



Air Quality Related Values (AQRVs) for Southeast Alaska Network (SEAN) Parks

Effects from Ozone; Visibility Reducing Particles; and Atmospheric Deposition of Acids, Nutrients and Toxics

Natural Resource Report NPS/SEAN/NRR—2016/1195



ON THE COVER

Photograph of air quality related values within various National Park units. Wildflowers, clear views, aquatic species, and lichens may all be threatened by air pollution.

Photographs courtesy of the National Park Service

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Summary

This section describes the Air Quality Related Values (AQRVs) of the Southeast Alaska Network (SEAN). AQRVs are those resources sensitive to air quality and include streams, lakes, soils, vegetation, fish and wildlife, and visibility. The SEAN parks that are included in the NPS Inventory and Monitoring (I&M) Program, and discussed in this report, are Glacier Bay National Park and Preserve (GLBA), Klondike Gold Rush National Historical Park (KLGO), and Sitka National Historical Park (SITK).

Sullivan et al. (2011a, 2011b) and Kohut (2007) conducted risk assessments for acidification, eutrophication, and ozone (O_3) for all of the SEAN parks; their results are described in this report. This report also describes air pollutant emissions and air quality in the SEAN, and their effects on AQRVs. The primary pollutants likely to affect AQRVs include nitrogen (N) and sulfur (S) compounds (nitrate [NO_3^-], ammonium [NH_4^+], and sulfate [SO_4^{2-}]), ground-level ozone (O_3), haze-causing particles, and airborne toxics. Background for this section can be found in “Air Quality Related Values (AQRVs) in National Parks: Effects from Ozone; Visibility Reducing Particles; and Atmospheric Deposition of Acids, Nutrients and Toxics” (Sullivan 2016).

Air quality in southeast Alaska is generally very good. The relatively small amount of industrial development in the vicinity of SEAN parks, coupled with few population centers and prevailing winds off the Pacific Ocean, all contribute to maintaining clean air in most locations in the region. However, localized air pollution from sources including marine vessels and cruise ships, wood-burning stoves, vehicle exhaust, diesel generators, mining operations, trains, incinerators, and unpaved roads, all contribute to the deterioration of air quality that can impact resources in the SEAN parks (Dillman et al. 2007). Transport of air pollutants from Asia is also a growing concern in the region.

Increased cruise ship traffic in southeast Alaska has raised concerns about associated air pollution, particularly near the ports of Skagway (adjacent to KLGO), and Sitka (near SITK; Geiser et al. 2010, Schirokauer et al. 2014). Lichens have been used extensively in southeast Alaska since 1989 to monitor air quality, as lichens serve as passive air pollution samplers and many lichen species are sensitive to air pollution. Lichens were first collected in KLGO in 1999 and analyzed for N, S, and a variety of heavy metals. Lichens in the Klondike-Skagway area were found to have higher levels of heavy metals and S in lichen tissues than baseline values for unpolluted areas of southeast Alaska (Furbish et al. 2000). In 2008-2009, the SEAN staff collected lichens again from the KLGO sites, and from additional sites in GLBA and SITK, as well as other southeast Alaska locations. They also sampled atmospheric concentrations of pollutants, and pollutant deposition (Schirokauer et al. 2014). Monitoring found elevated levels of N and S oxides in the air, and elevated deposition of S, N, and vanadium (a by-product of diesel combustion) in KLGO, compared to more remote sites in the Tongass National Forest (Geiser et al. 2010, Schirokauer et al. 2014). Levels of N and S in lichen tissues were elevated in KLGO and SITK compared to remote sites.

Cruise ship emissions also result in noticeable haze and odors throughout downtown Skagway and the KLGO-Skagway Historic District (Geiser et al. 2010). Haze from ship emissions is also common in GLBA (Air Resource Specialists [ARS] 2005).

