of hardwoods enhanced air scores about 0.5 units along the 2.5 unit air pollution axis compared to all-conifer stands. This effect was also observed in wOR/WA but the shift was only about 0.2 units (Geiser and Neitlich 2007). Hardwoods are known to favor eutrophs by providing more alkaline, nutrient-rich substrates preferred by eutrophs. In SE Alaska the larger shift in air score may be related to the fact that hardwoods typically occur only at low elevations along beach fringes and major river valleys, where nutrient enriched sea salt aerosols or Aeolian dust can contribute to nutrient enhancement at the site. Regardless of the explanation, because of the large effect of stand type on air score in SE Alaska, it was deemed prudent to compare air scores to the matching set of reference sites, i.e., hardwood-containing or all conifer.

Although lichen N was tightly correlated with N deposition; air scores were observed to increase then decrease with increasing SO_2 and sulfate deposition. High air scores in SE Alaska indicated sites with high nutrient N availability NOT impacted by SO_2 or acidity. For example, air scores were higher at Dyea and Sawyer Island than air scores at the more polluted Dewey and Sturgill's sites which also had much higher sulfate deposition and SO_2 levels. Both these latter pollutants are sources of acidity and many eutrophic lichens are known to be sensitive to SO_2 and acidity. Thus air scores were consistent with this biology.

Another observation was that elevated NO_x or HNO_3 did not necessarily result in elevated N deposition levels or lichen N concentrations surpassing thresholds. Lichen N was most tightly correlated with total nitrogen deposition at open sites, and with ammonium deposition at open and throughfall sites. Lichen N from sites across western NAm, including the SE Alaska study sites, has been directly calibrated to throughfall deposition (Root et al. 2013). Conversely, absorption of nitrate by the canopy at throughfall sites was not correlated with lower lichen N levels. It may be that the variability in tree density and height across the study areas created variability in throughfall deposition that was more related to tree structure (NO_3^--absorbing surface area) than to air quality.

Effects of Sulfur-containing Pollutants on Lichen Community Composition and Lichen S Levels in the Study Area

Seawater aerosols are an important component of total S and N deposition in hypermaritime climates. Both nitrate and sulfate containing salts are present in these areosols, though the nitrate component is relatively minor. The latest national scale Community Multivariable Air Quality (CMAQ) model (Dennis et al. 2013) of N and S deposition, provides a gauge of the expected contributions of sea salt to sulfur deposition with distance from the ocean. Sea salt components of sulfate deposition can be detected as far as 180 km from the ocean, but decrease exponentially within the first 10 km. Annual sulfate total deposition levels attributable solely to sea salt at sites within 10 km of the ocean (at least in the lower 48 states), can account for up to 3-4 kg S/ha/yr. Sulfate containing aerosols from seawater likely contributed to total sulfur deposition at all sites in the study area.

In contrast to nutrient N deposition, there were multiple lines of evidence that many of the study sites, including most of the Skagway/KLGO sites were potentially or probably adversely affected by either SO_2 or acidity. SO_2, sulfate deposition, lichen S, and the percentage of SO_2-sensitive species comprising the lichen community were all moderately to strongly correlated with each other. Thus the higher the availability of S-containing pollutants, the greater the number of measures that exceeded expected clean site ranges and thresholds. Hardwoods again modified the response, presumably because the more alkaline pH of their bark has a buffering effect that moderates both SO_2 and acidity effects (see further discussion under KLGO/Skagway below). A higher percentage of the lichen community consists of SO_2-sensitive species in hardwood stands at all distribution quantiles. Thus, in SE Alaska, species percentages are best compared to reference sites of comparable stand composition (hardwood-influenced or all conifer). Based on the relationship between sulfur dioxide and the percentage of SO_2 sensitive species comprising the lichen community in this study, we propose a critical level range for SO_2 from 3.1 $\mu g\ m^{-3}$ (for forests with a hardwood component) to 33.5 $\mu g\ m^{-3}$ ppb (for forests comprised only of hardwoods). Levels within this range occurred at Lower Dewey, Upper Dewy and Sturgils.

Cyanolichens are among the lichens most sensitive to SO_2 and acidity (Gilbert 1986). They are also highly suited to cool humid climates, which contributes to their exceptional diversity in SE Alaska. As nitrogen fixers, these lichens contribute substantial new fixed nitrogen to old-growth Pacific Northwest forests (Antoine 2004) and their large leafy form serves as preferred habitat for a diversity of canopy invertebrates (Neitlich 1993). Three of the most ecologically important cyanolichens in SE Alaska, *Lobaria oregana*, *L. linita* and *L. pulmonaria*, are abundant on conifer substrates and vulnerable to acidic deposition.

KLGO/Skagway

Lower Dewey, with the highest mean seasonal averages of NO, NO_x, HNO_3, SO_2, and throughfall sulfate, was clearly the most polluted site in the study area. Lichen responses corroborated air quality measurements with N, S, and toxic metals in lichens exceeding TNF thresholds and few SO_2-sensitive lichens at both hardwood and conifer sites relative to TNF reference sites. With biweekly ambient SO_2 concentrations up to 20 µg/m^3, this was the site where measured SO_2 levels alone were most likely to have been high enough to harm sensitive lichens. Although seasonal averages were only about 8 µg/m^3, literature reports generally find sensitive lichens can be intolerant to annual average levels as low as 14 µg/m^3. It is even more likely that the paucity of sensitive species was a combination of SO_2 and acidity effects (Wetmore 1983). Low pH can exacerbate SO_2 effects by compromising cell membrane integrity (Türk and Wirth 1975), especially if combined with heavy metal deposition (Tarhanen et al. 1999). Furthermore, pH levels in the lower canopy may be more acidic than bulk precipitation due to the promotion by acidic deposition of acid leachates from conifer needles (Kermit and Gauslaa 2001).

Many *Xanthoria* and *Physcia* species, typical eutrophs, are sensitive to SO_2 and acidity. With the relatively high SO_2, NO_x/NO, HNO_3 and sulfate deposition at Lower Dewey and other Skagway sites, it is possible that the combined acidifying and oxidizing effect of these pollutants has been inhibiting the growth of eutrophs, thus maintaining an artificially good air score. Sulfur dioxide typically decrease species diversity but, with 28 species, Lower Dewey scored near the middle of the range observed at the Skagway/KLGO sites (mean 26 spp, range 14–39). Historic species counts would be more informative. Very high sulfate deposition also occurred at Sturgills and Dewey 1700, and if accompanied by an acidifying effect, could also explain the relatively good air scores at these sites but low number of SO_2-sensitive species. Other sites flagged as probably or possibly affected by SO_2 or acidic deposition due to low proportions of SO_2 sensitive species were: Lost Lake, Icy Junction, Glacier Gorge, Dewey 1360 and Dewey 1480.

The only site in the KLGO/Skagway area flagged for exceeding expected ranges for air score among TNF sites as well as wOR/WA thresholds, was Dyea. Dyea had the richest species diversity, supporting oligotrophic as well as more mesotrophic and eutrophic species. The source of nutrients is not clear, but given the low deposition of nitrogenous compounds and ammonia at the site, and lichen N and S levels below TNF thresholds, the enhanced diversity is likely due to natural sources favoring eutrophs such as a combination of hardwood presence, proximity to sea salt spray, and sufficient distance from the acidifying/oxidizing pollutants in Skagway. Dyea had a low proportion of lichens sensitive to SO_2/acidity, the only measure inconsistent with a natural causes diagnosis. A possible explanation is biogenic emissions of H2S from the nearby tidal mudflats, which can mimic SO_2 effects in lichens (see Tracy Arm and SITK paragraphs below).

No trends were detected in air scores from 1998 to 2008 at Chilkoot and Dyea, consistent with the absence of trends in the tissue data for S and N at these sites. There appears to be no evidence that air quality is worsening.

Tracy Arm-Fords Terror Wilderness

The Sawyer Island site in TAFT received the highest air score for nutrient N deposition among the study sites, well above the wOR/WA thresholds and within the 97.5-99.5 % quantile for reference TNF hardwood sites. The air score was consistent with N levels in *P. glauca* that exceeded TNF thresholds in both 2009 and (not reported earlier) 2012. Ammonium ions comprised >90% of throughfall and bulk deposition N at this site and bird activity is high in the area. The fact that phosphate levels in the bulk and throughfall deposition were within same range as other sites indicate that bird droppings were not directly deposited into the samplers. However ammonia emissions from bird droppings on the site could still best explain the community effect. Other evidence supporting natural sources of nutrient enrichment at this site were low sulfate levels; TF sulfate was 0.57 kg/100 days, which extrapolated to a year, would sum to 2.1 kg S, within expected ranges for sea salt sulfate deposition at a site so close to salt water.

There are some indications of anthropogenic SO_2 effects at Sawyer Island. *Platismatia glauca* collected for elemental analysis in 2009 (and 2012, not reported earlier) exceeded TNF thresholds for S. Seven of the 13 lichens collected had SO_2-sensitivity ratings and, of those, 43% were sensitive. Such a score would place this site in the 'probably impacted from SO_2 or acidity' category. Because the cut-off was 9 rated species, this score was not considered reliable. Given the absence of SO_2 monitors at this site, it is not possible to confirm or discount an SO_2 effect. The reasons for the inconsistency between lichen %S and sulfate deposition at the site, with which lichen S was otherwise strongly correlated in the study area are not apparent.

Lichen community scores at the Bushy Creek, Sanford Cove and Williams Cove were among the best in the study set and well within ranges observed at reference TNF sites with regard to N and S-containing pollutants. There is no evidence of a pollution impact at these sites. Elemental analyses conducted in 2011 and 2012 were not included in results sections and tables because they arrived late in the report preparation process. However none of the samples exceeded TNF thresholds for S or N.

The low percentage of SO_2-sensitive lichens at Salmon Creek is a concern and additional surveys are needed there. The one sample collected for elemental analysis (in 2011) did not exceed TNF thresholds for either S or N. Because this site is located at the entranceway to Tracy Arm and boats entering either Tracy Arm or Fords Terror Arm pass near it, marine vessels could be an anthropogenic source of SO_2 affecting the lichens here. The site is also adjacent to a tidal mudflat. Tidal wetlands are a major nature source of DMS and H_2S emissions to the atmosphere (Bates et al. 1992). Because lichen response to H_2S can mimic that of SO_2 (Tetriach and Ganis 1999), emissions of H_2S from the mudflats offers an alternative explanation for the low percentage of SO_2 sensitive lichens at this site.

Sitka National Historical Park

The site along the intertidal meadow in SITK showed indications of both S and N enrichment, some of which is likely due to natural nitrates and sulfates in sea water aerosols, and some of which may be due to marine vessels or other activities in and near Sitka. Sulfur and nitrogen concentrations in the lichen *Platismatia glauca* were at 95 and 107% of TNF thresholds, respectively. Sulfate deposition was 1.1 kg S/ha/100 days, which if extrapolated to a full year would yield slightly over 4 kg/yr. Although ambient SO_2 concentrations at this site were low, some part of the deposition could be related to local transport of sulfates originating as SO_2 emissions from marine vessels in Sitka Harbor. This possibility is supported by the low number of SO_2-sensitive species at the site (36%, lower than all TNF reference hardwood sites) which in this case could be indicating a response to acidic deposition. Measurements of precipitation and/or bark pH at this site would help to confirm an anthropogenic component to sulfate deposition, if the origin is from SO_2 as opposed to sea salt aerosols, then some acidification should be detectable. Because the site is adjacent to an intertidal marsh, it is also possible that lichen community effects are driven by natural H_2S emissions (see preceding paragraph for TAFT). Air scores indicative of nutrient N were within TNF reference site ranges and lower than wOR/WA thresholds.

If the SITK site is affected by acidic deposition or by H_2S, the effect is short ranged because the Root et al. (in prep.) plot along the Indian River trail (HR20), about 1.5 km north of the park had an excellent air score (-1.47) and a very high proportion of SO_2-sensitive species (80%).

Glacier Bay National Park and Preserve

Compared to TNF reference sites, Blue Mouse and Bartlett Cove sites were among the most nutrient enriched. The sites are located very close to the ocean, a natural source of nutrients. Open and throughfall nitrogen deposition was very low at both sites but ammonia, which averaged 7.4 $\mu g/m^3$ during the 2009 season, was the third highest seasonal value among the study sites and is likely an important source of N for lichens and may explain why lichen N averaged about 90% of TNF thresholds. However, lichen community based air scores were well within ranges observed at TNF reference sites.

In contrast to N, there may be an anthropogenic component to sulfate deposition in GLBA. Although seasonal SO_2 concentrations were very low, throughfall sulfate deposition averaged 1.1 S/ha/100 days at Bartlett Cove and 1.5 kg S/ha/100 days at Blue Mouse Cove. If extrapolated to 365 days, this would be at least 1–1.5 kg more sulfate deposition than expected from sea salt alone. Therefore a portion of the observed sulfate deposition may be due to ship emissions. Sulfur concentrations in lichens were about 80% of TNF thresholds. Despite these multiple indications of S and N enrichment, community responses indicative of nutrient N and SO_2/acidity were within ranges observed among TNF reference sites. In other words, no adverse effects on lichen community composition due to nutrient N deposition, SO_2, or acidic deposition attributable to anthropogenic sources were detected at GLBA

Conclusions and Recommendations

Conclusions

- The primary pollutants detected through passive atmospheric and biological monitors were products of current fossil fuel combustion and historic mine ore transport operations.
- Locally, pollution levels decreased rapidly with distance from point sources (i.e., port activity in Skagway and Sitka). Because the most impacted areas coincide with the population centers, human health impacts are a potential concern. Lead, nickel and vanadium were significantly enhanced in the KLGO/Skagway area. Although NO_x was elevated at KLGO/Skagway, it was below levels known to cause direct human health or phytotoxic impacts. However, indirect effects on plant community composition, e.g., from atmospheric deposition of nitrogen and sulfur compounds are possible at the site where TNF thresholds and critical levels for SO_2 were exceeded (KLGO/Skagway and SITK). Lichen community changes should be assessed after the plots are read again in 2018 and 2019.
- Critical response thresholds signaling adverse shifts in lichen community composition from S and N were established using 97.5% quantiles for lichen community composition atTNF reference sites. The strong correlation between SO_2 and lichen community composition made it possible to quantify this relationship and apply response thresholds for hardwood and coniferous forests to the calculation of a SO_2 critical level range of 3.1 to 33.5 μg m^{-3}.
- The Western Airborne Contaminants Assessment Program study (Landers et al. 2008) reported elevated concentrations of nitrogen and certain polycyclic aromatic hydrocarbons (PAHs), both products of combustion, in lichens and conifer needles at Beartrack Cove, GLBA. Elevated nitrogen deposition is variable across SE Alaska. Nitrogen levels in lichens sampled in 2008 at Bartlett Cove, GLBA were within expected clean site ranges; other pollutants were also within expected clean site ranges. More work is needed to understand pollutants and their depositional patterns in GLBA. A project, managed by the NPS Southeast Alaska Coastal Cluster, is underway to extend the modeling work of Mölders et al. (2010) on the transport and fate of emissions from marine transportation in south central AK to SE Alaska. This will help predict nitrogen and sulfur depositional patterns from marine transportation sources.
- Increasing nitrogen levels in epiphytic lichens in KGLO/Skagway correlates with increasing NO_x from cruise-ship emissions and tourism. Greater trans-Pacific emissions associated with industrial expansion and energy production in Asia and more wildfires emissions from northern Alaska/Canada may be contributing to increased background regional NO_x levels and to the nitrogen accumulated by epiphytes at some TNF sites that are distant from local emission sources. Nitrogen concentrations in lichens at remote sites on the TNF have increased slightly (Dillman et al. 2007), suggesting that far-field sources are a factor across SE Alaska. On the other hand, some of the increased N may be an artifact of a changeover in N analysis instrumentation at the analytical laboratory, resulting in better recovery in samples since 2004. Sources contributing to elevated ammonium sulfate in fine particulates at the Petersburg IMPROVE site monitor during the past 10 years have not been identified. As evidenced by the continuing widespread distribution of sensitive epiphytes across the

Tongass National Forest (Dillman et al. 2007) there is as yet no evidence of widespread adverse ecological effects from nitrogen or sulfur deposition in SE Alaska.

- Nitrogen and sulfur containing pollutants are quickly processed or assimilated within the ecosystem compared to many metals, which have a much longer residence time (decades vs. years) in soils and vegetation.

Management Implications

- Reducing cruise ship emissions would have beneficial effects on visitor experiences of visibility and odor, and particularly in Skagway, reduce potential human health effects from combustion-related air pollutants such as fine particulates, PAHs, and metals.
- Because pollutant concentrations fall off rapidly with distance from sources, the worst impacts can be expected in locations close to docking areas or where topographic and meteorological conditions frequently combine to trap emissions close to the ground.
- Continued monitoring of established sites can be used to verify the effectiveness of air resource management policies. It could be important to measure atmospheric concentrations of particulate matter because sulfate, ammonium, and nitrate aerosols produced from gaseous N and S compounds are hazardous to inhale and strongly affect visibility.

Recommendation for Future SEAN Air Quality Work

- Study the feasibly of estimating dry deposition of S and N from the passive atmospheric sampler data; Bytnerowicz et al. (2010) suggest an approach. Estimates of dry deposition (in addition to wet deposition data, available in this report and from the Juneau NADP-NTN station AK02), are needed to 1) understand total deposition; and 2) formulate critical loads and understand ecological affect thresholds following Geiser at al. (2010).
- The passive wet deposition samplers were only deployed during the cruise ship season for this project; the data do not describe total annual deposition. Although local sources of emission are greater during the visitor season than during the winter, local and far field sources may contribute deposition during the fall, winter, and spring. The intra-annual variation in wet deposition is captured by the Juneau NADP station (AK02), but has not been analyzed. Before developing improved protocols for air quality monitoring, a full analysis of NADP data from AK02 is needed to look for patterns in intra-annual (or seasonal) deposition and test the assumption that most deposition occurs during the cruise ship season. This will take extra effort because most of the data from the winter season has not been analyzed by the NADP program because the sampling frequency did not meet program requirements. However, the full dataset is available from NADP if contacted directly (it is not all on the website).
- Acquire the raw data for NADP's AK02 NTN site (Juneau) and analyze it to determine inter seasonal variation in N and S deposition. This is needed to test the assumption that local, summer sources are more important contributors than winter and spring inputs from far-field sources. Another important data source that should be acquired is the IMPROVE site's data that operated in Petersburg for about 10 years (it was removed in 2010). IMPROVE provides seasonal data on ammonium nitrate and ammonium sulfates in fine particulates.

- These AK02 NTN data should be used to develop a calibration curve between the NTN data and bulk deposition data from the passive ion exchange resin tube samplers. This calibration curve should be compared to similar efforts conducted in other climatic regions. A similar calibration between NADP-NTN data and resin tubes results is being conducted in Denali National Park in 2012.
- Consider setting-up a visibility monitoring protocol following NPS ARD methods for Class One Areas. Considering that visibility is impacted even at the low levels of atmospheric pollutant observed in this study, visibility and viewshed impacts on visitor experience may be highly relevant to managers.
- The results from the Weather Research and Forecasting - Chemistry (WRF-Chem; Grell et al. 2005) atmospherics model being conducted by Mölders et al. (2011 proposal) should be reviewed to inform future monitoring strategies when this study is complete in 2013.
- Revisit lichen community plots in 2018–2019 to look for changes in plot scores to document effects related to status and trends in air quality and climate.
- Investigate the relationship between Hg concentration in lichen tissue and wet deposition of Hg as measured at the GLBA MDN (Mercury Deposition Network) site.

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Appendix A. Membrane sampler set-up procedure

Passive Samplers for Air Quality Protocol

Standard Operating Procedure (SOP) # 1: Pre-Season Preparation, Installation, Management, and Uninstallation of Equipment

Version 1.00 (April 2009)

Revision History Log:

Previous Version #	Revision Date	Author	Changes Made	Reason for Change	New Version #
					1.0

Prior to the field season each year, usually beginning in March or April, technicians should review this entire protocol, including SOPs. This SOP gives a brief description of how installation and maintenance should be scheduled. Preseason planning facilitates the completion and integrity of depositional sampling. All of the equipment and supplies listed in this SOP should be organized and made ready for the field season.

Preparation

1. An equipment list (Table A.1) should be compiled and equipment organized and made ready for the field season several weeks in advance. This allows time to make needed repairs and order equipment.
2. Inventory any existing equipment that will be reused in the coming season. Determine the materials that will need replacing and arrange the shipment of them, along with the first set of samplers, with the Forest Service in Riverside, California. *Note: extra Ogawa bells and nitric acid protective caps should be acquired in case of destruction by weather events or wildlife.*
3. Upon receiving the installation materials, conduct a second inventory of all equipment.
4. Posts on which the samplers will be installed should have one end sharpened for ease of securing in ground.
5. All wood should be painted or treated for outdoor use and made to look inconspicuous.
6. Create a Microsoft Excel spreadsheet that will be used to document the installation and uninstallation dates for each site, a log of hours, notes about each site visit, and location details (site description, coordinates, sampling years, etc.). This should be stored on the Resources T

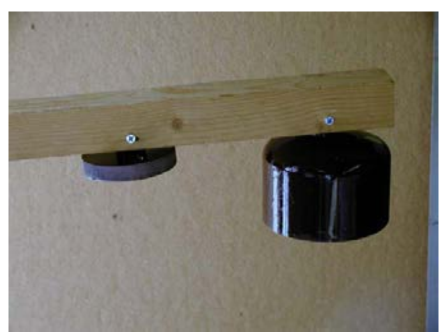
Drive under T:\NRM\Air Quality\Ogawa. All relevant fields should be completed following each site visit for management purposes.

Table A.1. Field equipment list for installing a single passive sampling assembly.

Number Req.	Description
1	2x2x8' wooden support post
2	2x2x30" wooden cross arms
4	Ogawa protective bells with metal clip
3	Nitric acid protective caps
2	Metal brackets
24	5/8" Wood screws
1	Hammering tool or post driver for pounding posts into ground
1	Leatherman multi-tool with Phillips head bit
1	Battery operated power drill with Phillips head bit (optional)
40'	Nylon rope for use as guyline (as needed)
4	Tent stakes for guyline (as needed)
1	Compass for navigation to plots
1	GPS unit for navigation to plots
1	Rite-in-the-Rain notebook
>1	Pencils
1	Backpack for carrying equipment
1	Two-way radio for logistical and emergency communication
1	Insect repellent
1	Sunscreen
1	First Aid kit

Installation

Once the materials are prepared, the site installations should occur as close to the same time as possible to maintain data consistency. It is reasonable to install the samplers in two groups (e.g., Dyea/Chilkoot and Dewey Lakes/Sturgill's), each within a day of the other, to ease logistical problems. The sites should be clear of snow to the point where it will not interfere with installation or affect the samplers. *See additional instructions at T:\NRM\Air Quality\Ogawa\Protocol.*



1. Install the support post.
   - For ease of carrying, support posts can be transported without crossarms attached. Once at the site, install the support post by pounding it into the ground using either a fencepost driver or hammer. This may require first digging a hole if the soil is greatly compacted or contains rocks. In some sites, the only appropriate location for the support post may be on rock without any soil. In this case, if there is no way to install the support post, it is permissible to install the crossarms directly onto a tree. If possible, they should still intersect each other at 90 degree angles.

2. Attach the protective bells and caps to the crossarms.
   - One bell should go on the outside end of each crossarm, and the caps each go just to the inside of a bell.
3. Install the crossarms.
   - Attach the crossarms to the top of the support post using two metal brackets. The arms should cross each other at a 90 degree angle. The Ogawa bells should be a minimum of six feet above the ground.
4. Attach guylines (optional).
   - Use nylon cord to create guylines for the support post if it will be prone to severe weather or disturbance. The lines can be secured halfway up the post on wood screws inserted into the post.
5. Install the Ogawa samplers.
   - With the sampling station fully installed, place an Ogawa sampler unit inside of each protective bell.
   - First remove the metal bell clip from the bell.
   - Remove the Ogawa sampler from its container, being careful to handle the sampler only by the attachment clip.
   - Attach the toothed clip on the sampler to the upward-pointing end of the bell clip. *Do not touch the perforated ends of the sampler with your bare hands! If necessary, use latex gloves to perform this task.* Avoid touching the sampler to anything else outside of the plastic bag it was stored in.
   - With the sampler attached to the bell clip, replace the bell clip on the bell. The sampler should sit securely inside of the protective bell.
   - Store the plastic bag and container in the provided bag for use in uninstallation.

6. Install the nitric acid samplers.
   - Remove the threaded plastic ring from the protective cap.
   - Remove the plastic lid from sampler disc.
   - Being careful not to touch the filter paper, attach the sampler disc to the protective cap using the Velcro strips.

- Replace the plastic ring on the protective cap.
- Store the plastic lid in the provided bag for use in uninstallation.

7. Record installation date and time.
   - Write the date and time of sampler installation on the provided sheet of paper, in addition to any relevant comments about the samplers or installation process (e.g., the NO_x sampler was dropped during installation). If a problem occurs with a nitric acid sampler, make sure that the individual sampler will be identifiable by marking the corresponding petri cover and noting it in the comments section.

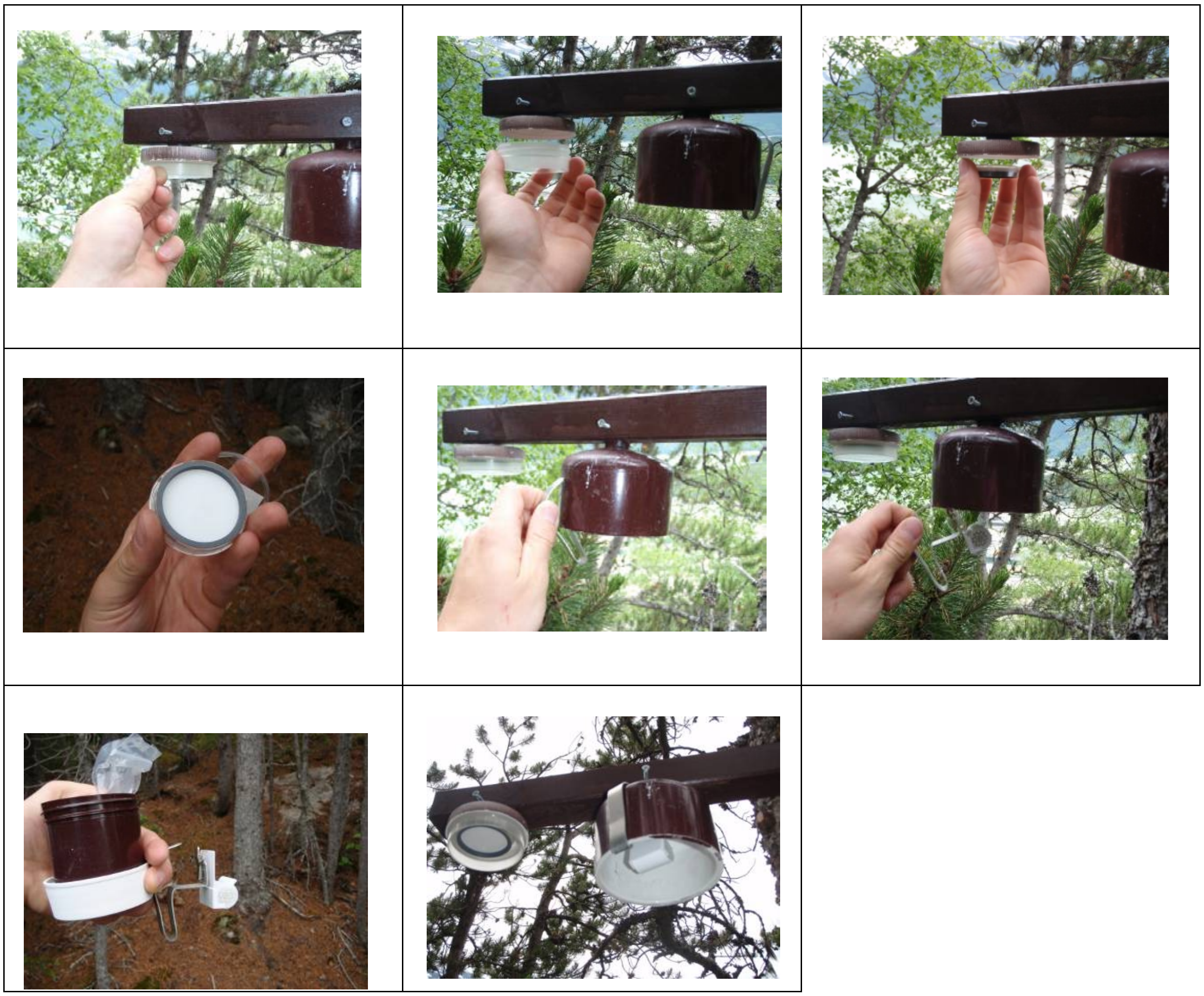


Figure A.1. Removing and replacing membrane sampler filters and Ogawa filter housing.

Uninstallation

The used samplers should be removed on the same day each week, and the new samplers installed immediately afterwards.

1. Remove the nitric acid samplers.

- Remove the threaded plastic ring from the protective cap.
- Replace the plastic lid on the sampler disc.
- Remove the sampler disc from the protective cap and store in provided bag.
- Replace the threaded plastic ring on the protective cap.

2. Remove the Ogawa samplers.
    - Remove the bell clip with sampler attached.
    - Carefully remove sampler from bell clip. *Do not touch the perforated ends of the sampler with your bare hands! If necessary, use latex gloves to perform this task.* Avoid touching the sampler to anything else outside of the plastic bag it was stored in.
    - Place sampler in provided plastic bag and into its corresponding plastic container.
    - Replace bell clip on bell.
3. Record uninstallation date and time.
    - Write the date and time of sampler removal on the provided sheet of paper, in addition to any relevant comments about the samplers or uninstallation process (e.g., the NO_x sampler fell from its bell during the week of sampling). If a problem occurs with a nitric acid sampler, make sure that the individual sampler will be identifiable by marking the corresponding petri cover and noting it in the comments section.
4. Mail samplers.
    - Package samplers in the box that they arrived in and mail to:

Diane Alexander, Chemist
USDA Forest Service
Riverside Fire Laboratory
4955 Canyon Crest Dr.
Riverside, CA 92507

End of Season

At the end of the field season, sampling stations may be left in place as they are, provided that they are not in imminent danger from weather during the winter. Make sure that all samplers have been mailed. Tools used for station installation and management should be stored either in the Hern-Clipper office cabinets or the Mascot garage. If there are known equipment replacement needs for the following season, please make note of them in a Microsoft Word file under T:\NRM\Air Quality\Ogawa. Ensure that the time log is complete and that there is a summary of hours for the season.

Labels for exposed membrane filters and Ogawa samplers

Park: ___________________________ Site: _____________________________ Installation Date: ________________ Installation Time (PDST): __________ Change Date: _____________________ Change Time (PDST): _____________	Park: ___________________________ Site: _____________________________ Installation Date: ________________ Installation Time (PDST): __________ Change Date: _____________________ Change Time (PDST): _____________
Park: ___________________________ Site: _____________________________ Installation Date: ________________ Installation Time (PDST): __________ Change Date: _____________________ Change Time (PDST): _____________	Park: ___________________________ Site: _____________________________ Installation Date: ________________ Installation Time (PDST): __________ Change Date: _____________________ Change Time (PDST): _____________
Park: ___________________________ Site: _____________________________ Installation Date: ________________ Installation Time (PDST): __________ Change Date: _____________________ Change Time (PDST): _____________	Park: ___________________________ Site: _____________________________ Installation Date: ________________ Installation Time (PDST): __________ Change Date: _____________________ Change Time (PDST): _____________

Appendix B. Methods for sampling atmospheric deposition with ion exchange resin tube collectors

Air Quality Sampling Protocol

Standard Operating Procedure (SOP) # 1: Pre-Season Preparations, Installation, Management, and Uninstallation of Equipment

Version 1.00 (April 2009)

Revision History Log:

Previous Version #	Revision Date	Author	Changes Made	Reason for Change	New Version #

Prior to the field season each year, beginning in March or April, all technicians should review this entire protocol, including SOPs. This SOP describes the pre-season preparations, installation, and uninstallation procedures, as well as station management during the field season.

Preparation

1. An equipment list (Tables B.1 and B.2) should be compiled, and equipment organized and made ready for the field season several weeks in advance. This allows time to make any necessary repairs and order equipment.
2. Inventory any existing equipment that will be reused in the coming season. Determine the materials that will need replacing and arrange the shipment of them, along with the necessary resin tubes, with the Forest Service in Riverside, California. *Note: at least 5 extra funnel apparatuses should be acquired in case of destruction by bears, squirrels, or other wildlife.*
3. Upon receiving the installation materials, conduct a second inventory of all equipment.
4. Materials being reused should be cleaned in the office with distilled water before installation.
5. Posts on which the bulk samplers will be installed should have one end sharpened for ease of securing in ground.
6. All wood should be painted or treated for outdoor use and made to look inconspicuous.
7. Create a Microsoft Excel spreadsheet that will be used to document the installation and uninstallation dates for each site, a log of hours, notes about each site visit, and location details (site description, coordinates, sampling years, etc.). All relevant fields should be completed following each site visit for management purposes.

Table B.1. Field equipment list for installing a single bulk sampling station.

Number Req.	Description
5	Funnel apparatuses
6	IER columns (1 is a blank)
5	Perforated filter disks
5	Spiked metal rings (bird deterrents)
5	Zip-ties (optional)
5	Wooden posts
6	Hose clamps
1	Hammering tool for pounding posts into ground
40'	Nylon rope for use as guyline (as needed)
1	Compass for navigation to plots
1	GPS unit for navigation to plots
1	Rite-in-the-Rain notebook
>1	Pencils
1	Backpack for carrying equipment
2	Two-way radios for logistical and emergency communication
1	Insect repellent
1	Sunscreen
1	First Aid kit

Table B.2. Field equipment list for installing a single throughfall sampling station.

Number Req.	Description
10	Funnel apparatuses
12	IER columns (2 are blanks)
10	Perforated filter disks
5	2x4x4 wooden boards
6'	Plumber's tape
5	Lag screws
30	Wood screws
1	Compass for navigation to plots
1	GPS unit for navigation to plots
1	Rite-in-the-Rain notebook
>1	Pencils
1	Backpack for carrying equipment
2	Two-way radios for logistical and emergency communication
1	Insect repellent
1	Sunscreen
1	First Aid kit

Installa tion

Once the materials are prepared, site installations should occur as close to the same time as possible to maintain data consistency. The sites should also be clear of snow to the point where it will not interfere with installation or affect the Ion Exchange Resin (IER) columns.

Bulk Sampling

1. Install the five wooden support posts (Figure B.2).
2. Using a fencepost driver or hammer, pound the posts into the substrate until secure. At minimum, each post should be placed away from the nearest trees by a distance equal to that of the tallest trees in the area. This is to prevent contamination of the samplers by windfall. There should also be a minimum distance of 5m between each post.
3. Depending on soil composition, a hole may need to be dug in order to secure the post deep enough in the ground.
4. For ease of transportation and installation, tall posts may be shortened to a height that still allows the funnel apparatus to be attached above waist level.
5. Install the blank.
6. Attach a single IER column (the blank “control”) to any one of the posts using a hose clamp. Make sure it will not interfere with the funnel that will also be placed on that post.
7. The cap should be left in place on this blank.
8. Install the funnels.
9. Attach one funnel apparatus to the top of each of the five posts using hose clamps.
10. Being careful to minimize hand contact, place a single perforated filter disk in the depression inside of each funnel.
11. Attach a wire bird ring to the top perimeter of each funnel, using a zip-tie to secure the ends together if necessary.
12. Install the IER columns.
13. Remove the plastic cap from each column, making sure to remove the *closed* end and not the one with a drain hole, and ensure that the ball of floss material remains inside the top end of the column and does not stick inside the cap. This serves as an additional means of keeping debris from entering the sampling column.
14. Keep all caps together in a plastic bag for later use and to prevent contamination. These caps are not site-specific.
15. Thread each IER column onto the bottom of a funnel.

Figure B.4. Bulk depositional sampling site at Upper Dewey, Skagway.

Throughfall Sampling

1. Install the five 2x4x4 wooden boards.
2. Attach the wooden boards to suitably sized trees using one lag screw for each, orienting them horizontally. Ideally, these should be placed high enough so that it is difficult for a bear to reach from the ground (approximately 11 feet; Figure B.2).
3. Install the blanks.
4. Attach one uncapped IER column (the blank "control") to two of the five wooden boards, for a total of two blanks per site that are not on the same tree, using plumber's tape and wood screws. They should be placed towards the middle of the board where they will not interfere with funnel installation.
5. Install the funnels.
6. Attach two funnel apparatuses to each board, one on each end, using plumbers tape and wood screws.
7. Being careful to minimize hand contact, place a single perforated filter disk in the depression inside of each funnel.
8. Install the IER columns.
9. Remove the plastic cap from each column, making sure to remove the *closed* end and not the one with a drain hole, and ensure that the ball of floss material remains inside the top end of the column and does not stick inside the cap. This serves as an additional means of keeping debris from entering the sampling column.

10. Keep all caps together in a plastic bag for later use and to prevent contamination. These caps are not site-specific.
11. Thread each IER column onto the bottom of a funnel.

Figure B.5. Throughfall deposition samplers (far left and right) and blank IER column (center).

Once installed, the samplers should not need managing until it comes time to remove them from their sites. However, due to harsh weather events and unpredictable animals, each site should be checked whenever possible. If Ogawa or other weekly air sampling is taking place in the area, this would be an opportune time to check on the sites.

Uninstallation

At the end of the season (approximately October), the samplers will need to be removed and mailed back to the USFS in Riverside, California. All sites should undergo uninstallation as close to the same time as possible in order to maintain data consistency. The funnel apparatuses should also be removed at this time to prevent damage during the winter and for ease of cleaning before reinstallation in the spring.

1. Prepare Ziploc bags for each site by labeling each bag with the site name and number of IER columns that the bag will hold. If the bag will contain a blank(s), note as such.

2. Prepare column labels for each site. Every label should contain the site name, date of installation, date of uninstallation, and column number. For bulk sites, column numbers will be 1–5 and the blank should be labeled “blank #1”. For throughfall sites, column numbers will be 1–10 and blanks will be numbered “blank #1” and “blank #2”.

3. Remove the IER columns by unthreading them from the funnels and replacing the caps that were on them during installation. Apply the prepared labels to each column as they are removed and place them in their corresponding bags, sealing each shut to minimize contamination.

4. Remove the funnels from the posts and boards, being careful to collect the perforated filter disks in Ziploc bags. Used plumbers tape and hose clamps may be left attached to the posts and boards for use in the following season, if desired. The posts and boards themselves should be left in place in the off-season to expedite reinstallation.

5. Package the IER columns into mailing boxes, ensuring that all are contained in sealed bags, and ship to:

   Dr. Mark Fenn
   USDA, Forest Service
   4955 Canyon Crest Dr.
   Riverside, CA 92507
   Phone: (951) 680-1565
   Fax: (951) 680-1501
   Email: mfenn@fs.fed.us

6. All tools and hardware used for installation and management should be stored in the Hern-Clipper office cabinets or the Mascot garage.

Appendix C. Collecting lichens for elemental analysis

Southeast Alaska Air Quality Monitoring Field Methods

Collecting lichen for elemental analysis

Version 1.0 (September 2009)

Revision History Log

Previous Version #	Revision Date	Author	Changes Made	Reasons for Change	New Version #

1. Introduction

The concentrations of chemical elements in lichens from Klondike Gold Rush National Historical Park (KLGO) and neighboring lands in the Skagway area are used to assess local air quality. A pilot study was conducted for lichen-air quality sampling in KLGO in 2000 (Furbish et al. 2000) and concluded that the Klondike-Skagway area exceeded air pollution indication thresholds for the USDA-Forest Service Pacific Northwest and Alaska Regions for toxic metals, sulfur, and other elements (Furbish et al 2000). As a result, an air quality monitoring program was established that includes the collection of lichen samples for elemental analysis. The background and sampling design for air quality monitoring are described in the Manual for Monitoring Air Quality Using Lichens on National Forests of the Pacific Northwest (Geiser 2004). Data from lichen elemental analyses, combined with data from passive air samplers deployed at lichen collection sites, will contribute to the development of models linking ambient air quality to concentrations of pollutants in three lichens with broad distributions in Southeast Alaska.