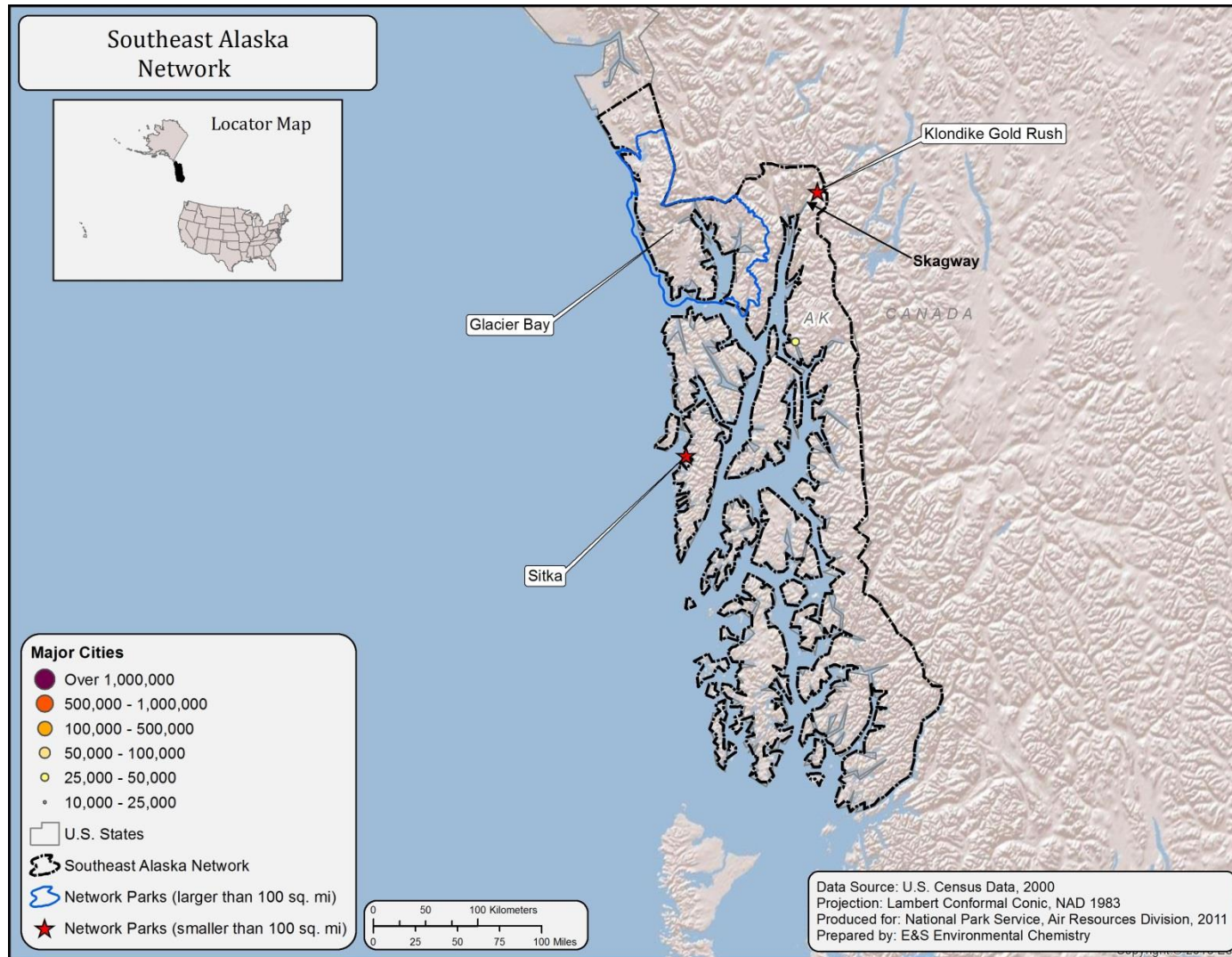
Atmospheric N and S pollutants can cause acidification of streams, lakes, and soils. N deposition can also cause undesirable nutrient enrichment of natural ecosystems, leading to changes in plant species diversity and soil nutrient cycling. Sulfur and N levels associated with adverse effects to sensitive lichens were observed in KLGO and SITK, but monitoring through 2008 found no evidence of widespread adverse ecological effects from N or S deposition in SEAN parks (Geiser et al. 2010).

Ozone pollution can harm human health, reduce plant growth, and cause visible injury to foliage. However, generally low levels of O₃ precursor pollutants and meteorological conditions not conducive to O₃ formation, are expected to result in low atmospheric O₃ levels in the SEAN parks.

Airborne toxics, including mercury (Hg) and other heavy metals, can accumulate in food webs, reaching toxic levels in top predators. Although there are no significant emissions sources of Hg near the SEAN parks, models of global atmospheric Hg transport suggest that emissions from Asia may deposit in Alaska. Levels of Hg in lichens sampled in 2008 and 2009 in the SEAN were an order of magnitude higher than levels detected in arctic national parks, but similar to those found in Oregon and Washington (Schirokauer et al. 2014). The Western Airborne Contaminants Assessment Project (WACAP) reported elevated concentrations of polycyclic aromatic hydrocarbons (PAHs), products of combustion, in lichens and conifer needles at Beartrack Cove, GLBA (Landers et al. 2008). Levels of nickel, zinc, cadmium, and lead, associated with past uncontained mining ore transfers in Skagway Harbor, and vanadium from cruise ships and other sources, were found to be elevated at KLGO (Geiser et al. 2010). Analysis of sediment cores from three remote lakes in GLBA indicated about a factor of two increase since preindustrial times in sediment Hg concentration, likely reflecting an increase in atmospheric Hg deposition.

Background

There are three parks in the Southeast Alaska Network (SEAN): Glacier Bay National Park and Preserve (GLBA), Klondike Gold Rush National Historical Park (KLGO), and Sitka National Historical Park (SITK). Only GLBA is larger than 100 square miles. Larger parks generally have more available data with which to evaluate air pollution sensitivities and effects. In addition, the larger parks generally contain more extensive resources in need of protection against the adverse impacts of air pollution. There are no urban centers larger than 50,000 people near the SEAN, and only one larger than 25,000 people. Map 1 shows a map of the network boundary along with locations of each park and population centers with more than 10,000 people around the network. The predominant cover types within this network are generally forested and unvegetated areas covered by perennial ice and snow.



Map 1. Map showing network boundary and locations of parks and population centers greater than 10,000 people near the SEAN.

Atmospheric Emissions and Deposition

Air pollutant emissions are generally low throughout the SEAN region. However, during the height of the summer tourist season cruise ships arrive daily in Skagway harbor and, while docked, continue to operate their engines and boilers to provide electrical power, heat, and steam to passengers. Buses and trains take tourists on various historical and scenic rides around Skagway and KLGO. Waste generated in town is incinerated at the municipal incinerator. Emissions from the ships have contributed approximately 1,100 pounds per hour (lbs/hr) of nitrogen oxides (NO_x) and 800 lbs/hr of sulfur dioxide (SO₂) in Skagway during busy periods (Graw et al. 2010). Monitoring in 2008-2009 found that N oxides were elevated and 5 to 10 times higher in KLGO and Skagway near the ship docks compared to SITK and GLBA. Sulfur dioxide was also elevated in Skagway (Geiser et al. 2010, Schirokauer et al. 2014). In 2010, many U.S. coastal areas, including the coast of southeast Alaska, were designated as Emission Control Areas under the International Convention for the Prevention of Pollution from Ships (MARPOL Annex VI) and, as a result, EPA set new emissions standards for marine ships (U.S. EPA 2010).

Implementation of these new standards is expected to decrease emissions from cruise ships in the SEAN region (Graw et al. 2010). Model simulations predict that the new standards will reduce seasonal emissions of SO₂, NO_x, and particulate matter (PM_{2.5}, and PM₁₀) by 87%, 78%, 56% and 74% respectively, with improvements in visibility anticipated across southeast Alaska coastal areas and in GLBA (Mölders et al. 2013). Although the standards require the use of low-sulfur (S) fuel in ships, in 2013 several cruise lines negotiated with EPA to reduce S through the use of scrubbers instead of low-S fuel

(<http://yosemite.epa.gov/opa/admpress.nsf/e51aa292bac25b0b85257359003d925f/4c89a38454e4c17685257bdd004a44c6!OpenDocument&Highlight=0,cruise,ships>).

Cruise ship tourism is an important industry in coastal Alaska. Passengers account for more than 45% of all visitors to GLBA, and there is concern about impacts on in-park biota, air quality, and visitor experience (Mölders et al. 2013). Although cruise ships contribute only marginally to overall ship traffic emissions near the SEAN, they often affect air quality in remote areas (Eijgelaar et al. 2010), where they may constitute most of the local emissions of S and N (Mölders et al. 2013). In a pristine wilderness setting, one or a few cruise ships can disproportionately impact air quality and visibility (Schembari et al. 2012).