2. Sample Site Locations and Descriptions for sites in KLGO

Lichens are collected for contaminant analysis from 5 sites in the Skagway and Dyea area: Lower Dewey, Sturgills, Upper Dewey, Chilkoot, and Icy Junction (Figure C.1).

<u>Lower Dewey</u>

This site is situated on a low bench along the lower edge of the 1500 meter ridge that is the east wall of the Skagway River valley, overlooking the Skagway small boat harbor (Figure C.1). The plot elevation ranges from about 50 meters to about 175 meters. The plot slope ranges from about 10 degrees to about 45 degrees, facing west northwest (295 degrees). Vegetative cover is western hemlock- lodgepole pine- Sitka spruce- paper birch woodland in mid-seral stage (pole timber stage). Burn scars remain from a fire 50+ years ago. Understory is sparse, composed of rusty menziesia, feather and other mosses, and foliose and fruticose lichens.

Northing: 0482226 Easting: 6590103 (UTM Zone8 NAD83)
Lat: 59.44909 Long: 135.31339
Elev: 187 meters

<u>Sturgill's</u>

This site sits on a 150 meter high bench at the base of the 1500 meter ridge that is the east wall of the Skagway River valley, approximately 1 kilometer south of the Lower Dewey site (Figure C.1). The Sturgill's 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 menziesia, feather and other mosses, and foliose and fruticose lichens.

Northing: 0481805 Easting: 6588874 (UTM Zone8 NAD83)
Lat: 59.43798 Long: 135.32074
Elev: 151meters

<u>Upper Dewey</u>

This site is located at about 1400 ft. elevation, along the trail to Upper Dewey Lake (Figure C.1).

Northing: 0483228 Easting: 6590196 (UTM Zone8 NAD83)

<u>Icy Junction</u>

This site is located along the trail to Upper Dewey Lake at 1800 ft. along a creek (Figure C.1).

Northing: 0483425 Easting: 6590052 (UTMZone8 NAD83)

<u>Chilkoot</u>

This site sits on a small hill along the Taiya river, known locally as 'Saintly Hill' (Figure C.2). It is accessed by hiking along the first half-mile of the Chilkoot Trail. Saintly Hill is a low section of the AB Mountain ridge that forms the east wall of the Taiya River valley. The plot elevation ranges from 85 to 110 meters. The plot slopes to the west northwest (280 degrees) at 20 to 40 degrees. Vegetative cover is a western hemlock - lodgepole pine - Sitka spruce - paper birch woodland in mid-seral stage. Burn scars remain from a fire 10+ years ago. Understory is sparse, composed of rusty menziesia, shag, feather and other mosses, and foliose and fruticose lichens.

Northing: 0480747 Easting: 6597927 (UTM Zone8 NAD83)
Elev: 147 meters

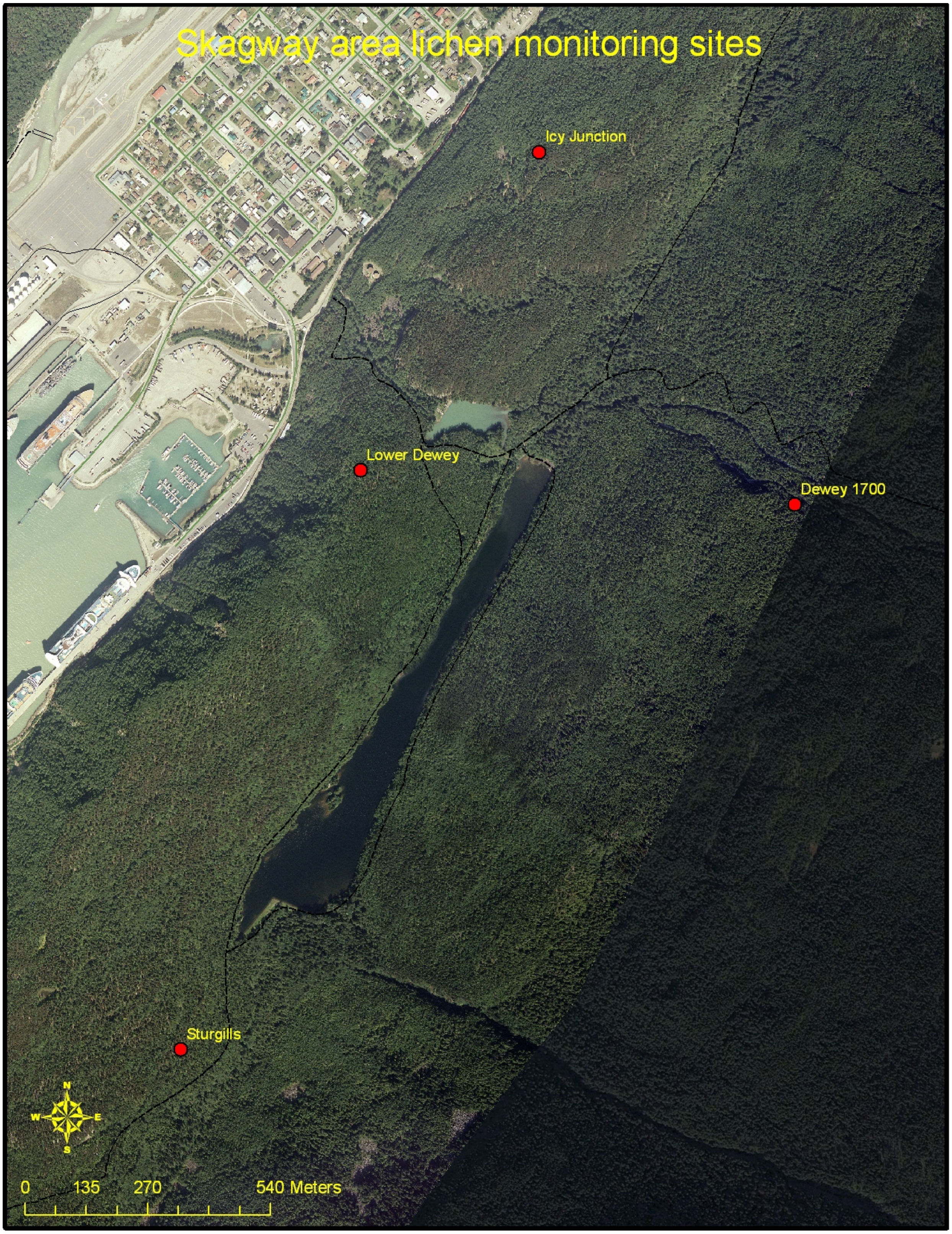


Figure C.1. Skagway area lichen monitoring sites for collection of elemental analysis lichen tissue.

Figure C.2. Elemental analysis lichen tissue is collected from the Chilkoot site in Dyea.

3. Field Schedule

Sampling is conducted from mid-August to the end of September.

4. **Equipment and Supplies**

- 4 x 7” metalized polyester sample bags (Kapak bags), stored in gallon-size Ziploc bags
- Non-powdered, disposable vinyl or nitrile gloves, one pair of gloves per plot stored in Ziploc bags
- 100 g Pesola spring scale
- Rolls of laboratory tape (VWR ¾”)
- Black waterproof markers
- 100% cotton herbarium blotter sheets (11.5 x 16”), replace as they become visibly stained or smudged
- Dissecting kit

5. **Field Methods**

5.1 What to collect

Three lichen species are collected at each site: *Hypogymnia enteromorpha*, *Hypogymnia inactive*, and *Platismatia glauca* (Figure C.3). It is imperative to correctly identify the lichen and distinguish them from other lichen species that have similar characteristics. Training and use of the lichen photos and descriptions are useful in identifying the three lichen species to be collected.

Hypogymnia enteromorpha *Hypogymnia inactiva* *Platismatia glauca*

Figure C.3. Three lichen species are collected at each monitoring site.

5.2 Where to collect

Lichen samples are collected outside of each monitoring plot but not more than 1 km (.65 miles) away from the plot perimeter. The target species should be collected from a minimum of 8 different locations near the site. Lichens attached to tree branches, shrubs or tree boles, and, if fresh, in the litter or on fallen branches, may be used.

5.3 How to collect

Samples should be collected with the fingers. New non-powdered vinyl or nitrile gloves are worn at each site to prevent contamination of the samples. While wearing gloves the field crew should not touch anything brought with them onto the plot except the Kapak bag. Unused Kapak bags should be stored in a clean zip-loc plastic bag. New gloves will be used at each plot and replaced if they become torn or contaminated.

A sample consists of at least 14 grams of clean, dry lichen. Collect 3 bags of each of the 3 lichen species at every site. Each site will have a total of 9 bags collected. The exception is the Upper Dewey site, where *Hypogymnia inactiva* is not found. At Upper Dewey, there will be a total of 6 bags of lichen collected. Do not mix lichen species in one bag. Samples should be collected as clean and free from bark and other foreign surface material as practical and will be cleaned carefully later in the office. Dusty, gritty, discolored, or decaying material should be avoided.

Place samples in metalized polyester Kapak bags and weigh on a 100-gram Pesola spring scale. Empty Kapak bags weigh 10 grams each. If the lichens are dry, the sample and bag together should weigh at least 24 g. If the lichens are wet, adequacy of the sample size should be judged by volume rather than weight. Dry lichens may weigh only 5 % of the wet weight. After enough material has been collected, press out excess air, fold the open edge of the bag over three times, and carefully seal with waterproof, removable, laboratory tape. The bag should be airtight. Sealed, airtight, sample bags should be placed in clean zip-loc plastic bag, which is sealed in turn, and placed in a shady location or inside a daypack so they do not overheat while the remaining work on the plot is performed.

5.4 What to record

The following information should be recorded directly on the Kapak bag with an indelible marker:

1. Plot name
2. Date
3. Substrate(s): Host species name and substrate location in order by the amount of sample in the bag from that substrate. E.g., *"Pinus contorta* branches and boles"
4. Target species acronym (Hypent, Hypina, or Plagla)
5. Collector's initials
6. Moisture status of sample at the time of collection: dry, damp, or wet.

5.5 Drying and cleaning lichens

Samples should be cleaned and air dried as quickly as possible after returning from the field, preferably the same day. Dry lichens make a crunch sound when the Kapak bag is squeezed; if the contents feel soft, they are damp (even if marked 'dry' by the field crew) and need to be dried to avoid decomposition of the samples. If unsure of the moisture status, dry the sample. Spread the lichens onto a clean 100% acid free blotter paper laid over a flat surface covered with clean plastic wrap. Label blotters so that sample identity is retained. Using tweezers from a dissection kit, and while wearing clean disposable gloves, clean the lichen specimens. Lichen are cleaned by removing insects, spiders, loose leaves and any twigs, bark or non-target lichens adhering to the lichen tissue.

Leave lichen on blotter paper to dry. Lichens and mosses should not be air-dried in areas subject to contamination (e.g., near cooking areas, roads, or in rooms where organic solvents are used, dust levels are high, or smoking is permitted). Kapak bags can be dried by crimping them open and leaving them upright, or by hanging them open on a line with a clothespin. Once dry, place the lichens back in the dried Kapak bags and carefully reseal. Sealed bags should be airtight. Specimens must be thoroughly air dried to avoid fungal decay. Store dry samples in a clean, dry, dark place (bags are not opaque).

5.6 Sample delivery

Dried, resealed samples are mailed to a laboratory for elemental analysis. Bags should be packed closely, but without excessive crushing, in a sturdy cardboard box. Bags from several plots can be mailed in the same box. A packing list should be kept by the field crew specifying the plot number, forest, species, and mailing date of each sample.

Specimens are sent to:

Research Analytical Laboratory
University of Minnesota
135 Crops Research Building
1902 Dudley Avenue
St. Paul, Minnesota 55108

Please insure that a contract (or agreement) is in place for analysis work costing more than the government credit card limit.

Details of the laboratory methods can be found at the University of Minnesota web site (http://ral.coafes.umn.edu).

5.7 Common problems and solutions

If none, or only one, of the target species is present in sufficient quantities for collection, even if the sampling area is expanded to the 1 km maximum sampling radius, then no samples or only one sample should be collected. Do not substitute non-target species.

If more than 1 hour has been spent collecting but sample weight is still very low, get help from other crew members or switch to a more easily collected target species. Usually it's a good idea to stop collecting after two hours and process the collection that has been made. The decision to send the sample to the laboratory will be made in the office after the sample is cleaned.

It is not acceptable for all of the sample material to come from one or two trees. The material must evenly represent at least eight locations. Expand the area of collection up to the maximum size allowed. If material is still too scarce, collect a different species or collect nothing.

Field collection methods require careful discrimination among species in the field and should only be performed by people who have completed lichen identification training. Because of the potential for lead and other heavy metal contamination, no smoking is allowed on the plot or in the vicinity of the plot during the visit.

References

Furbish, C. E., L. Geiser, and C. Rector. 2000. Lichen-air quality pilot study for Klondike Gold Rush National Historical Park and the city of Skagway, Alaska. Klondike Gold Rush National Historical Park Natural Resources Management Program. Unpublished. 49 pp.

Geiser, L. 2004. Manual for monitoring air quality using lichens on national forests of the Pacific Northwest. USDA-Forest Service Pacific Northwest Region Technical Paper, R6-NR-AQ-TP-1-04. 126pp.

McCune, B., and L. Geiser. 2009. Macrolichens of the Pacific Northwest. Oregon State University Press, Corvallis, OR. 464 pp.

Species that are easy to confuse with one another:

1. ***Hypogymnia enteromorpha* and *apinnata***. Separated definitively by a P test though generally *H. apinnata* lacks the small side buds and can have a more appressed, “melted” look. Study examples in the herbarium and in *Macrolichens of the Pacific Northwest* (McCune and Geiser 2009). Because *H. apinnata* was described after the first round of monitoring was completed on the Tongass NF, it is assumed that historic collections were a mix of these two species. For this reason, it is not considered essential to separate the two species in new collections.

2. ***H. occidentalis and enteromorpha***: *H. occidentalis* is usually narrower lobed and more appressed than *H. enteromorpha*. The upper surface of *H. occidentalis* has a dark, continuous margin and older parts are more rugose than *H. enteromorpha*. *H. occidentalis* and *enteromorpha* can be definitively separated in the office with a P test.

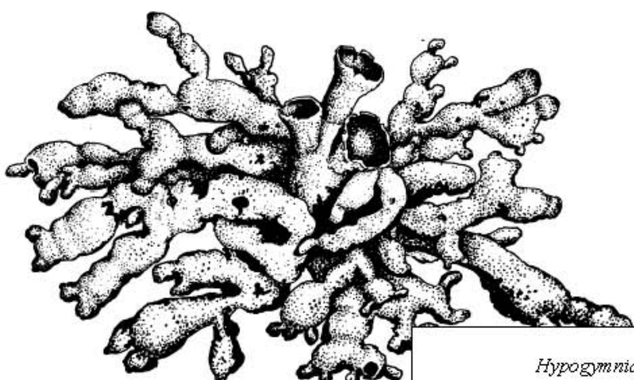
3. ***H. inactiva* and *H. imshaugii***. These species are easily confused. Check insides of lobes in several places. *H. imshaugii* is white inside throughout; *H. inactiva* has a black floor.

4. ***Platismatia glauca* and *norvegica*.** *P.glauca* has no distinct ridges or veins.

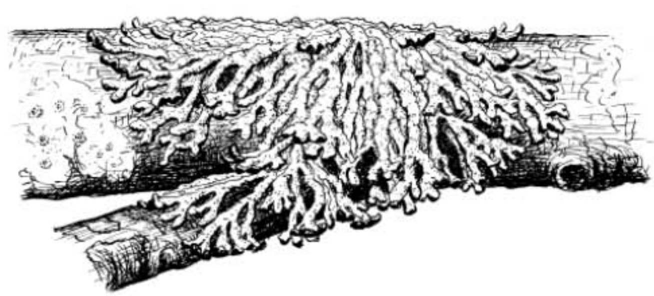
Hypogymnia physodes
- flattened
- powder tips
- inflated tips

Hypogymnia inactiva – only been found on shore pine so far
- hollow lobes
- rounded lobes
- dark on inside
- never dust on tips
- closed tips
- lobe interior is dark
- upright growth pattern

Hypogymnia enteromorpha
- heavyweight
- constricted lateral lobes (pinched at the base of the lobe) – careful to distinguish lateral lobes from end lobes and apothesia (cup-like sex organs)
- often hugging branch closer than *H. apinnata*

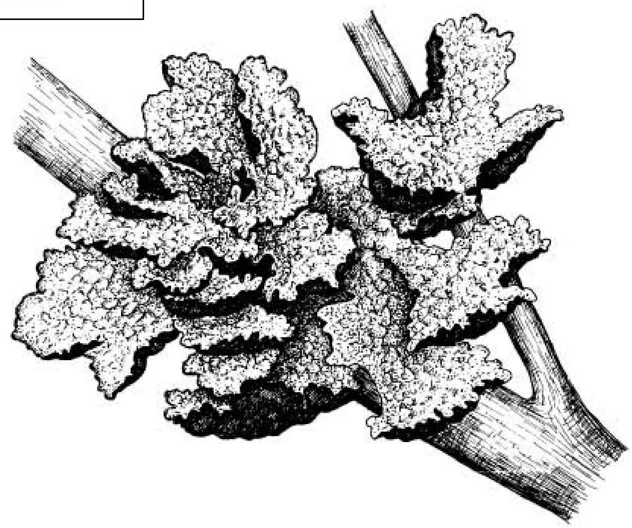


Hypogymnia apinnata
- super heavyweight
- often hanging from branch (vs. clinging *H. enteromorpha*)
- often green-grey (vs. white *H. occidentalis*)
- "bean pod" shape

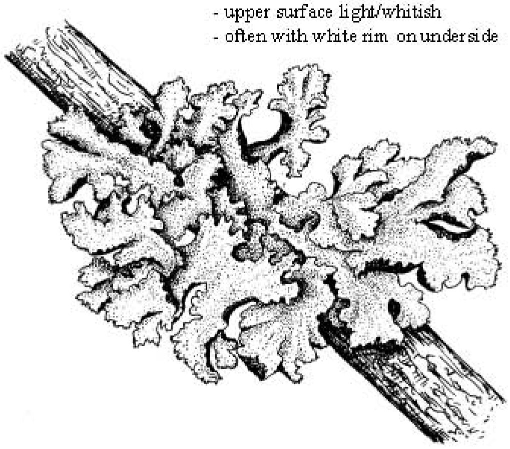


Hypogymnia occidentalis
- bulky but not as "heavy" as H. enteromorpha or apinnata
- whiter than H. apinnata

Plastismatia norvegica
- distinct ridges/veins



Platismatia glauca
- no ridges/veins
- no rhizines
- foliate
- upper surface light/whitish
- often with white rim on underside



Parmelia sp.
- rhizines (small nodes on underside)

Appendix D. Membrane sampler exposure periods

Table D.1. 2008 Ogawa / membrane sampler exposure period (date on, date off, number of days) by site.

2008 Sampler Exposure Period		Site							
Period	**Dates on/off and days**	**Bartlett Cove**	**Chilkoot Saintly Hill**	**Dewey 1700'**	**Dyea**	**Lower Dewey**	**Sturgills**	**Icy Junction**	**Sitka**
EXP01	Date on				4/28/08	5/1/08			4/30/08
	Date off				5/6/08	5/8/08			5/7/08
	# Days				7.8	7.0			7.1
EXP02	Date on		5/7/08		5/6/08	5/8/08	5/6/08	5/9/08	5/7/08
	Date off		5/14/08		5/14/08	5/15/08	5/15/08	5/15/08	5/14/08
	# Days		6.9		8.1	7.2	9.1	5.9	7.0
EXP03	Date on	5/11/08	5/14/08		5/14/08	5/15/08	5/15/08	5/15/08	5/14/08
	Date off	5/21/08	5/21/08		5/21/08	5/22/08	5/22/08	5/22/08	5/21/08
	# Days	9.9	7.0		7.0	7.0	7.0	7.0	7.0
EXP04	Date on	5/21/08	5/21/08		5/21/08	5/22/08	5/22/08	5/22/08	5/21/08
	Date off	5/28/08	5/28/08		5/28/08	5/29/08	5/29/08	5/29/08	5/28/08
	# Days	7.1	7.2		7.2	6.9	7.0	7.0	7.0
EXP05	Date on	5/28/08							5/28/08
	Date off	6/4/08							6/4/08
	# Days	6.7							7.0
EXP06	Date on	6/4/08	6/4/08		6/4/08	6/3/08	6/3/08	6/3/08	6/4/08
	Date off	6/10/08	6/11/08		6/11/08	6/10/08	6/10/08	6/10/08	6/11/08
	# Days	6.1	6.7		6.8	7.1	7.1	7.1	7.0
EXP07	Date on	6/10/08	6/11/08		6/11/08	6/10/08	6/10/08	6/10/08	6/11/08
	Date off	6/18/08	6/18/08		6/18/08	6/17/08	6/17/08	6/17/08	6/18/08
	# Days	8.0	7.0		7.1	6.8	6.8	6.9	7.0
EXP08	Date on	6/18/08	6/18/08		6/18/08	6/17/08	6/17/08	6/17/08	6/18/08
	Date off	6/25/08	6/25/08		6/25/08	6/24/08	6/24/08	6/24/08	6/25/08
	# Days	7.1	7.0		7.1	6.8	6.8	6.8	7.0
EXP09	Date on	6/25/08	6/25/08	6/24/08	6/25/08	6/24/08	6/24/08		6/25/08
	Date off	7/2/08	7/2/08	7/1/08	7/2/08	7/1/08	7/1/08		7/2/08
	# Days	6.8	7.0	7.1	6.8	7.2	7.2		7.0
EXP10	Date on	7/2/08	7/2/08	7/1/08	7/2/08	7/1/08	7/1/08		7/2/08
	Date off	7/9/08	7/9/08	7/8/08	7/9/08	7/8/08	7/8/08		7/9/08
	# Days	6.9	7.0	6.9	6.9	6.9	6.9		7.0
EXP11	Date on	7/9/08	7/9/08	7/8/08	7/9/08	7/8/08	7/8/08		7/9/08
	Date off	7/16/08	7/16/08	7/15/08	7/16/08	7/15/08	7/15/08		7/16/08
	# Days	7.4	7.1	7.1	7.0	7.1	7.1		7.0
EXP12	Date on	7/16/08	7/16/08	7/15/08	7/16/08	7/15/08	7/15/08		7/16/08
	Date off	7/23/08	7/23/08	7/22/08	7/23/08	7/22/08	7/22/08		7/23/08
	# Days	7.0	7.1	7.0	7.1	6.9	6.9		6.9
EXP13	Date on	7/23/08	7/23/08	7/22/08	7/23/08	7/22/08	7/22/08		7/23/08

2008 Sampler Exposure Period		Site							
Period	**Dates on/off and days**	**Bartlett Cove**	**Chilkoot Saintly Hill**	**Dewey 1700'**	**Dyea**	**Lower Dewey**	**Sturgills**	**Icy Junction**	**Sitka**
	Date off	7/30/08	7/30/08	7/29/08	7/30/08	7/29/08	7/29/08		7/30/08
	# Days	7.0	6.8	6.9	7.0	6.9	6.9		7.0
EXP14	Date on	7/30/08	7/30/08	7/29/08	7/30/08	7/29/08	7/29/08		7/30/08
	Date off	8/6/08	8/6/08	8/5/08	8/6/08	8/5/08	8/5/08		8/6/08
	# Days	7.0	7.2	7.1	7.0	7.0	7.0		7.1
EXP15	Date on	8/6/08	8/6/08	8/5/08	8/6/08	8/5/08	8/5/08		8/6/08
	Date off	8/14/08	8/13/08	8/12/08	8/13/08	8/12/08	8/12/08		8/14/08
	# Days	7.9	7.0	7.1	7.1	7.1	7.1		8.0
EXP16	Date on	8/14/08	8/13/08	8/12/08	8/13/08	8/12/08	8/12/08		8/14/08
	Date off	8/21/08	8/20/08	8/19/08	8/20/08	8/19/08	8/19/08		8/20/08
	# Days	7.0	6.8	6.8	7.0	6.8	6.8		5.9
EXP17	Date on	8/21/08	8/20/08	8/19/08	8/20/08	8/19/08	8/19/08		8/20/08
	Date off	8/28/08	8/27/08	8/26/08	8/27/08	8/26/08	8/26/08		8/27/08
	# Days	6.9	7.2	7.2	7.0	7.4	7.3		7.1
EXP18	Date on	8/28/08	8/27/08	8/26/08	8/27/08	8/26/08	8/26/08		8/27/08
	Date off	9/10/08	9/3/08	9/2/08	9/3/08	9/2/08	9/2/08		9/3/08
	# Days	13.1	7.0	7.0	7.0	6.8	6.9		7.0
EXP19	Date on	8/28/08	9/3/08	9/2/08	9/3/08	9/2/08	9/2/08		9/3/08
	Date off	9/10/08	9/10/08	9/9/08	9/10/08	9/9/08	9/9/08		9/10/08
	# Days	13.1	7.0	7.0	7.0	7.0	7.0		7.0
EXP20	Date on	9/10/08	9/10/08	9/9/08	9/10/08	9/9/08	9/9/08		9/10/08
	Date off	9/17/08	9/17/08	9/16/08	9/17/08	9/16/08	9/16/08		9/17/08
	# Days	6.9	7.0	7.0	7.0	7.2	7.1		7.0
EXP21	Date on	9/17/08	9/17/08	9/16/08	9/17/08	9/16/08	9/16/08		9/17/08
	Date off	9/24/08	9/24/08	9/23/08	9/24/08	9/23/08	9/23/08		9/24/08
	# Days	7.2	7.0	7.1	7.0	6.9	6.9		7.0
EXP22	Date on	9/24/08	9/24/08	9/23/08	9/24/08	9/23/08	9/23/08		9/24/08
	Date off	10/1/08	10/22/08	9/30/08	10/1/08	9/30/08	9/30/08		10/1/08
	# Days	6.8	28.0	7.0	7.1	7.0	7.0		7.0
EXP23	Date on	10/1/08		9/30/08	10/1/08	9/30/08	9/30/08		10/1/08
	Date off	10/19/08		10/18/08	10/28/08	10/14/08	10/14/08		10/8/08
	# Days	18.3		17.8	26.9	14.0	14.0		7.0

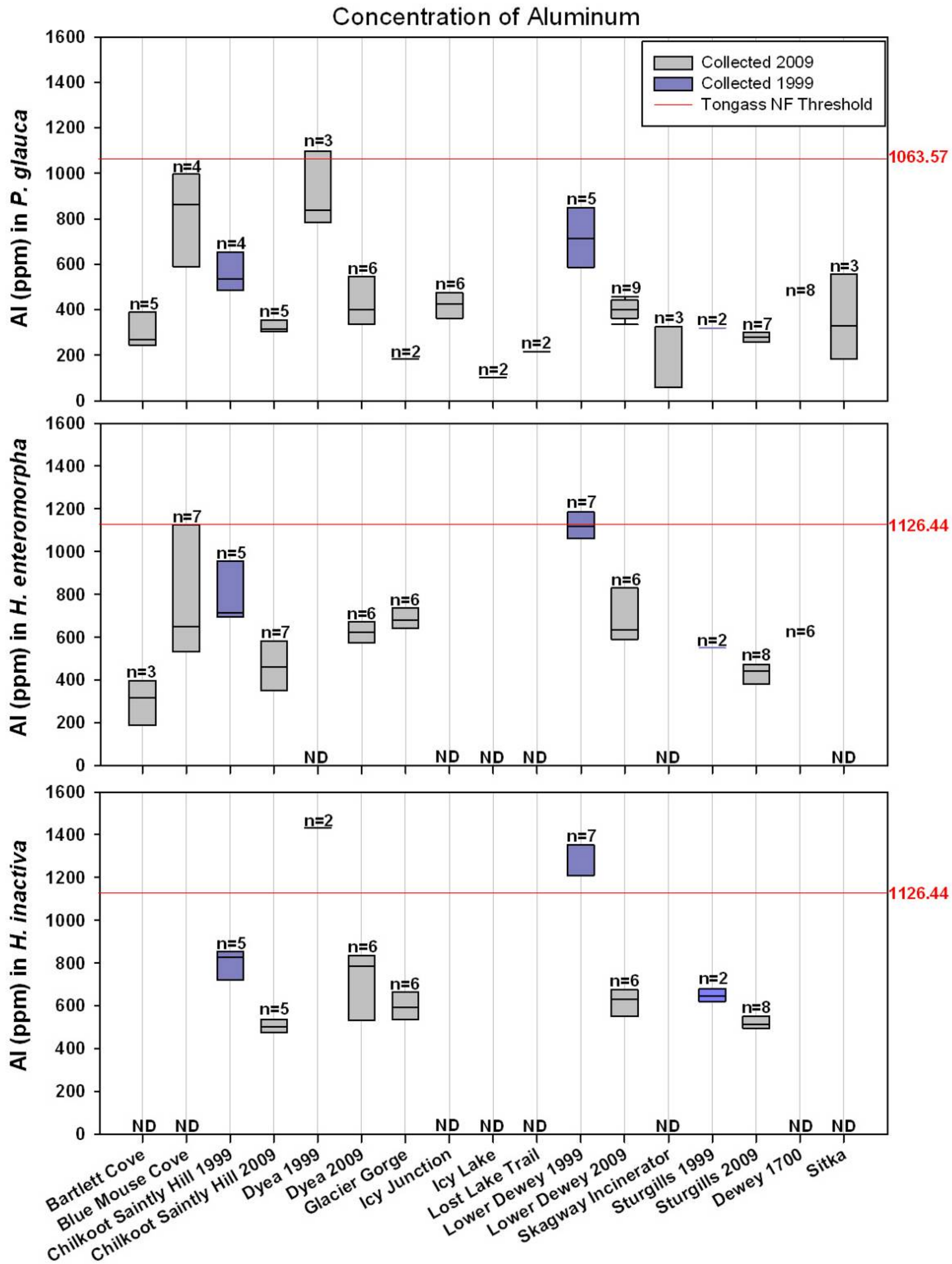
Table D.2. 2009 Ogawa / membrane sampler exposure periods (date on, date off, number of days) by site.

2009 Sampler Exposure Period		Site						
Period	Dates on/off and days	Bartlett Cove	Chilkoot Saintly Hill	Dewey 1700'	Dyea	Lower Dewey	Sturgills	Sitka
EXP0901	Date on	4/22/2009	4/23/2009	4/21/2009	4/24/2009	4/21/2009	4/21/2009	4/22/2009
	Date off	4/30/2009	4/30/2009	4/29/2009	4/30/2009	4/29/2009	4/29/2009	4/29/2009
	Max of # days	7.7	7.0	7.9	6.3	8.2	8.0	7.0
EXP0902	Date on	4/30/2009	4/30/2009	4/29/2009	4/30/2009	4/29/2009	4/29/2009	4/29/2009
	Date off	5/7/2009	5/7/2009	5/6/2009	5/7/2009	5/6/2009	5/6/2009	5/6/2009
	Max of # days	7.3	7.0	7.0	6.7	6.8	6.9	7.0
EXP0903	Date on	5/7/2009	5/7/2009	5/6/2009	5/7/2009	5/6/2009	5/6/2009	5/6/2009
	Date off	5/13/2009	5/14/2009	5/13/2009	5/14/2009	5/13/2009	5/13/2009	5/13/2009
	Max of # days	6.0	7.0	7.0	7.1	7.0	7.0	6.9
EXP0904	Date on	5/13/2009	5/14/2009	5/13/2009	5/14/2009	5/13/2009	5/13/2009	5/13/2009
	Date off	5/20/2009	5/21/2009	5/20/2009	5/21/2009	5/20/2009	5/20/2009	5/20/2009
	Max of # days	7.0	6.9	7.0	6.9	7.0	7.1	7.0
EXP0905	Date on	5/20/2009	5/21/2009	5/20/2009	5/21/2009	5/20/2009	5/20/2009	5/20/2009
	Date off	5/27/2009	5/28/2009	5/27/2009	5/28/2009	5/27/2009	5/27/2009	5/27/2009
	Max of # days	7.0	6.9	7.0	7.0	6.9	6.8	7.0
EXP0906	Date on	5/27/2009	5/28/2009	5/27/2009	5/28/2009	5/27/2009	5/27/2009	5/27/2009
	Date off	6/3/2009	6/4/2009	6/3/2009	6/4/2009	6/3/2009	6/3/2009	6/3/2009
	Max of # days	6.8	7.1	6.8	7.1	6.8	6.8	7.0
EXP0907	Date on	6/3/2009	6/4/2009	6/3/2009	6/4/2009	6/3/2009	6/3/2009	6/3/2009
	Date off	6/10/2009	6/11/2009	6/10/2009	6/11/2009	6/10/2009	6/10/2009	6/10/2009
	Max of # days	7.2	7.0	7.1	7.0	7.2	7.1	7.0
EXP0908	Date on	6/10/2009	6/11/2009	6/10/2009	6/11/2009	6/10/2009	6/10/2009	6/10/2009
	Date off	6/18/2009	6/18/2009	6/17/2009	6/18/2009	6/17/2009	6/17/2009	6/17/2009
	Max of # days	8.1	7.0	7.1	7.1	7.0	7.3	7.0
EXP0909	Date on	6/18/2009	6/18/2009	6/17/2009	6/18/2009	6/17/2009	6/17/2009	6/17/2009
	Date off	6/24/2009	6/25/2009	6/24/2009	6/25/2009	6/24/2009	6/24/2009	6/24/2009
	Max of # days	5.9	7.0	7.0	6.9	7.0	6.9	7.0
EXP0910	Date on	6/24/2009	6/25/2009	6/24/2009	6/25/2009	6/24/2009	6/24/2009	6/24/2009
	Date off	7/1/2009	7/2/2009	7/1/2009	7/2/2009	7/1/2009	7/1/2009	7/1/2009
	Max of # days	7.0	7.0	7.0	7.0	7.0	7.0	7.0
EXP0911	Date on	7/1/2009	7/2/2009	7/1/2009	7/2/2009	7/1/2009	7/1/2009	7/1/2009
	Date off	7/10/2009	7/9/2009	7/8/2009	7/9/2009	7/8/2009	7/8/2009	7/8/2009
	Max of # days	8.7	7.0	6.8	6.9	6.8	6.8	7.0
EXP0912	Date on	7/10/2009	7/9/2009	7/8/2009	7/9/2009	7/8/2009	7/8/2009	7/8/2009
	Date off	7/15/2009	7/16/2009	7/15/2009	7/16/2009	7/15/2009	7/15/2009	7/15/2009
	Max of # days	5.3	7.1	7.0	7.3	7.0	7.0	7.0
EXP0913	Date on	7/16/2009	7/16/2009	7/15/2009	7/16/2009	7/15/2009	7/15/2009	7/15/2009
	Date off	7/23/2009	7/23/2009	7/22/2009	7/23/2009	7/22/2009	7/22/2009	7/22/2009
	Max of # days	7.0	6.7	7.2	6.7	7.3	7.5	7.0
EXP0914	Date on	7/23/2009	7/23/2009	7/22/2009	7/23/2009	7/22/2009	7/22/2009	7/22/2009

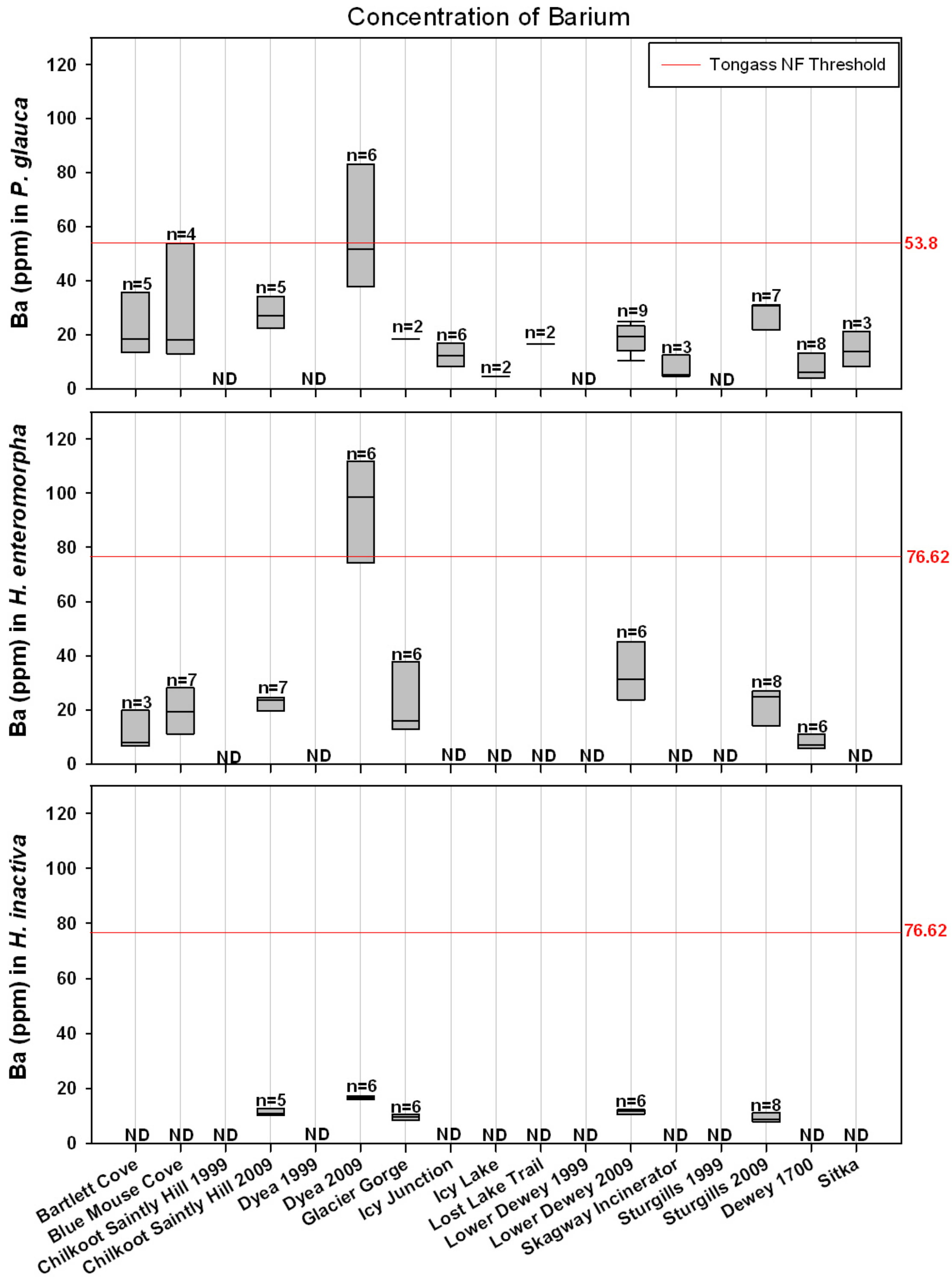
2009 Sampler Exposure Period		Site						
Period	**Dates on/off and days**	**Bartlett Cove**	**Chilkoot Saintly Hill**	**Dewey 1700'**	**Dyea**	**Lower Dewey**	**Sturgills**	**Sitka**
	Date off	7/29/2009	7/30/2009	7/29/2009	7/30/2009	7/29/2009	7/29/2009	7/29/2009
	Max of # days	6.0	7.2	6.9	7.1	6.9	6.7	7.0
EXP0915	Date on	7/29/2009	7/30/2009	7/29/2009	7/30/2009	7/29/2009	7/29/2009	7/29/2009
	Date off	8/6/2009	8/6/2009	8/5/2009	8/6/2009	8/5/2009	8/5/2009	8/5/2009
	Max of # days	8.2	7.1	6.8	7.3	6.8	6.8	7.0
EXP0916	Date on	8/6/2009	8/6/2009	8/5/2009	8/6/2009	8/5/2009	8/5/2009	8/5/2009
	Date off	8/12/2009	8/13/2009	8/12/2009	8/13/2009	8/12/2009	8/12/2009	8/12/2009
	Max of # days	6.0	6.8	7.1	6.9	7.1	7.1	7.0
EXP0917	Date on	8/12/2009	8/13/2009	8/12/2009	8/13/2009	8/12/2009	8/12/2009	8/12/2009
	Date off	8/21/2009	8/20/2009	8/19/2009	8/20/2009	8/19/2009	8/19/2009	8/19/2009
	Max of # days	8.8	7.1	7.2	7.0	6.9	6.9	7.0
EXP0918	Date on	8/21/2009	8/20/2009	8/19/2009	8/20/2009	8/19/2009	8/19/2009	8/19/2009
	Date off	8/31/2009	8/27/2009	8/26/2009	8/27/2009	8/26/2009	8/26/2009	8/26/2009
	Max of # days	10.0	6.9	6.8	0.0	7.3	7.2	7.0
EXP0919	Date on	8/31/2009	8/27/2009	8/26/2009	8/27/2009	8/26/2009	8/26/2009	8/26/2009
	Date off	9/4/2009	9/3/2009	9/2/2009	9/3/2009	9/2/2009	9/2/2009	9/2/2009
	Max of # days	3.9	6.8	7.1	6.9	6.8	6.9	7.0
EXP0920	Date on	9/4/2009	9/3/2009	9/2/2009	9/3/2009	9/2/2009	9/2/2009	9/2/2009
	Date off	9/10/2009	9/10/2009	9/9/2009	9/10/2009	9/9/2009	9/9/2009	9/9/2009
	Max of # days	6.2	7.1	7.1	7.1	7.1	7.1	7.0
EXP0921	Date on	9/10/2009	9/10/2009	9/9/2009	9/10/2009	9/9/2009	9/9/2009	9/9/2009
	Date off	9/17/2009	9/17/2009	9/16/2009	9/17/2009	9/16/2009	9/16/2009	9/16/2009
	Max of # days	7.2	6.9	6.9	6.9	7.1	6.9	7.0
EXP0922	Date on	9/17/2009	9/17/2009	9/16/2009	9/17/2009	9/16/2009	9/16/2009	9/16/2009
	Date off	9/25/2009	9/24/2009	9/23/2009	9/23/2009	9/23/2009	9/23/2009	9/23/2009
	Max of # days	7.8	7.2	7.0	6.2	7.0	7.2	7.0
EXP0923	Date on	9/25/2009		9/30/2009		9/23/2009	9/23/2009	9/23/2009
	Date off	10/1/2009		10/7/2009		9/30/2009	9/30/2009	9/30/2009
	Max of # days	5.9		7.0		7.0	7.0	7.0
EXP0924	Date on	10/1/2009				9/30/2009	9/30/2009	9/30/2009
	Date off	10/16/2009		10/7/2009		10/8/2009	10/7/2009	10/7/2009
	Max of # days	15.3				8.1	7.0	7.0
EXP0925	Date on							10/7/2009
	Date off	10/16/2009						10/14/2009
	Max of # days							7.0