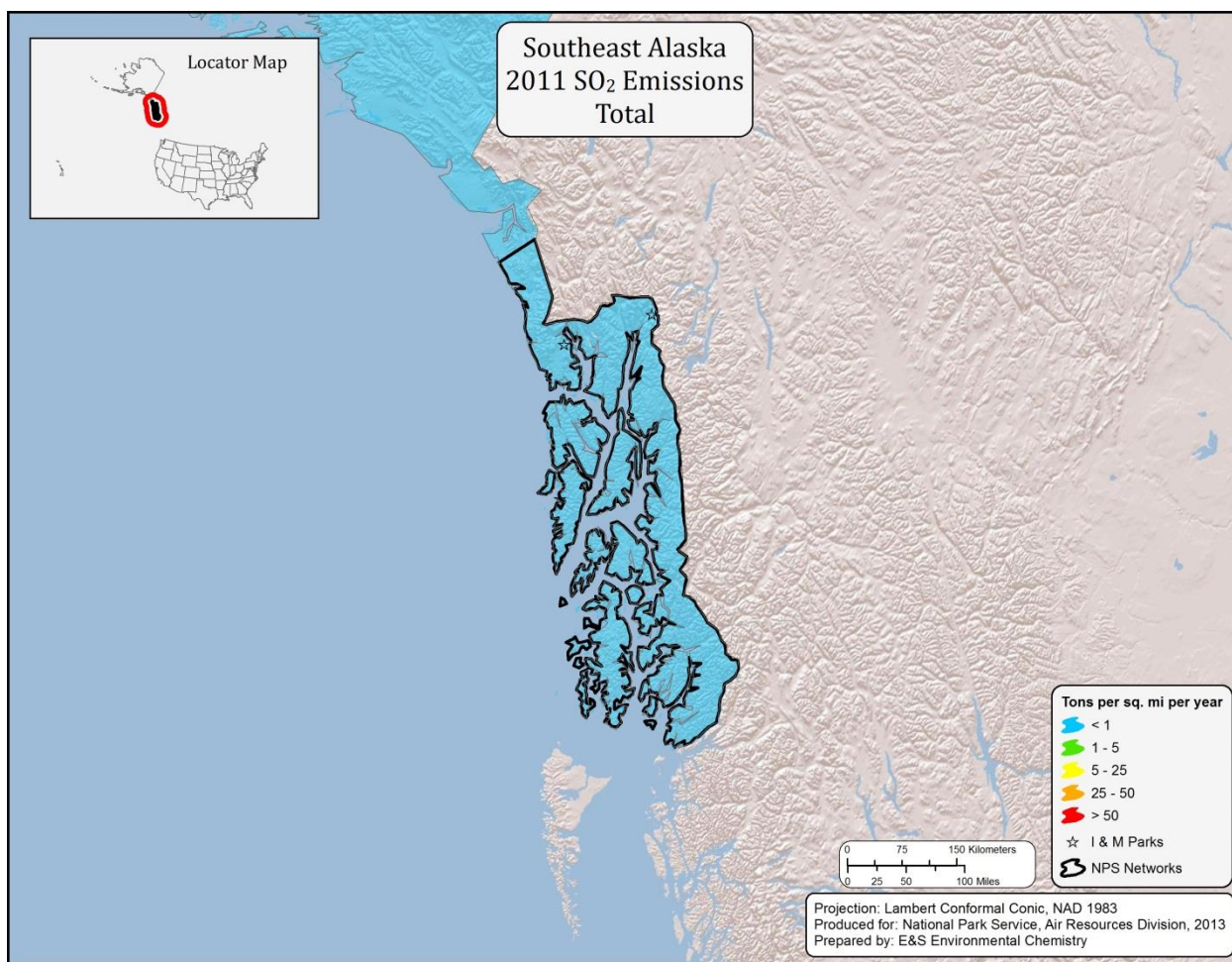
Increased tourism in southeast Alaska has contributed to concerns regarding air pollutants emitted from cruise ships in dock and in transit to and from Skagway harbor (Geiser et al. 2010). Preliminary monitoring results suggest elevated atmospheric concentrations of NO_x and S oxides (SO_x) and deposition of S, lead (Pb), zinc (Zn), and vanadium in KLGO and the adjacent Skagway municipality. Atmospheric deposition of S and N has been higher than clean-site comparison levels (Geiser et al. 2010).

An increase in ship traffic over the previous decade has been connected with minor increases in N accumulation in epiphytic lichens at locations close to Skagway harbor (Geiser et al. 2010). Levels of Pb, nickel (Ni), cadmium (Cd), and Zn in lichens have been elevated at monitoring sites in KLGO

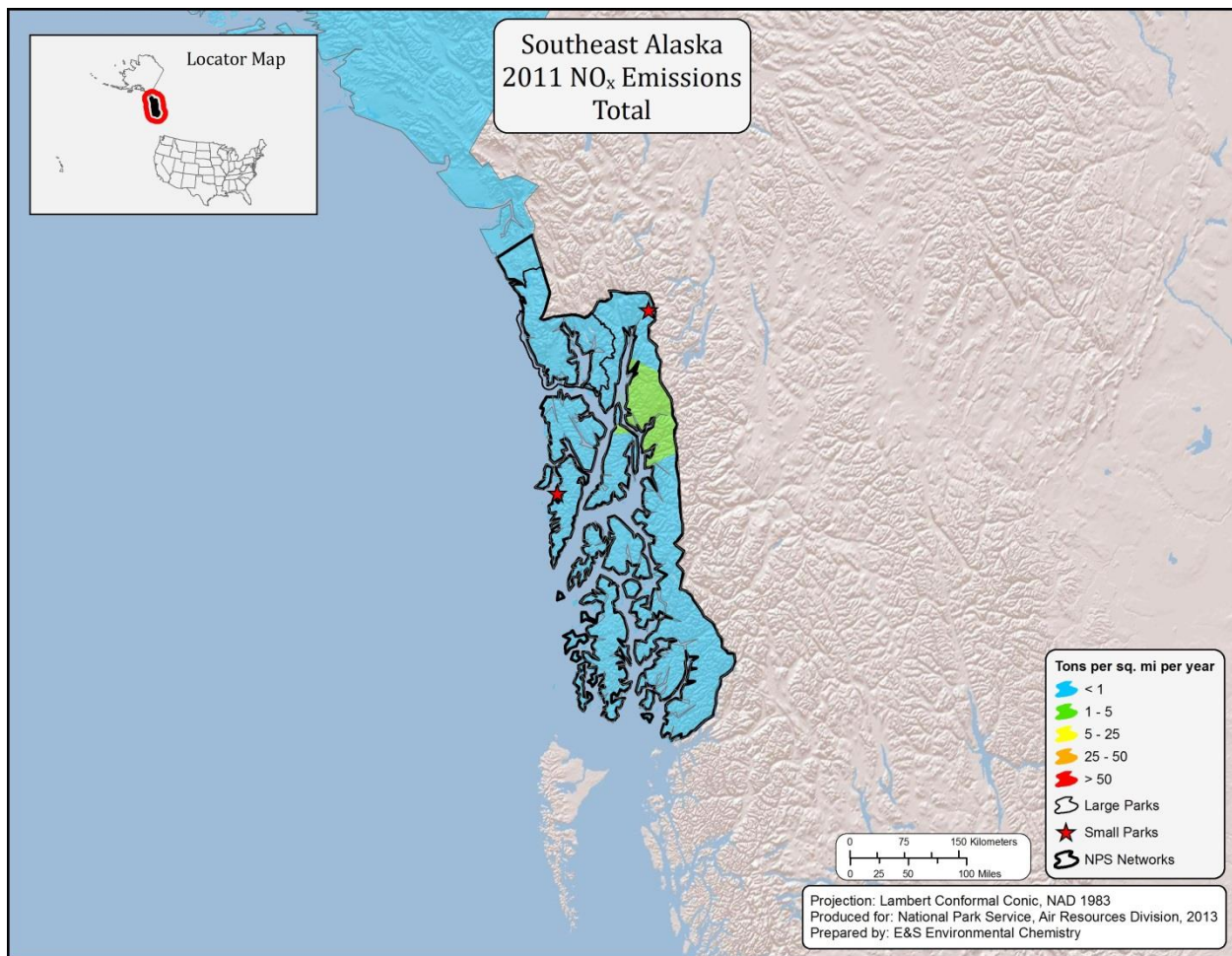
close to Skagway harbor. Geiser et al. (2010) attributed this pattern to historical use of the harbor to transfer metal ores from open rail cars to barges.