Appendix E. Elemental concentrations in lichen tissue

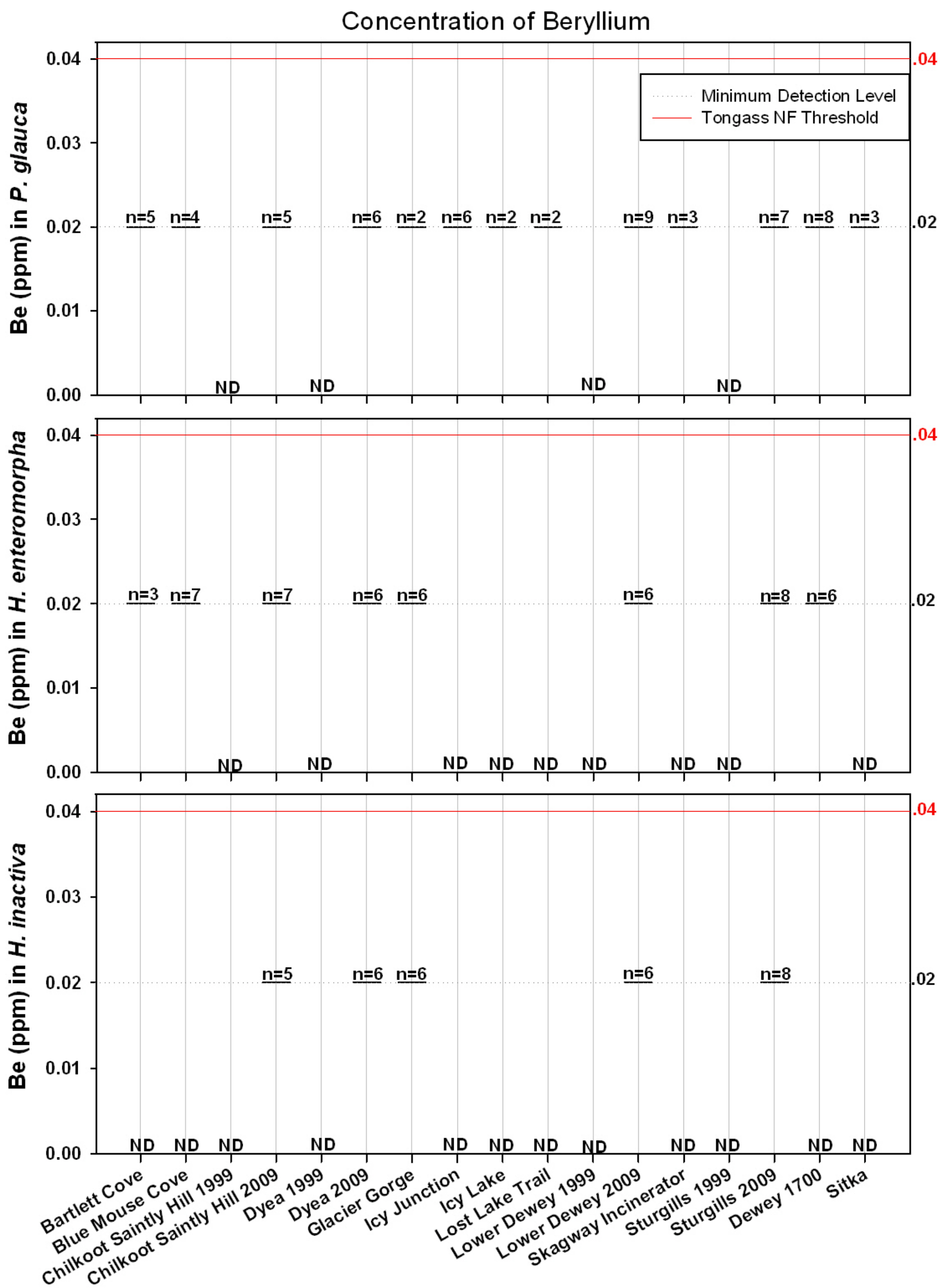
Aluminum



Barium

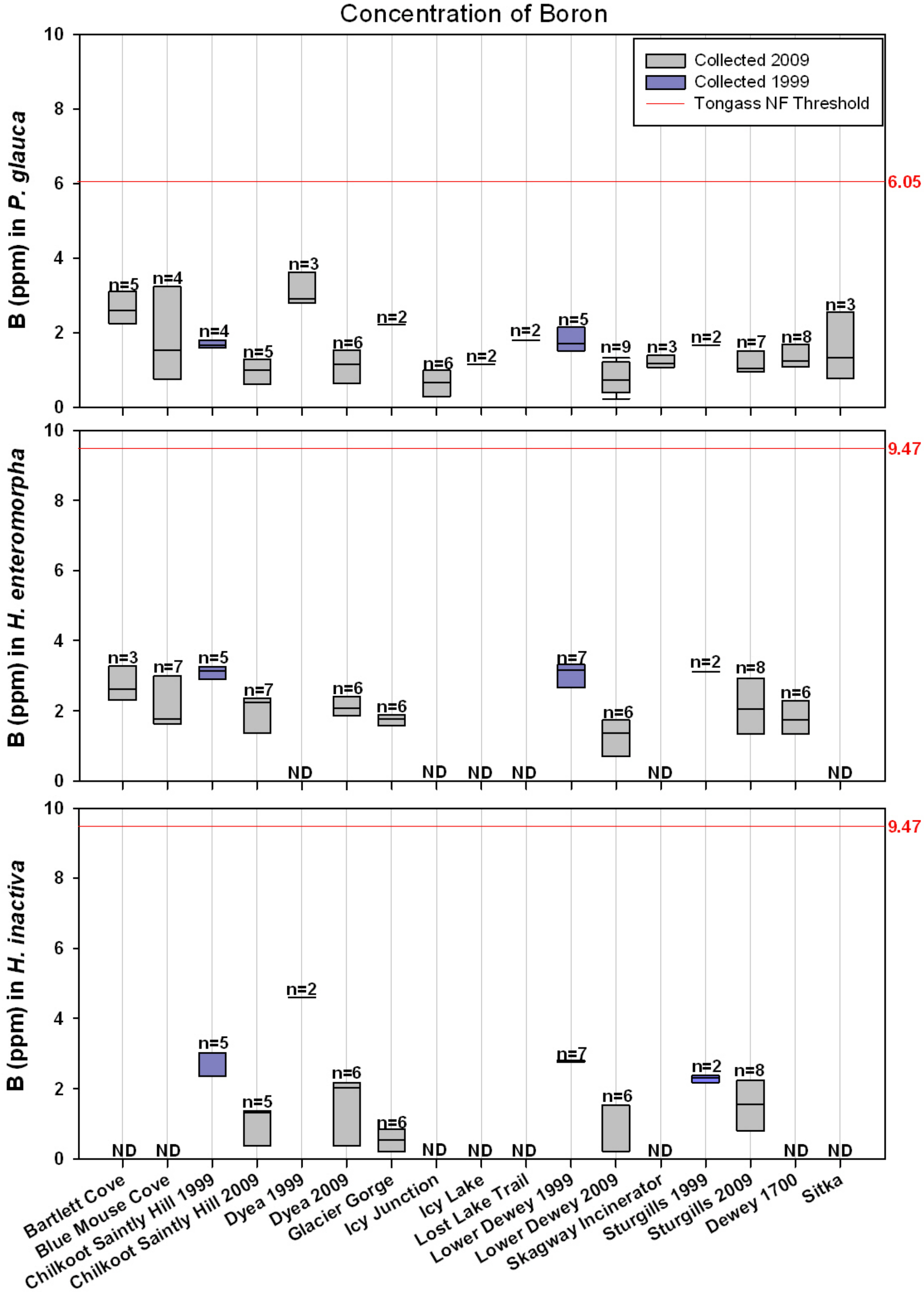

Concentration of Barium
Tongass NF Threshold
Ba (ppm) in P. glauca
53.8
Ba (ppm) in H. enteromorpha
76.62
Ba (ppm) in H. inactiva
76.62
0
20
40
60
80
100
120
n=5
n=4
n=6
n=2
n=9
n=3
n=7
n=8
ND
Bartlett Cove
Blue Mouse Cove
Chilkoot Saintly Hill 1999
Chilkoot Saintly Hill 2009
Dyea 1999
Dyea 2009
Glacier Gorge
Icy Junction
Icy Lake
Lost Lake Trail
Lower Dewey 1999
Lower Dewey 2009
Skagway Incinerator
Sturgills 1999
Sturgills 2009
Dewey 1700
Sitka

Beryllium

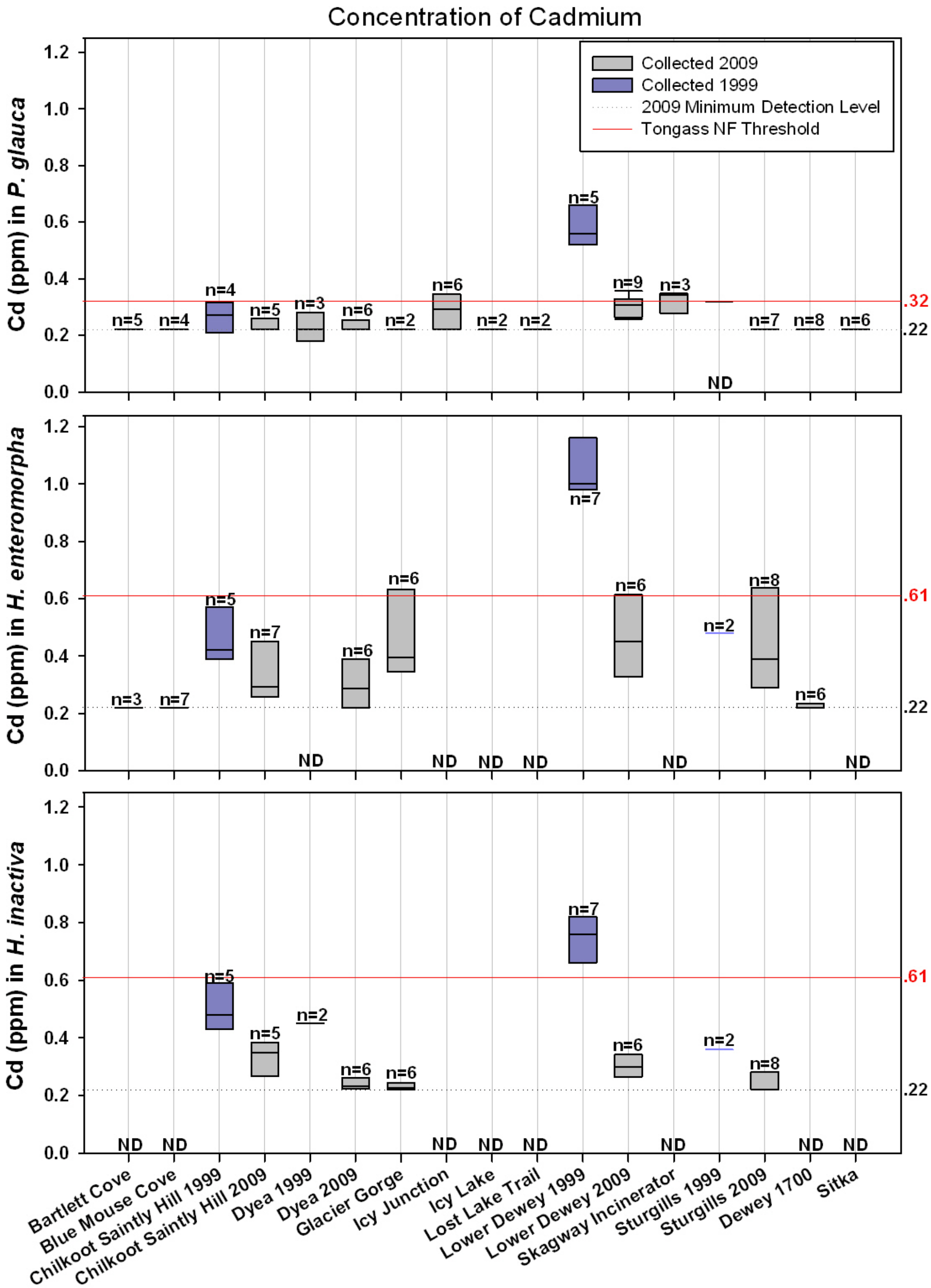


Concentration of Beryllium
Minimum Detection Level
Tongass NF Threshold
Be (ppm) in *P. glauca*
Be (ppm) in *H. enteromorpha*
Be (ppm) in *H. inactiva*
0.04
0.03
0.02
0.01
0.00
.04
.02
n=5 n=4 n=5 n=6 n=2 n=6 n=2 n=2 n=9 n=3 n=7 n=8 n=3
ND
n=3 n=7 n=7 n=6 n=6 n=6 n=8 n=6
n=5 n=6 n=6 n=6 n=8
Bartlett Cove
Blue Mouse Cove
Chilkoot Saintly Hill 1999
Chilkoot Saintly Hill 2009
Dyea 1999
Dyea 2009
Glacier Gorge
Icy Junction
Icy Lake
Lost Lake Trail
Lower Dewey 1999
Lower Dewey 2009
Skagway Incinerator
Sturgills 1999
Sturgills 2009
Dewey 1700
Sitka

Boron

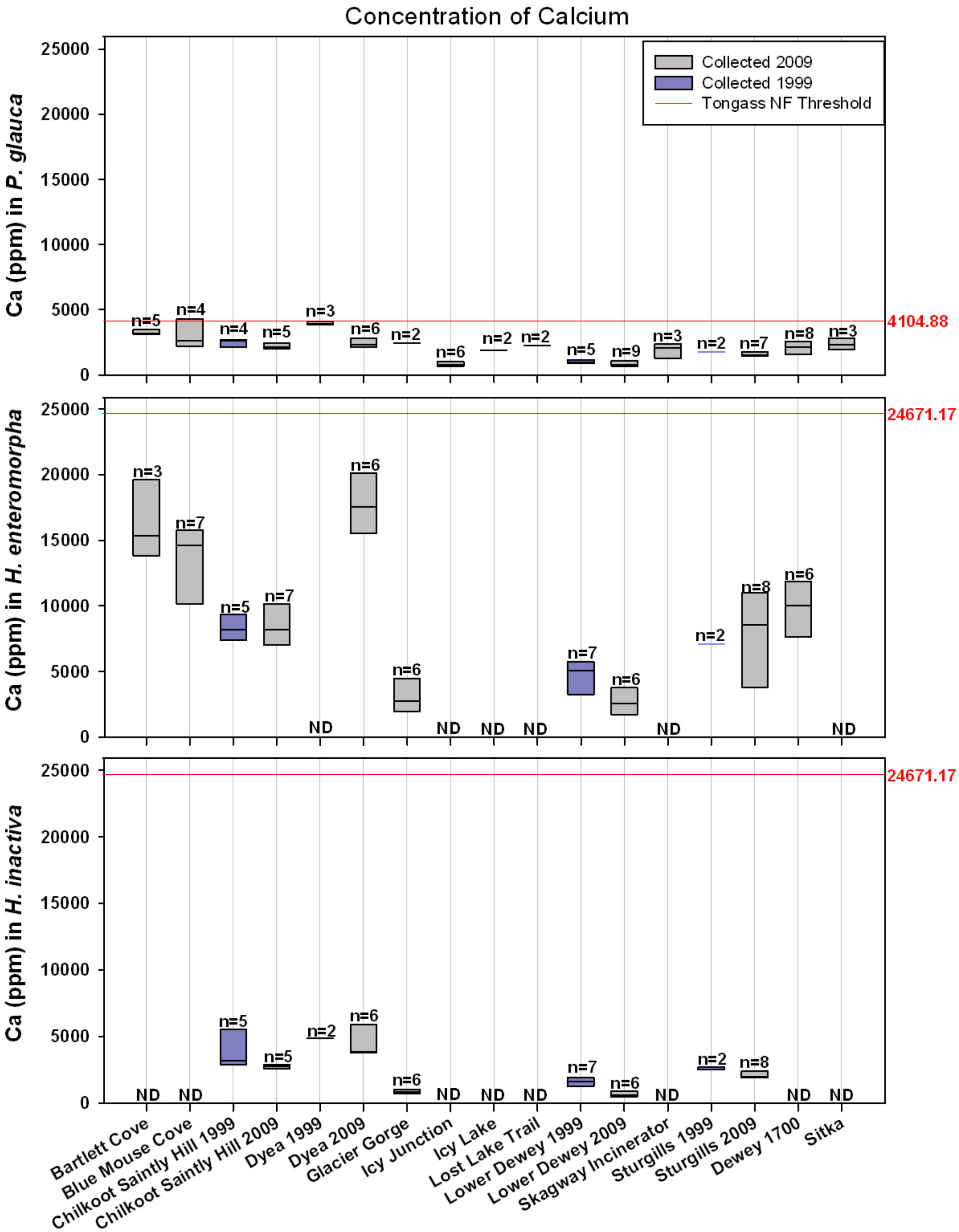

Concentration of Boron
Collected 2009
Collected 1999
Tongass NF Threshold
B (ppm) in P. glauca
B (ppm) in H. enteromorpha
B (ppm) in H. inactiva
6.05
9.47
9.47
ND
Bartlett Cove
Blue Mouse Cove
Chilkoot Saintly Hill 1999
Chilkoot Saintly Hill 2009
Dyea 1999
Dyea 2009
Glacier Gorge
Icy Junction
Icy Lake
Lost Lake Trail
Lower Dewey 1999
Lower Dewey 2009
Skagway Incinerator
Sturgills 1999
Sturgills 2009
Dewey 1700
Sitka

Cadmium



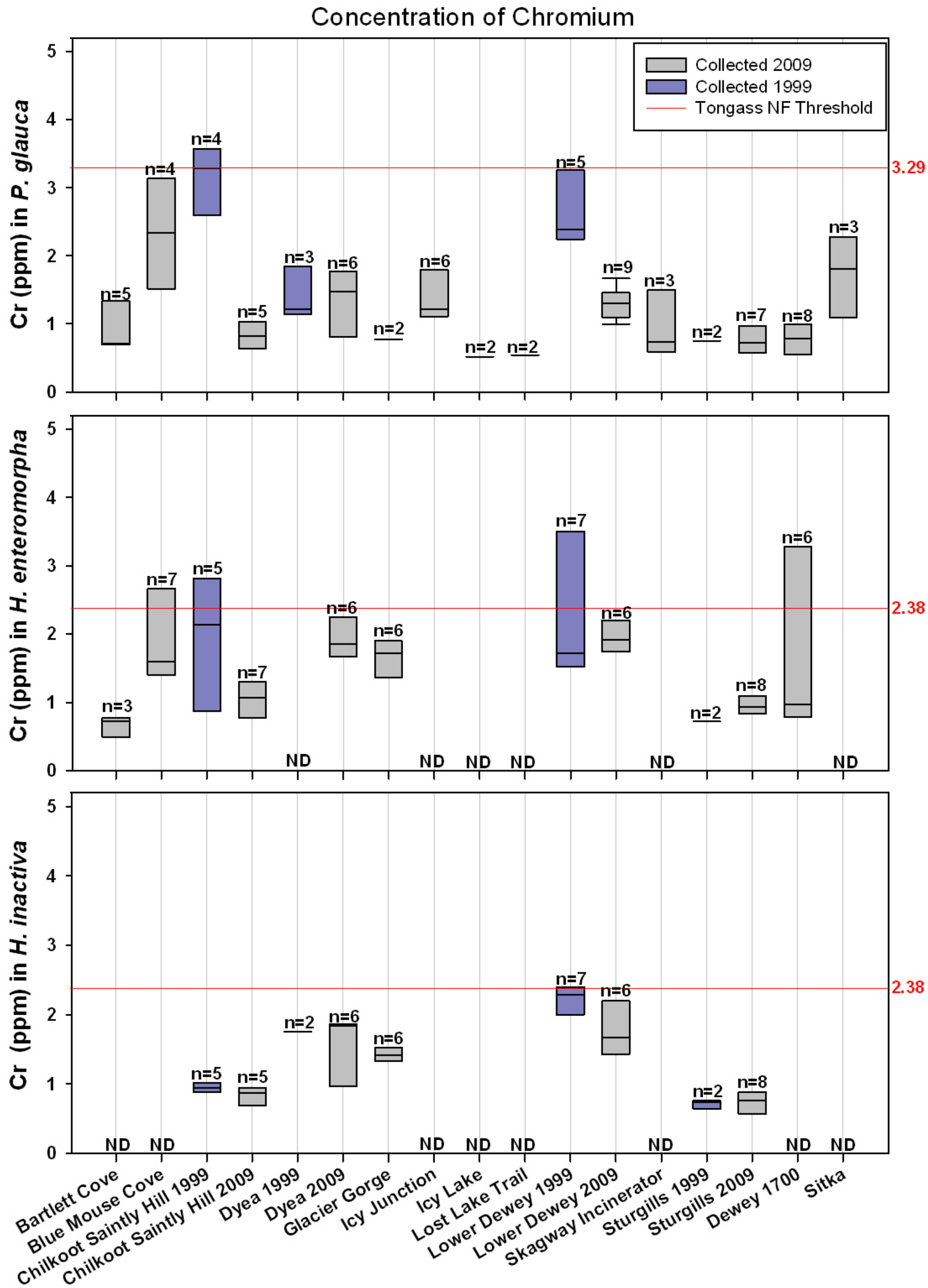
Concentration of Cadmium
Collected 2009
Collected 1999
2009 Minimum Detection Level
Tongass NF Threshold
Cd (ppm) in P. glauca
Cd (ppm) in H. enteromorpha
Cd (ppm) in H. inactiva
.32
.22
.61
ND
Bartlett Cove
Blue Mouse Cove
Chilkoot Saintly Hill 1999
Chilkoot Saintly Hill 2009
Dyea 1999
Dyea 2009
Glacier Gorge
Icy Junction
Icy Lake
Lost Lake Trail
Lower Dewey 1999
Lower Dewey 2009
Skagway Incinerator
Sturgills 1999
Sturgills 2009
Dewey 1700
Sitka

Calcium



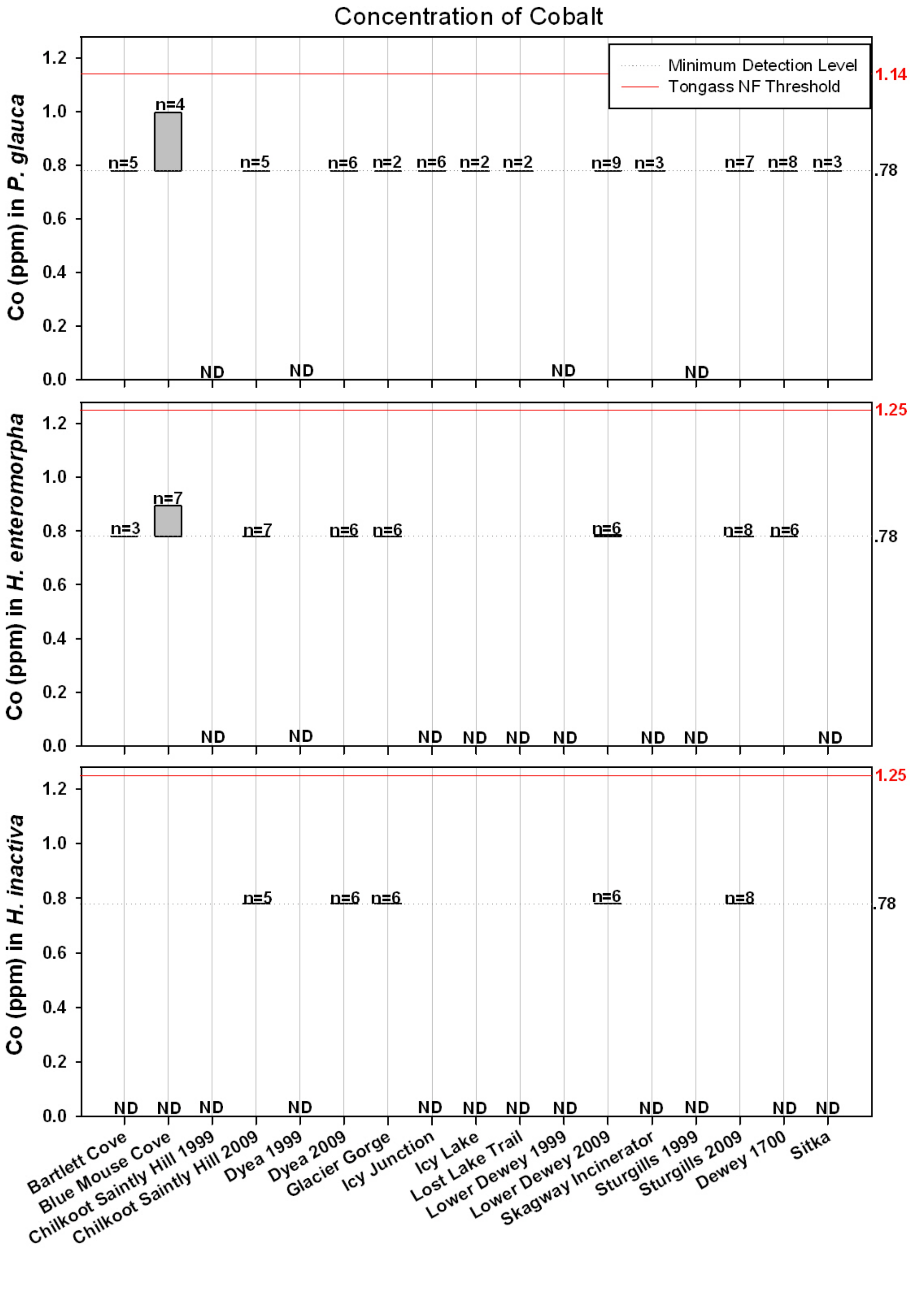
Concentration of Calcium
Collected 2009
Collected 1999
Tongass NF Threshold
Ca (ppm) in P. glauca
Ca (ppm) in H. enteromorpha
Ca (ppm) in H. inactiva
4104.88
24671.17
24671.17
ND
Bartlett Cove
Blue Mouse Cove
Chilkoot Saintly Hill 1999
Chilkoot Saintly Hill 2009
Dyea 1999
Dyea 2009
Glacier Gorge
Icy Junction
Icy Lake
Lost Lake Trail
Lower Dewey 1999
Lower Dewey 2009
Skagway Incinerator
Sturgills 1999
Sturgills 2009
Dewey 1700
Sitka

Chromium



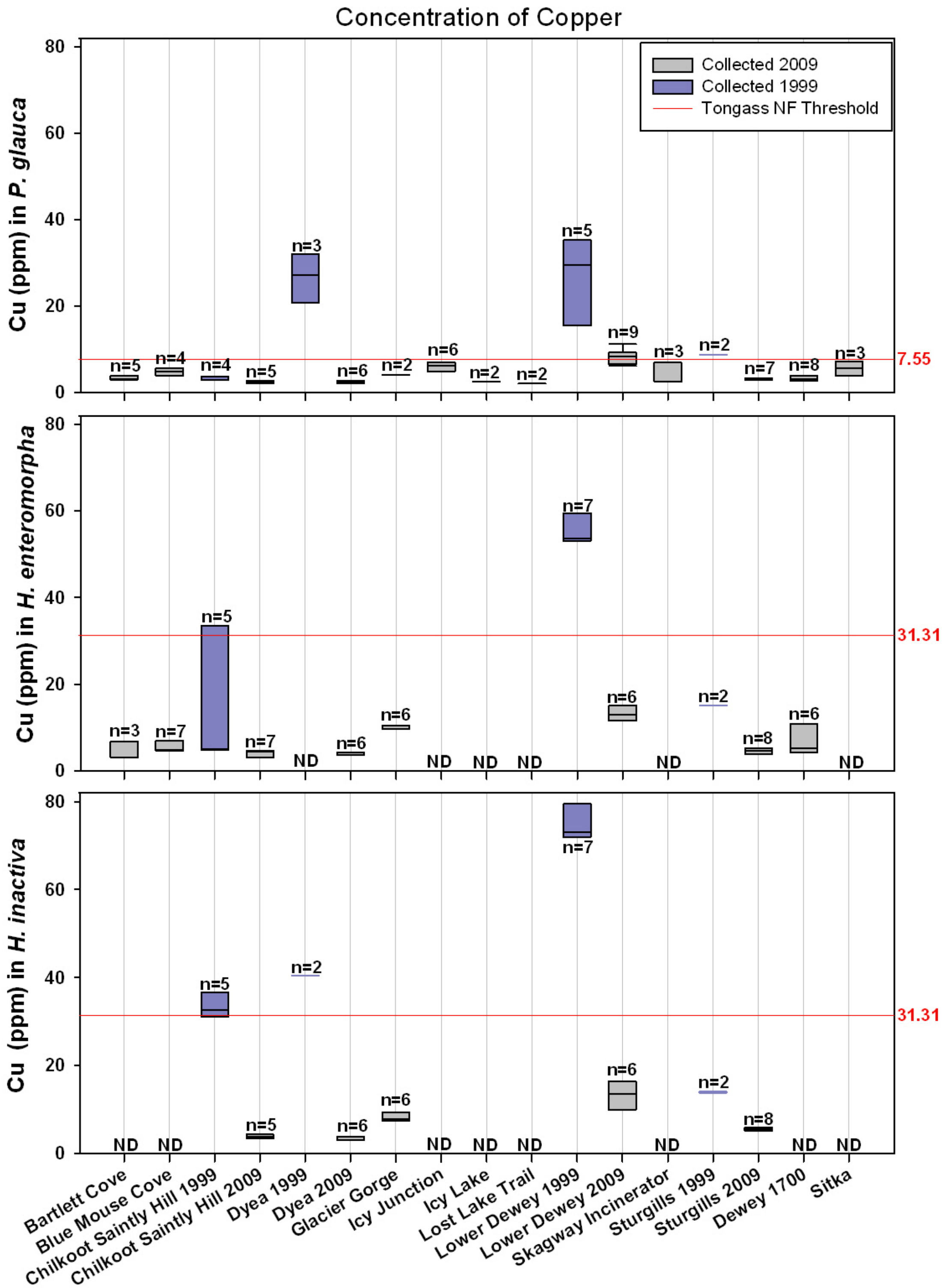
Concentration of Chromium
Collected 2009
Collected 1999
Tongass NF Threshold
Cr (ppm) in *P. glauca*
Cr (ppm) in *H. enteromorpha*
Cr (ppm) in *H. inactiva*
3.29
2.38
2.38
ND
Bartlett Cove
Blue Mouse Cove
Chilkoot Saintly Hill 1999
Chilkoot Saintly Hill 2009
Dyea 1999
Dyea 2009
Glacier Gorge
Icy Junction
Icy Lake
Lost Lake Trail
Lower Dewey 1999
Lower Dewey 2009
Skagway Incinerator
Sturgills 1999
Sturgills 2009
Dewey 1700
Sitka

Cobalt

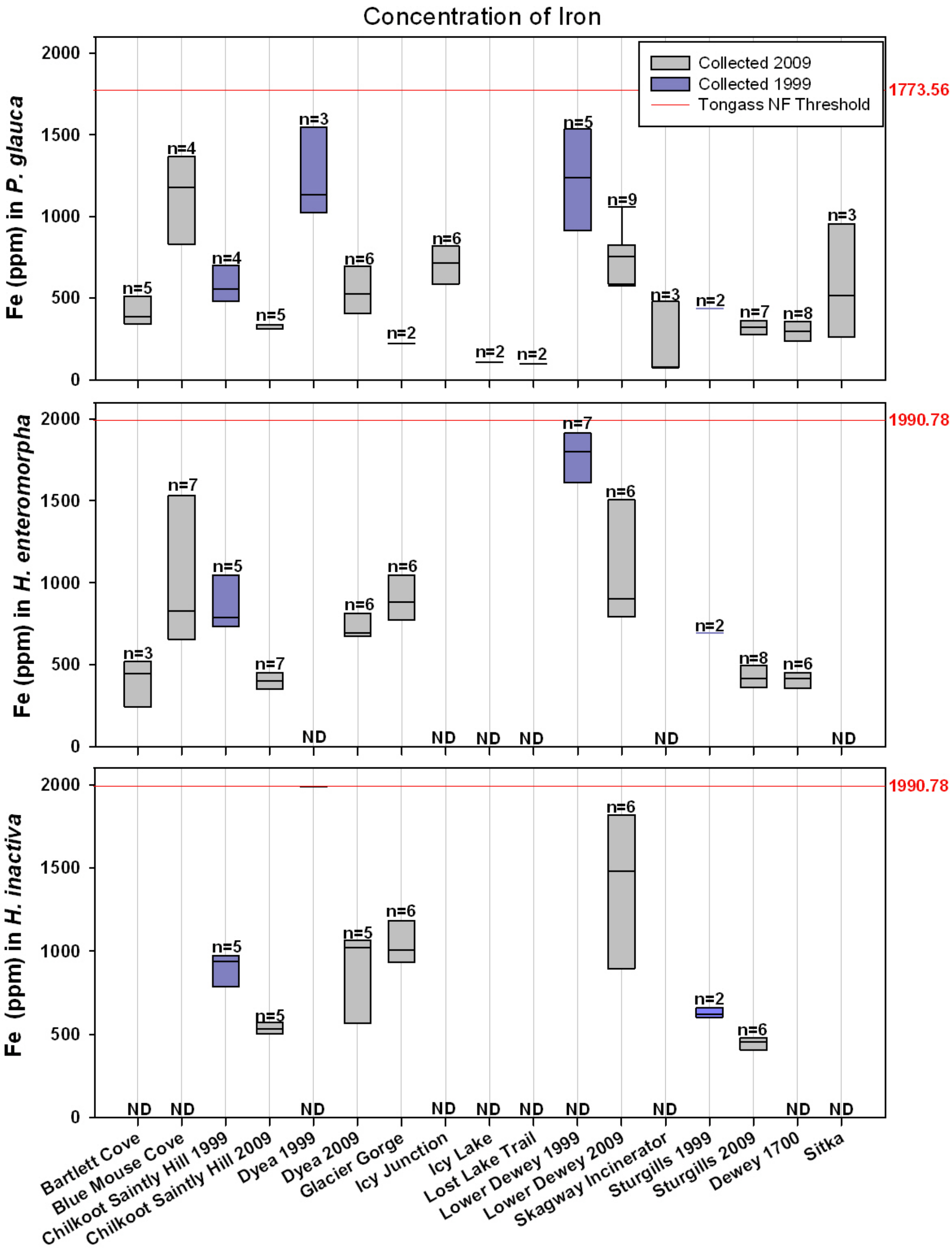


Concentration of Cobalt
Minimum Detection Level
Tongass NF Threshold
1.14
.78
1.25
.78
1.25
.78
Co (ppm) in P. glauca
Co (ppm) in H. enteromorpha
Co (ppm) in H. inactiva
n=5
n=4
n=5
n=6
n=2
n=6
n=2
n=2
n=9
n=3
n=7
n=8
n=3
ND
n=3
n=7
n=7
n=6
n=6
n=6
n=8
n=6
n=5
n=6
n=6
n=6
n=8
Bartlett Cove
Blue Mouse Cove
Chilkoot Saintly Hill 1999
Chilkoot Saintly Hill 2009
Dyea 1999
Dyea 2009
Glacier Gorge
Icy Junction
Icy Lake
Lost Lake Trail
Lower Dewey 1999
Lower Dewey 2009
Skagway Incinerator
Sturgills 1999
Sturgills 2009
Dewey 1700
Sitka

Copper

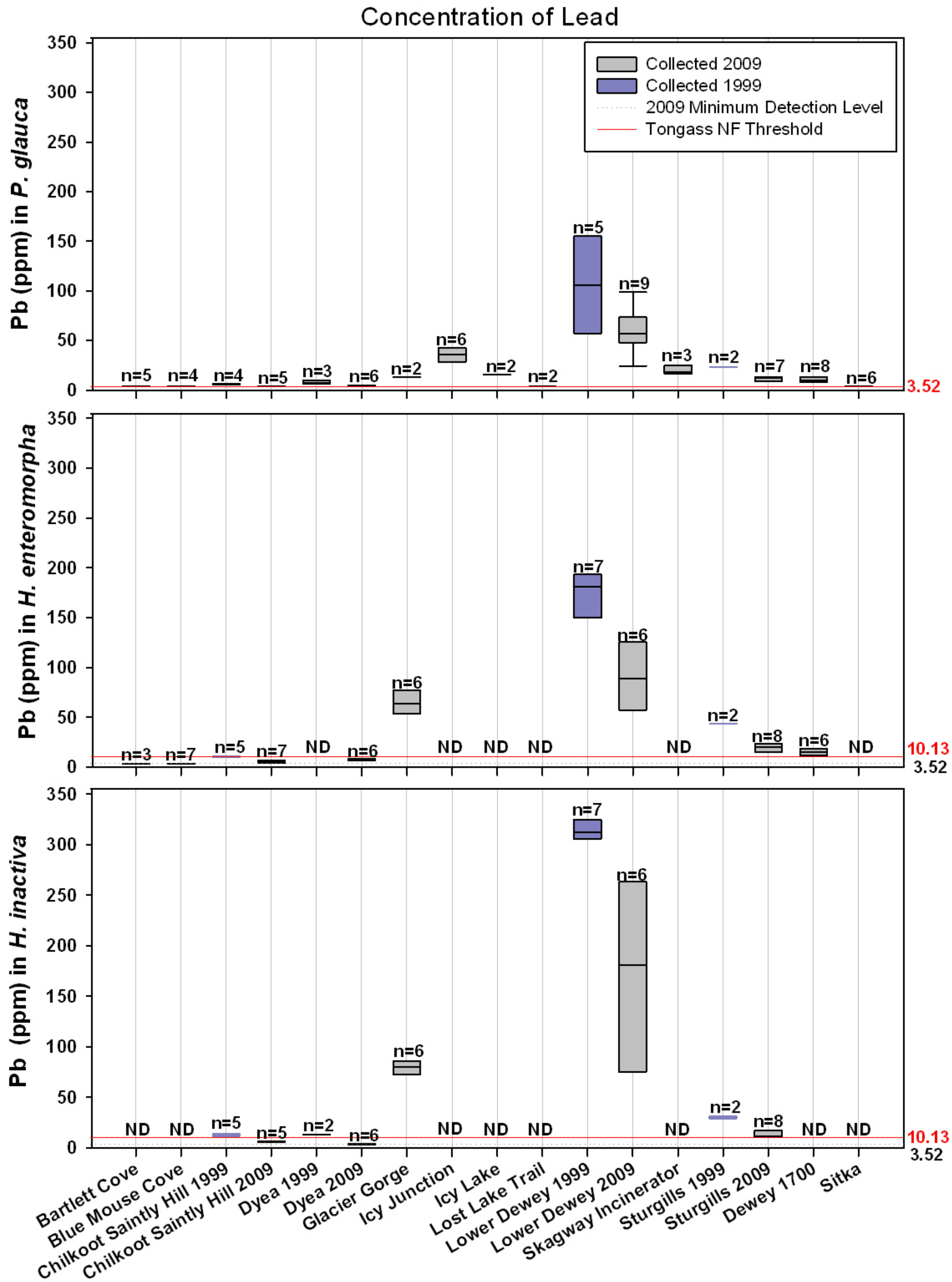

Concentration of Copper
Collected 2009
Collected 1999
Tongass NF Threshold
Cu (ppm) in P. glauca
Cu (ppm) in H. enteromorpha
Cu (ppm) in H. inactiva
7.55
31.31
31.31
Bartlett Cove
Blue Mouse Cove
Chilkoot Saintly Hill 1999
Chilkoot Saintly Hill 2009
Dyea 1999
Dyea 2009
Glacier Gorge
Icy Junction
Icy Lake
Lost Lake Trail
Lower Dewey 1999
Lower Dewey 2009
Skagway Incinerator
Sturgills 1999
Sturgills 2009
Dewey 1700
Sitka