The NPS and USDA Forest Service constructed an air pollution emissions inventory for Skagway, focused on NO_x and SO_x (Graw and Faure 2010). The inventory included cruise ships, buses, trains, and the municipal incinerator associated with the tourism industry. Cruise ships constituted the largest emissions source, accounting for an estimated 73% of NO_x emissions and 99% of SO_x emissions.

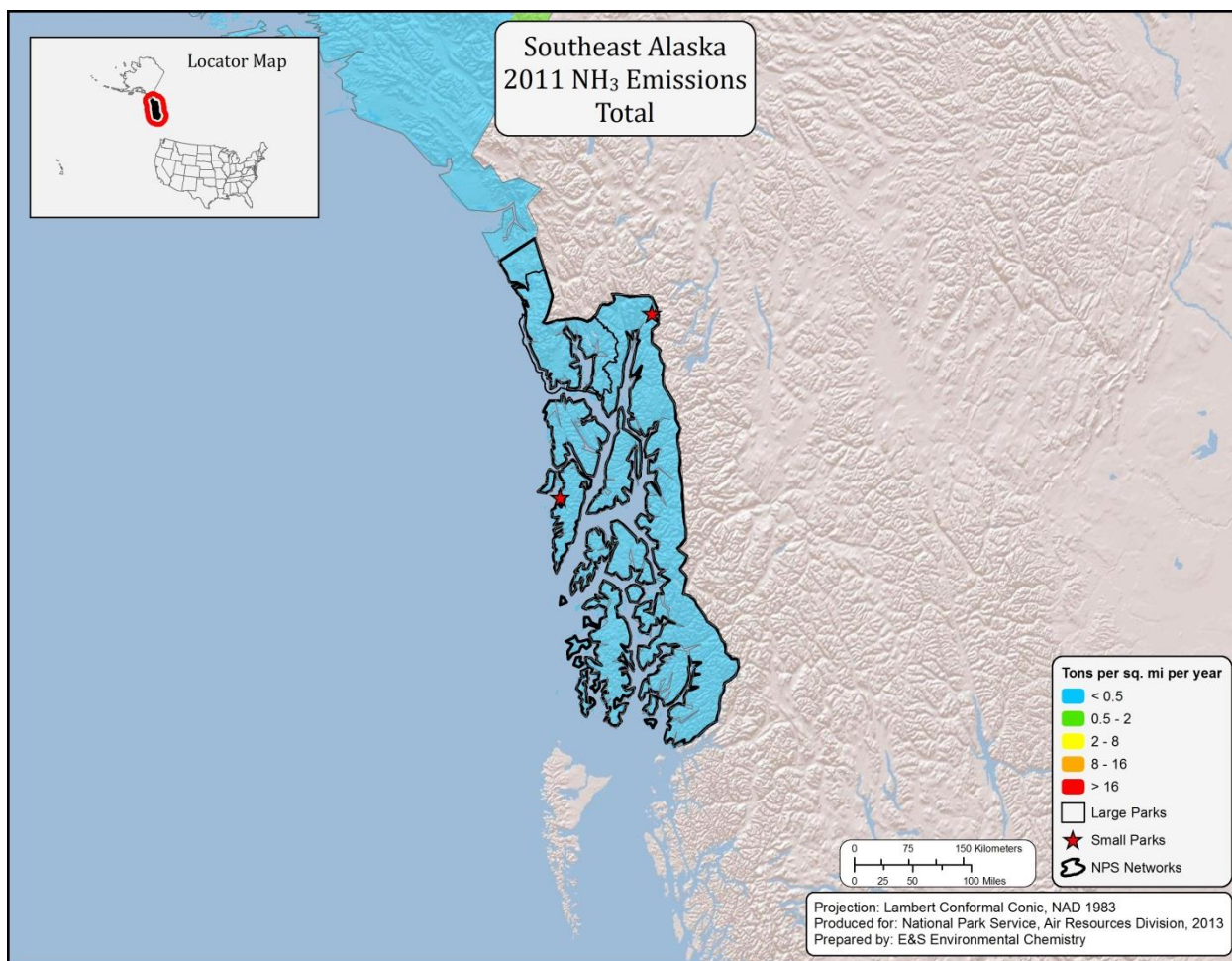
Emissions near SEAN, based on data from the EPA's National Emissions Inventory (NEI) during a recent time period (2011), are depicted in Maps 2 through 4 for SO_2 , oxidized N (NO_x), and reduced N (NH_3), respectively. Emissions of S and N near the SEAN parks were mostly $< 1 \text{ ton/mi}^2/\text{yr}$.



Map 2. Total SO_2 emissions near SEAN for the year 2011. Data from EPA's National Emissions Inventory.



Map 3. Total NO_x emissions near SEAN for the year 2011. Data from EPA's National Emissions Inventory.



Map 4. Total NH₃ emissions near SEAN for the year 2011. Data from EPA's National Emissions Inventory.

Atmospheric deposition of S and N have been measured as part of the NADP from 2004 to the present in Juneau (site ID AK02); the site received deposition of S near 1 kg/ha/yr and N deposition near 0.5 kg/ha/yr. These rates of deposition are very low. In 2008 and 2009, SEAN staff deployed resin tube deposition samplers in and around the SEAN parks during the height of tourist season to examine fine-scale differences in deposition between areas close to cruise ships and other emissions sources and areas more remote. They found wet N deposition rates to be among the lowest in North America, generally less than 0.5 kg/ha/yr, rates much lower than the wet deposition of 1.6 kg N/ha/yr reported from relatively unimpacted areas in the Pacific Northwest (Schirokauer et al. 2014). The S deposition was also low at most sites in the SEAN parks, from 1-2 kg/ha/yr, although S deposition exceeded 10 kg/ha/yr at sites in Skagway and KLGO near the cruise ship docks. Some portion of this S deposition may be attributable to sea salt aerosols, but the higher levels in Skagway and KLGO are likely from cruise ship and port activity (Schirokauer et al. 2014).

Lichens act as passive air quality monitors, accumulating pollutants over time. They were sampled as part of the SEAN deposition monitoring in 2009. Tissue concentrations of S, Pb, Zn, and vanadium were higher near the Skagway docks compared to more remote areas in the SEAN. Sulfur and

vanadium are by-products of diesel combustion, whereas Pb and Zn are indicative of ore processing and transport. Although ore transport methods were modified in 2006 to greatly reduce Pb and Zn dust, it is likely that these metals will persist in the environment for a considerable period of time (Schirokauer et al. 2014). At other sites in the SEAN, concentrations of N, S, and heavy metals in lichens were very low, but somewhat higher than concentrations found at the more remote Tongass National Forest (Dillman et al. 2007, Schirokauer et al. 2014). Landers et al. (2008) found elevated concentrations of N and certain PAHs, both products of combustion, in lichens and conifer needles in GLBA. The concentration of N in lichens sampled at another location in GLBA in 2008 was not elevated (Geiser et al. 2010). Over the last 10 years, N content in lichen tissue in Skagway and KLGO has increased slightly, and that change in concentration was correlated with an increase in ship traffic. There may, however, be causes in addition to local emissions for the increase (e.g., increased trans-Pacific emissions, increased wildfire emissions from northern Alaska and Canada; Schirokauer et al. 2014).

Atmospheric deposition of Hg was measured as part of the NADP-MDN from 2010 to 2013 at GLBA; funding for the site was subsequently discontinued. Lichens collected in 2008-2009 were analyzed for Hg; levels were within ranges observed in Oregon and Washington, but an order of magnitude higher than levels detected in arctic national parks (Schirokauer et al. 2014).

Engstrom and Swain (1997) inferred trends in atmospheric deposition of Hg in 210 Pb-dated sediment cores collected from three remote lakes in GLBA. The lakes are located about 2 km from the Gulf of Alaska, with no anthropogenic Hg sources in the region, little human development within several hundred km of the lakes, and the closest volcanic source more than 800 km to the northwest. Therefore, the sediment concentrations of Hg were deemed to represent global Hg pollution in the Northern Hemisphere, with virtually no local or regional contribution. The Alaskan sediment records indicated about a factor of two increase since preindustrial times in sediment Hg concentration, in agreement with studies in remote areas of northern Sweden, Finland, and Canada (Hermanson 1993, Lucotte et al. 1995).