Iron



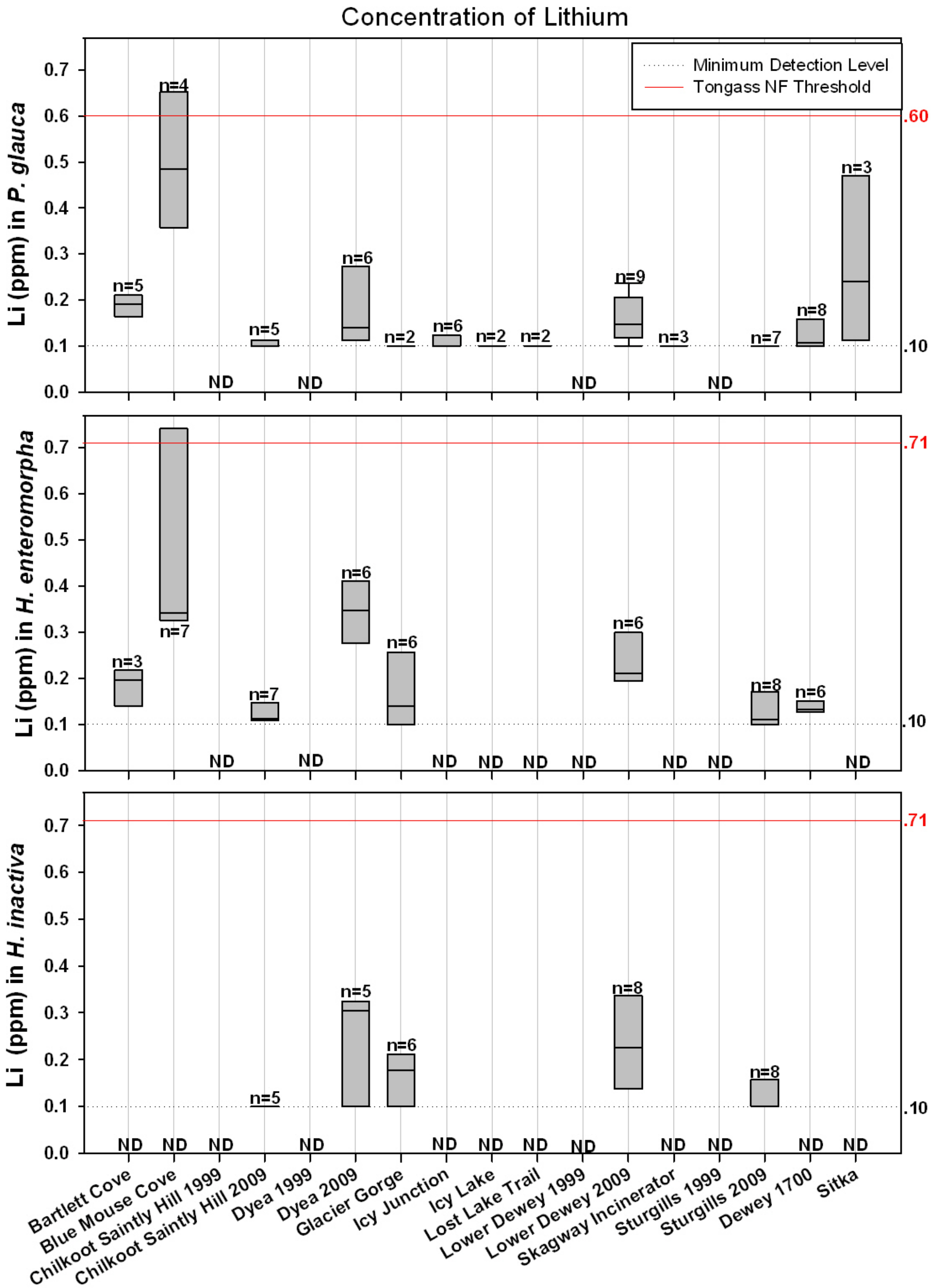
Concentration of Iron
Collected 2009
Collected 1999
Tongass NF Threshold
1773.56
1990.78
1990.78
Fe (ppm) in P. glauca
Fe (ppm) in H. enteromorpha
Fe (ppm) in H. inactiva
ND
Bartlett Cove
Blue Mouse Cove
Chilkoot Saintly Hill 1999
Chilkoot Saintly Hill 2009
Dyea 1999
Dyea 2009
Glacier Gorge
Icy Junction
Icy Lake
Lost Lake Trail
Lower Dewey 1999
Lower Dewey 2009
Skagway Incinerator
Sturgills 1999
Sturgills 2009
Dewey 1700
Sitka

Lead



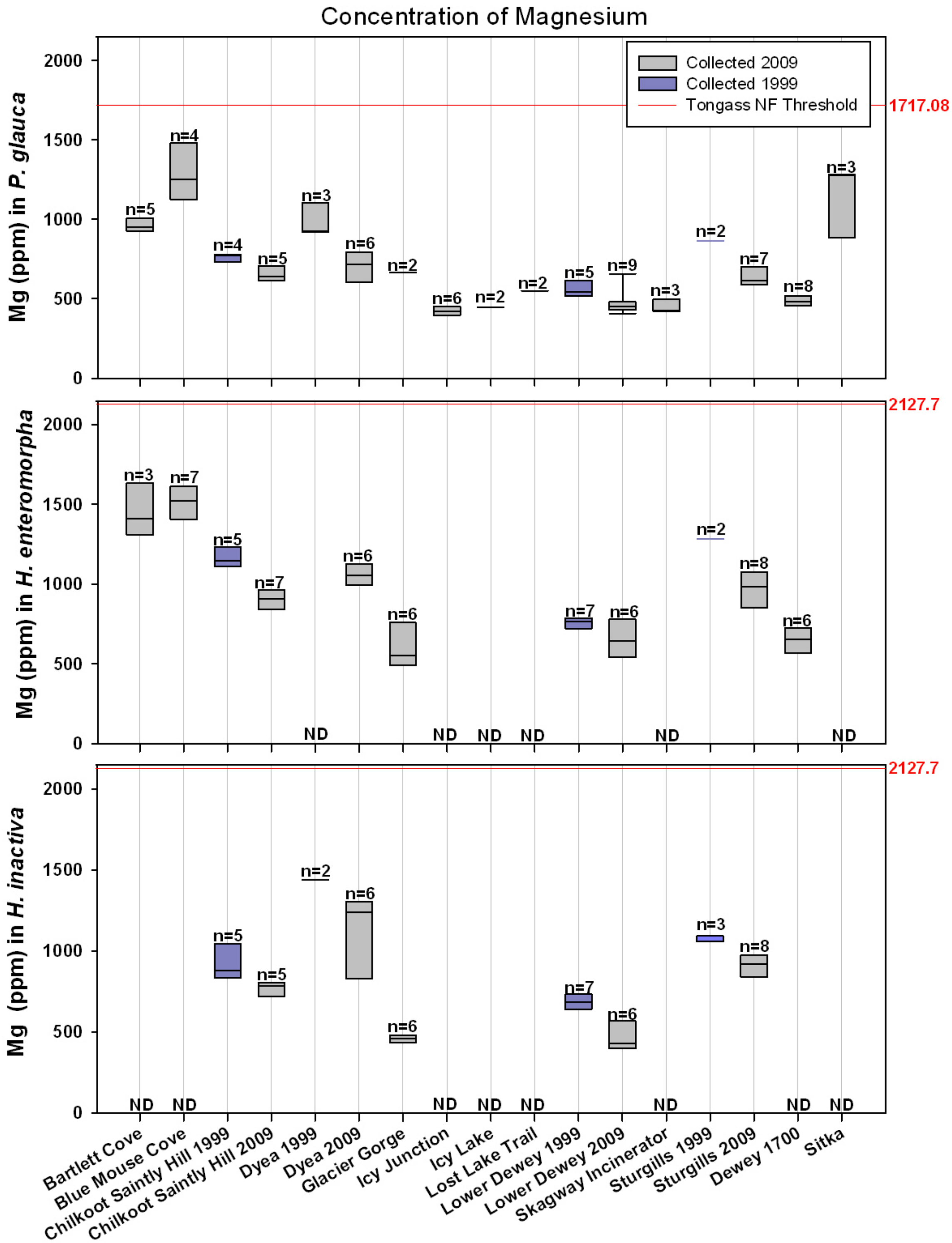
Concentration of Lead
Collected 2009
Collected 1999
2009 Minimum Detection Level
Tongass NF Threshold
Pb (ppm) in P. glauca
Pb (ppm) in H. enteromorpha
Pb (ppm) in H. inactiva
3.52
10.13
Bartlett Cove
Blue Mouse Cove
Chilkoot Saintly Hill 1999
Chilkoot Saintly Hill 2009
Dyea 1999
Dyea 2009
Glacier Gorge
Icy Junction
Icy Lake
Lost Lake Trail
Lower Dewey 1999
Lower Dewey 2009
Skagway Incinerator
Sturgills 1999
Sturgills 2009
Dewey 1700
Sitka

Lithium



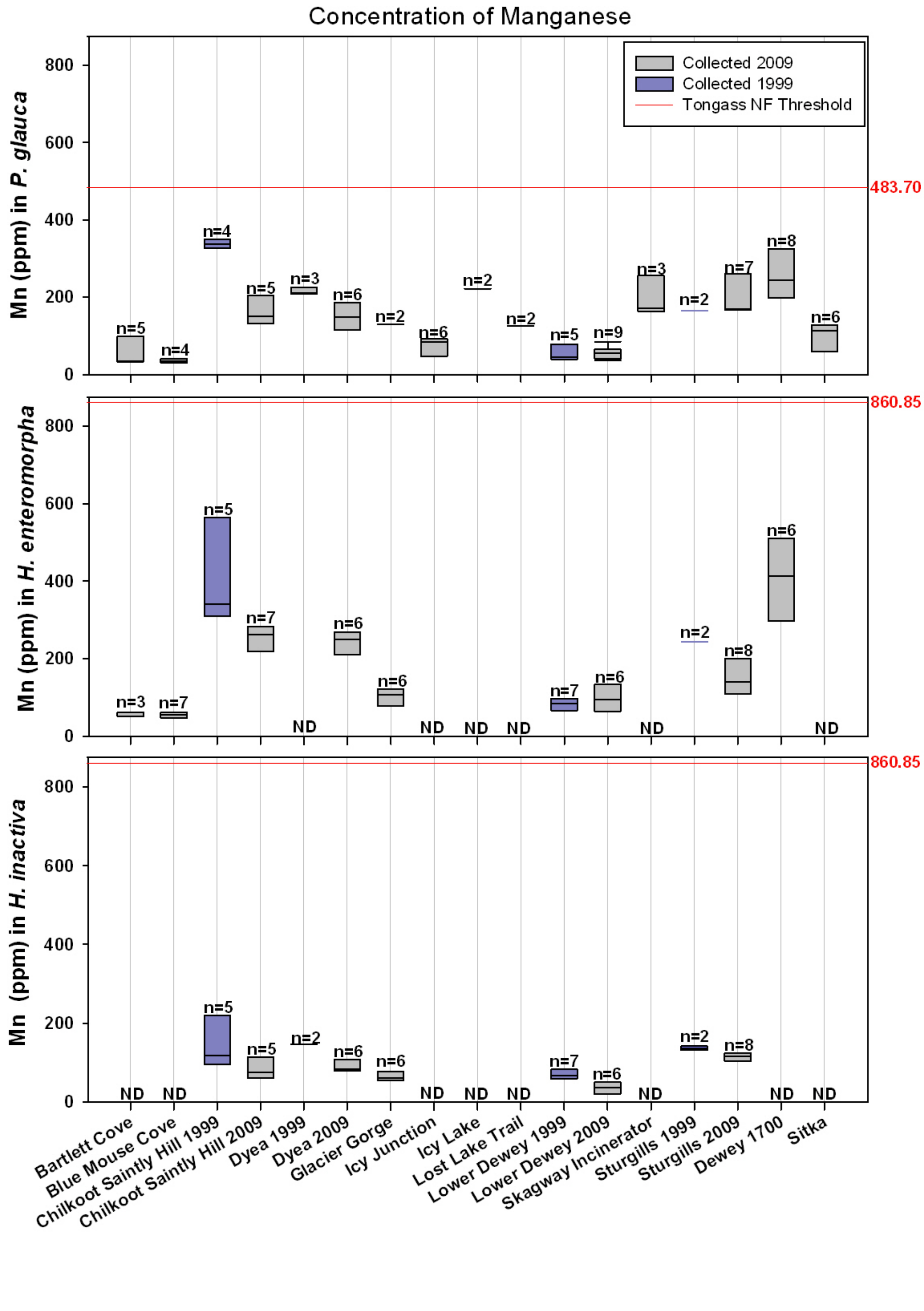
Concentration of Lithium
Minimum Detection Level
Tongass NF Threshold
Li (ppm) in P. glauca
Li (ppm) in H. enteromorpha
Li (ppm) in H. inactiva
.60
.71
.71
.10
ND
Bartlett Cove
Blue Mouse Cove
Chilkoot Saintly Hill 1999
Chilkoot Saintly Hill 2009
Dyea 1999
Dyea 2009
Glacier Gorge
Icy Junction
Icy Lake
Lost Lake Trail
Lower Dewey 1999
Lower Dewey 2009
Skagway Incinerator
Sturgills 1999
Sturgills 2009
Dewey 1700
Sitka

Magnesium



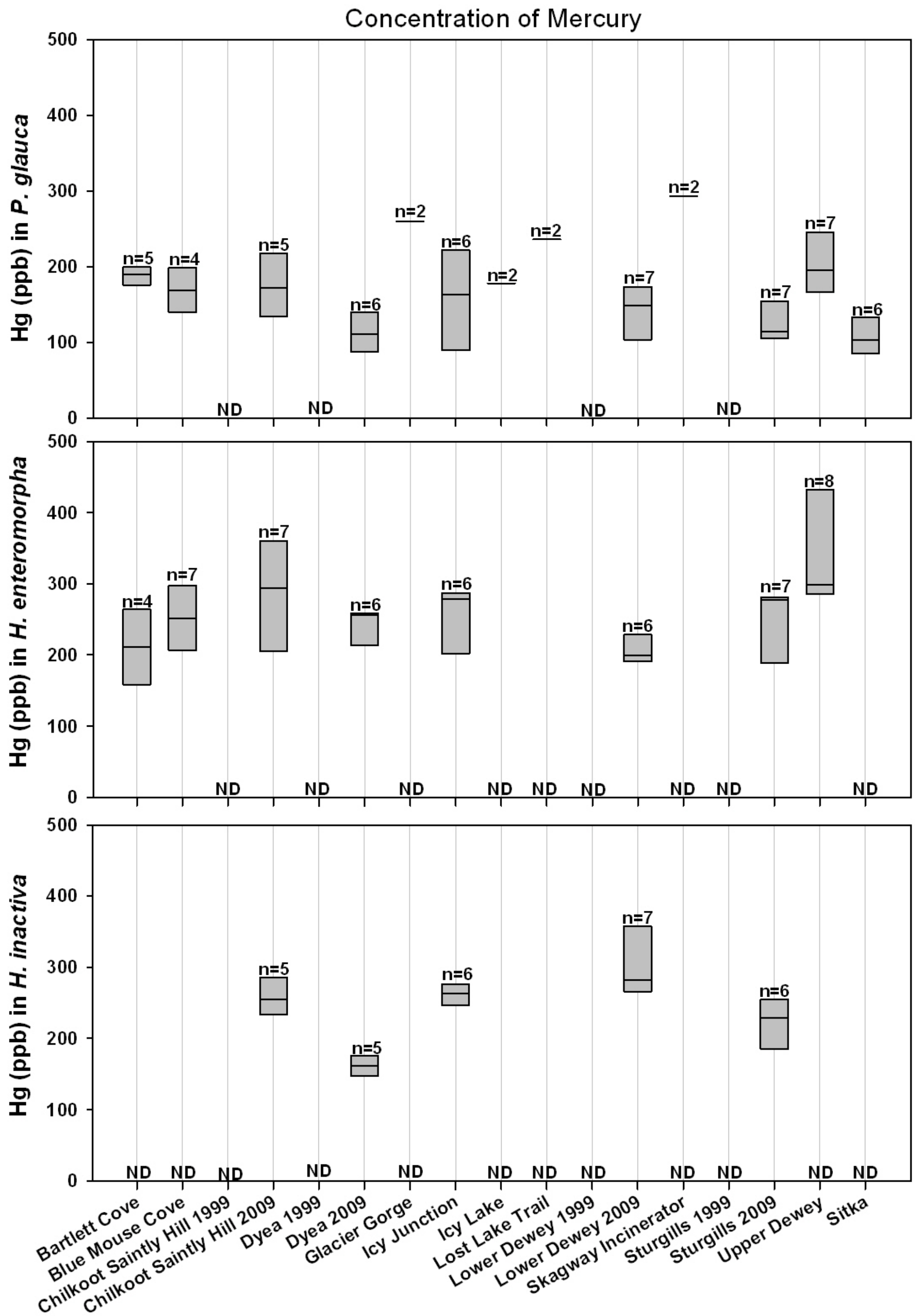
Concentration of Magnesium
Collected 2009
Collected 1999
Tongass NF Threshold
1717.08
2127.7
2127.7
Mg (ppm) in P. glauca
Mg (ppm) in H. enteromorpha
Mg (ppm) in H. inactiva
Bartlett Cove
Blue Mouse Cove
Chilkoot Saintly Hill 1999
Chilkoot Saintly Hill 2009
Dyea 1999
Dyea 2009
Glacier Gorge
Icy Junction
Icy Lake
Lost Lake Trail
Lower Dewey 1999
Lower Dewey 2009
Skagway Incinerator
Sturgills 1999
Sturgills 2009
Dewey 1700
Sitka

Manganese



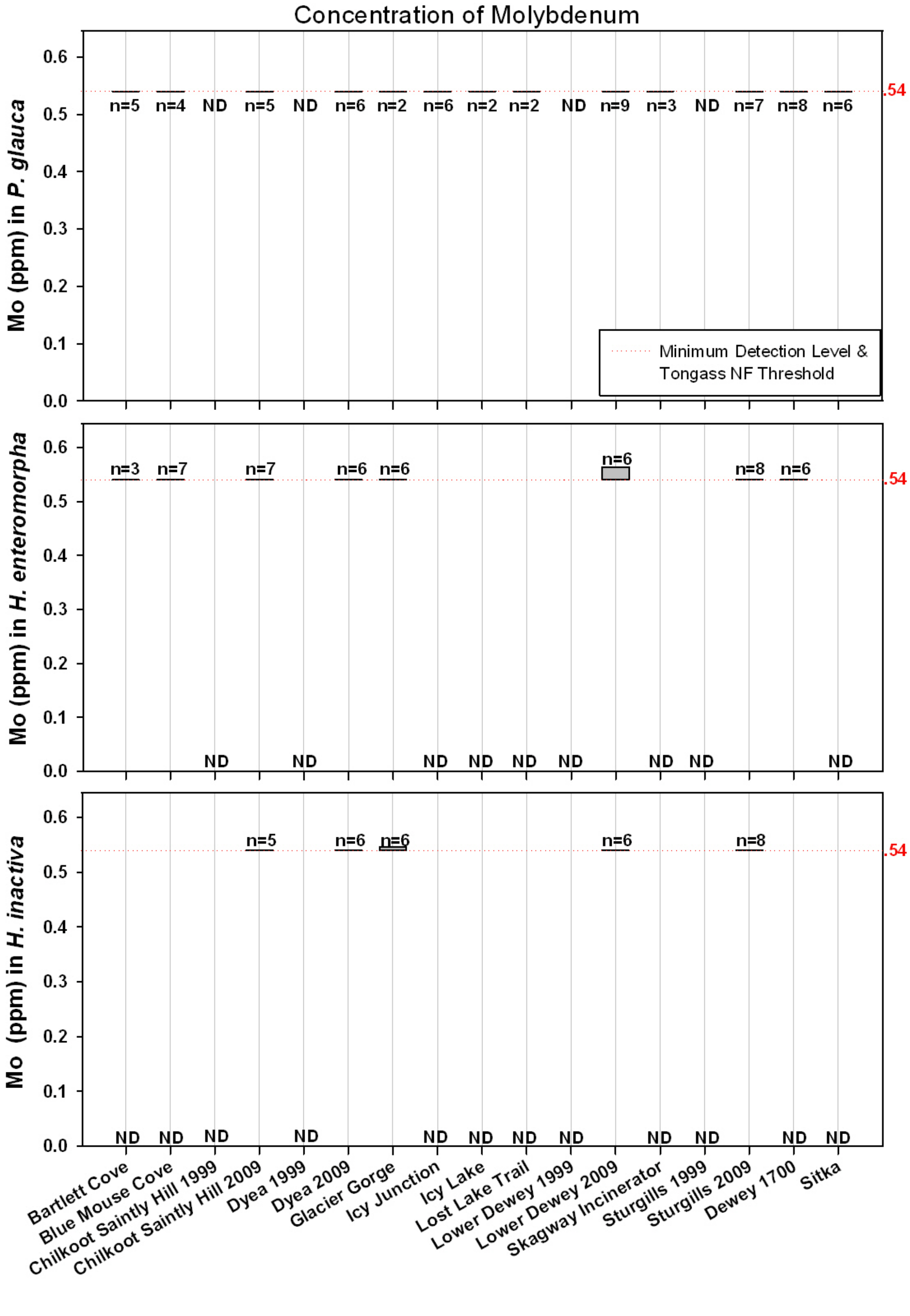
Concentration of Manganese
Collected 2009
Collected 1999
Tongass NF Threshold
483.70
860.85
860.85
Mn (ppm) in P. glauca
Mn (ppm) in H. enteromorpha
Mn (ppm) in H. inactiva
0
200
400
600
800
ND
Bartlett Cove
Blue Mouse Cove
Chilkoot Saintly Hill 1999
Chilkoot Saintly Hill 2009
Dyea 1999
Dyea 2009
Glacier Gorge
Icy Junction
Icy Lake
Lost Lake Trail
Lower Dewey 1999
Lower Dewey 2009
Skagway Incinerator
Sturgills 1999
Sturgills 2009
Dewey 1700
Sitka

Mercury



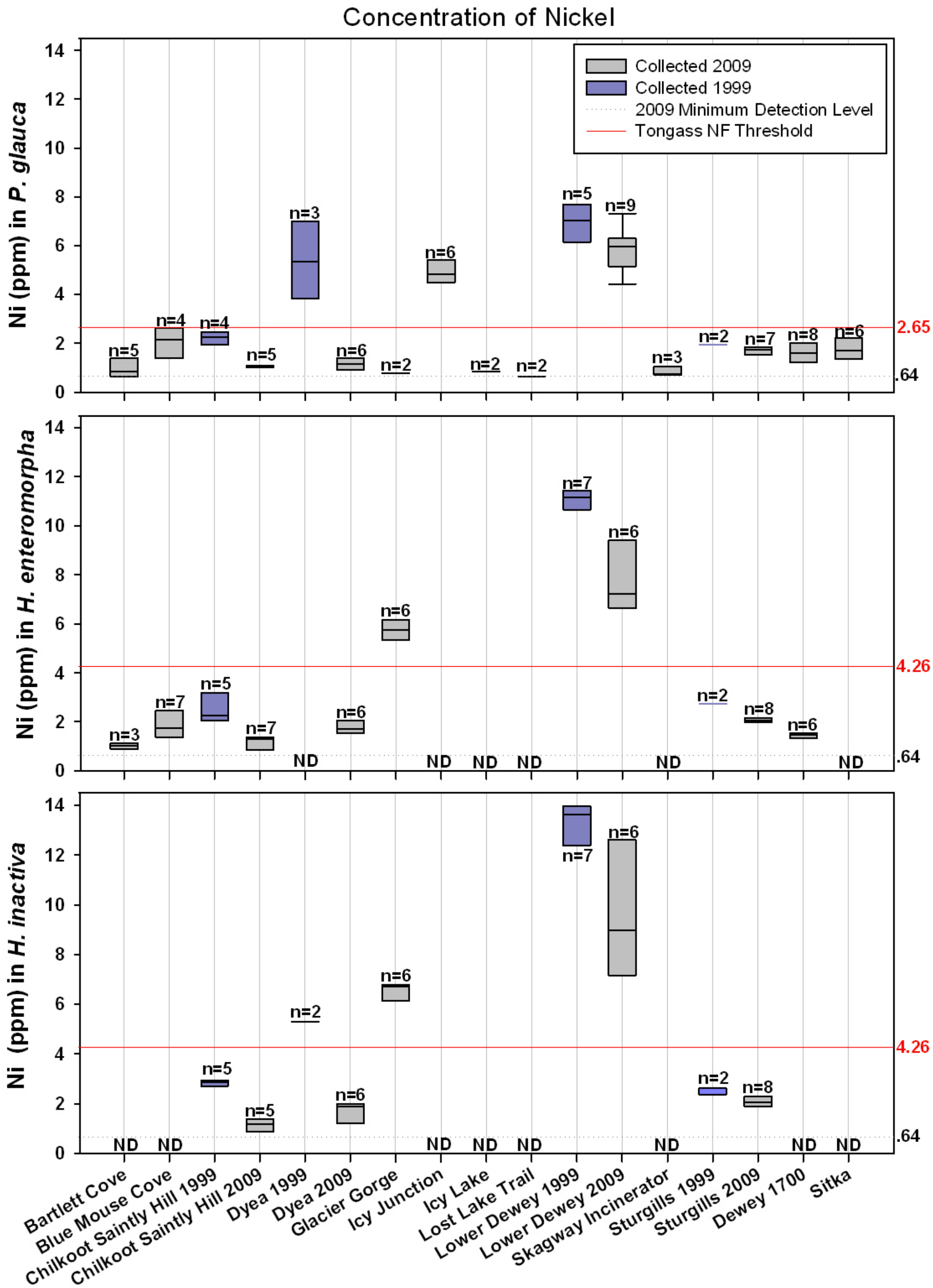
Concentration of Mercury
Hg (ppb) in P. glauca
Hg (ppb) in H. enteromorpha
Hg (ppb) in H. inactiva
0
100
200
300
400
500
n=5
n=4
n=5
n=6
n=2
n=6
n=2
n=2
n=7
n=2
n=7
n=7
n=6
n=8
n=3
n=4
n=7
n=6
ND
Bartlett Cove
Blue Mouse Cove
Chilkoot Saintly Hill 1999
Chilkoot Saintly Hill 2009
Dyea 1999
Dyea 2009
Glacier Gorge
Icy Junction
Icy Lake
Lost Lake Trail
Lower Dewey 1999
Lower Dewey 2009
Skagway Incinerator
Sturgills 1999
Sturgills 2009
Upper Dewey
Sitka

Molybdenum



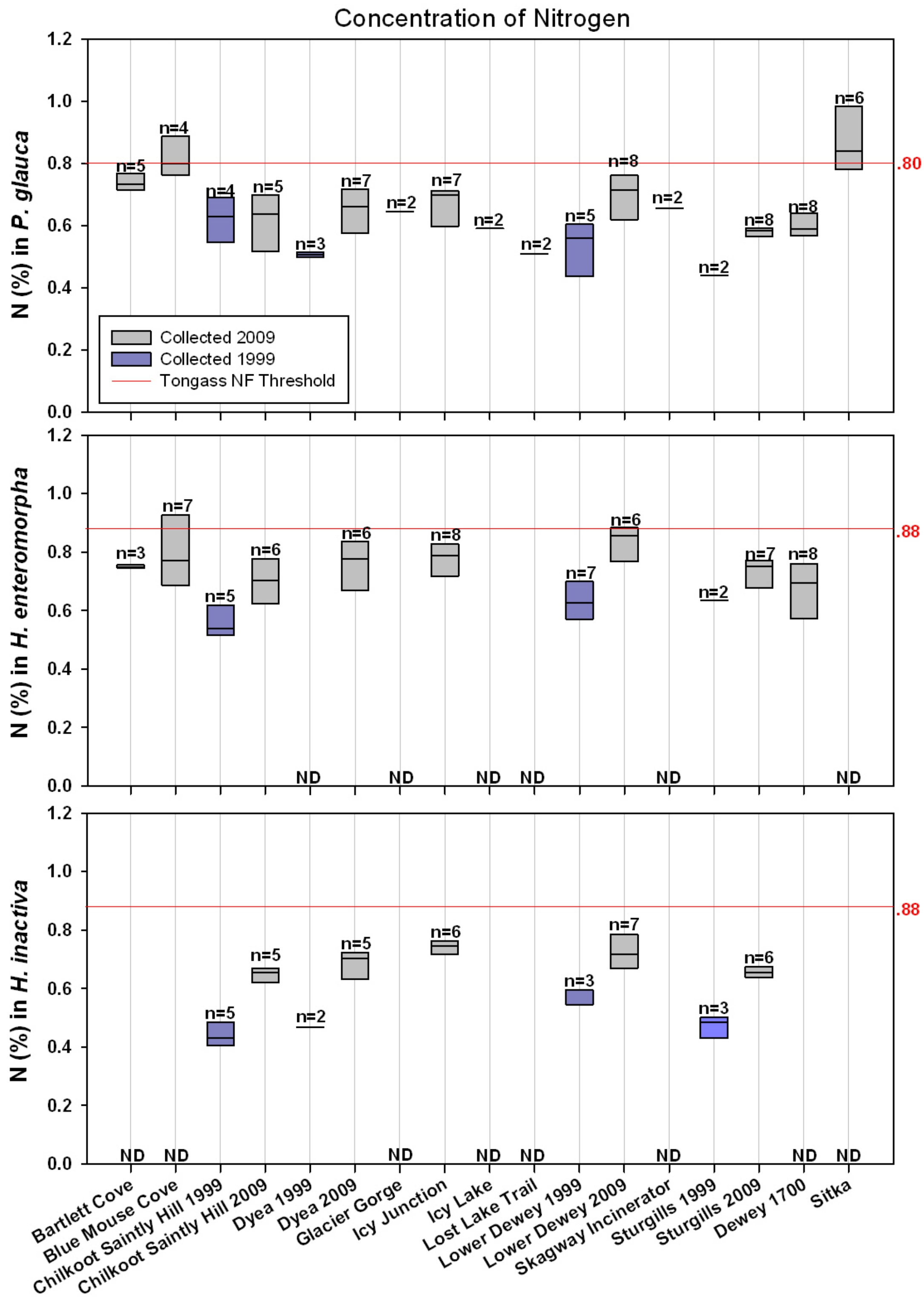
Concentration of Molybdenum
Mo (ppm) in P. glauca
0.6
0.5
0.4
0.3
0.2
0.1
0.0
n=5 n=4 ND n=5 ND n=6 n=2 n=6 n=2 n=2 ND n=9 n=3 ND n=7 n=8 n=6
.54
Minimum Detection Level & Tongass NF Threshold
Mo (ppm) in H. enteromorpha
n=3 n=7 n=7 n=6 n=6 n=6 n=8 n=6
ND ND ND ND ND ND ND ND ND
Mo (ppm) in H. inactiva
n=5 n=6 n=6 n=6 n=8
ND ND ND ND ND ND ND ND ND ND ND ND
Bartlett Cove
Blue Mouse Cove
Chilkoot Saintly Hill 1999
Chilkoot Saintly Hill 2009
Dyea 1999
Dyea 2009
Glacier Gorge
Icy Junction
Icy Lake
Lost Lake Trail
Lower Dewey 1999
Lower Dewey 2009
Skagway Incinerator
Sturgills 1999
Sturgills 2009
Dewey 1700
Sitka

Nickel



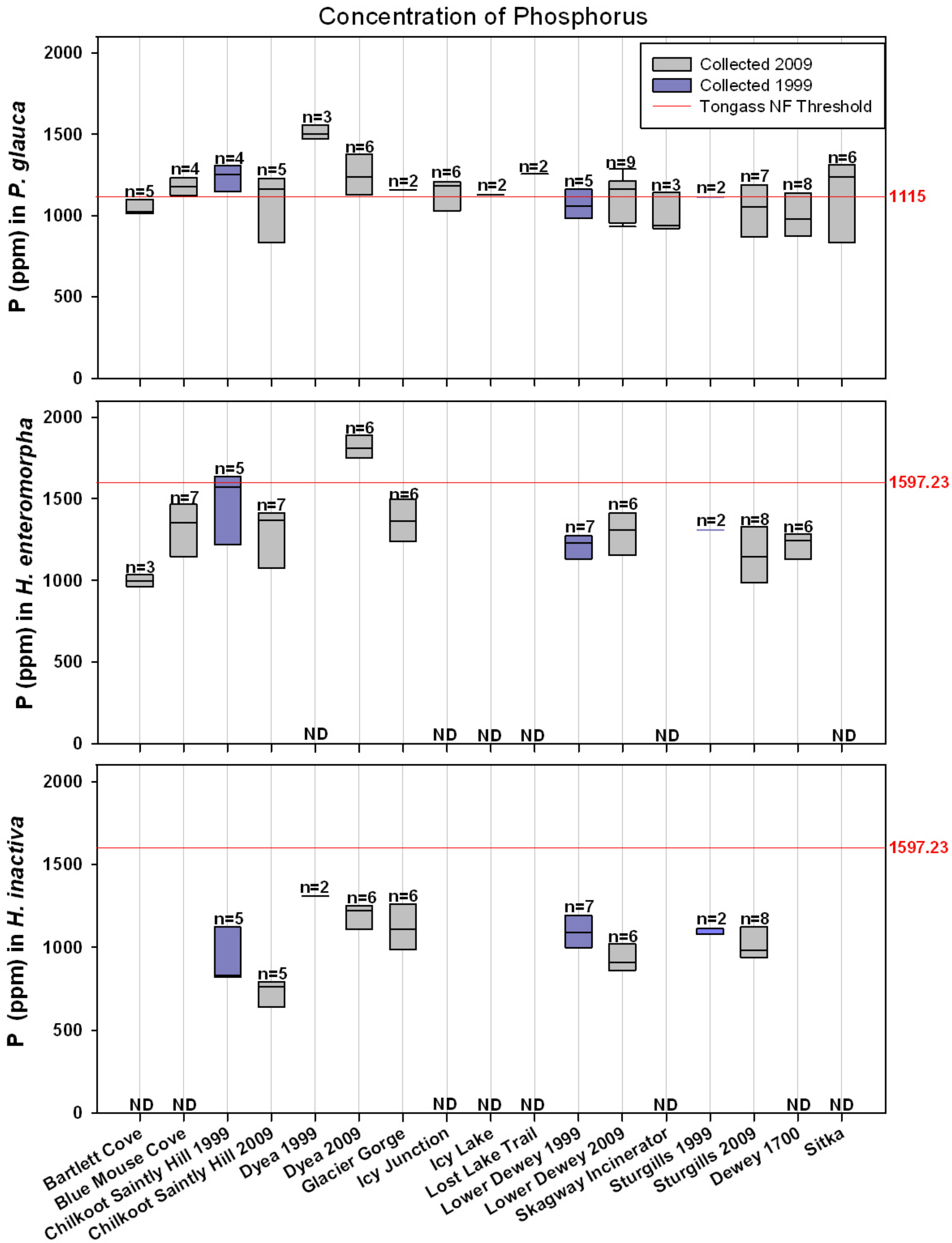
Concentration of Nickel
Collected 2009
Collected 1999
2009 Minimum Detection Level
Tongass NF Threshold
Ni (ppm) in P. glauca
Ni (ppm) in H. enteromorpha
Ni (ppm) in H. inactiva
2.65
4.26
4.26
.64
ND
Bartlett Cove
Blue Mouse Cove
Chilkoot Saintly Hill 1999
Chilkoot Saintly Hill 2009
Dyea 1999
Dyea 2009
Glacier Gorge
Icy Junction
Icy Lake
Lost Lake Trail
Lower Dewey 1999
Lower Dewey 2009
Skagway Incinerator
Sturgills 1999
Sturgills 2009
Dewey 1700
Sitka

Nitrogen

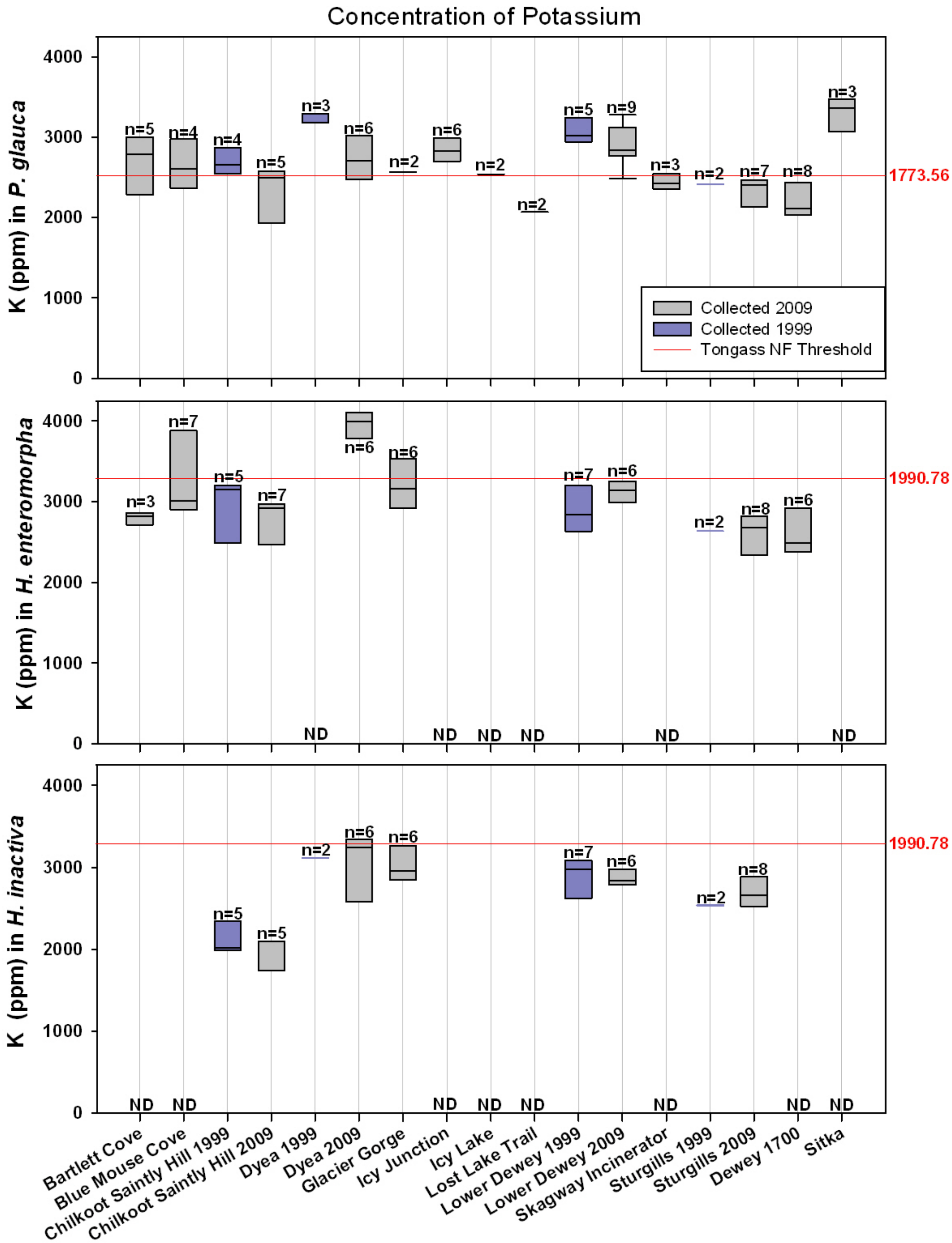


Concentration of Nitrogen
N (%) in P. glauca
N (%) in H. enteromorpha
N (%) in H. inactiva
Collected 2009
Collected 1999
Tongass NF Threshold
.80
.88
.88
ND
Bartlett Cove
Blue Mouse Cove
Chilkoot Saintly Hill 1999
Chilkoot Saintly Hill 2009
Dyea 1999
Dyea 2009
Glacier Gorge
Icy Junction
Icy Lake
Lost Lake Trail
Lower Dewey 1999
Lower Dewey 2009
Skagway Incinerator
Sturgills 1999
Sturgills 2009
Dewey 1700
Sitka