Acidification

In addition to serving as passive indicators of atmospheric deposition, lichens can be adversely impacted by acidic or nutrient deposition. Furbish et al. (2000) reported elevated levels of S in lichens from the KLGO-Skagway area in 1999, with 67% of lichen samples exceeding levels expected at clean sites. In 2008-2009, the same sites were re-sampled, as well as additional sites in KLGO, GLBA, SITK and other locations in southeast Alaska. Based on analysis of lichen community composition, Schirokauer et al. (2014) found that many of the study sites in the KLGO and Skagway area, and one in SITK, were potentially adversely affected by exposure to SO₂, S deposition, or acidity. The lichen community is considered to be one of the most air pollution sensitive components of vegetation within a given ecosystem, and many acid-sensitive species have been identified (Dillman et al. 2007). Study sites in the SEAN were compared to reference “clean” sites at Tongass National Forest to determine possible or probable impacts. Study sites with fewer acid-sensitive species than 97.5% of reference sites were likely adversely affected by SO₂ or acidic deposition; those with fewer sensitive species than 90% of reference plots were considered possibly impacted. However, acid-sensitive species are still present in many areas and there is no evidence of widespread ecological effects from acidification in the SEAN parks (Geiser et al. 2010). Most impacted sites were located in urban areas near marine transportation terminals.

A relative risk evaluation of all NPS I&M parks ranked ecosystems at both GLBA and KLGO as highly sensitive to acidification, whereas SITK was ranked low (Table 1). Because estimated acid pollutant exposure was very low compared to all parks, the overall risk for acidification effects in the SEAN was judged by Sullivan et al. (2011b) to be Low. These rankings did not consider the presence of acid-sensitive lichens. The ecosystem rankings did take into account elevation and land slope, which often influence the degree of acid neutralization provided to streams by soils and bedrock within the watershed. While rankings are an indication of risk, park-specific data, particularly data on ecosystem sensitivity, are needed to fully evaluate risk from acidification.

Table 1. Estimated I&M park rankings¹ according to risk of acidification impacts on sensitive receptors (Source: Sullivan et al. 2011b)

Park Name ²	Park Code	Estimated Acid Pollutant Exposure	Estimated Ecosystem Sensitivity to Acidification
Glacier Bay	GLBA	Very Low	High
Klondike Gold Rush	KLGO	Very Low	High
Sitka	SITK	Very Low	Low

¹ Relative park rankings are designated according to quintile ranking, among all I&M Parks, from the lowest quintile (Very Low risk) to the highest quintile (Very High risk). Rankings did not consider potential impacts on lichens.

² Park names are printed in bold italic for parks larger than 100 mi².

The slope for most of the parkland in the SEAN is between 10° and 20°. SITK has average slope less than 10°, as do small portions of GLBA. Most watersheds in GLBA have average slope between 10° and 20°; there is one small area in GLBA where the slope is steeper, between 20° and 30°, suggesting increased potential for acid sensitivity of aquatic ecosystems in this area. There is no evidence of stream acidification in any of the parks in SEAN.

Nutrient Nitrogen Enrichment

Lichens are among the most sensitive bioindicators of N enrichment in terrestrial ecosystems (Bobbink et al. 2003, Glavich and Geiser 2008). Epiphytic macrolichens in southeastern Alaska have been shown to respond to even relatively low levels of N deposition. Hotspots of N deposition were first identified in 1989 in the vicinity of KLGO near downtown Skagway based on the concentration of N in *Hypogymnia enteromorpha*, *H. inactiva*, and *Platismatia glauca* (Dillman et al. 2007, Furbish et al. 2000). In 2008-2009, the KLGO sites were re-sampled, and lichens were also sampled from additional sites in GLBA and SITK, and other locations in southeast Alaska. Nitrogen in lichens at two sites (Dyea in KLGO and Sawyer Island in the Tracy Arm-Fords Terror Wilderness of the Tongass National Forest) exceeded clean-site reference ranges expected for both western Oregon and Washington and southeast Alaska (Schirokauer et al. 2014). Study sites with fewer N-sensitive species than 97.5% of reference sites were considered likely to be adversely affected by enhanced nutrient N, those with fewer N-sensitive species than 90% of reference plots were considered possibly impacted. Nevertheless, N-sensitive species are still present in many areas and there is no evidence of widespread ecological effects to date from nutrient N enrichment in the SEAN parks (Schirokauer et al. 2014).

Schirokauer et al. (2014) reported that lichen assemblages near the Skagway cruise ship terminal reflected shifts towards species that favor enhanced N and S deposition. Other sites in the SEAN study area contained lichen species indicative of clean air. Nitrogen concentrations in epiphytic lichens did not show evidence of increase since 1999 except near local, seasonal pollution sources. The study of Schirokauer et al. (2014) suggested that local emissions sources around SEAN parks had a greater impact on air quality in parks than the more distant sources.