Phosphorus

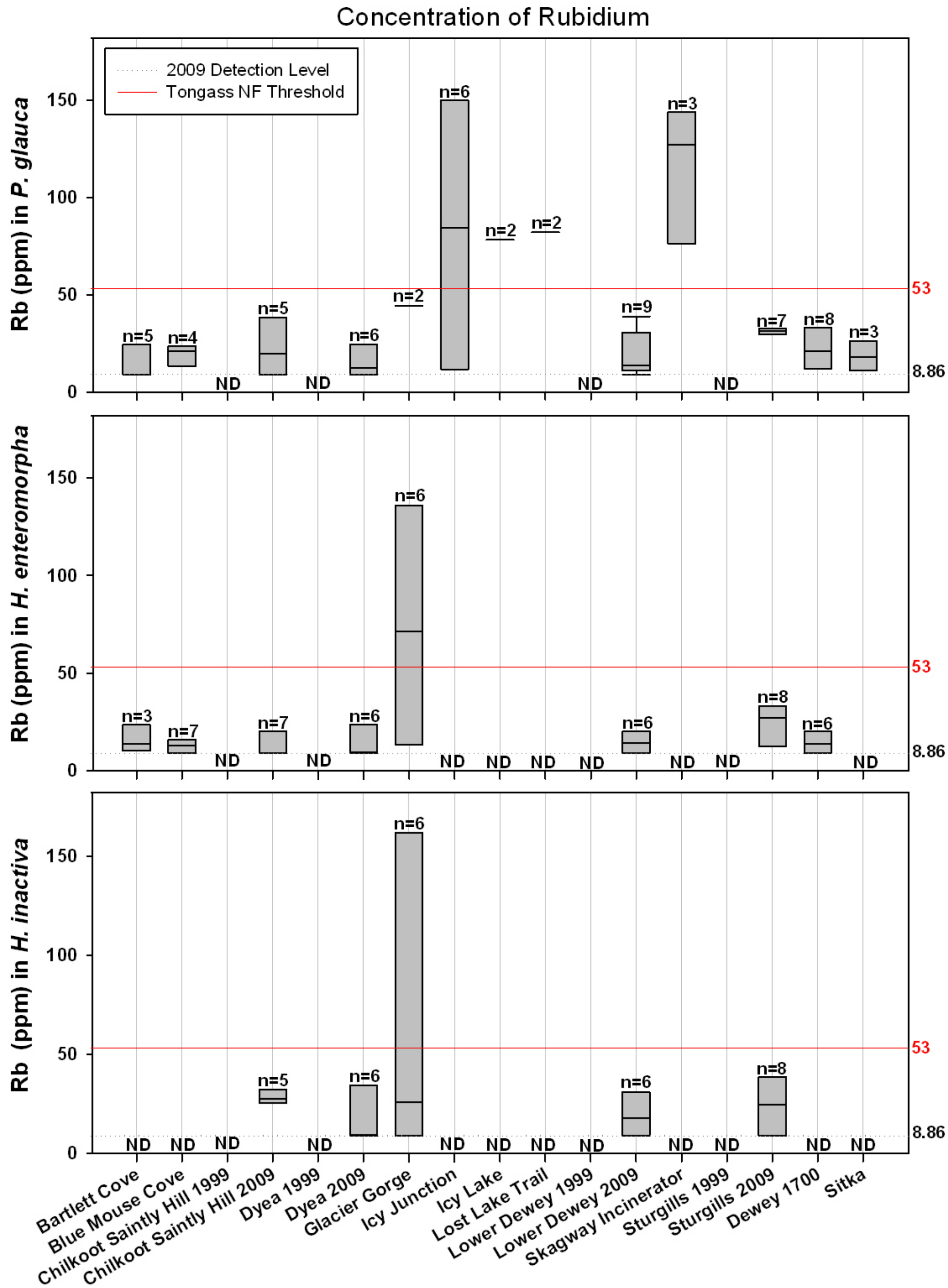

Concentration of Phosphorus
Collected 2009
Collected 1999
Tongass NF Threshold
P (ppm) in P. glauca
1115
P (ppm) in H. enteromorpha
1597.23
P (ppm) in H. inactiva
1597.23
ND
Bartlett Cove
Blue Mouse Cove
Chilkoot Saintly Hill 1999
Chilkoot Saintly Hill 2009
Dyea 1999
Dyea 2009
Glacier Gorge
Icy Junction
Icy Lake
Lost Lake Trail
Lower Dewey 1999
Lower Dewey 2009
Skagway Incinerator
Sturgills 1999
Sturgills 2009
Dewey 1700
Sitka

Potassium



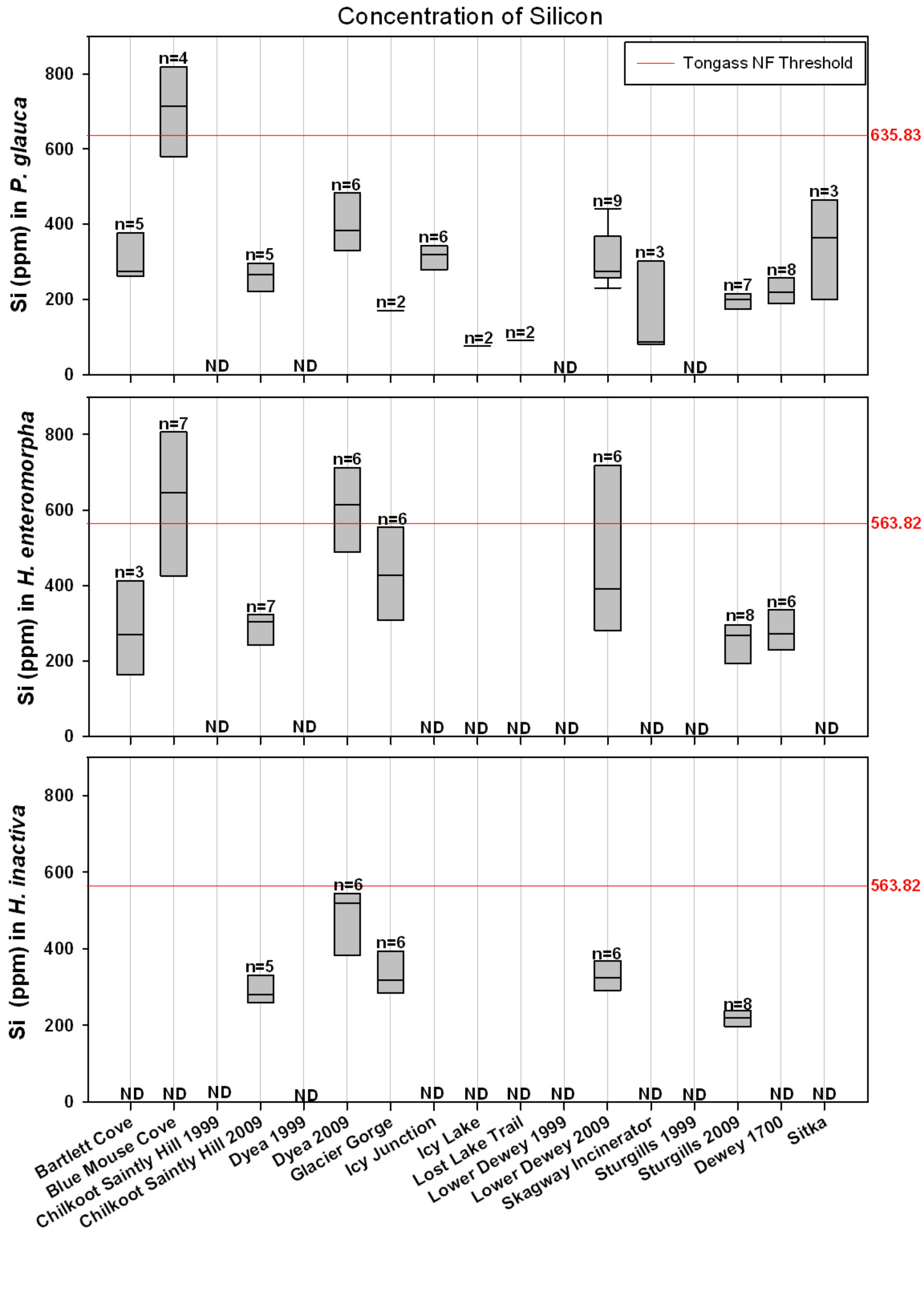
Concentration of Potassium
K (ppm) in P. glauca
K (ppm) in H. enteromorpha
K (ppm) in H. inactiva
Collected 2009
Collected 1999
Tongass NF Threshold
1773.56
1990.78
1990.78
Bartlett Cove
Blue Mouse Cove
Chilkoot Saintly Hill 1999
Chilkoot Saintly Hill 2009
Dyea 1999
Dyea 2009
Glacier Gorge
Icy Junction
Icy Lake
Lost Lake Trail
Lower Dewey 1999
Lower Dewey 2009
Skagway Incinerator
Sturgills 1999
Sturgills 2009
Dewey 1700
Sitka

Rubidium



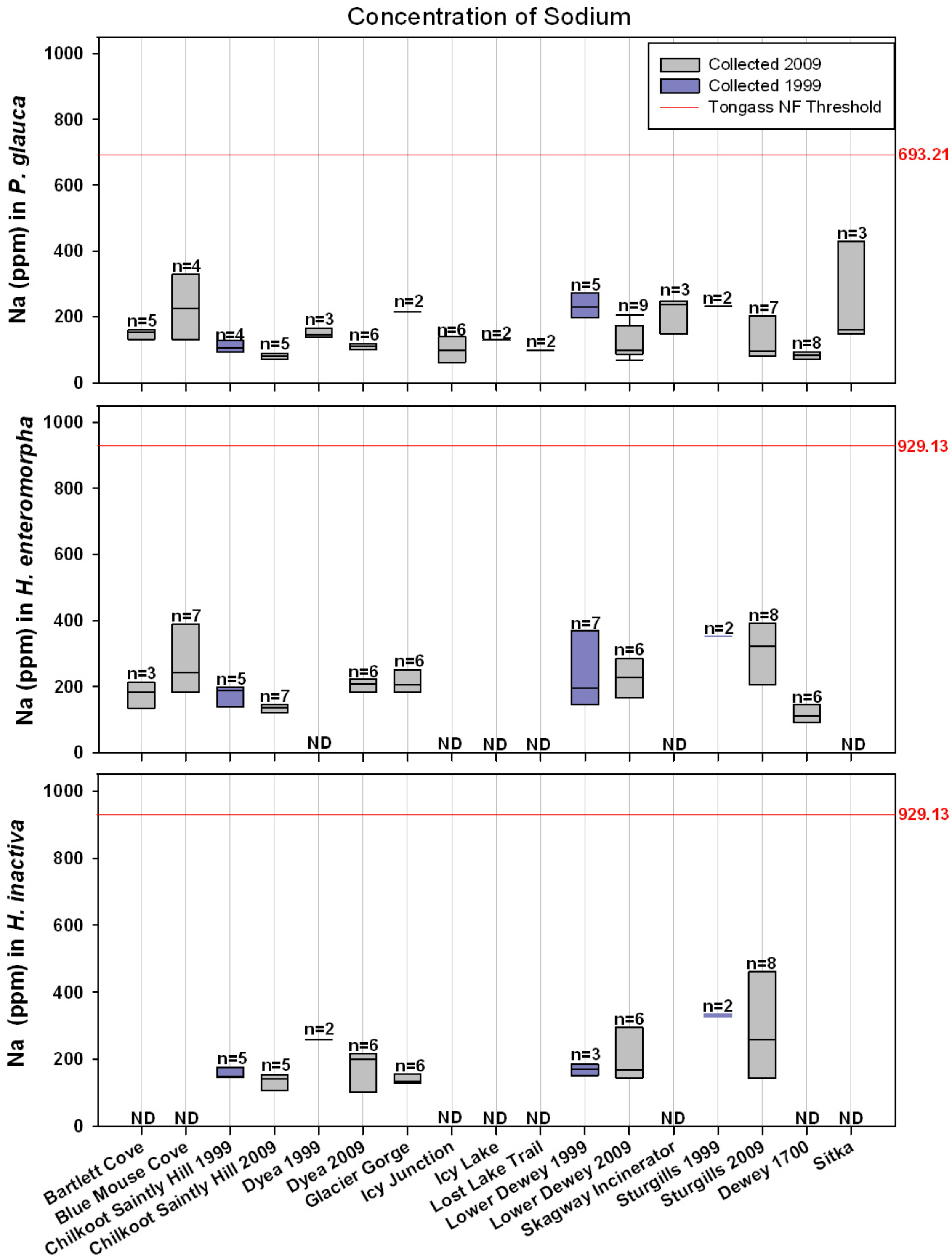
Concentration of Rubidium
2009 Detection Level
Tongass NF Threshold
Rb (ppm) in P. glauca
Rb (ppm) in H. enteromorpha
Rb (ppm) in H. inactiva
0
50
100
150
53
8.86
n=5
n=4
n=6
n=2
n=9
n=3
n=7
n=8
ND
Bartlett Cove
Blue Mouse Cove
Chilkoot Saintly Hill 1999
Chilkoot Saintly Hill 2009
Dyea 1999
Dyea 2009
Glacier Gorge
Icy Junction
Icy Lake
Lost Lake Trail
Lower Dewey 1999
Lower Dewey 2009
Skagway Incinerator
Sturgills 1999
Sturgills 2009
Dewey 1700
Sitka

Silicon



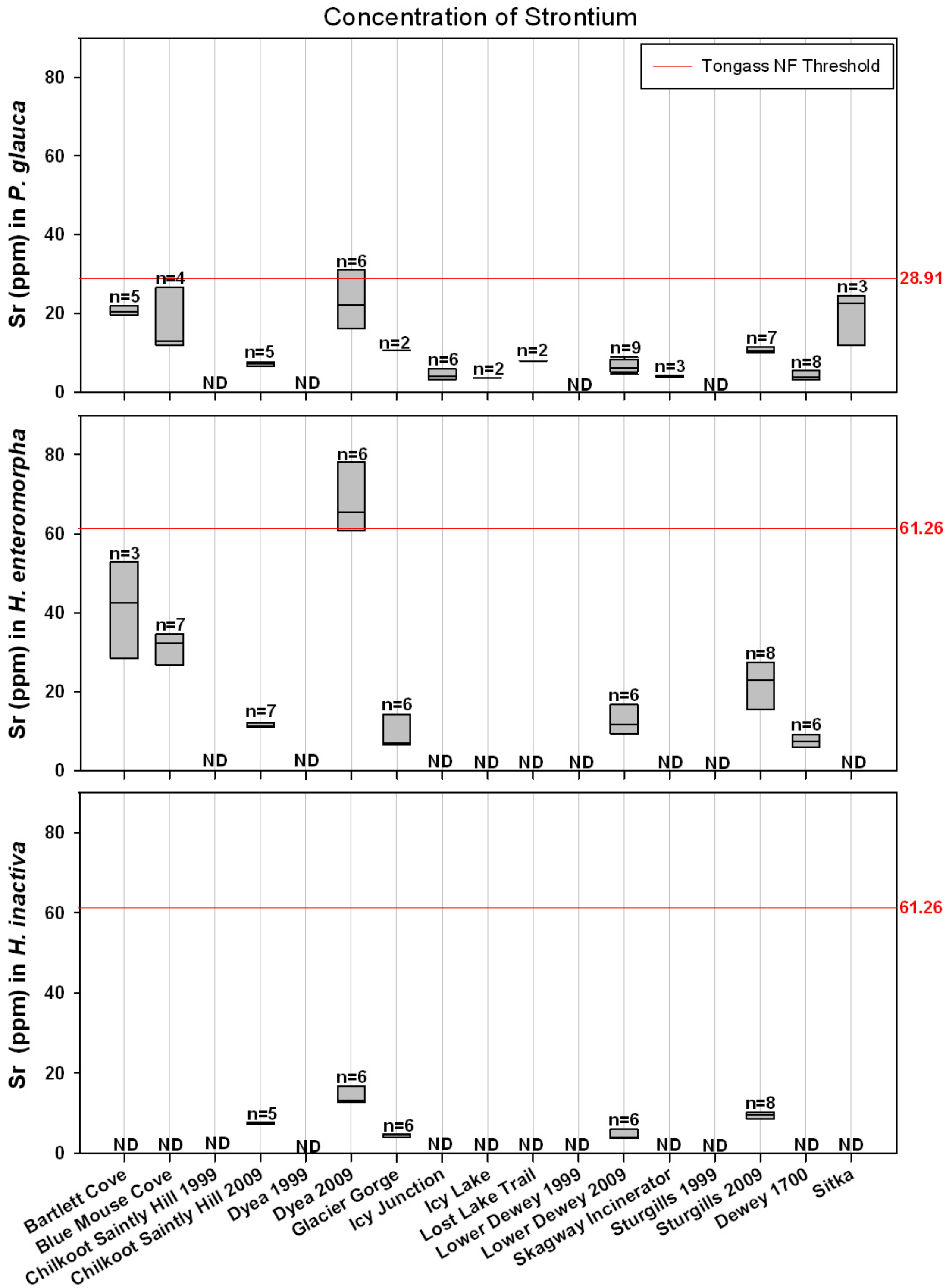
Concentration of Silicon
Tongass NF Threshold
635.83
563.82
563.82
Si (ppm) in P. glauca
Si (ppm) in H. enteromorpha
Si (ppm) in H. inactiva
0
200
400
600
800
n=4
n=5
n=5
n=6
n=2
n=6
n=2
n=2
n=9
n=3
n=7
n=8
n=3
n=7
n=3
n=7
n=6
n=6
n=6
n=8
n=6
n=5
n=6
n=6
n=6
n=8
ND
Bartlett Cove
Blue Mouse Cove
Chilkoot Saintly Hill 1999
Chilkoot Saintly Hill 2009
Dyea 1999
Dyea 2009
Glacier Gorge
Icy Junction
Icy Lake
Lost Lake Trail
Lower Dewey 1999
Lower Dewey 2009
Skagway Incinerator
Sturgills 1999
Sturgills 2009
Dewey 1700
Sitka

Sodium



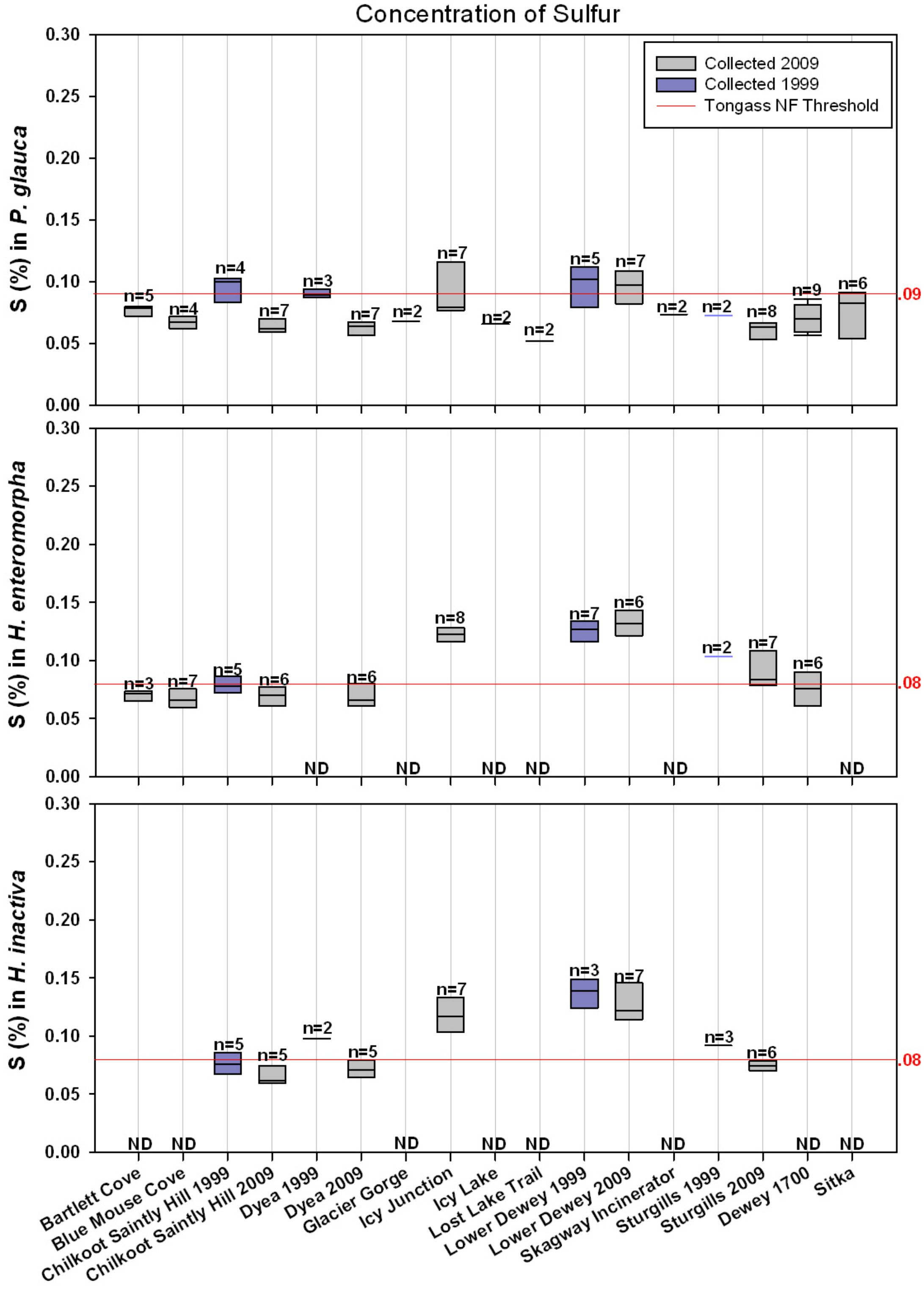
Concentration of Sodium
Collected 2009
Collected 1999
Tongass NF Threshold
693.21
929.13
929.13
Na (ppm) in P. glauca
Na (ppm) in H. enteromorpha
Na (ppm) in H. inactiva
0
200
400
600
800
1000
n=5
n=4
n=4
n=5
n=3
n=6
n=2
n=6
n=2
n=2
n=5
n=9
n=3
n=2
n=7
n=8
n=3
n=3
n=7
n=5
n=7
n=6
n=6
n=7
n=6
n=2
n=8
n=6
n=5
n=5
n=2
n=6
n=6
n=3
n=6
n=2
n=8
ND
Bartlett Cove
Blue Mouse Cove
Chilkoot Saintly Hill 1999
Chilkoot Saintly Hill 2009
Dyea 1999
Dyea 2009
Glacier Gorge
Icy Junction
Icy Lake
Lost Lake Trail
Lower Dewey 1999
Lower Dewey 2009
Skagway Incinerator
Sturgills 1999
Sturgills 2009
Dewey 1700
Sitka

Strontium



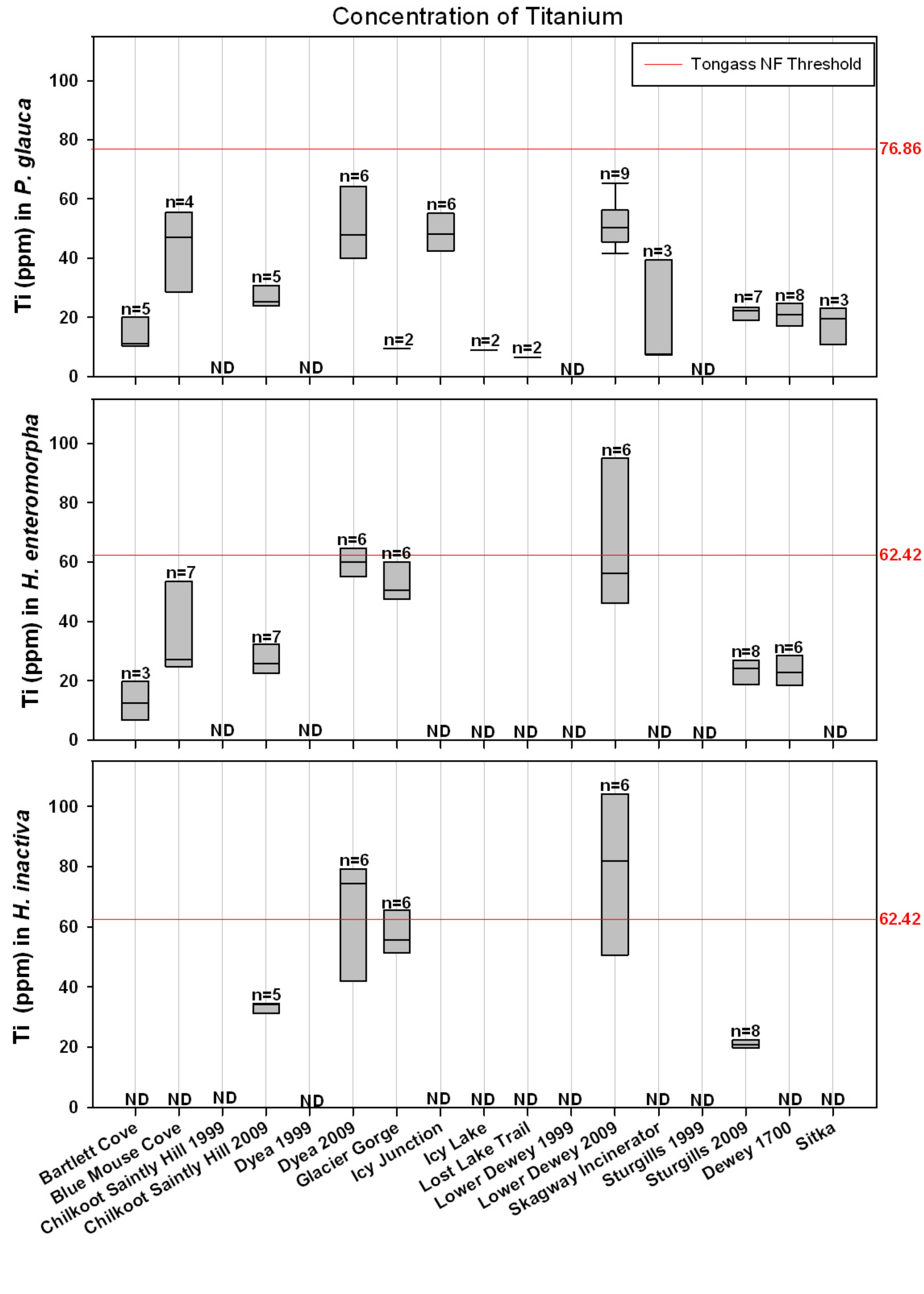
Concentration of Strontium
Tongass NF Threshold
Sr (ppm) in P. glauca
Sr (ppm) in H. enteromorpha
Sr (ppm) in H. inactiva
28.91
61.26
61.26
0
20
40
60
80
n=5
n=4
n=6
n=2
n=9
n=3
n=7
n=8
ND
Bartlett Cove
Blue Mouse Cove
Chilkoot Saintly Hill 1999
Chilkoot Saintly Hill 2009
Dyea 1999
Dyea 2009
Glacier Gorge
Icy Junction
Icy Lake
Lost Lake Trail
Lower Dewey 1999
Lower Dewey 2009
Skagway Incinerator
Sturgills 1999
Sturgills 2009
Dewey 1700
Sitka

Sulfur



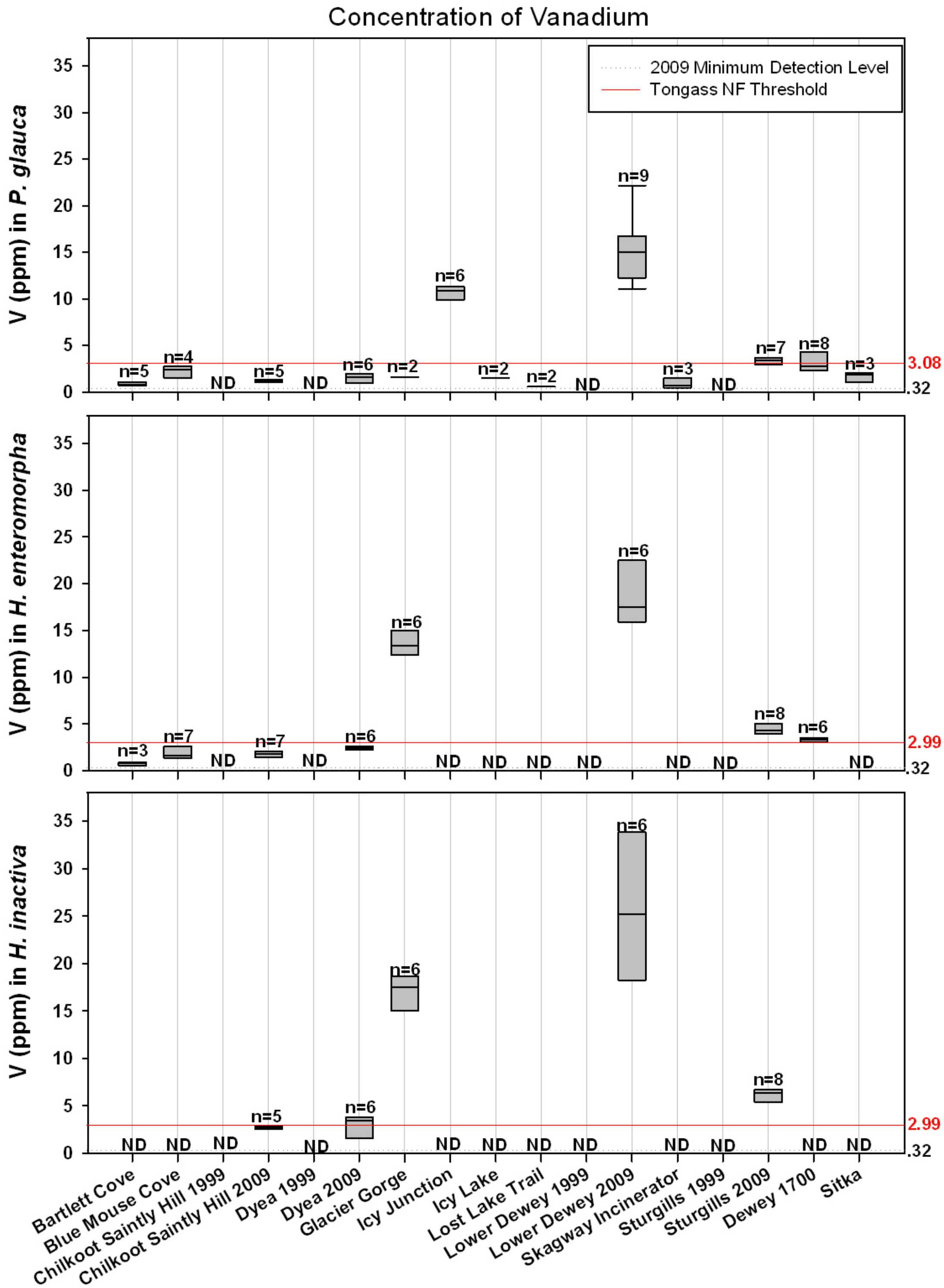
Concentration of Sulfur
Collected 2009
Collected 1999
Tongass NF Threshold
S (%) in P. glauca
S (%) in H. enteromorpha
S (%) in H. inactiva
0.30
0.25
0.20
0.15
0.10
0.05
0.00
.09
.08
.08
ND
Bartlett Cove
Blue Mouse Cove
Chilkoot Saintly Hill 1999
Chilkoot Saintly Hill 2009
Dyea 1999
Dyea 2009
Glacier Gorge
Icy Junction
Icy Lake
Lost Lake Trail
Lower Dewey 1999
Lower Dewey 2009
Skagway Incinerator
Sturgills 1999
Sturgills 2009
Dewey 1700
Sitka

Titanium



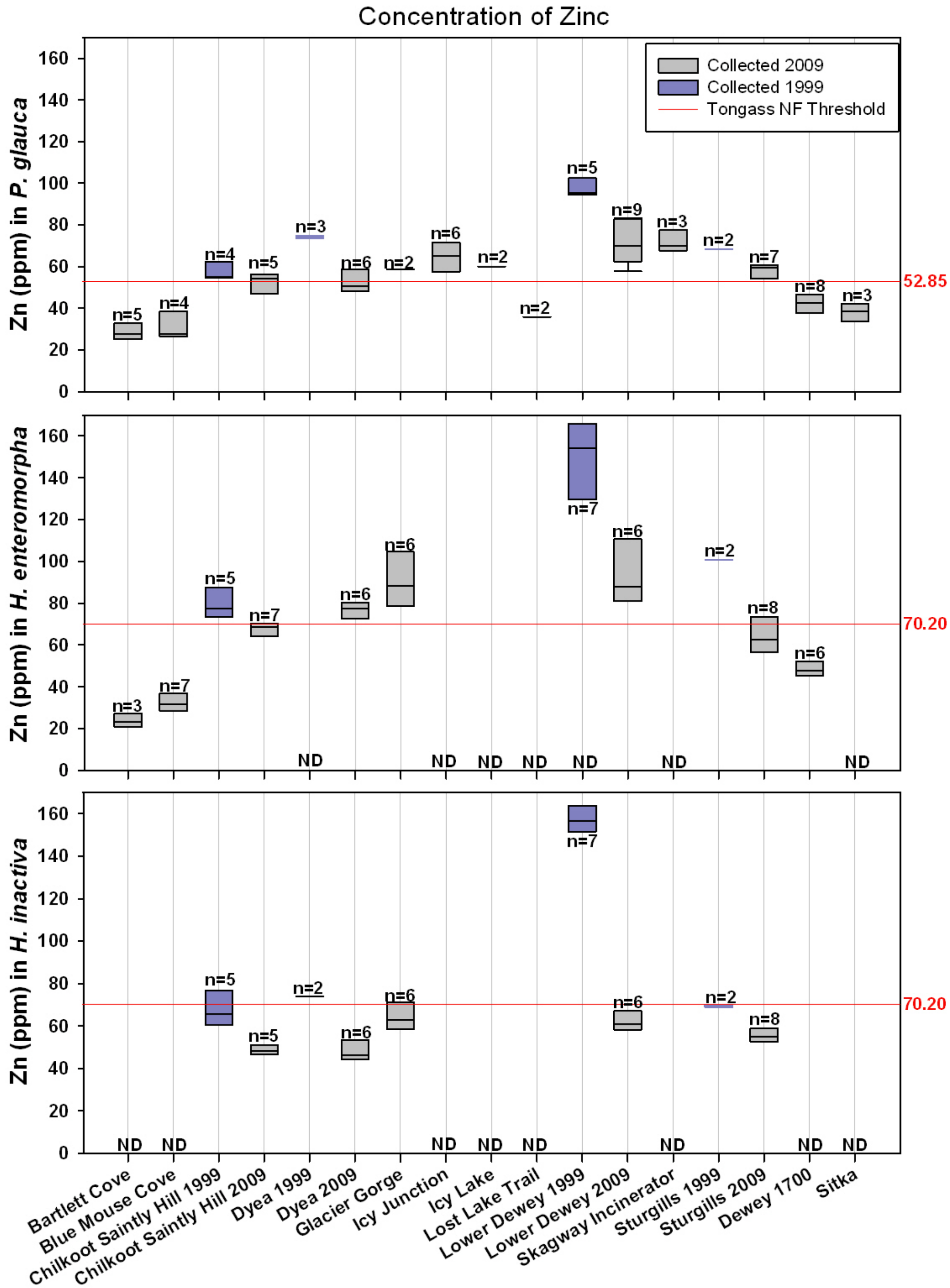
Concentration of Titanium
Tongass NF Threshold
Ti (ppm) in P. glauca
76.86
n=5
n=4
ND
n=5
ND
n=6
n=2
n=6
n=2
n=2
ND
n=9
n=3
ND
n=7
n=8
n=3
Ti (ppm) in H. enteromorpha
62.42
n=3
n=7
ND
n=7
ND
n=6
n=6
ND
ND
ND
ND
n=6
ND
ND
n=8
n=6
ND
Ti (ppm) in H. inactiva
62.42
ND
ND
ND
n=5
ND
n=6
n=6
ND
ND
ND
ND
n=6
ND
ND
n=8
ND
ND
Bartlett Cove
Blue Mouse Cove
Chilkoot Saintly Hill 1999
Chilkoot Saintly Hill 2009
Dyea 1999
Dyea 2009
Glacier Gorge
Icy Junction
Icy Lake
Lost Lake Trail
Lower Dewey 1999
Lower Dewey 2009
Skagway Incinerator
Sturgills 1999
Sturgills 2009
Dewey 1700
Sitka

Vanadium



Concentration of Vanadium
2009 Minimum Detection Level
Tongass NF Threshold
V (ppm) in P. glauca
V (ppm) in H. enteromorpha
V (ppm) in H. inactiva
3.08
2.99
2.99
.32
ND
Bartlett Cove
Blue Mouse Cove
Chilkoot Saintly Hill 1999
Chilkoot Saintly Hill 2009
Dyea 1999
Dyea 2009
Glacier Gorge
Icy Junction
Icy Lake
Lost Lake Trail
Lower Dewey 1999
Lower Dewey 2009
Skagway Incinerator
Sturgills 1999
Sturgills 2009
Dewey 1700
Sitka

Zinc



Concentration of Zinc
Collected 2009
Collected 1999
Tongass NF Threshold
Zn (ppm) in P. glauca
Zn (ppm) in H. enteromorpha
Zn (ppm) in H. inactiva
52.85
70.20
70.20
ND
Bartlett Cove
Blue Mouse Cove
Chilkoot Saintly Hill 1999
Chilkoot Saintly Hill 2009
Dyea 1999
Dyea 2009
Glacier Gorge
Icy Junction
Icy Lake
Lost Lake Trail
Lower Dewey 1999
Lower Dewey 2009
Skagway Incinerator
Sturgills 1999
Sturgills 2009
Dewey 1700
Sitka

Appendix F. Lichen sample elemental analysis results, 2008–2009.

Table F.1. Lichen sample elemental analysis results (S%, N%, Al, As, B, Ba, Be, Ca, Cd) for Glacier Bay National Park and Preserve, 2008-2009.

Year	PlotNo	SampleNo	SciCode	S%	N%	Al ppm	As ppm	B ppm	Ba ppm		Be ppm	Ca ppm		Cd ppm
2008	GLBA_BCA	BC01	Plagla	0.0722	0.7140	269.6500	4.6400	2.5840	18.4720		0.020	3296.900		0.220
2008	GLBA_BCA	BC01	Plagla	0.0711	0.7120	254.1500	4.6400	2.4770	17.2240		0.020	3109.400		0.220
2008	GLBA_BCA	BC02	Plagla	0.0782	0.7520	231.9900	4.6400	1.9790	9.2670		0.020	3164.400		0.220
2008	GLBA_BCA	BC03	Hypent	0.0715	0.7460	397.9800	4.6400	2.6290	19.8090		0.020	19647.000		0.220
2008	GLBA_BCA	BC04	Hypent	0.0736	0.7490	317.3000	4.6400	3.2760	8.1020		0.020	15371.000		0.220
2008	GLBA_BCA	BC04	Hypent											
2008	GLBA_BCA	BC05	Hypent	0.0649	0.7550	187.1200	4.6400	2.2990	6.6320		0.020	13809.000		0.220
2008	GLBA_BMA	BM01	Hypent	0.0657	0.6860	715.0600	4.6400	1.8400	11.2170		0.020	10161.000		0.235
2008	GLBA_BMA	BM02	Plagla	0.0691	0.7560	505.2300	4.6400	1.0070	21.6660		0.020	3036.800		0.220
2008	GLBA_BMA	BM03	Plagla	0.0722	0.7800	843.8500	4.6400	0.6670	14.3040		0.020	2207.200		0.220
2008	GLBA_BMA	BM04	Hypent	0.0598	0.7760	554.7700	4.6400	1.5590	18.9740		0.020	15756.000		0.220
2008	GLBA_BMA	BM04	Hypent	0.0596	0.7640	530.5900	4.6400	1.6780	19.2650		0.020	17647.000		0.220
2008	GLBA_BMA	BM05	Hypent	0.0402	0.6840	650.2300	4.6400	1.6290	9.5060		0.020	15426.000		0.220
2008	GLBA_BMA	BM06	Hypent	0.0754	0.7700	496.8400	4.6400	1.7750	26.5880		0.020	14619.000		0.220
2008	GLBA_BMA	BM06	Hypent											
2009	GLBA_BCB	BC01-09	Alesar	0.0431	0.5490	33.7760		0.6600	6.4970	<	0.020	4270.100	<	0.220
2009	GLBA_BCB	BC01-09	Alesar	0.0443	0.5330	30.5400		0.5830	6.4630	<	0.020	4604.500	<	0.220
2009	GLBA_BCB	BC02-09	Alesar	0.0370	0.5630	41.9580		0.7960	8.4740	<	0.020	5578.000	<	0.220
2009	GLBA_BCB	BC03-09	Plagla	0.0785	0.7840	413.4800		3.3770	37.2440	<	0.020	3694.300	<	0.220
2009	GLBA_BCB	BC04-09	Plagla	0.0804	0.7310	365.4100		2.8150	33.9970	<	0.020	3093.600	<	0.220
2009	GLBA_BMB	BM01-09	Hypent	0.0684	0.9510	1180.8000		2.9990	28.1380	<	0.020	10089.000	<	0.220
2009	GLBA_BMB	BM02-09	Hypent	0.0888	0.9270	1124.6000		3.4020	73.9110	<	0.020	14045.000	<	0.220
2009	GLBA_BMB	BM03-09	Plagla	0.0642	0.8180	1034.5000		2.0460	12.2640	<	0.020	2210.400	<	0.220
2009	GLBA_BMB	BM04-09	Plagla	0.0609	0.9090	878.8500		3.6160	64.6260	<	0.020	4682.300	<	0.220

Table F.2. Lichen sample elemental analysis results (Co, Cr, Cu, Fe, Hg, K, Li, Mg, Mn, Mo) for Glacier Bay National Park and Preserve, 2008-2009.

Year	PlotNo	SampleNo	SciCode		Co ppm	Cr ppm	Cu ppm	Fe ppm	Hg ppb	K ppm		Li ppm	Mg ppm	Mn ppm		Mo ppm
2008	GLBA_BCA	BC01	Plagla		0.780	0.714	3.064	387.370	192.60	2920.600		0.163	978.520	34.926		0.540
2008	GLBA_BCA	BC01	Plagla		0.780	0.679	2.872	358.900	178.90	2789.200		0.190	921.260	33.393		0.540
2008	GLBA_BCA	BC02	Plagla		0.780	0.704	2.961	325.790	189.30	3084.400		0.165	1034.200	32.004		0.540
2008	GLBA_BCA	BC03	Hypent		0.780	0.772	3.033	518.930	279.50	2712.900		0.196	1308.700	62.311		0.540
2008	GLBA_BCA	BC04	Hypent		0.780	0.717	3.159	443.500	205.90	2814.200		0.218	1633.200	61.147		0.540
2008	GLBA_BCA	BC04	Hypent						217.20							
2008	GLBA_BCA	BC05	Hypent		0.780	0.494	6.758	244.430	142.90	2864.700		0.140	1410.300	51.870		0.540
2008	GLBA_BMA	BM01	Hypent		0.780	1.489	5.425	936.150	339.00	3005.600		0.342	1404.700	56.684		0.540
2008	GLBA_BMA	BM02	Plagla		0.780	1.357	3.725	724.010	130.00	3076.100		0.327	1108.900	31.945		0.540
2008	GLBA_BMA	BM03	Plagla		0.780	1.978	4.302	1221.100	167.80	2674.100		0.444	1173.100	42.238		0.540
2008	GLBA_BMA	BM04	Hypent		0.780	1.628	4.743	671.820	189.10	3878.300		0.369	1590.800	47.622		0.540
2008	GLBA_BMA	BM04	Hypent		0.780	1.597	4.750	619.000		3925.000		0.341	1523.800	48.126		0.540
2008	GLBA_BMA	BM05	Hypent		0.780	1.313	4.657	829.040	251.40	3002.000		0.325	1435.400	54.342		0.540
2008	GLBA_BMA	BM06	Hypent		0.780	1.400	4.591	654.110	210.10	3502.000		0.299	1368.600	58.536		0.540
2008	GLBA_BMA	BM06	Hypent						207.00							
2009	GLBA_BCB	BC01-09	Alesar	<	0.780	0.302	1.171	51.207	155.95	1620.800	<	0.100	502.310	52.365	<	0.540
2009	GLBA_BCB	BC01-09	Alesar	<	0.780	0.375	1.109	49.870	168.19	1537.500	<	0.100	464.400	47.115	<	0.540
2009	GLBA_BCB	BC02-09	Alesar	<	0.780	0.442	1.256	95.088	144.93	1713.600	<	0.100	470.380	120.960	<	0.540
2009	GLBA_BCB	BC03-09	Plagla	<	0.780	1.308	3.820	528.270	205.48	2193.200		0.218	928.700	125.980	<	0.540
2009	GLBA_BCB	BC04-09	Plagla	<	0.780	1.358	3.619	496.430	171.94	2370.400		0.202	948.570	70.656	<	0.540
2009	GLBA_BMB	BM01-09	Hypent		0.897	2.704	6.932	1572.900	279.98	2898.700		0.741	1923.300	62.102	<	0.540
2009	GLBA_BMB	BM02-09	Hypent		0.894	2.668	7.229	1534.200	297.95	2369.800		0.749	1612.600	75.304	<	0.540
2009	GLBA_BMB	BM03-09	Plagla		1.068	3.287	5.088	1416.400	167.98	2306.900		0.695	1330.300	36.978	<	0.540
2009	GLBA_BMB	BM04-09	Plagla	<	0.780	2.704	5.711	1136.000	208.19	2534.600		0.524	1530.200	28.757	<	0.540

Table F.3. Lichen sample elemental analysis results (Na, Ni, P, Pb, Rb, Si, Sr, Ti, V, Zn) for Glacier Bay National Park and Preserve, 2008-2009.

Year	PlotNo	SampleNo	SciCode	Na ppm	Ni ppm	P ppm	Pb ppm	Rb ppm	Si ppm	Sr ppm	Ti ppm	V ppm	Zn ppm
2008	GLBA_BCA	BC01	Plagla	152.740	0.649	1084.400	3.520	8.860	273.600	21.628	11.031	0.715	27.617
2008	GLBA_BCA	BC01	Plagla	142.470	0.842	1021.400	3.520	8.860	262.350	20.378	11.068	0.723	26.415
2008	GLBA_BCA	BC02	Plagla	121.190	0.640	1116.400	3.520	8.860	259.090	19.161	9.266	0.663	23.629
2008	GLBA_BCA	BC03	Hypent	212.360	1.118	996.530	3.520	23.441	412.950	52.882	19.819	0.794	27.161
2008	GLBA_BCA	BC04	Hypent	182.990	1.024	1034.200	3.520	10.081	269.550	42.527	12.441	0.884	23.211
2008	GLBA_BCA	BC04	Hypent										
2008	GLBA_BCA	BC05	Hypent	134.850	0.880	960.670	3.520	13.631	162.500	28.415	6.659	0.536	20.930
2008	GLBA_BMA	BM01	Hypent	265.280	2.017	1186.400	3.520	10.220	425.920	19.857	24.740	1.586	36.806
2008	GLBA_BMA	BM02	Plagla	114.630	1.201	1243.000	3.520	10.842	552.040	13.171	23.359	1.260	26.257
2008	GLBA_BMA	BM03	Plagla	177.530	1.888	1208.600	3.520	21.097	661.580	11.586	44.301	2.078	28.820
2008	GLBA_BMA	BM04	Hypent	182.250	1.372	1465.000	3.520	8.860	679.680	32.473	27.545	1.604	31.570
2008	GLBA_BMA	BM04	Hypent	193.830	1.333	1492.800	3.520	8.860	645.410	34.666	25.719	1.644	31.781
2008	GLBA_BMA	BM05	Hypent	243.400	1.741	1144.900	3.520	12.939	409.070	26.685	27.019	1.356	28.589
2008	GLBA_BMA	BM06	Hypent	175.030	1.489	1351.000	3.520	16.004	432.690	29.620	17.888	1.200	28.521
2008	GLBA_BMA	BM06	Hypent										
2009	GLBA_BCB	BC01-09	Alesar	111.130	< 0.640	490.590	< 3.520	< 8.860	63.863	11.611	1.977	< 0.320	25.431
2009	GLBA_BCB	BC01-09	Alesar	106.140	< 0.640	498.210	< 3.520	< 8.860	58.472	12.137	1.725	< 0.320	22.958
2009	GLBA_BCB	BC02-09	Alesar	80.115	< 0.640	684.120	< 3.520	11.225	71.188	14.227	2.080	< 0.320	29.582
2009	GLBA_BCB	BC03-09	Plagla	164.590	1.426	1012.700	< 3.520	22.715	385.860	19.903	21.364	1.180	33.613
2009	GLBA_BCB	BC04-09	Plagla	157.890	1.377	1009.500	< 3.520	25.881	367.030	22.124	18.682	0.963	32.213
2009	GLBA_BMB	BM01-09	Hypent	390.610	3.177	1465.300	< 3.520	24.868	806.280	32.335	60.672	3.090	32.694
2009	GLBA_BMB	BM02-09	Hypent	388.620	2.458	1107.300	< 3.520	14.600	845.040	41.018	53.516	2.568	49.883
2009	GLBA_BMB	BM03-09	Plagla	274.770	2.702	1116.300	< 3.520	24.361	766.930	12.747	57.540	2.689	26.175
2009	GLBA_BMB	BM04-09	Plagla	348.650	2.408	1142.900	< 3.520	20.410	837.000	31.032	49.638	2.786	41.977

Table F.4. Lichen sample elemental analysis results (S%, N%, Al, As, B, Ba, Be, Ca, Cd) for Klondike Gold Rush National Historical Park, 2008-2009.

Year	PlotNo	SampleNo	SciCode	S%	N%	Al ppm	As ppm	B ppm	Ba ppm	Be ppm	Ca ppm	Cd ppm
2008	KLGO_CHD	CH02	Hypina	0.0582	0.6210	456.0300	4.6400	0.2770	12.1350	0.020	2773.700	0.410
2008	KLGO_CHD	CH03	Hypent	0.0547	0.5980	350.4300	4.6400	0.9010	24.7090	0.020	7003.300	0.451
2008	KLGO_CHD	CH04	Hypent	0.0732	0.6770	438.9900	4.6400	1.3610	25.2090	0.020	5236.300	0.419
2008	KLGO_CHD	CH04	Hypent									
2008	KLGO_CHD	CH05	Hypent	0.0626	0.6330	238.7800	4.6400	1.9140	17.4820	0.020	9320.000	0.487
2008	KLGO_CHD	CH06	Hypina	0.0850	0.6220	545.6300	4.6400	0.4790	13.0710	0.020	2452.600	0.356
2008	KLGO_CHD	CH07	Plagla	0.0569	0.5220	306.5000	4.6400	0.6050	28.5480	0.020	1889.200	0.275
2008	KLGO_CHD	CH07	Plagla									
2008	KLGO_CHD	CH08	Plagla	0.0618	0.5160	304.6000	4.6400	0.6150	19.2120	0.020	2149.300	0.246
2008	KLGO_CHD	CH08	Plagla	0.0620	0.5120							
2008	KLGO_DYC	DY01	Hypina	0.0643	0.6140	533.4400	4.6400	0.4490	17.7060	0.020	6437.900	0.248
2008	KLGO_DYC	DY02	Plagla	0.0555	0.5430	292.1700	4.6400	0.7290	70.7930	0.020	2409.100	0.220
2008	KLGO_DYC	DY02	Plagla									
2008	KLGO_DYC	DY03	Hypent	0.0704	0.7580	640.0400	4.6400	2.4080	102.2600	0.020	15135.000	0.221
2008	KLGO_DYC	DY04	Hypent	0.0793	0.6770	580.7600	4.6400	1.8780	112.3000	0.020	16692.000	0.220
2008	KLGO_DYC	DY06	Hypent	0.0607	0.6430	559.4400	4.6400	1.8070	111.5400	0.020	22550.000	0.220
2008	KLGO_DYC	DY07	Plagla	0.0636	0.5760	350.4400	4.6400	0.3570	58.4810	0.020	2232.600	0.350
2008	KLGO_DYC	DY08	Hypina	0.0645	0.6500	534.9300	4.6400	0.3010	16.2260	0.020	5342.300	0.274
2008	KLGO_IJA	IJ01	Hypent	0.1200	0.8180	703.4000	4.6400	1.1680	30.9430	0.020	3014.500	0.339
2008	KLGO_IJA	IJ02	Hypina	0.1000	0.7110	559.0900	4.6400	0.2510	7.2070	0.020	744.890	0.220
2008	KLGO_IJA	IJ02	Hypina	0.1030								
2008	KLGO_IJA	IJ03	Hypent	0.1280	0.7060	831.7200	4.6400	1.7490	10.5180	0.020	1754.500	0.346
2008	KLGO_IJA	IJ04	Plagla	0.0764	0.5930	292.5300	4.6400	0.4280	8.5540	0.020	592.790	0.220
2008	KLGO_IJA	IJ04	Plagla									
2008	KLGO_IJA	IJ05	Hypent	0.1150	0.7560	625.9800	4.6400	1.7230	58.3270	0.020	5740.200	0.734
2008	KLGO_IJA	IJ05	Hypent	0.1150	0.7520							
2008	KLGO_IJA	IJ06	Hypina	0.1170	0.7600	657.1000	4.6400	0.2200	9.4810	0.020	849.960	0.220
2008	KLGO_IJA	IJ06	Hypina									
2008	KLGO_IJA	IJ07	Plagla	0.0698	0.5950	385.9600	4.6400	0.2200	12.1690	0.020	677.030	0.220
2008	KLGO_IJA	IJ07	Plagla									
2008	KLGO_IJA	IJ08	Plagla	0.0786	0.6730	403.3700	4.6400	0.3030	22.0050	0.020	995.830	0.291
2008	KLGO_IJA	IJ08	Plagla	0.0791	0.6980							
2008	KLGO_IJA	IJ09	Hypina	0.1110	0.7470	683.8600	4.6400	0.2200	10.4720	0.020	852.190	0.220

Table F.4. Lichen sample elemental analysis results (S%, N%, Al, As, B, Ba, Be, Ca, Cd) for Klondike Gold Rush National Historical Park, 2008-2009 (continued).

Year	PlotNo	SampleNo	SciCode	S%	N%	Al ppm	As ppm	B ppm	Ba ppm	Be ppm	Ca ppm	Cd ppm
2008	KLGO_IJA	IJ09	Hypina									
2008	KLGO_LDC	LD01	Hypent	0.1220	0.8740	1019.8000	4.6400	0.5190	71.9020	0.020	3652.000	0.722
2008	KLGO_LDC	LD02	Plagla	0.0956	0.7250	382.6100	4.6400	0.3140	11.0800	0.020	631.480	0.268
2008	KLGO_LDC	LD03	Hypina	0.1350	0.7840	693.2200	4.6400	0.2200	12.2920	0.020	509.420	0.381
2008	KLGO_LDC	LD03	Hypina			670.0300	4.6400	0.2200	11.6640	0.020	481.780	0.326
2008	KLGO_LDC	LD04	Plagla	0.1040	0.7450	401.4200	4.6400	0.4510	24.8680	0.020	1023.600	0.315
2008	KLGO_LDC	LD04A	Plagla	0.0905	0.5930	334.2600	4.6400	0.7200	23.6040	0.020	1056.900	0.356
2008	KLGO_LDC	LD04A	Plagla			340.0900	4.6400	0.6740	23.0250	0.020	1056.500	0.320
2008	KLGO_LDC	LD05	Hypina	0.1220	0.7170	634.9000	4.6400	0.2200	8.9070	0.020	689.230	0.259
2008	KLGO_LDC	LD06	Hypent	0.1250	0.8370	587.1700	4.6400	1.3060	29.3600	0.020	4135.500	0.577
2008	KLGO_LDC	LD07	Plagla	0.1190	0.7730	456.8200	4.6400	0.2200	19.2190	0.020	779.250	0.337
2008	KLGO_LDC	LD08	Hypina	0.1510	0.7900	626.6900	4.6400	0.2200	12.0150	0.020	411.430	0.305
2008	KLGO_LDC	LD08	Hypina									
2008	KLGO_LDC	LD09	Hypent	0.1560	0.8730	766.4600	4.6400	0.7600	33.1500	0.020	1755.700	0.461
2008	KLGO_LDC	LD10	Hypina	0.1460	0.7760	677.5700	4.6400	0.2200	12.1470	0.020	537.120	0.278
2008	KLGO_STC	ST02	Plagla	0.0635	0.5640	231.5500	4.6400	0.9450	34.6970	0.020	1704.300	0.220
2008	KLGO_STC	ST02	Plagla	0.0671	0.5670							
2008	KLGO_STC	ST03	Plagla	0.0614	0.5780	271.2400	4.6400	0.9460	30.7080	0.020	1456.700	0.220
2008	KLGO_STC	ST04	Plagla	0.0667	0.5960	312.0200	4.6400	1.0400	31.0200	0.020	1752.500	0.220
2008	KLGO_STC	ST05	Plagla	0.0624	0.5600	279.0400	4.6400	0.8070	31.1050	0.020	1493.400	0.220
2008	KLGO_STC	ST06	Hypent	0.0890	0.7840	471.2400	4.6400	1.3750	21.6090	0.020	7918.700	0.450
2008	KLGO_STC	ST07	Hypent	0.0783	0.6890	370.9400	4.6400	1.3180	27.1010	0.020	4401.900	0.288
2008	KLGO_STC	ST08	Hypent	0.0717	0.6000	444.6100	4.6400	1.3200	9.8050	0.020	2022.500	0.289
2008	KLGO_STC	ST09	Hypent	0.0838	0.6770	514.5800	4.6400	1.8000	11.5550	0.020	3593.500	0.287
2008	KLGO_STC	ST10	Hypina	0.0730	0.6420	543.1500	4.6400	0.8220	8.0180	0.020	1901.000	0.220
2008	KLGO_STC	ST11	Hypina	0.0816	0.7060	574.4000	4.6400	1.0950	13.4090	0.020	2744.200	0.258
2008	KLGO_STC	ST12	Hypina	0.0698	0.6270	453.9200	4.6400	0.7040	10.5030	0.020	2012.400	0.220
2008	KLGO_TL	TL2	n.d.	0.0764	0.6290	264.3300	4.6400	0.8710	30.2230	0.020	1591.700	0.251
2008	KLGO_TL	TL4	n.d.	0.0752	0.7470	503.2900	4.6400	1.6670	27.9070	0.020	11402.000	0.634
2008	KLGO_TL	TL4	n.d.	0.0773	0.7310							
2008	KLGO_TL	TL4A	n.d.	0.0861	0.8160	596.5400	4.6400	2.1720	34.3700	0.020	12329.000	0.398
2008	KLGO_TL	TL4A	n.d.									
2008	KLGO_TL	TL4B	n.d.	0.0635	0.5430	307.5000	4.6400	1.2580	9.2600	0.020	1798.200	0.220
2008	KLGO_TL	TL6	Plagla	0.0656	0.5170	607.0900	4.6400	1.7880	22.2500	0.020	8758.800	0.220

Table F.4. Lichen sample elemental analysis results (S%, N%, Al, As, B, Ba, Be, Ca, Cd) for Klondike Gold Rush National Historical Park, 2008-2009 (continued).

Year	PlotNo	SampleNo	SciCode	S%	N%	Al ppm	As ppm	B ppm	Ba ppm		Be ppm	Ca ppm		Cd ppm
2008	KLGO_TL	TL7	n.d.	0.0615	0.5810	262.6300	4.6400	1.5140	74.0320		0.020	8941.900		0.273
2008	KLGO_TL	TL7A	n.d.	0.0741	0.6310	325.0100	4.6400	2.0630	77.0510		0.020	6223.600		0.220
2008	KLGO_TL	TL7A	n.d.											
2008	KLGO_UDA	UD01	Hypent	0.0767	0.8030	570.8400	5.9960	0.9620	12.8600		0.020	7435.500		0.273
2008	KLGO_UDA	UD01	Hypent											
2008	KLGO_UDA	UD02	Hypent	0.0754	0.5670	554.7500	4.6400	1.4800	5.9060		0.020	10182.000		0.220
2008	KLGO_UDA	UD03	Plagla	0.0695	0.6040	412.0000	4.6400	1.1800	13.3270		0.020	2137.400		0.220
2008	KLGO_UDA	UD04	Plagla	0.0851	0.6490	472.4400	4.6400	1.2510	12.6990		0.020	2089.000		0.220
2008	KLGO_UDA	UD05	Plagla	0.0566	0.4690	463.8900	4.6400	1.0540	3.8260		0.020	1749.100		0.220
2008	KLGO_UDA	UD05	Plagla			398.2400	4.6400	1.2040	3.3350		0.020	1528.300		0.220
2008	KLGO_UDA	UD06	Hypent	0.0612	0.5730	582.8200	4.6400	1.8710	5.2040		0.020	9882.300		0.220
2008	KLGO_UDA	UD07	Plagla	0.0772	0.6690	271.2700	4.6400	0.8120	30.2930		0.020	1500.400		0.220
2008	KLGO_UDA	UD07	Plagla	0.0749										
2009	KLGO_CHE	CH01-09	Plagla	0.0704	0.7380	389.2400		1.4740	27.0040	<	0.020	2466.400	<	0.220
2009	KLGO_CHE	CH02-09	Plagla	0.0589	0.6350	317.0900		1.0900	25.6270	<	0.020	2064.500	<	0.220
2009	KLGO_CHE	CH03-09	Plagla	0.0700	0.6980	314.1200		0.9970	39.8840	<	0.020	2423.600	<	0.220
2009	KLGO_CHE	CH03-09	Plagla	0.0682	0.6850									
2009	KLGO_CHE	CH04-09	Hypent	0.0663	0.7280	462.3300		2.2510	19.7800	<	0.020	10137.000		0.292
2009	KLGO_CHE	CH05-09	Hypent	0.0757	0.7890	580.3100		2.3460	21.4730	<	0.020	10504.000		0.284
2009	KLGO_CHE	CH06-09	Hypent	0.0815	0.7720	580.7600		2.4360	24.3180	<	0.020	8168.600		0.257
2009	KLGO_CHE	CH06-09	Hypent			607.1800		2.3560	23.5760	<	0.020	7230.800		0.256
2009	KLGO_CHE	CH07-09	Hypina	0.0612	0.6540	498.0700		1.4120	10.2160	<	0.020	2858.300		0.267
2009	KLGO_CHE	CH08-09	Hypina	0.0614	0.6600	500.8600		1.3290	10.1300	<	0.020	2700.700		0.266
2009	KLGO_CHE	CH09-09	Hypina	0.0643	0.6780	529.2400		1.3110	10.7390	<	0.020	2905.700		0.349
2009	KLGO_DYD	DY01-09	Hypina	0.0706	0.7220	830.1500		2.0310	16.5080	<	0.020	3763.100		0.231
2009	KLGO_DYD	DY02-09	Hypina	0.0827	0.7230	787.0900		2.0670	16.5770	<	0.020	3850.000		0.227
2009	KLGO_DYD	DY02-09	Hypina											
2009	KLGO_DYD	DY03-09	Hypina	0.0753	0.7010	841.7800		2.2550	15.5300	<	0.020	3799.700	<	0.220
2009	KLGO_DYD	DY04-09	Plagla	0.0633	0.6710	413.4500		1.1800	44.6150	<	0.020	2226.500	<	0.220
2009	KLGO_DYD	DY04-09	Plagla	0.0648	0.6590									
2009	KLGO_DYD	DY05-08	Plagla	0.0956	0.7250	605.6800		1.8750	120.1000	<	0.020	3887.600	<	0.220
2009	KLGO_DYD	DY05-08	Plagla											
2009	KLGO_DYD	DY05-09	Plagla	0.0670	0.7150	525.3800		1.3970	40.0700	<	0.020	2397.800	<	0.220
2009	KLGO_DYD	DY06-09	Plagla	0.0566	0.6030	388.3600		1.1000	30.4980	<	0.020	1898.100	<	0.220

Table F.4. Lichen sample elemental analysis results (S%, N%, Al, As, B, Ba, Be, Ca, Cd) for Klondike Gold Rush National Historical Park, 2008-2009 (continued).

Year	PlotNo	SampleNo	SciCode	S%	N%	Al ppm	As ppm	B ppm	Ba ppm		Be ppm	Ca ppm		Cd ppm
2009	KLGO_DYD	DY06-09	Plagla											
2009	KLGO_DYD	DY07-09	Hypent	0.0816	0.8740	730.2100		2.0510	95.0020	<	0.020	15653.000		0.353
2009	KLGO_DYD	DY08-09	Hypent	0.0607	0.7940	653.3600		2.4040	76.4220	<	0.020	18420.000		0.371
2009	KLGO_DYD	DY09-09	Hypent	0.0598	0.8240	608.4900		2.0980	68.1060	<	0.020	19310.000		0.441
2009	KLGO_GGA	GG01-09	Alesar	0.0307	0.5570	19.1460		0.8890	7.5070	<	0.020	2388.900	<	0.220
2009	KLGO_GGA	GG01-09	Alesar			17.1660		0.7450	7.2300	<	0.020	2466.100	<	0.220
2009	KLGO_GGA	GG02-09	Plagla	0.0607	0.6130	200.2100		2.2490	22.2850	<	0.020	2620.000	<	0.220
2009	KLGO_GGA	GG03-09	Alesar	0.0456	0.5770	28.7910		1.6470	10.5080	<	0.020	4020.300	<	0.220
2009	KLGO_GGA	GG04-09	Plagla	0.0740	0.6740	167.9400		2.1630	14.5270	<	0.020	2212.900	<	0.220
2009	KLGO_GGA	GG04-09	Plagla											
2009	KLGO_GGA	GG05-09	Hypapi	0.0811	0.7650	247.5600		3.4410	32.2410	<	0.020	9484.600	<	0.220
2009	KLGO_GGA	GG05-09	Hypapi	0.0791	0.7670									
2009	KLGO_IJB	IJ01-09	Hypent	0.1180	0.5750	661.0200		1.7800	15.9360	<	0.020	2421.600		0.410
2009	KLGO_IJB	IJ01-09	Hypent	0.1250										
2009	KLGO_IJB	IJ02-09	Hypent	0.1370	0.8260	700.5600		2.0830	13.5560	<	0.020	4032.100		0.599
2009	KLGO_IJB	IJ02-09	Hypent		0.8290									
2009	KLGO_IJB	IJ03-09	Hypent	0.1280	0.8550	647.5000		1.8100	16.2970	<	0.020	1997.700		0.382
2009	KLGO_IJB	IJ04-09	Plagla	0.1180	0.7830	520.0500		1.1020	14.9850	<	0.020	1021.000		0.364
2009	KLGO_IJB	IJ05-09	Plagla	0.1150	0.7060	460.1500		0.8610	12.3040	<	0.020	827.830		0.338
2009	KLGO_IJB	IJ06-09	Plagla	0.1160	0.7100	449.0600		0.9390	7.2120	<	0.020	639.990		0.293
2009	KLGO_IJB	IJ07-09	Hypina	0.1330	0.7650	546.3500		0.8390	9.6610	<	0.020	984.500		0.242
2009	KLGO_IJB	IJ08-09	Hypina	0.1370	0.7180	498.9000		0.8190	8.7020	<	0.020	709.570		0.231
2009	KLGO_IJB	IJ09-09	Hypina	0.1180	0.7430	626.3600		0.8570	10.5210	<	0.020	1024.500		0.251
2009	KLGO_IJB	IJ09-09	Hypina	0.1130										
2009	KLGO_LDD	LD01-09	Plagla	0.0982	0.6250	412.7100		1.1850	10.2370	<	0.020	727.040		0.257
2009	KLGO_LDD	LD01-09	Plagla		0.6160									
2009	KLGO_LDD	LD02-09	Plagla	0.0791	0.7030	395.8700		0.7960	17.7370	<	0.020	1099.200		0.306
2009	KLGO_LDD	LD02-09	Plagla											
2009	KLGO_LDD	LD03-09	Plagla	0.1100	0.7660	425.0600		1.2290	16.8980	<	0.020	685.530		0.258
2009	KLGO_LDD	LD03-09	Plagla			456.3800		1.3140	19.1390	<	0.020	723.070		0.286
2009	KLGO_LDD	LD04-09	Hypent	0.1190	0.7630	645.0200		1.6650	36.4450	<	0.020	3252.000		0.343
2009	KLGO_LDD	LD05-09	Hypent	0.1380	0.7680	625.7200		1.4470	24.6350	<	0.020	1649.000		0.279
2009	KLGO_LDD	LD06-09	Hypent	0.1390	0.9090	591.0100		1.9510	21.2210	<	0.020	1901.900		0.439
2009	KLGO_LDD	LD07-09	Hypina	0.1220	0.6680	539.6600		1.5360	10.5010	<	0.020	848.060		0.347

Table F.4. Lichen sample elemental analysis results (S%, N%, Al, As, B, Ba, Be, Ca, Cd) for Klondike Gold Rush National Historical Park, 2008-2009 (continued).

Year	PlotNo	SampleNo	SciCode	S%	N%	Al ppm	As ppm	B ppm	Ba ppm		Be ppm	Ca ppm		Cd ppm
2009	KLGO_LDD	LD08-09	Hypina	0.1130	0.6450	513.5100		1.5460	12.9510	<	0.020	1055.500	<	0.220
2009	KLGO_LDD	LD09-09	Hypina	0.1140	0.6840	580.2700		1.5370	10.9530	<	0.020	919.660		0.291
2009	KLGO_STD	ST01-09	Plagla	0.0501	0.5850	301.1100		1.5000	3.8160	<	0.020	2471.300	<	0.220
2009	KLGO_STD	ST02-09	Plagla	0.0642	0.5890	294.9100		2.2100	24.8200	<	0.020	1416.800		0.250
2009	KLGO_STD	ST03-09	Plagla	0.0500	0.5900	258.1200		1.5080	21.6060	<	0.020	1418.400	<	0.220
2009	KLGO_STD	ST04-09	Hypent	0.0801	0.7500	319.7500		2.3230	26.0220	<	0.020	9145.800		0.326
2009	KLGO_STD	ST05-09	Hypent	0.1100	0.7710	410.2100		2.9920	23.6330	<	0.020	11361.000		0.637
2009	KLGO_STD	ST05-09	Hypent			474.2500		2.9610	26.3910	<	0.020	9905.400		0.634
2009	KLGO_STD	ST06-09	Hypent	0.1080	0.7680	435.3600		2.8030	43.0190	<	0.020	14889.000		0.982
2009	KLGO_STD	ST07-09	Hypina	0.0772	0.6640	509.5200		2.0300	8.8760	<	0.020	2322.100	<	0.220
2009	KLGO_STD	ST07-09	Hypina											
2009	KLGO_STD	ST08-09	Hypina	0.0750	0.6620	511.1800		2.6980	8.5060	<	0.020	2002.400	<	0.220
2009	KLGO_STD	ST09-09	Hypina	0.0697	0.6480	514.1500		2.1030	7.6990	<	0.020	1856.100		0.353
2009	KLGO_UDB	UD01-09	Plagla	0.0597	0.5740	343.3000		1.7510	4.2830	<	0.020	2625.000	<	0.220
2009	KLGO_UDB	UD01-09	Plagla	0.0580	0.5740									
2009	KLGO_UDB	UD02-09	Plagla	0.0599	0.5660	277.9200		1.4660	4.3710	<	0.020	2247.300	<	0.220
2009	KLGO_UDB	UD03-09	Plagla	0.0854	0.6020	390.5900		1.7360	7.3430	<	0.020	2733.200	<	0.220
2009	KLGO_UDB	UD04-09	Hypent	0.0970	0.7450	612.1700		2.5590	7.6380	<	0.020	7724.000	<	0.220
2009	KLGO_UDB	UD04-09	Hypent											
2009	KLGO_UDB	UD05-09	Hypent	0.0872	0.7390	470.2000		1.5980	10.4540	<	0.020	11230.000	<	0.220
2009	KLGO_UDB	UD06-09	Hypent	0.0609	0.6510	386.0300		2.1970	6.8100	<	0.020	13762.000	<	0.220

Table F.5. Lichen sample elemental analysis results (Co, Cr, Cu, Fe, Hg, K, Li, Mg, Mn, Mo) for Klondike Gold Rush National Historical Park, 2008-2009.

Year	PlotNo	SampleNo	SciCode	Co ppm	Cr ppm	Cu ppm	Fe ppm	Hg ppb	K ppm	Li ppm	Mg ppm	Mn ppm	Mo ppm
2008	KLGO_CHD	CH02	Hypina	0.780	0.597	3.305	482.590	282.70	1670.800	0.100	668.680	104.660	0.540
2008	KLGO_CHD	CH03	Hypent	0.780	0.771	3.098	380.000	156.00	2109.800	0.100	838.520	238.210	0.540
2008	KLGO_CHD	CH04	Hypent	0.780	0.812	3.327	401.440	249.40	2466.400	0.113	966.400	209.890	0.540
2008	KLGO_CHD	CH04	Hypent					265.00					
2008	KLGO_CHD	CH05	Hypent	0.780	0.602	3.119	198.780	190.60	2719.900	0.112	969.380	218.180	0.540
2008	KLGO_CHD	CH06	Hypina	0.780	0.793	3.637	581.260	288.70	1812.600	0.100	766.950	123.130	0.540
2008	KLGO_CHD	CH07	Plagla	0.780	0.638	1.954	313.680	137.40	1963.900	0.100	640.050	150.550	0.540
2008	KLGO_CHD	CH07	Plagla					135.80					
2008	KLGO_CHD	CH08	Plagla	0.780	0.642	1.910	308.960	131.20	1886.600	0.100	587.420	130.550	0.540
2008	KLGO_CHD	CH08	Plagla										
2008	KLGO_DYC	DY01	Hypina	0.780	0.963	3.057	556.350	137.70	2730.700	0.100	967.890	120.180	0.540
2008	KLGO_DYC	DY02	Plagla	0.780	0.805	1.620	334.740	75.90	2540.200	0.100	605.320	154.610	0.540
2008	KLGO_DYC	DY02	Plagla					73.80					
2008	KLGO_DYC	DY03	Hypent	0.780	1.755	4.184	704.520	255.80	4126.900	0.440	1116.100	255.530	0.540
2008	KLGO_DYC	DY04	Hypent	0.780	1.679	3.641	687.110	191.20	4097.400	0.345	890.390	242.360	0.540
2008	KLGO_DYC	DY06	Hypent	0.780	1.958	3.514	638.230	220.80	4038.800	0.400	1036.100	282.520	0.540
2008	KLGO_DYC	DY07	Plagla	0.780	0.796	2.046	431.070	99.80	2736.200	0.117	687.240	162.810	0.540
2008	KLGO_DYC	DY08	Hypina	0.780	0.972	2.869	571.940	158.10	2429.300	0.100	694.880	95.490	0.540
2008	KLGO_IJA	IJ01	Hypent	0.780	1.784	10.345	1041.900	194.40	3535.100	0.312	734.730	111.900	0.540
2008	KLGO_IJA	IJ02	Hypina	0.780	1.438	7.263	1001.800	234.30	3016.100	0.182	460.100	57.388	0.540
2008	KLGO_IJA	IJ02	Hypina										
2008	KLGO_IJA	IJ03	Hypent	0.780	1.840	10.036	1065.900	296.00	2773.200	0.237	555.690	53.450	0.540
2008	KLGO_IJA	IJ04	Plagla	0.780	1.176	4.859	486.610	96.00	2982.700	0.112	426.550	43.228	0.540
2008	KLGO_IJA	IJ04	Plagla					93.80					
2008	KLGO_IJA	IJ05	Hypent	0.780	1.389	8.213	785.710	204.80	2981.300	0.179	832.120	151.990	0.540
2008	KLGO_IJA	IJ05	Hypent										
2008	KLGO_IJA	IJ06	Hypina	0.780	1.497	7.435	1162.300	261.10	2851.000	0.192	455.080	47.928	0.562
2008	KLGO_IJA	IJ06	Hypina					247.90					
2008	KLGO_IJA	IJ07	Plagla	0.780	0.931	4.737	616.690	68.00	2488.400	0.100	417.410	81.857	0.540

Table F.5. Lichen sample elemental analysis results (Co, Cr, Cu, Fe, Hg, K, Li, Mg, Mn, Mo) for Klondike Gold Rush National Historical Park, 2008-2009 (continued).

Year	PlotNo	SampleNo	SciCode	Co ppm	Cr ppm	Cu ppm	Fe ppm	Hg ppb	K ppm	Li ppm	Mg ppm	Mn ppm	Mo ppm
2008	KLGO_IJA	IJ07	Plagla					74.80					
2008	KLGO_IJA	IJ08	Plagla	0.780	1.165	5.581	714.430	112.70	2820.300	0.159	471.010	89.028	0.540
2008	KLGO_IJA	IJ08	Plagla					118.80					
2008	KLGO_IJA	IJ09	Hypina	0.780	1.321	7.425	1240.400	251.10	2824.600	0.172	458.640	60.560	0.540
2008	KLGO_IJA	IJ09	Hypina					241.80					
2008	KLGO_LDC	LD01	Hypent	0.803	2.535	14.515	1502.800	299.60	2872.500	0.378	822.110	145.450	0.540
2008	KLGO_LDC	LD02	Plagla	0.780	0.995	7.701	780.470	115.00	3277.700	0.192	407.060	54.833	0.540
2008	KLGO_LDC	LD03	Hypina	0.780	2.331	16.511	1961.900	357.50	3010.400	0.341	422.260	20.742	0.540
2008	KLGO_LDC	LD03	Hypina	0.780	2.287	15.479	1846.000		2824.400	0.273	395.780	19.534	0.540
2008	KLGO_LDC	LD04	Plagla	0.780	1.163	9.097	831.610	178.60	3078.600	0.147	433.180	66.106	0.540
2008	KLGO_LDC	LD04A	Plagla	0.780	1.060	6.138	589.100	99.20	2796.000	0.100	451.810	63.061	0.540
2008	KLGO_LDC	LD04A	Plagla	0.780	1.130	6.027	582.190		2860.200	0.100	449.380	63.032	0.540
2008	KLGO_LDC	LD05	Hypina	0.780	1.632	11.552	1247.400	266.70	3174.200	0.177	441.820	54.450	0.540
2008	KLGO_LDC	LD06	Hypent	0.780	1.797	12.905	827.090	198.30	3264.100	0.187	524.790	83.282	0.540
2008	KLGO_LDC	LD07	Plagla	0.780	1.302	11.112	1058.200	148.80	3168.200	0.237	423.680	53.090	0.540
2008	KLGO_LDC	LD08	Hypina	0.780	1.928	16.198	1739.500	369.90	2687.800	0.325	380.680	13.765	0.540
2008	KLGO_LDC	LD08	Hypina					368.30					
2008	KLGO_LDC	LD09	Hypent	0.780	2.091	16.835	1516.900	194.70	3141.300	0.273	546.750	65.094	0.636
2008	KLGO_LDC	LD10	Hypina	0.780	1.696	16.997	1715.200	343.60	2888.900	0.406	401.050	24.798	0.540
2008	KLGO_STC	ST02	Plagla	0.780	0.574	2.800	274.790	104.80	2412.400	0.100	587.450	169.850	0.540
2008	KLGO_STC	ST02	Plagla										
2008	KLGO_STC	ST03	Plagla	0.780	0.611	2.672	323.180	95.60	2310.700	0.100	597.800	173.450	0.540
2008	KLGO_STC	ST04	Plagla	0.780	0.741	3.222	363.960	106.10	2523.300	0.100	616.130	259.830	0.540
2008	KLGO_STC	ST05	Plagla	0.780	0.527	2.817	361.920	122.80	2400.300	0.147	634.270	169.140	0.540
2008	KLGO_STC	ST06	Hypent	0.780	1.158	3.679	390.130	277.20	2461.400	0.100	819.530	113.250	0.540
2008	KLGO_STC	ST07	Hypent	0.780	0.981	3.687	445.650	174.00	2296.800	0.100	1096.600	157.360	0.540
2008	KLGO_STC	ST08	Hypent	0.780	0.714	4.531	354.030	230.50	2619.500	0.185	716.100	107.850	0.540
2008	KLGO_STC	ST09	Hypent	0.780	1.082	4.287	526.170	279.20	2250.000	0.105	969.490	83.938	0.540
2008	KLGO_STC	ST10	Hypina	0.780	0.687	5.317	461.580	210.80	2561.500	0.160	886.960	122.310	0.540
2008	KLGO_STC	ST11	Hypina	0.780	0.581	5.484	519.690	187.10	2592.600	0.157	872.770	126.420	0.540
2008	KLGO_STC	ST12	Hypina	0.780	0.525	4.705	407.490	181.50	2381.200	0.100	752.520	104.760	0.540
2008	KLGO_TL	TL2	n.d.	0.780	0.542	3.025	307.350	179.00	2502.800	0.100	480.610	117.640	0.540

Table F.5. Lichen sample elemental analysis results (Co, Cr, Cu, Fe, Hg, K, Li, Mg, Mn, Mo) for Klondike Gold Rush National Historical Park, 2008-2009 (continued).

Year	PlotNo	SampleNo	SciCode		Co ppm	Cr ppm	Cu ppm	Fe ppm	Hg ppb	K ppm		Li ppm	Mg ppm	Mn ppm		Mo ppm
2008	KLGO_TL	TL4	n.d.		0.780	0.794	3.945	349.180	337.00	3517.100		0.162	932.240	467.060		0.540
2008	KLGO_TL	TL4	n.d.													
2008	KLGO_TL	TL4A	n.d.		0.780	0.868	4.226	319.620	451.20	4004.400		0.187	896.950	382.680		0.540
2008	KLGO_TL	TL4A	n.d.						391.20							
2008	KLGO_TL	TL4B	n.d.		0.780	0.663	2.828	202.920	170.70	3226.500		0.196	659.210	254.740		0.540
2008	KLGO_TL	TL6	Plagla		0.780	0.817	4.562	444.160	326.40	2449.600		0.202	682.600	359.060		0.540
2008	KLGO_TL	TL7	n.d.		0.780	0.764	3.518	291.570	290.50	2718.500		0.197	695.570	471.610		0.540
2008	KLGO_TL	TL7A	n.d.		0.780	0.948	3.449	387.520	351.80	3017.700		0.225	847.600	363.540		0.540
2008	KLGO_TL	TL7A	n.d.						371.60							
2008	KLGO_UDA	UD01	Hypent		0.780	9.314	26.405	430.390	304.60	2544.500		0.122	543.410	309.450		0.540
2008	KLGO_UDA	UD01	Hypent						289.00							
2008	KLGO_UDA	UD02	Hypent		0.780	1.136	5.573	402.710	231.50	2437.500		0.133	578.840	340.000		0.540
2008	KLGO_UDA	UD03	Plagla		0.780	0.562	2.988	329.270	212.20	2032.300		0.103	454.930	249.680		0.540
2008	KLGO_UDA	UD04	Plagla		0.780	0.761	6.959	668.940	168.00	2494.700		0.163	553.630	194.600		0.540
2008	KLGO_UDA	UD05	Plagla		0.780	0.796	2.484	270.340	195.30	2243.900		0.100	481.210	239.540		0.540
2008	KLGO_UDA	UD05	Plagla		0.780	0.538	2.209	217.030		2035.500		0.100	437.750	207.390		0.540
2008	KLGO_UDA	UD06	Hypent		0.780	0.795	3.419	375.540	292.60	2411.200		0.128	647.370	263.360		0.540
2008	KLGO_UDA	UD07	Plagla		0.780	0.520	3.307	367.180	166.00	2837.800		0.143	490.590	142.880		0.540
2008	KLGO_UDA	UD07	Plagla													
2009	KLGO_CHE	CH01-09	Plagla	<	0.780	1.087	2.826	354.910	215.81	2647.600		0.112	716.670	212.810	<	0.540
2009	KLGO_CHE	CH02-09	Plagla	<	0.780	0.824	2.321	310.370	171.35	2495.100	<	0.100	697.230	130.970	<	0.540
2009	KLGO_CHE	CH03-09	Plagla	<	0.780	0.982	2.508	319.690	218.28	2494.600		0.114	639.030	194.970	<	0.540
2009	KLGO_CHE	CH03-09	Plagla													
2009	KLGO_CHE	CH04-09	Hypent	<	0.780	1.062	4.432	351.740	322.79	3263.400		0.109	842.880	274.620	<	0.540
2009	KLGO_CHE	CH05-09	Hypent	<	0.780	1.300	4.896	441.040	362.05	2918.300		0.158	907.660	283.500	<	0.540
2009	KLGO_CHE	CH06-09	Hypent	<	0.780	1.335	4.574	451.810	374.35	2973.900		0.147	857.390	262.150	<	0.540
2009	KLGO_CHE	CH06-09	Hypent	<	0.780	1.289	4.592	510.480	355.01	2962.900		0.139	929.790	283.830	<	0.540
2009	KLGO_CHE	CH07-09	Hypina	<	0.780	0.976	4.165	534.130	237.99	2098.000	<	0.100	786.280	60.814	<	0.540
2009	KLGO_CHE	CH08-09	Hypina	<	0.780	0.918	3.842	524.010	255.16	2096.400	<	0.100	783.860	60.491	<	0.540
2009	KLGO_CHE	CH09-09	Hypina	<	0.780	0.866	4.372	559.190	228.76	2091.200	<	0.100	821.270	74.453	<	0.540
2009	KLGO_DYD	DY01-09	Hypina	<	0.780	1.874	3.837	1069.400	170.20	3310.700		0.305	1238.600	81.650	<	0.540
2009	KLGO_DYD	DY02-09	Hypina	<	0.780	1.838	3.902	1020.800	180.45	3377.500		0.329	1310.800	82.563	<	0.540
2009	KLGO_DYD	DY02-09	Hypina						197.04							

Table F.5. Lichen sample elemental analysis results (Co, Cr, Cu, Fe, Hg, K, Li, Mg, Mn, Mo) for Klondike Gold Rush National Historical Park, 2008-2009 (continued).

Year	PlotNo	SampleNo	SciCode		Co ppm	Cr ppm	Cu ppm	Fe ppm	Hg ppb	K ppm		Li ppm	Mg ppm	Mn ppm		Mo ppm
2009	KLGO_DYD	DY03-09	Hypina	<	0.780	1.852	3.777	1060.500	161.96	3241.600		0.318	1303.600	78.105	<	0.540
2009	KLGO_DYD	DY04-09	Plagla	<	0.780	1.597	2.373	545.560	120.58	2927.500		0.155	743.840	142.840	<	0.540
2009	KLGO_DYD	DY04-09	Plagla													
2009	KLGO_DYD	DY05-08	Plagla	<	0.780	1.763	3.315	812.700	163.87	3301.100		0.389	938.960	256.410	<	0.540
2009	KLGO_DYD	DY05-08	Plagla						161.55							
2009	KLGO_DYD	DY05-09	Plagla	<	0.780	1.796	2.433	658.220	131.96	2680.300		0.235	741.060	127.360	<	0.540
2009	KLGO_DYD	DY06-09	Plagla	<	0.780	1.343	2.364	504.770	90.92	2261.500		0.126	602.810	79.569	<	0.540
2009	KLGO_DYD	DY06-09	Plagla						105.27							
2009	KLGO_DYD	DY07-09	Hypent	<	0.780	2.506	4.332	892.100	256.77	3775.800		0.350	1162.800	264.680	<	0.540
2009	KLGO_DYD	DY08-09	Hypent	<	0.780	2.165	4.279	784.650	264.71	3949.200		0.298	1072.500	213.230	<	0.540
2009	KLGO_DYD	DY09-09	Hypent	<	0.780	1.634	4.265	687.240	256.11	3786.000		0.210	1030.200	198.510	<	0.540
2009	KLGO_GGA	GG01-09	Alesar	<	0.780	0.475	1.277	25.808	189.13	1949.300	<	0.100	619.670	159.560	<	0.540
2009	KLGO_GGA	GG01-09	Alesar	<	0.780	0.394	1.078	23.353		1942.800	<	0.100	640.810	169.810	<	0.540
2009	KLGO_GGA	GG02-09	Plagla	<	0.780	0.802	3.982	226.440	260.74	2500.100	<	0.100	653.030	119.730	<	0.540
2009	KLGO_GGA	GG03-09	Alesar	<	0.780	0.422	1.347	43.069	260.10	2304.800	<	0.100	855.780	135.640	<	0.540
2009	KLGO_GGA	GG04-09	Plagla	<	0.780	0.745	3.970	214.730	258.77	2635.900	<	0.100	672.950	141.030	<	0.540
2009	KLGO_GGA	GG04-09	Plagla						271.12							
2009	KLGO_GGA	GG05-09	Hypapi	<	0.780	0.816	7.368	332.550	487.22	3414.300	<	0.100	1026.100	211.240	<	0.540
2009	KLGO_GGA	GG05-09	Hypapi						525.71							
2009	KLGO_IJB	IJ01-09	Hypent	<	0.780	2.062	10.457	828.020	284.55	3338.800	<	0.100	495.320	110.780	<	0.540
2009	KLGO_IJB	IJ01-09	Hypent													
2009	KLGO_IJB	IJ02-09	Hypent	<	0.780	1.304	10.677	746.220	273.95	2970.400	<	0.100	478.010	85.156	<	0.540
2009	KLGO_IJB	IJ02-09	Hypent													
2009	KLGO_IJB	IJ03-09	Hypent	<	0.780	1.655	10.439	937.260	283.05	3530.400	<	0.100	552.870	104.300	<	0.540
2009	KLGO_IJB	IJ04-09	Plagla	<	0.780	2.055	7.127	866.480	238.11	3015.100	<	0.100	446.300	84.557	<	0.540
2009	KLGO_IJB	IJ05-09	Plagla	<	0.780	1.708	6.797	803.270	212.75	2840.300	<	0.100	400.410	99.287	<	0.540
2009	KLGO_IJB	IJ06-09	Plagla	<	0.780	1.252	6.462	715.440	216.58	2760.600	<	0.100	386.170	46.958	<	0.540
2009	KLGO_IJB	IJ07-09	Hypina	<	0.780	1.384	8.850	959.090	265.64	3132.400	<	0.100	472.140	73.634	<	0.540
2009	KLGO_IJB	IJ08-09	Hypina	<	0.780	1.329	8.297	862.840	283.92	2904.600	<	0.100	375.210	61.307	<	0.540
2009	KLGO_IJB	IJ09-09	Hypina	<	0.780	1.593	10.800	1008.000	272.98	3654.300		0.266	509.660	90.114	<	0.540
2009	KLGO_IJB	IJ09-09	Hypina													

Table F.5. Lichen sample elemental analysis results (Co, Cr, Cu, Fe, Hg, K, Li, Mg, Mn, Mo) for Klondike Gold Rush National Historical Park, 2008-2009 (continued).

Year	PlotNo	SampleNo	SciCode		Co ppm	Cr ppm	Cu ppm	Fe ppm	Hg ppb	K ppm		Li ppm	Mg ppm	Mn ppm		Mo ppm
2009	KLGO_LDD	LD01-09	Plagla	<	0.780	1.433	8.213	665.440	166.31	2777.000		0.135	478.110	42.996	<	0.540
2009	KLGO_LDD	LD01-09	Plagla													
2009	KLGO_LDD	LD02-09	Plagla	<	0.780	1.408	6.748	574.610	102.96	2483.000		0.147	655.640	84.531	<	0.540
2009	KLGO_LDD	LD02-09	Plagla						88.90							
2009	KLGO_LDD	LD03-09	Plagla	<	0.780	1.481	8.947	755.550	173.26	2752.700		0.197	463.710	35.200	<	0.540
2009	KLGO_LDD	LD03-09	Plagla	<	0.780	1.667	9.324	818.830		2833.700		0.215	482.470	37.835	<	0.540
2009	KLGO_LDD	LD04-09	Hypent	<	0.780	1.576	11.605	762.280	201.22	3145.800		0.196	767.330	130.460	<	0.540
2009	KLGO_LDD	LD05-09	Hypent	<	0.780	1.936	13.155	977.680	205.00	3024.100		0.217	623.360	61.984	<	0.540
2009	KLGO_LDD	LD06-09	Hypent	<	0.780	1.894	11.533	801.590	178.25	3249.200		0.205	669.080	105.110	<	0.540
2009	KLGO_LDD	LD07-09	Hypina	<	0.780	1.362	10.859	880.890	282.49	2844.000		0.135	571.250	49.424	<	0.540
2009	KLGO_LDD	LD08-09	Hypina	<	0.780	1.394	9.461	896.660	260.23	2803.500		0.144	607.900	50.250	<	0.540
2009	KLGO_LDD	LD09-09	Hypina	<	0.780	1.522	9.543	893.020	266.16	2777.900		0.115	566.740	47.078	<	0.540
2009	KLGO_STD	ST01-09	Plagla	<	0.780	0.718	2.743	196.890	215.24	1937.400	<	0.100	401.610	282.680	<	0.540
2009	KLGO_STD	ST02-09	Plagla	<	0.780	1.046	3.400	282.870	154.21	2458.600	<	0.100	777.290	167.680	<	0.540
2009	KLGO_STD	ST03-09	Plagla	<	0.780	0.973	3.167	319.560	113.56	2134.000	<	0.100	700.140	129.020	<	0.540
2009	KLGO_STD	ST04-09	Hypent	<	0.780	0.812	4.874	300.300	188.67	3009.600	<	0.100	1220.700	122.380	<	0.540
2009	KLGO_STD	ST05-09	Hypent	<	0.780	0.884	5.303	385.140	305.84	2828.700		0.115	944.800	198.490	<	0.540
2009	KLGO_STD	ST05-09	Hypent	<	0.780	0.884	5.430	494.240		2778.900		0.125	1022.400	201.830	<	0.540
2009	KLGO_STD	ST06-09	Hypent	<	0.780	1.102	5.268	491.370	281.28	2742.200		0.191	1001.000	243.100	<	0.540
2009	KLGO_STD	ST07-09	Hypina	<	0.780	0.900	6.266	467.180	247.14	2935.200	<	0.100	950.140	113.850	<	0.540
2009	KLGO_STD	ST07-09	Hypina						247.01							
2009	KLGO_STD	ST08-09	Hypina	<	0.780	0.827	5.597	447.800	266.68	2872.600	<	0.100	1030.900	102.770	<	0.540
2009	KLGO_STD	ST09-09	Hypina	<	0.780	0.879	5.719	404.800	250.69	2716.600	<	0.100	958.220	118.840	<	0.540
2009	KLGO_UDB	UD01-09	Plagla	<	0.780	1.025	2.869	236.920	245.53	2153.800	<	0.100	464.490	335.220	<	0.540
2009	KLGO_UDB	UD01-09	Plagla													
2009	KLGO_UDB	UD02-09	Plagla	<	0.780	0.978	2.865	244.960	164.98	1933.000		0.109	480.280	294.540	<	0.540
2009	KLGO_UDB	UD03-09	Plagla	<	0.780	1.001	3.976	326.670	256.90	2076.300		0.171	523.030	375.260	<	0.540
2009	KLGO_UDB	UD04-09	Hypent	<	0.780	1.258	4.871	492.790	474.57	3092.600		0.207	659.820	537.980	<	0.540
2009	KLGO_UDB	UD04-09	Hypent						474.08							
2009	KLGO_UDB	UD05-09	Hypent	<	0.780	0.763	5.362	436.980	284.09	2278.500		0.133	774.750	500.470	<	0.540
2009	KLGO_UDB	UD06-09	Hypent	<	0.780	0.799	4.470	293.500	305.36	2867.600		0.133	708.410	486.560	<	0.540

Table F.6. Lichen sample elemental analysis results (Na, Ni, P, Pb, Rb, Si, Sr, Ti, V, Zn) for Klondike Gold Rush National Historical Park, 2008-2009.

Year	PlotNo	Sample No	Sci Code	Na ppm	Ni ppm	P ppm	Pb ppm	Rb ppm	Si ppm	Sr ppm	Ti ppm	V ppm	Zn ppm
2008	KLGO_CHD	CH02	Hypina	99.055	1.194	597.530	6.143	32.318	308.030	6.997	29.775	2.456	47.328
2008	KLGO_CHD	CH03	Hypent	104.510	1.282	877.270	5.906	25.501	304.510	10.100	22.447	2.056	69.129
2008	KLGO_CHD	CH04	Hypent	146.930	1.012	1077.000	6.654	20.302	394.210	12.062	25.847	2.121	68.753
2008	KLGO_CHD	CH04	Hypent										
2008	KLGO_CHD	CH05	Hypent	136.530	0.640	1238.000	4.107	8.860	204.250	10.975	13.112	1.300	52.569
2008	KLGO_CHD	CH06	Hypina	114.940	1.515	680.260	5.995	31.885	354.240	7.804	34.813	2.870	51.176
2008	KLGO_CHD	CH07	Plagla	88.191	1.143	823.620	3.520	36.324	307.260	7.149	24.283	1.297	51.472
2008	KLGO_CHD	CH07	Plagla										
2008	KLGO_CHD	CH08	Plagla	87.268	0.994	840.830	3.520	40.438	284.940	6.017	23.410	1.009	42.183
2008	KLGO_CHD	CH08	Plagla										
2008	KLGO_DYC	DY01	Hypina	106.540	1.192	1180.100	3.520	30.910	396.470	19.499	40.547	1.635	54.701
2008	KLGO_DYC	DY02	Plagla	110.020	0.947	1245.000	3.520	30.261	348.610	27.247	33.620	0.693	50.447
2008	KLGO_DYC	DY02	Plagla										
2008	KLGO_DYC	DY03	Hypent	227.640	1.743	1916.700	7.225	8.860	744.510	65.916	59.825	2.630	77.854
2008	KLGO_DYC	DY04	Hypent	158.220	1.661	1779.600	6.267	8.860	676.000	73.012	60.363	2.359	83.735
2008	KLGO_DYC	DY06	Hypent	216.020	1.655	1834.600	7.607	8.860	700.610	93.838	56.171	2.300	79.092
2008	KLGO_DYC	DY07	Plagla	100.180	0.988	1323.800	3.520	15.216	391.620	24.842	42.072	0.963	50.671
2008	KLGO_DYC	DY08	Hypina	98.338	1.221	1032.500	3.655	37.515	367.530	12.890	43.252	1.529	51.912
2008	KLGO_IJA	IJ01	Hypent	179.220	7.158	1435.600	85.836	8.860	571.730	12.401	63.716	18.709	100.570
2008	KLGO_IJA	IJ02	Hypina	135.230	6.168	1000.700	77.830	8.860	255.500	3.977	54.244	17.281	58.795
2008	KLGO_IJA	IJ02	Hypina										
2008	KLGO_IJA	IJ03	Hypent	328.520	5.850	1101.900	55.543	15.902	549.580	5.938	58.706	13.714	74.823
2008	KLGO_IJA	IJ04	Plagla	60.040	4.334	1190.300	30.217	12.503	329.970	3.090	35.403	12.339	58.581
2008	KLGO_IJA	IJ04	Plagla										
2008	KLGO_IJA	IJ05	Hypent	224.990	5.503	1290.800	61.434	14.525	496.810	19.445	48.043	13.272	116.670
2008	KLGO_IJA	IJ05	Hypent										
2008	KLGO_IJA	IJ06	Hypina	131.360	6.759	1003.300	93.130	22.855	384.850	4.505	64.805	19.099	57.425
2008	KLGO_IJA	IJ06	Hypina										
2008	KLGO_IJA	IJ07	Plagla	62.286	4.835	890.720	28.727	26.690	319.610	3.887	44.712	9.916	60.029
2008	KLGO_IJA	IJ07	Plagla										
2008	KLGO_IJA	IJ08	Plagla	63.784	6.244	1072.400	26.684	8.860	262.170	6.115	48.332	10.944	70.459
2008	KLGO_IJA	IJ08	Plagla										
2008	KLGO_IJA	IJ09	Hypina	130.610	6.783	938.690	83.145	28.773	418.830	4.688	67.200	18.456	61.116
2008	KLGO_IJA	IJ09	Hypina										
2008	KLGO_LDC	LD01	Hypent	121.710	9.176	1328.900	105.490	11.371	745.470	16.672	114.030	20.070	137.710

Table F.6. Lichen sample elemental analysis results (Na, Ni, P, Pb, Rb, Si, Sr, Ti, V, Zn) for Klondike Gold Rush National Historical Park, 2008-2009 (continued).

Year	PlotNo	Sample No	Sci Code	Na ppm	Ni ppm	P ppm	Pb ppm	Rb ppm	Si ppm	Sr ppm	Ti ppm	V ppm	Zn ppm
2008	KLGO_LDC	LD02	Plagla	69.471	6.294	1246.400	51.880	8.860	229.990	4.569	50.205	17.290	57.744
2008	KLGO_LDC	LD03	Hypina	152.560	13.579	899.480	268.230	8.860	372.540	3.953	107.070	37.146	61.409
2008	KLGO_LDC	LD03	Hypina	142.600	12.716	846.670	247.590	8.860	376.670	3.750	102.110	33.819	58.360
2008	KLGO_LDC	LD04	Plagla	80.107	5.972	1165.300	88.678	12.709	273.890	7.741	55.587	16.201	70.075
2008	KLGO_LDC	LD04A	Plagla	96.938	4.514	1178.900	57.088	38.662	430.770	8.794	44.926	12.270	82.714
2008	KLGO_LDC	LD04A	Plagla	97.614	4.422	1175.600	56.604	35.669	441.660	8.745	45.934	12.224	82.946
2008	KLGO_LDC	LD05	Hypina	131.280	7.284	1224.500	116.590	11.833	306.530	3.814	67.182	20.506	60.485
2008	KLGO_LDC	LD06	Hypent	179.880	6.460	1447.400	92.625	23.010	487.380	12.350	52.407	16.212	92.784
2008	KLGO_LDC	LD07	Plagla	106.370	7.321	1286.400	98.671	19.300	303.110	5.593	65.346	22.138	76.746
2008	KLGO_LDC	LD08	Hypina	175.960	12.301	804.080	245.700	23.268	359.230	3.388	104.850	33.838	53.803
2008	KLGO_LDC	LD08	Hypina										
2008	KLGO_LDC	LD09	Hypent	250.830	10.117	1401.500	184.760	19.301	709.310	8.633	88.710	29.657	78.634
2008	KLGO_LDC	LD10	Hypina	159.370	10.674	916.160	283.720	8.860	340.600	3.661	96.352	29.930	58.220
2008	KLGO_STC	ST02	Plagla	88.263	1.544	1148.800	10.624	32.718	174.550	12.331	18.871	3.253	59.336
2008	KLGO_STC	ST02	Plagla										
2008	KLGO_STC	ST03	Plagla	102.520	1.739	1013.000	12.679	31.622	199.830	11.235	22.104	3.506	54.393
2008	KLGO_STC	ST04	Plagla	96.817	1.703	1236.200	12.442	40.499	228.720	10.012	24.742	3.353	60.835
2008	KLGO_STC	ST05	Plagla	78.017	1.778	1055.600	11.850	8.860	196.560	11.391	22.792	4.074	58.806
2008	KLGO_STC	ST06	Hypent	240.050	1.972	997.890	16.081	25.804	245.430	21.699	23.244	3.586	62.399
2008	KLGO_STC	ST07	Hypent	194.670	2.345	984.760	23.100	33.785	295.970	19.188	24.870	5.144	74.510
2008	KLGO_STC	ST08	Hypent	150.390	2.168	963.760	11.221	17.585	167.250	8.074	17.845	6.033	55.176
2008	KLGO_STC	ST09	Hypent	374.350	2.074	992.540	18.223	41.567	409.880	14.389	30.435	4.474	54.062
2008	KLGO_STC	ST10	Hypina	147.830	2.158	964.460	10.989	8.860	198.320	8.418	21.753	6.459	54.208
2008	KLGO_STC	ST11	Hypina	166.390	2.176	975.510	16.877	8.860	232.990	10.741	24.629	6.877	58.971
2008	KLGO_STC	ST12	Hypina	127.810	1.932	867.850	10.608	13.360	188.760	8.700	19.033	6.211	52.791
2008	KLGO_TL	TL2	n.d.	108.220	2.148	1111.300	13.343	43.285	319.480	11.435	23.749	4.065	52.419
2008	KLGO_TL	TL4	n.d.	79.706	1.715	1566.000	15.207	14.397	303.260	24.059	19.801	3.446	83.972
2008	KLGO_TL	TL4	n.d.										
2008	KLGO_TL	TL4A	n.d.	96.663	1.723	1920.800	16.367	18.783	304.400	21.031	18.499	3.489	72.930
2008	KLGO_TL	TL4A	n.d.										
2008	KLGO_TL	TL4B	n.d.	43.934	1.550	1519.600	7.722	8.860	224.310	5.491	14.590	3.408	62.786
2008	KLGO_TL	TL6	Plagla	70.377	1.216	988.750	9.037	8.860	352.500	10.999	23.306	2.519	48.721
2008	KLGO_TL	TL7	n.d.	53.768	0.943	1341.700	5.694	8.860	234.610	22.538	14.307	2.273	57.050

Table F.6. Lichen sample elemental analysis results (Na, Ni, P, Pb, Rb, Si, Sr, Ti, V, Zn) for Klondike Gold Rush National Historical Park, 2008-2009 (continued).

Year	PlotNo	Sample No	Sci Code	Na ppm	Ni ppm	P ppm	Pb ppm	Rb ppm	Si ppm	Sr ppm	Ti ppm	V ppm	Zn ppm
2008	KLGO_TL	TL7A	n.d.	74.731	1.073	1446.800	5.957	8.860	355.830	24.445	19.919	2.190	56.264
2008	KLGO_TL	TL7A	n.d.										
2008	KLGO_UDA	UD01	Hypent	173.710	1.332	1152.500	10.871	19.566	369.300	9.701	31.236	3.269	59.927
2008	KLGO_UDA	UD01	Hypent										
2008	KLGO_UDA	UD02	Hypent	99.774	1.619	1236.400	20.782	13.112	325.280	6.078	22.693	3.504	49.176
2008	KLGO_UDA	UD03	Plagla	51.221	1.178	964.930	10.044	11.640	202.110	5.881	21.209	2.520	42.876
2008	KLGO_UDA	UD04	Plagla	95.824	3.289	1118.800	52.423	12.247	322.300	4.206	41.226	9.109	47.166
2008	KLGO_UDA	UD05	Plagla	78.188	1.562	1145.300	9.647	31.712	260.540	3.025	20.634	3.001	42.414
2008	KLGO_UDA	UD05	Plagla	68.850	1.119	993.990	8.829	29.771	208.580	2.546	17.237	2.265	37.609
2008	KLGO_UDA	UD06	Hypent	74.241	1.345	1267.000	17.877	13.985	250.080	5.815	19.350	2.926	44.686
2008	KLGO_UDA	UD07	Plagla	76.410	2.036	1262.100	14.154	8.860	229.760	10.325	24.890	4.503	59.614
2008	KLGO_UDA	UD07	Plagla										
2009	KLGO_CHE	CH01-09	Plagla	80.843	1.045	1263.500	3.673	< 8.860	265.060	7.231	32.121	1.279	54.176
2009	KLGO_CHE	CH02-09	Plagla	81.217	1.031	1161.800	3.731	19.769	210.720	6.944	25.110	1.130	55.203
2009	KLGO_CHE	CH03-09	Plagla	62.846	1.015	1195.300	3.560	< 8.860	231.160	7.926	29.053	1.096	57.560
2009	KLGO_CHE	CH03-09	Plagla										
2009	KLGO_CHE	CH04-09	Hypent	132.350	0.861	1551.800	4.475	< 8.860	242.710	11.559	24.844	1.413	64.212
2009	KLGO_CHE	CH05-09	Hypent	121.250	1.423	1370.800	6.463	< 8.860	262.920	12.420	29.225	1.744	83.516
2009	KLGO_CHE	CH06-09	Hypent	135.830	1.360	1374.600	5.989	9.581	304.300	11.162	32.222	1.649	67.997
2009	KLGO_CHE	CH06-09	Hypent	149.870	1.358	1412.800	5.880	9.158	322.000	10.970	36.430	1.758	70.367
2009	KLGO_CHE	CH07-09	Hypina	142.220	0.916	778.250	5.802	26.277	248.680	7.799	32.662	2.629	48.239
2009	KLGO_CHE	CH08-09	Hypina	156.150	0.835	760.920	5.821	27.280	281.040	7.747	34.212	2.594	45.914
2009	KLGO_CHE	CH09-09	Hypina	149.780	1.222	803.110	6.290	24.873	268.950	7.632	34.254	2.705	50.573
2009	KLGO_DYD	DY01-09	Hypina	200.600	2.062	1227.500	< 3.520	< 8.860	519.310	13.182	78.756	3.787	45.556
2009	KLGO_DYD	DY02-09	Hypina	210.670	1.902	1277.000	3.980	9.231	519.300	13.995	74.324	3.425	46.151
2009	KLGO_DYD	DY02-09	Hypina										
2009	KLGO_DYD	DY03-09	Hypina	224.520	1.896	1221.000	4.086	< 8.860	569.820	12.798	79.514	3.873	42.661
2009	KLGO_DYD	DY04-09	Plagla	109.360	1.347	1228.100	< 3.520	< 8.860	374.490	19.531	48.687	1.533	50.629
2009	KLGO_DYD	DY04-09	Plagla										
2009	KLGO_DYD	DY05-08	Plagla	128.200	1.576	1529.800	5.531	< 8.860	568.980	42.254	75.524	2.369	73.545
2009	KLGO_DYD	DY05-08	Plagla										

Table F.6. Lichen sample elemental analysis results (Na, Ni, P, Pb, Rb, Si, Sr, Ti, V, Zn) for Klondike Gold Rush National Historical Park, 2008-2009 (continued).

Year	PlotNo	Sample No	Sci Code	Na ppm	Ni ppm	P ppm	Pb ppm	Rb ppm	Si ppm	Sr ppm	Ti ppm	V ppm	Zn ppm
2009	KLGO_DYD	DY05-09	Plagla	116.280	1.300	1188.800	4.472	9.341	455.110	17.157	60.258	1.838	53.693
2009	KLGO_DYD	DY06-09	Plagla	97.936	0.867	937.190	< 3.520	22.165	275.020	12.815	47.096	1.529	40.973
2009	KLGO_DYD	DY06-09	Plagla										
2009	KLGO_DYD	DY07-09	Hypent	190.300	2.171	1665.800	7.349	10.185	550.420	65.050	73.243	2.522	71.146
2009	KLGO_DYD	DY08-09	Hypent	221.760	2.028	1880.900	8.676	19.953	504.290	62.233	61.860	2.413	73.201
2009	KLGO_DYD	DY09-09	Hypent	200.470	1.249	1787.300	7.813	33.902	444.500	56.467	52.055	2.048	77.102
2009	KLGO_GGA	GG01-09	Alesar	246.920	< 0.640	632.300	4.630	36.006	31.187	5.799	1.102	< 0.320	43.512
2009	KLGO_GGA	GG01-09	Alesar	243.440	< 0.640	647.030	5.099	44.632	27.848	5.565	1.023	< 0.320	43.712
2009	KLGO_GGA	GG02-09	Plagla	228.110	0.894	1156.000	14.107	43.930	179.770	14.114	10.131	1.697	61.623
2009	KLGO_GGA	GG03-09	Alesar	337.010	< 0.640	902.670	9.578	40.921	45.459	14.107	1.866	< 0.320	50.209
2009	KLGO_GGA	GG04-09	Plagla	203.330	< 0.640	1157.500	11.307	44.331	160.950	6.915	8.744	1.518	55.589
2009	KLGO_GGA	GG04-09	Plagla										
2009	KLGO_GGA	GG05-09	Hypapi	351.940	1.090	1514.600	26.020	40.737	172.940	26.552	9.639	1.952	88.808
2009	KLGO_GGA	GG05-09	Hypapi										
2009	KLGO_IJB	IJ01-09	Hypent	216.180	5.804	1464.400	65.712	126.450	295.610	6.744	48.386	13.523	79.988
2009	KLGO_IJB	IJ01-09	Hypent										
2009	KLGO_IJB	IJ02-09	Hypent	193.090	4.777	1283.300	47.928	149.770	311.050	7.289	46.101	11.056	91.726
2009	KLGO_IJB	IJ02-09	Hypent										
2009	KLGO_IJB	IJ03-09	Hypent	183.290	5.689	1588.900	74.305	131.210	356.030	6.809	52.412	12.847	85.035
2009	KLGO_IJB	IJ04-09	Plagla	138.740	5.160	1260.900	43.133	142.040	377.110	5.735	59.642	10.840	74.235
2009	KLGO_IJB	IJ05-09	Plagla	133.010	4.799	1188.100	40.576	150.020	318.290	3.971	53.542	9.755	70.407
2009	KLGO_IJB	IJ06-09	Plagla	141.370	4.537	1175.800	42.203	150.400	283.950	3.192	47.681	10.975	53.571
2009	KLGO_IJB	IJ07-09	Hypina	164.900	6.657	1247.900	66.664	157.260	322.370	4.489	52.543	15.594	69.559
2009	KLGO_IJB	IJ08-09	Hypina	154.030	6.041	1216.200	74.779	175.720	293.220	3.577	47.930	13.271	64.371
2009	KLGO_IJB	IJ09-09	Hypina	122.720	6.827	1287.600	81.612	< 8.860	315.530	4.729	57.045	17.649	75.574
2009	KLGO_IJB	IJ09-09	Hypina										
2009	KLGO_LDD	LD01-09	Plagla	205.430	5.797	940.270	43.895	25.428	259.160	4.506	46.210	14.955	62.513
2009	KLGO_LDD	LD01-09	Plagla										
2009	KLGO_LDD	LD02-09	Plagla	93.762	5.834	985.840	24.096	13.605	253.780	6.447	41.689	11.069	83.392
2009	KLGO_LDD	LD02-09	Plagla										
2009	KLGO_LDD	LD03-09	Plagla	167.960	6.003	931.780	53.382	13.146	260.050	5.490	53.347	13.886	62.225

Table F.6. Lichen sample elemental analysis results (Na, Ni, P, Pb, Rb, Si, Sr, Ti, V, Zn) for Klondike Gold Rush National Historical Park, 2008-2009 (continued).

Year	PlotNo	Sample No	Sci Code	Na ppm	Ni ppm	P ppm	Pb ppm		Rb ppm	Si ppm	Sr ppm	Ti ppm	V ppm	Zn ppm
2009	KLGO_LDD	LD03-09	Plagla	179.880	6.299	968.750	57.868	<	8.860	278.390	5.981	56.815	14.963	63.918
2009	KLGO_LDD	LD04-09	Hypent	204.000	6.703	1291.500	58.126	<	8.860	280.670	16.773	46.566	14.993	101.600
2009	KLGO_LDD	LD05-09	Hypent	271.550	7.507	1033.500	84.698		16.705	292.550	10.949	60.103	18.412	83.096
2009	KLGO_LDD	LD06-09	Hypent	323.750	6.945	1192.400	54.024		9.241	279.170	9.541	44.651	16.540	81.817
2009	KLGO_LDD	LD07-09	Hypina	287.990	7.161	1026.700	82.763		31.910	265.620	5.548	47.679	18.682	69.225
2009	KLGO_LDD	LD08-09	Hypina	298.030	7.169	1004.900	72.510		28.596	285.800	6.403	50.342	18.093	65.140
2009	KLGO_LDD	LD09-09	Hypina	317.650	6.674	899.650	65.397		31.655	308.340	6.110	51.051	17.811	67.710
2009	KLGO_STD	ST01-09	Plagla	81.459	1.128	839.660	5.660		29.361	152.570	3.105	14.815	1.839	34.104
2009	KLGO_STD	ST02-09	Plagla	350.080	1.841	1185.300	9.098		30.126	215.260	10.399	19.231	2.886	59.356
2009	KLGO_STD	ST03-09	Plagla	203.060	1.861	866.910	13.209		31.273	211.600	10.277	23.262	3.642	63.590
2009	KLGO_STD	ST04-09	Hypent	279.450	2.042	1290.800	14.426		27.959	176.260	28.174	15.468	4.150	73.922
2009	KLGO_STD	ST05-09	Hypent	396.780	2.020	1336.800	21.373	<	8.860	249.260	25.258	21.127	3.884	61.004
2009	KLGO_STD	ST05-09	Hypent	420.720	2.095	1351.200	22.818		30.126	287.370	24.266	26.709	4.329	62.923
2009	KLGO_STD	ST06-09	Hypent	366.790	1.990	1300.000	23.960		10.748	291.790	36.024	26.885	4.236	72.504
2009	KLGO_STD	ST07-09	Hypina	393.940	2.608	1218.100	17.853		35.478	226.410	9.683	21.136	6.651	59.128
2009	KLGO_STD	ST07-09	Hypina											
2009	KLGO_STD	ST08-09	Hypina	662.710	1.806	1094.200	12.368		38.919	251.550	10.139	20.495	5.468	52.252
2009	KLGO_STD	ST09-09	Hypina	351.470	1.929	985.520	9.355		38.154	213.430	9.473	19.957	5.160	56.011
2009	KLGO_UDB	UD01-09	Plagla	89.880	1.294	853.370	7.751		39.683	183.610	3.385	16.807	1.861	37.536
2009	KLGO_UDB	UD01-09	Plagla											
2009	KLGO_UDB	UD02-09	Plagla	86.766	1.619	808.180	7.384		33.694	183.710	3.288	16.791	2.379	36.187
2009	KLGO_UDB	UD03-09	Plagla	103.150	1.883	936.050	10.306		12.263	248.260	4.372	23.740	3.514	45.228
2009	KLGO_UDB	UD04-09	Hypent	136.340	1.514	1327.300	12.839	<	8.860	293.950	6.511	27.606	3.644	46.488
2009	KLGO_UDB	UD04-09	Hypent											
2009	KLGO_UDB	UD05-09	Hypent	121.520	1.454	1073.900	17.346		21.927	242.530	8.940	23.002	3.416	49.615
2009	KLGO_UDB	UD06-09	Hypent	97.430	1.496	1256.500	12.179	<	8.860	190.700	8.121	16.138	3.082	45.287

Table F.7. Lichen sample elemental analysis results (S%, N%, Al, As, B, Ba, Be, Ca, Cd) for Sitka National Historical Park, 2008-2009.

Year	PlotNo	Sample No	SciCode	S%	N%	Al ppm	As ppm	B ppm	Ba ppm	Be ppm	Ca ppm	Cd ppm
2008	SITK_IR1A	IR01	Plagla	0.0978	0.9880	573.4500	4.6400	1.3770	20.9140	0.020	2479.900	0.220
2008	SITK_IR1A	IR01	Plagla			548.8300	4.6400	1.2640	21.2890	0.020	2549.200	0.220
2008	SITK_IR1A	IR02	Plagla	0.0889	0.9830	381.9800	4.6400	1.9790	15.0030	0.020	2146.800	0.220
2008	SITK_IR1A	IR02	Plagla									
2008	SITK_IR1A	IR03	Plagla	0.0758	0.7300	273.6500	4.6400	0.8570	6.9260	0.020	1412.800	0.220
2009	SITK_IR1B	SK01-09	Plagla	0.0890	0.8690	217.1900		4.2660	12.3410	< 0.020	2197.500	< 0.220
2009	SITK_IR1B	SK01-09	Plagla									
2009	SITK_IR1B	SK02-09	Plagla	0.0522	0.8080	79.2840		0.5230	8.6920	< 0.020	3603.800	< 0.220
2009	SITK_IR1B	SK02-09	Plagla	0.0541	0.7960							

Table F.8. Lichen sample elemental analysis results (Co, Cr, Cu, Fe, Hg, K, Li, Mg, Mn, Mo) for Sitka National Historical Park, 2008-2009.

Year	PlotNo	Sample No	Sci Code	Co ppm	Cr ppm	Cu ppm	Fe ppm	Hg ppb	K ppm	Li ppm	Mg ppm	Mn ppm	Mo ppm
2008	SITK_IR1A	IR01	Plagla	0.780	2.292	7.034	977.810	85.90	3370.400	0.494	1282.900	127.960	0.540
2008	SITK_IR1A	IR01	Plagla	0.780	2.276	7.159	947.210	85.10	3443.600	0.461	1283.900	128.490	0.540
2008	SITK_IR1A	IR02	Plagla	0.780	1.859	5.920	643.630	120.60	3557.400	0.292	1282.900	112.470	0.540
2008	SITK_IR1A	IR02	Plagla					119.60					
2008	SITK_IR1A	IR03	Plagla	0.780	1.758	4.020	391.210	84.40	3161.700	0.189	918.890	53.488	0.540
2009	SITK_IR1B	SK01-09	Plagla	< 0.780	1.240	5.020	311.330	134.59	3359.800	0.115	1275.500	60.312	< 0.540
2009	SITK_IR1B	SK01-09	Plagla					123.63					
2009	SITK_IR1B	SK02-09	Plagla	< 0.780	0.649	2.817	110.270	132.62	2782.200	< 0.100	772.410	115.380	< 0.540
2009	SITK_IR1B	SK02-09	Plagla										

Table F.9. Lichen sample elemental analysis results (Na, Ni, P, Pb, Rb, Si, Sr, Ti, V, Zn) for Sitka National Historical Park, 2008-2009.

Year	PlotNo	Sample No	Sci Code	Na ppm	Ni ppm	P ppm		Pb ppm	Rb ppm	Si ppm	Sr ppm	Ti ppm		V ppm	Zn ppm
2008	SITK_IR1A	IR01	Plagla	155.000	2.168	1308.000		3.520	17.169	492.070	22.514	25.682		2.030	39.892
2008	SITK_IR1A	IR01	Plagla	155.400	2.329	1299.600		3.520	19.058	455.670	22.506	18.312		1.962	41.090
2008	SITK_IR1A	IR02	Plagla	165.950	1.864	1176.100		3.520	8.860	337.840	22.683	20.455		1.749	35.341
2008	SITK_IR1A	IR02	Plagla												
2008	SITK_IR1A	IR03	Plagla	129.670	1.566	920.980		3.520	11.926	389.350	10.369	22.206		1.233	29.235
2009	SITK_IR1B	SK01-09	Plagla	1047.800	1.513	1318.800	<	3.520	25.411	233.140	29.703	11.865		1.848	36.701
2009	SITK_IR1B	SK01-09	Plagla												
2009	SITK_IR1B	SK02-09	Plagla	222.680	0.935	573.140	<	3.520	27.959	100.890	12.220	7.082	<	0.320	45.133
2009	SITK_IR1B	SK02-09	Plagla												

Appendix G. Atmospheric wet deposition data, 2008–2009.

Table G.1. Annual data values for wet deposition of nitrogen as ammonium (NH_4^+) and nitrate (NO_3^-), and sulfur as sulfate (SO_4^{2-}) at open and canopy throughfall sites in 2008 and 2009.

Atmospheric Deposition Samples	NH_4-N (kg/ha)		NO_3-N (kg/ha)		SO_4-S (kg/ha)		# days		2008 Date Installed	2008 Date Removed	2009 Date Installed	2009 Date Removed
Open Sites	**2008**	**2009**	**2008**	**2009**	**2008**	**2009**	**2008**	**2009**				
Dyea	0.17	0.10	0.15	0.05	0.45	0.19	164	153	4/28/08	10/9/08	4/24/09	9/24/09
Lower Dewey	0.35	0.06	0.20	0.03	1.49	0.31	170	168	5/1/08	10/18/08	4/21/09	10/6/09
Upper Dewey	0.06	0.02	0.09	0.04	0.28	0.14	94	146	6/25/08	9/27/08	4/24/09	9/17/09
Tarr Inlet	0.13	0.03	0.25	0.04	0.82	0.12	118	123	6/11/08	10/7/08	6/26/09	10/27/09
Tongass (Tracy Arm)	0.25	0.29	0.21	0.11	0.56	0.67	nd	130	5/13/08	unk	5/8/09	9/15/09
Juneau	0.17	0.06	0.47	0.12	1.17	0.35	302	290	7/1/08	4/29/09	4/29/09	2/13/10
Canopy Throughfall Sites												
Bartlett Cove	0.36	0.19	0.02	0.02	1.03	1.89	114	136	6/17/08	10/9/08	6/21/09	11/4/09
Blue Mouse Cove	0.30	0.03	0.00	0.17	1.12	2.05	120	133	6/10/08	10/8/08	6/16/09	10/27/09
Chilkoot	0.17	0.12	0.01	0.01	0.87	0.54	174	147	5/2/08	10/23/08	4/23/09	9/17/09
Dewey 1700	0.04	0.03	0.00	0.02	5.51	5.48	116	77	6/24/08	10/18/08	6/10/09	8/26/09
Dyea	0.43	0.21	0.01	0.01	2.42	1.43	163	146	4/29/08	10/9/08	4/24/09	9/17/09
Lower Dewey	0.11	0.11	0.00	0.00	14.23	10.46	169	168	5/2/08	10/18/08	4/21/09	10/6/09
Sitka	0.24	0.17	0.00	0.01	1.71	2.21	167	181	4/30/08	10/14/08	4/23/09	10/21/09
Sturgills	0.20	0.11	0.00	0.01	5.49	5.65	165	168	5/6/08	10/18/08	4/21/09	10/6/09
Tarr	0.49	0.18	0.05	0.05	2.71	1.56	118	132	6/11/08	10/7/08	6/17/09	10/27/09
Tongass (Tracy Arm)	1.46	0.85	0.13	0.01	0.88	0.47	nd	130	5/13/08	unk	5/8/09	9/15/09

Appendix H. Ogawa ambient atmospheric condition sample data, 2008–2009.

Table H.1. Average NO_2 concentrations from Ogawa ambient atmospheric condition samplers at all study sites, 2008.

	Average NO_2 conc. (ppb)							
2008 Exposure Period	**Bartlett Cove**	**Chilkoot Saintly Hill**	**Dewey 1700'**	**Dyea**	**Icy Junction**	**Lower Dewey**	**Sitka**	**Sturgills**
EXP0801				1.16		9.44	0.43	
EXP0802		4.21		2.93	17.42	19.51	3.06	3.86
EXP0803	1.46	2.76		2.75	18.55	11.33	3.29	5.79
EXP0804	1.89	2.74		3.08	22.25	13.80	3.48	4.51
EXP0805	1.55	-99.00		-99.00	-99.00	-99.00	5.10	-99.00
EXP0806	0.63	1.40		2.17	11.79	14.03	1.38	1.44
EXP0807	2.13	2.99		4.63	12.16	17.43	3.04	3.70
EXP0808	1.10	3.12		3.32	15.02	20.16	2.26	3.74
EXP0809	2.16	2.69	2.77	3.26		19.07	4.40	3.16
EXP0810	1.64	2.23	2.23	3.30		15.57	4.14	4.73
EXP0811	1.28	3.43	3.07	3.24		18.87	1.53	4.34
EXP0812	1.32	1.97	2.70	2.47		-99.00	2.30	3.49
EXP0813	1.37	0.71	2.89	12.96		3.10	1.04	4.54
EXP0814	2.50	2.89	4.95	3.59		16.15	2.88	4.20
EXP0815	2.55	3.92	5.29	3.23		13.47	1.85	6.52
EXP0816	3.01	2.34	4.29	2.54		14.10	3.50	6.30
EXP0817	2.10	2.24	2.96	2.07		15.60	3.81	5.45
EXP0818	0.98	4.05	4.54	2.76		14.94	2.99	5.62
EXP0819	-77.00	3.14	5.52	3.49		16.56	2.77	4.97
EXP0820	0.98	2.26	2.61	3.95		16.53	3.15	6.00
EXP0821	2.09	2.26	3.73	3.80		11.40	1.82	4.08
EXP0822	0.99	0.29	1.87	1.03		3.76	2.68	2.09
EXP0823	0.00	-77.00	0.01	0.00		0.71	1.87	0.58

-99 values (no data) and -77 values (long exposure); Icy Junction sampling discontinued after 6/24/08.

Table H.2. Average NO_2 concentrations from Ogawa ambient atmospheric condition samplers at all study sites, 2009.

	Average NO_2 conc. (ppb)						
2009 Exposure Period	**Bartlett Cove**	**Chilkoot Saintly Hill**	**Dewey 1700'**	**Dyea**	**Lower Dewey**	**Sitka**	**Sturgills**
EXP0901	0.55	0.66	3.24	3.68	6.65	1.15	0.96
EXP0902	0.84	1.92	0.33	0.51	3.43	2.75	2.51
EXP0903	0.61	3.05	1.09	0.38	8.73	2.44	1.40
EXP0904	1.51	1.26	0.99	1.59	14.64	0.76	1.24
EXP0905	0.71	4.92	4.67	1.24	10.84	1.63	2.19
EXP0906	1.10	2.08	2.11	2.81	18.02	3.73	6.07
EXP0907	3.21	4.55	5.44	4.20	14.98	3.26	4.86
EXP0908	2.15	1.89	2.55	2.53	19.83	1.45	2.39
EXP0909	0.54	2.03	1.63	2.49	21.52	1.88	2.90
EXP0910	0.74	2.93	8.27	4.69	13.80	1.84	4.91
EXP0911	1.22	2.21	5.65	3.06	10.38	2.81	6.81
EXP0912	1.30	2.82	4.58	3.26	21.79	3.52	7.43
EXP0913	1.32	3.59	4.90	3.20	19.35	2.29	2.55
EXP0914	1.89	3.37	6.04	3.10	16.98	3.18	7.12
EXP0915	1.67	2.62	5.30	4.20	15.96	2.77	7.13
EXP0916	2.16	2.37	8.76	2.25	22.38	2.74	8.97
EXP0917	1.21	1.86	3.16	4.63	17.67	2.82	4.21
EXP0918	1.90	1.68	3.58	-99.00	11.40	1.80	6.11
EXP0919	4.24	2.97	0.71	2.33	12.36	1.10	8.51
EXP0920	1.27	5.82	7.67	3.74	13.48	1.76	7.24
EXP0921	1.20	0.66	1.46	1.58	10.61	1.73	4.21
EXP0922	0.12	0.74	-99.00	0.86	7.70	1.10	0.00
EXP0923	-99.00		1.46		4.31	3.10	4.72
EXP0924	0.36		-77.00		0.88	1.19	1.79
EXP0925	-77.00					1.70	

-99 values (no data) and -77 values (long exposure); Icy Junction sampling discontinued after 6/24/08.

Table H.3. Average NO_x concentrations from Ogawa ambient atmospheric condition samplers at all study sites, 2008.

	Average NO_X conc. (ppb)							
Exposure Period	**Bartlett Cove**	**Chilkoot Saintly Hill**	**Dewey 1700'**	**Dyea**	**Icy Junction**	**Lower Dewey**	**Sitka**	**Sturgills**
EXP0801				7.60		19.95	6.50	
EXP0802		7.30		8.15	41.55	36.30	7.53	8.86
EXP0803	10.31	6.10		10.25	53.38	45.63	9.69	14.59
EXP0804	9.62	8.36		9.24	105.22	73.47	12.95	11.58
EXP0805	10.53	-99.00		-99.00	-99.00	-99.00	10.07	-99.00
EXP0806	9.00	6.52		7.67	38.19	82.72	8.35	6.39
EXP0807	6.31	7.63		13.09	55.89	61.39	6.89	12.71
EXP0808	8.57	11.48		18.55	56.78	82.84	8.96	15.42
EXP0809	11.92	11.76	15.11	11.64		59.24	11.62	7.77
EXP0810	14.51	16.80	14.76	16.44		80.59	18.40	28.39
EXP0811	9.58	9.86	22.46	20.78		111.93	14.36	13.58
EXP0812	18.62	20.05	21.93	25.71		-99.00	14.41	20.89
EXP0813	8.88	10.90	15.81	15.65		63.61	8.80	23.70
EXP0814	14.25	17.15	22.60	16.64		86.81	12.74	23.93
EXP0815	13.01	14.21	29.12	17.07		62.68	11.25	32.17
EXP0816	10.86	7.55	19.02	12.61		46.76	10.26	27.06
EXP0817	5.79	10.61	9.88	9.75		60.79	13.91	21.91
EXP0818	6.74	14.06	22.76	12.44		71.46	11.68	30.24
EXP0819	-77.00	8.05	18.02	11.15		64.12	6.88	20.41
EXP0820	9.79	9.12	14.67	11.76		64.46	10.97	13.01
EXP0821	10.16	11.75	14.23	20.69		38.66	14.91	13.35
EXP0822	7.88	1.80	12.77	10.77		9.61	8.62	12.04
EXP0823	7.11	-77.00	3.97	3.53		4.58	15.52	2.31

-99 values (no data) and -77 values (long exposure); Icy Junction sampling discontinued after 6/24/08.

Table H.4. Average NO_x concentrations from Ogawa ambient atmospheric condition samplers at all study sites, 2009.

	Average NO_X conc. (ppb)						
Exposure Period	**Bartlett Cove**	**Chilkoot Saintly Hill**	**Dewey 1700'**	**Dyea**	**Lower Dewey**	**Sitka**	**Sturgills**
EXP0901	8.63	4.11	6.71	7.66	12.74	6.93	7.26
EXP0902	9.50	7.53	6.48	6.42	13.31	8.93	6.78
EXP0903	5.33	3.33	5.59	12.47	31.70	6.34	7.25
EXP0904	11.24	11.24	7.32	8.62	44.93	7.11	13.44
EXP0905	6.72	7.86	8.89	7.33	51.88	5.64	8.82
EXP0906	8.61	14.34	3.72	10.70	89.42	8.77	6.86
EXP0907	7.77	5.03	12.88	-99.00	72.86	9.83	10.88
EXP0908	5.41	-77.00	-77.00	9.28	-77.00	-99.00	-77.00
EXP0909	3.24	3.97	6.66	7.60	76.40	7.62	6.58
EXP0910	6.66	6.04	12.24	10.85	69.16	3.44	8.44
EXP0911	6.49	11.08	9.08	15.92	31.58	6.51	15.67
EXP0912	5.61	10.46	12.13	9.96	108.96	8.16	19.33
EXP0913	5.91	11.11	12.42	17.31	90.67	7.73	8.06
EXP0914	9.87	10.15	19.70	13.70	71.91	14.19	27.45
EXP0915	6.14	12.37	12.93	9.78	56.81	7.47	19.51
EXP0916	4.76	5.81	18.59	7.99	79.50	5.95	26.85
EXP0917	4.82	5.22	9.55	7.10	64.86	6.29	10.21
EXP0918	4.28	6.66	8.14	6.60	30.11	7.59	18.90
EXP0919	9.31	10.94	15.48	24.77	45.40	5.02	27.99
EXP0920	4.58	27.22	26.41	20.11	54.04	24.87	46.71
EXP0921	4.62	7.02	7.98	7.83	38.43	6.53	15.81
EXP0922	5.04	6.98	8.02	10.93	25.40	6.32	6.62
EXP0923	-99.00		23.72		19.12	4.52	16.85
EXP0924	2.35		5.28		4.96	9.35	7.60
EXP0925	-77.00					7.47	

-99 values (no data) and -77 values (long exposure); Icy Junction sampling discontinued after 6/24/08.

Table H.5. Average NH_3 concentrations from Ogawa ambient atmospheric condition samplers at all study sites, 2008.

	Average NH_3 conc. ($\mu g/m^3$)							
Exposure Period	**Bartlett Cove**	**Chilkoot Saintly Hill**	**Dewey 1700'**	**Dyea**	**Icy Junction**	**Lower Dewey**	**Sitka**	**Sturgills**
EXP0801				0.00		0.00	0.00	
EXP0802		0.00		0.00	3.94	2.42	4.58	0.00
EXP0803	0.00	1.35		1.01	1.89	1.60	0.00	1.86
EXP0804	0.96	0.00		0.00	0.05	0.36	1.34	0.60
EXP0805	3.81	-99.00		-99.00	-99.00	-99.00	0.00	-99.00
EXP0806	4.03	0.00		0.00	0.63	0.00	0.15	0.00
EXP0807	1.66	3.00		3.81	3.49	2.88	2.66	5.49
EXP0808	2.29	2.25		2.51	3.45	1.83	4.08	2.01
EXP0809	5.61	6.56	4.79	3.38		3.64	4.03	2.60
EXP0810	6.69	3.02	-99.00	3.43		3.95	3.28	-99.00
EXP0811	4.21	1.28	1.77	2.62		1.94	3.57	2.18
EXP0812	7.22	3.64	3.34	4.17		-99.00	3.74	3.61
EXP0813	4.40	4.54	2.92	4.39		3.48	2.93	4.19
EXP0814	1.92	2.78	2.29	1.45		2.56	2.66	2.50
EXP0815	2.97	4.23	-99.00	3.09		4.15	3.08	3.23
EXP0816	4.90	4.22	6.08	3.33		3.28	4.83	4.77
EXP0817	4.19	5.08	5.35	3.42		3.68	3.87	6.21
EXP0818	2.58	3.81	4.22	10.20		5.38	6.11	3.61
EXP0819	-77.00	6.04	4.98	3.56		3.16	-99.00	3.05
EXP0820	4.54	8.28	4.15	3.40		11.18	-99.00	6.57
EXP0821	3.36	9.26	3.18	5.78		5.50	2.88	7.75
EXP0822	5.43	3.94	3.74	4.86		4.51	3.28	4.67
EXP0823	2.58	-77.00	6.99	1.92		3.59	11.81	4.18

-99 values (no data) and -77 values (long exposure); Icy Junction sampling discontinued after 6/24/08.

Table H.6. Average NH_3 concentrations from Ogawa ambient atmospheric condition samplers at all study sites, 2009.

	Average NH_3 conc. (µg/m^3)						
Exposure Period	**Bartlett Cove**	**Chilkoot Saintly Hill**	**Dewey 1700'**	**Dyea**	**Lower Dewey**	**Sitka**	**Sturgills**
EXP0901	0.00	0.96	0.85	0.68	-99.00	1.16	1.29
EXP0902	1.15	1.35	0.40	0.00	1.08	1.41	0.79
EXP0903	0.26	1.60	0.71	1.30	0.90	1.04	0.00
EXP0904	2.15	0.74	1.10	1.16	-99.00	0.34	0.34
EXP0905	0.13	3.92	1.02	0.88	0.32	1.44	0.64
EXP0906	2.29	2.79	3.32	3.01	2.07	1.90	3.20
EXP0907	2.06	2.90	0.99	2.62	2.19	2.66	3.22
EXP0908	1.45	2.76	1.50	3.07	1.37	4.98	2.86
EXP0909	6.86	3.28	2.84	4.61	3.72	2.50	4.58
EXP0910	3.22	2.56	4.80	3.85	4.45	3.22	2.64
EXP0911	5.03	2.67	4.31	3.42	2.97	3.74	5.87
EXP0912	5.22	1.48	2.13	2.13	2.07	2.20	2.49
EXP0913	19.77	2.23	6.15	2.31	7.99	5.78	2.24
EXP0914	17.94	1.37	1.89	3.46	3.31	2.05	2.02
EXP0915	8.97	5.21	3.81	3.90	3.38	4.28	2.78
EXP0916	4.09	3.86	3.68	6.22	5.80	3.21	9.39
EXP0917	1.99	8.51	0.00	3.59	3.85	1.54	3.11
EXP0918	5.84	27.24	12.64	72.30	5.90	1.69	3.64
EXP0919	6.64	8.58	12.50	18.30	8.77	3.28	7.26
EXP0920	39.81	14.43	63.40	14.22	9.11	4.57	9.84
EXP0921	12.16	21.42	22.28	4.93	1.96	5.25	35.00
EXP0922	16.62	5.21	34.27	6.89	66.51	5.40	4.17
EXP0923	9.55		181.10		19.18	9.34	-99.00
EXP0924	4.59		32.46		39.32	5.70	42.36
EXP0925	-77.00					7.00	

-99 values (no data) and -77 values (long exposure); Icy Junction sampling discontinued after 6/24/08.

Table H.7. Average HNO_3 concentrations from Ogawa ambient atmospheric condition samplers at all study sites, 2008.

	Average HNO_3 conc. ($\mu g/m^3$)							
Exposure Period	**Bartlett Cove**	**Chilkoot Saintly Hill**	**Dewey 1700'**	**Dyea**	**Icy Junction**	**Lower Dewey**	**Sitka**	**Sturgills**
EXP0801				0.35		0.49	0.33	
EXP0802		0.12		0.34	0.36	0.49	0.21	0.18
EXP0803	0.31	4.20		3.62	0.74	2.57	1.20	0.71
EXP0804	0.57	0.39		0.56	1.48	1.33	0.57	1.37
EXP0805	1.39	-99.00		-99.00	-99.00	-99.00	0.73	-99.00
EXP0806	4.95	0.42		7.00	1.30	13.42	4.45	7.36
EXP0807	6.71	10.33		10.15	14.80	0.54	5.18	9.21
EXP0808	12.28	5.87		16.80	11.96	20.71	6.25	11.27
EXP0809	0.46	0.33	0.38	0.34		0.30	0.34	0.29
EXP0810	0.38	0.40	0.16	0.41		0.46	0.17	0.49
EXP0811	0.25	0.22	0.20	0.64		0.18	0.27	0.25
EXP0812	0.19	0.14	0.58	0.42		-99.00	0.31	0.48
EXP0813	0.06	0.28	-99.00	0.28		0.37	0.37	0.20
EXP0814	0.37	0.31	0.25	0.28		0.32	0.27	0.36
EXP0815	0.26	0.43	-99.00	0.26		0.05	0.17	0.25
EXP0816	0.50	0.29	0.41	0.36		0.51	0.88	0.39
EXP0817	0.28	0.20	0.20	0.40		0.33	0.24	0.35
EXP0818	0.29	0.24	0.12	0.26		0.46	0.32	0.24
EXP0819	-77.00	0.31	0.15	0.06		0.32	0.23	0.03
EXP0820	0.30	0.17	0.11	0.40		0.09	0.27	0.31
EXP0821	0.17	0.15	0.18	0.06		0.37	0.19	0.31
EXP0822	0.18	-99.00	0.13	0.06		0.06	0.04	0.33
EXP0823	0.07	-99.00	-99.00	-99.00		-99.00	0.16	-99.00

-99 values (no data) and -77 values (long exposure); Icy Junction sampling discontinued after 6/24/08.

Table H.8. Average HNO_3 concentrations from Ogawa ambient atmospheric condition samplers at all study sites, 2009.

	Average HNO_3 conc. ($\mu g/m^3$)						
Exposure Period	**Bartlett Cove**	**Chilkoot Saintly Hill**	**Dewey 1700'**	**Dyea**	**Lower Dewey**	**Sitka**	**Sturgills**
EXP0901	3.58	10.52	8.68	9.89	5.25	9.25	10.04
EXP0902	4.07	6.45	4.99	6.85	0.63	11.40	2.29
EXP0903	13.37	7.22	7.20	19.83	21.10	11.08	7.03
EXP0904	0.93	18.07	7.69	13.33	1.24	8.99	10.33
EXP0905	0.47	6.46	3.27	0.94	10.09	2.02	10.99
EXP0906	9.31	6.88	1.99	26.73	15.23	6.00	5.88
EXP0907	0.40	10.47	0.31	1.75	22.60	3.22	0.35
EXP0908	0.25	3.42	4.73	0.82	1.56	0.25	1.08
EXP0909	8.01	2.37	4.16	0.43	3.02	2.54	1.23
EXP0910	8.24	12.44	10.76	11.77	15.14	5.76	11.75
EXP0911	13.38	2.85	0.21	31.76	44.87	0.50	8.50
EXP0912	0.19	0.25	0.18	0.37	0.46	0.13	0.26
EXP0913	0.68	0.32	0.26	0.46	0.31	0.20	0.27
EXP0914	0.40	0.33	4.04	0.65	1.18	0.40	0.54
EXP0915	1.67	1.30	1.80	2.07	1.34	1.02	1.28
EXP0916	0.91	0.74	1.07	1.18	1.12	0.74	1.13
EXP0917	0.46	1.16	0.35	0.67	1.16	0.65	0.34
EXP0918	0.22	0.23	0.34	0.31	0.40	1.36	0.21
EXP0919	0.35	0.00	0.36	0.41	0.44	0.54	0.03
EXP0920	0.18	3.58	0.90	0.99	8.64	0.29	4.88
EXP0921	0.46	0.89	0.54	0.75	0.65	0.42	0.45
EXP0922	0.52	0.44	0.44	0.54	0.69	15.50	0.36
EXP0923	0.36		0.73		0.80	7.32	-99.00
EXP0924	0.06		0.14		0.45	0.22	0.22
EXP0925	-77.00					0.30	

-99 values (no data) and -77 values (long exposure); Icy Junction sampling discontinued after 6/24/08.

Table H.9. Average SO_2 concentrations from Ogawa ambient atmospheric condition samplers at all study sites, 2008.

	Average SO_2 conc. (µg/m^3)							
Exposure Period	**Bartlett Cove**	**Chilkoot Saintly Hill**	**Dewey 1700'**	**Dyea**	**Icy Junction**	**Lower Dewey**	**Sitka**	**Sturgills**
EXP0801				0.09		5.62	0.06	
EXP0802		0.57		0.93	7.19	8.17	0.43	1.47
EXP0803	0.44	0.46		0.76	6.87	9.23	0.39	2.61
EXP0804	0.36	1.34		2.41	15.43	14.14	1.45	1.54
EXP0805	0.35	-99.00		-99.00	-99.00	-99.00	0.30	-99.00
EXP0806	0.36	1.11		1.73	18.55	20.97	0.45	0.85
EXP0807	0.69	1.06		2.60	19.72	7.90	0.96	2.41
EXP0808	0.49	1.20		2.47	7.93	8.77	0.52	2.53
EXP0809	0.52	0.95	1.56	1.57		9.58	0.26	1.99
EXP0810	0.38	1.07	0.98	2.33		8.72	0.28	4.38
EXP0811	0.10	1.04	1.31	2.20		9.13	0.07	1.88
EXP0812	0.18	0.64	1.22	1.15		-99.00	0.37	1.53
EXP0813	0.50	0.47	1.03	1.06		9.52	0.17	3.68
EXP0814	0.49	1.30	2.51	1.93		9.66	0.39	3.94
EXP0815	0.17	1.05	4.26	1.89		8.85	0.35	5.53
EXP0816	0.55	0.51	2.52	0.92		8.12	0.61	4.58
EXP0817	0.06	0.42	0.47	0.76		7.55	0.24	3.75
EXP0818	0.31	1.16	3.49	1.86		10.98	0.45	5.84
EXP0819	-77.00	0.91	1.33	1.33		7.24	0.20	2.29
EXP0820	0.36	0.34	0.92	0.89		7.51	0.19	2.42
EXP0821	0.11	0.26	0.71	0.31		6.47	0.78	2.16
EXP0822	0.24	-99.00	0.38	0.00		0.98	0.12	0.34
EXP0823	0.00	-99.00	-99.00	-99.00		-99.00	0.06	-99.00

-99 values (no data) and -77 values (long exposure); Icy Junction sampling discontinued after 6/24/08.

Table H.10. Average SO_2 concentrations from Ogawa ambient atmospheric condition samplers at all study sites, 2009.

	Average SO_2 conc. (µg/m^3)						
Exposure Period	Bartlett Cove	Chilkoot Saintly Hill	Dewey 1700'	Dyea	Lower Dewey	Sitka	Sturgills
EXP0901	0.37	0.65	0.60	0.67	0.78	0.33	0.37
EXP0902	0.21	0.44	0.62	0.59	4.33	0.46	0.01
EXP0903	0.41	0.35	0.65	0.30	6.66	0.20	1.09
EXP0904	0.37	0.68	0.90	0.93	8.42	0.17	1.42
EXP0905	0.44	1.28	2.21	2.12	8.14	0.52	2.44
EXP0906	0.54	1.09	1.28	1.83	9.08	0.48	1.38
EXP0907	0.82	1.63	5.25	2.64	8.03	1.21	4.00
EXP0908	0.37	0.61	2.43	1.03	8.45	0.38	2.24
EXP0909	0.24	0.75	0.71	1.96	7.93	0.38	1.33
EXP0910	0.40	1.23	2.61	1.93	7.79	0.36	2.47
EXP0911	0.47	1.21	2.51	1.81	6.54	0.48	3.82
EXP0912	0.41	1.75	3.21	2.31	8.57	0.82	4.64
EXP0913	0.28	0.89	2.60	1.48	8.45	0.41	1.57
EXP0914	0.65	1.79	4.19	2.39	9.02	1.26	5.69
EXP0915	0.69	2.16	4.56	2.71	7.91	0.98	6.45
EXP0916	0.44	1.30	6.02	1.52	10.37	0.95	6.51
EXP0917	0.26	0.53	2.27	0.88	7.54	0.40	2.34
EXP0918	0.13	0.46	0.64	0.68	7.77	0.28	4.74
EXP0919	0.51	0.99	1.86	1.03	10.09	0.29	4.45
EXP0920	0.22	0.82	4.06	1.77	7.89	0.29	5.54
EXP0921	0.07	0.50	0.06	0.34	6.98	0.09	2.06
EXP0922	0.12	0.22	0.17	0.54	5.69	0.06	1.22
EXP0923	0.12		0.16		2.99	0.25	-99.00
EXP0924	0.09		0.17		0.15	0.10	0.11
EXP0925	-77.00					0.05	

-99 values (no data) and -77 values (long exposure); Icy Junction sampling discontinued after 6/24/08.

Appendix I. Tasks, organization, schedule, and expenditures.

The schedule below was part of the project implementation plan. Field work was completed on schedule; however, lab work at the University of Minnesota Research Analytical Lab and the USDA Forest Service, Pacific Southwest Research Station, Riverside Science Lab took longer than anticipated. Final lab results were received in early 2011. Fiscal year 2008 and 2009 expenditures are detailed in Tables I.2 and I.3.

Table I.1. Project implementation tasks schedule.

Completion Date	**FY2008**								**FY2009**								**FY2012**
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**	**12/31**
Compliance into PEPC and get signature on Categorical Exclusion	■																
Hire seasonal bio-techs		■									■						
Complete set-up / conduct training in operating 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 (USFS)						■											
Complete training in lichen ID and collection methods					■									■			
Initiate lichen collecting							■								■		
Clean and dry lichens							■	■							■	■	
Terminate passive air and throughfall sampling									■							■	
Ship lichen samples to lab								■								■	
I&M draft protocol and final report submitted.																	■

Table I.2. FY2008 Budget for monitoring air quality in the Southeast Alaska Network.

FY08 Item	Funding Source Total Spent	AQD Eco Effects	SEAN I&M	NPS Coastal Cluster	KLGO Small Parks and Base	Municipality of Skagway
Project oversight fieldwork and misc supplies						
GS-7 Bio Tech 4.5 pp @ $1678/pp	$ 7578				$7578	
USFS Linda Geiser travel (7 d)	$ 2000		$ 2000[+]			
USFS Geiser salary	$ 4500	$ 4500[+]				
Visibility camera equipment	$ 1500			$ 500	$1000	
Supplies: sample bags, misc shipping, contingency	$ 1315		$ 1160			$ 155
Lichen community bio-monitoring						
Karen Dillman USFS PI: Travel costs to set up and read 4 plots per site						
Dillman salary for plots and collections (1.5 pp)	$ 5602	$ 1200[+]	$ 3862[+]			
KLGO lichen community plots - 12	$ 800	$ 800[+]				
GLBA lichen community plots – 6	$ 900		$ 900[+]			
SITK lichen community plots – 2	$ 500		$ 500[+]			
Lichen elemental analysis:						
3 samples ($150@) for 3 species per site ($1350 per site)						
KLGO Lichen elemental analysis – 5 sites	$ 6750	$ 6100			$ 650	
GLBA Lichen elemental analysis – 3 sites	$ 4050		$ 4050			
SITK Lichen elemental analysis – 1 sites	$ 1350		$ 1350			
Airborne concentration analysis, shipping, and startup supplies						
SO_2, NO_2, NO_x, NH_3, HNO_3 for 23 weeks @ 10 samples per week per site[1]						
Dr. Andrzej Bytnerowicz PI						
Bytnerowicz Travel USFS PI (5 days)	$ 1600		$ 1600[+]			
KLGO Skagway – Ogawa sampler analysis 5 sites	$10120	$ 5660[+]	$ 4460[+]			
KLGO Skagway – Ogawa sample pads (SO_2, NO_2, NO_x, NH_3) for 5 sites [2]	$ 2834				$1086[3]	$1748
KLGO Skagway – Pel Gelman sample pads (HNO_3) for 5 sites [4]	$ 1767				$1000	$ 767
KLGO Skagway HNO_3 analysis	$ 4784	$ 4784[+]				
GLBA – Ogawa sampler analysis 1 sites	$ 2760		$ 2760[+]			

FY08 Item	Funding Source					
	Total Spent	AQD Eco Effects	SEAN I&M	NPS Coastal Cluster	KLGO Small Parks and Base	Municipality of Skagway
GLBA – Ogawa sample pads (SO_2, NO_2, NO_x, NH_3) for 1 sites [2]	$ 773					$ 773
GLBA – Pel Gelman sample pads (HNO_3) for 1 sites [4]	$ 392					$ 392
GLBA HNO_3 analysis	$1196	$ 1196[+]				
SITK – Ogawa sampler analysis for 1 site	$2760		$ 2760[+]			
SITK – Ogawa sample pads (SO_2, NO_2, NO_x, NH_3) for 1 sites [2]	$ 773					$ 773
SITK – Pel Gelman sample pads (HNO_3) for 1 sites [4]	$ 392					$ 392
SITK HNO_3 analysis	$ 1196	$ 1196[+]				
Shipping and misc	$ 1000		$ 1000[+]			
Throughfall & bulk sampling resins filters, start-up supplies [5], analysis and shipping - Dr Mark Fenn USFS PI						
KLGO Skagway - 5 forested sites (15 collectors per site)	$ 6500	$ 6500[+]	[+]			
GLBA - 2 forested (15 collectors/site)	$ 2600		$ 2600[+]			
GLBA - 1 open (5 collectors/site)	$ 500		$ 500[+]			
SITK - 1 forested site (15 collectors per site)	$ 1300		$ 1300[+]			
Atmospheric Model of Skagway Airshed– Dr. Rick Graw USFS PI						
USFS Rick Graw travel (5 days)	$ 1400			$ 1400[+]		
USFS Rick Graw salary	$ 3000			$ 3000 [+]		
Met data from US Weather Service for GIS model	$ 140					
Totals	$83382	$31936	$29902	$ 5040	$11314	$5000
Totals to transfer to USFS	$54478	$25836	$24242	$ 4400	$4,840	

1 Analysis and shipping costs for USFS lab are $10 per sample for SO_2, NO_2, NO_x, NH_3, and $13 per sample for HNO_3 = $106 per site per week

2 Ogawa collections pads are run with a replicate and cost $2.80 each. Blanks for each location are an additional $52 per week.

3 Paid for with FY07 funds

4 Pel Gelman collections pads for HNO_3 are run with filter types (Pel Gelman 66509-$2.08 & p5pj047-$2.90) 3 each site per week – and cost $14.94 per site per week. Blanks for each location are an additional $15 per week.

+ Funds to be transferred to the USFS – Cooperative Agreement between NPS-ARD and USFS Pacific Northwest Research Station. SE Alaska Coastal Cluster (9815-1001-NZI) $4,400; SE Alaska I&M Program (2104-0801-NII) $24,242; WASO ARD Ecological Effects $25,836.

Table I.3. FY2009 Budget for monitoring air quality in the Southeast Alaska Network.

FY2009 Item	Total	Funding Source AQD Eco Effects	SEAN I&M	NPS Coastal Cluster	KLGO NRPP Small Parks	Municipality of Skagway
Project Oversight fieldwork and misc supplies						
GS-7 Bio Tech 5.6 pp @ $1,787 pp	$10,000		$ 2,400		$3,600	$4,000
USFS Linda Geiser Salary	$ 4,500		$ 1,145[+]		$3,355[+]	
Winter Intern – Skagway High school Student	$ 3,740		$ 2,940[+]			$800
Supplies: Sample bags, misc shipping, contingency	$ 1,020		$ 60		$960	
Lichen community bio-monitoring						
Karen Dillman USFS PI: Travel costs to set up & read plots and collect						
Karen Dillman Salary for plots and collections (1.5 pp)	$ 3,400		$ 3,400 [+]			
Karen Dillman Travel KLGO lichen community plots & collections						
Karen Dillman Travel GLBA lichen community plots & collections	$ 900		$ 900 [+]			
Karen Dillman Travel SITK lichen community plots & collections	$ 500		$ 500 [+]			
Lichen elemental analysis: 3 samples for 3 species per site - $1,350 per site						
Dr Linda Geiser and Karen Dillman USFS PIs						
KLGO Lichen elemental analysis - 5 sites (45 samples)	$ 2,700		$ 2,700			
GLBA Lichen elemental analysis - 3 sites (27 Samples)	$ 1,620		$ 1,620			
SITK Lichen elemental analysis - 1 sites (9 Samples)	$ 540		$ 540			
KLGO Lichen Hg analysis - 5 sites (22 samples)	$ 880		$ 880			
GLBA Lichen Hg analysis - 3 sites (13 Samples)	$ 520		$ 520			
SITK Lichen Hg analysis - 1 sites (5 Samples)	$ 200		$ 200			
Air Concentration Analysis - Dr Andrzej Bytnerowicz						
KLGO Skagway - Ogawa & HNO_3 pads & analysis 5 sites	$28,605	$27,120 [+]			$1,485[+]	
GLBA - Ogawa & HNO_3 pads & analysis 1 site	$ 5,721		$ 5,721[+]			
SITK - Ogawa & HNO_3 pads & analysis 1 site	$ 5,721		$ 5,721			
Deposition Analysis - Dr Mark Fenn						
KLGO Skagway - 5 forested sites (15 collectors per site)	$ 600		$ 600 [+]			

FY2009 Item	Total	Funding Source				
		AQD Eco Effects	SEAN I&M	NPS Coastal Cluster	KLGO NRPP Small Parks	Municipality of Skagway
GLBA - 2 forested (15 collectors/site), 1 open (5 collectors/site)	$ 350		$ 350 [+]			
SITK - 1 forested site (15 collectors per site)	$ 300		$ 300 [+]			
Atmospheric Model of Skagway Airshed– Dr. Rick Graw USFS PI						
USFS Rick Graw Salary	$ 5,000			$5,000 [+]		
Totals	$76,817	$27,120	$30,497	$5,000	$9,400	$4,800
Totals to transfer to USFS		$27,120 [+]	$21,637 [+]	$5,000 [+]	$4,840[+]	
Total Available	$78,620	$27,120	$30,500	$5,000	$9,400	$6,600

[+] Funds to be transferred to the US Forest Service – Cooperative Agreement between NPS ARD and Linda Geiser USFS Pacific Northwest Research Station. SE Alaska Coastal Cluster (9815-1001-NZI) $5000; SE Alaska I&M Program (2014-0901-NII) $21,637; WASO ARD Ecological Effects (9825-0924-NNS) $27,120; KLGO NRPP Small Parks (9825-XXX-NSS) $4,840.

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National Park Service
U.S. Department of the Interior

Natural Resource Stewardship and Science
1201 Oakridge Drive, Suite 150
Fort Collins, CO 80525

www.nature.nps.gov