Evidence for widespread effects of N (and also S) deposition in and around SEAN is not conclusive. Effects on plant community composition are possible in KLGO/Skagway and SITK (Geiser et al. 2010). However, levels of N in lichens in 2008 at Bartlett Cove in GLBA were within expected clean-site ranges. In addition, Geiser et al. (2010) noted continued widespread distribution of sensitive epiphytes across the nearby Tongass National Forest.

A nutrient N relative risk ranking of all NPS I&M parks ranked ecosystems in the SEAN parks to range from Low to High risk, based on presence of N-sensitive alpine and wetland plant communities. These rankings did not consider the presence of N-sensitive lichens. Because N pollutant exposure is very low in the region, the overall risk for nutrient N enrichment effects on SEAN parks was judged by Sullivan et al. (2011a) to be Very Low (Table 2). This finding is attributable more to the relatively low levels of atmospheric N deposition than to the ecosystem sensitivity (which is considered to be relatively high). Although rankings provide an indication of risk, park-specific data, particularly regarding nutrient-enrichment sensitivity, are needed to fully evaluate risk from nutrient N addition.

Empirical critical loads of atmospheric N deposition were estimated by Pardo et al. (2011) to be low (reflecting a high degree of sensitivity), generally 5 kg N/ha/yr or less (Table 3). Pardo et al.'s assessment was based on limited available data. Other than lichens, the response of coastal forests in the SEAN to atmospheric N deposition has not been well studied (Perakis et al. 2011).

Table 2. Estimated park rankings¹ according to risk of nutrient enrichment impacts on sensitive receptors (Source: Sullivan et al. 2011a)

Park Name ²	Park Code	Estimated Nutrient N Pollutant Exposure	Estimated Ecosystem Sensitivity to Nutrient N Enrichment
Glacier Bay	GLBA	Very Low	Low
Klondike Gold Rush	KLGO	Very Low	High
Sitka	SITK	Very Low	Moderate

¹ Relative park rankings are designated according to quintile ranking, among all I&M Parks, from the lowest quintile (Very Low risk) to the highest quintile (Very High risk).

² Park names are printed in bold italic for parks larger than 100 mi².

Table 3. Empirical critical loads for nitrogen in the SEAN, by ecoregion and receptor from Pardo et al. (2011).

NPS Unit	Ecoregion	N Deposition (kg N/ha/yr)	Critical Load (kg N/ha/yr)				Nitrate Leaching
			Mycorrhizal Fungi	Lichen	Herbaceous Plant	Forest	
Glacier Bay NP & Pres	Marine West Coast Forests	NA	5	2.7	NA	5	NA
Klondike Gold Rush NHP	Marine West Coast Forests	NA	5	2.7	NA	5	NA
Sitka NHP	Marine West Coast Forests	NA	5	2.7	NA	5	NA

Ozone Injury to Vegetation

Ground-level O₃ is not monitored in southeast Alaska. Ozone concentrations are likely to be quite low because of the low levels of O₃ precursor pollutants, N oxides and volatile organic compounds. Because of this, injury to vegetation is unlikely. However, plant species known to be sensitive to O₃ occur in the SEAN parks and are listed in Table 4. Those considered to be bioindicators because they exhibit distinctive symptoms when injured by O₃ (e.g., dark stipple) are designated by an asterisk. Each of the parks within the network contained at least three O₃-sensitive and/or bioindicator species. GLBA and KLGO each contained five sensitive species. Four of the species in GLBA were bioindicators; there were three bioindicators in KLGO.

Table 4. Ozone-sensitive and bioindicator plant species known or thought to occur in the I&M parks of the SEAN. (Data Source: E. Porter, National Park Service, pers. comm., August 30, 2012); lists are periodically updated at <https://irma.nps.gov/NPSpecies/Report>.

Species	Common Name	Park ¹		
		GLBA	KLGO	SITK
<i>Alnus rubra</i> *	Red alder	x	x	x
<i>Amelanchier alnifolia</i> var. <i>semiintegrifolia</i>	Saskatoon serviceberry		x	
<i>Populus tremuloides</i> *	Quaking aspen	x		
<i>Rubus parviflorus</i>	Thimbleberry	x	x	x
<i>Salix scouleriana</i> *	Scouler's willow	x	x	
<i>Sambucus racemosa</i> var. <i>racemosa</i> *	Red elderberry	x		x
<i>Sambucus racemosa</i> *	Red elderberry		x	

¹ Park acronyms are printed in bold italic for parks larger than 100 mi².

* Bioindicator species

Visibility Degradation

Haze is produced by a variety of fine particulate air pollutants that absorb or scatter light. Some haze is natural, resulting from sea salt and natural processes. Haze from human-caused air pollution is a significant problem in many national parks and occurs at times during the winter in the SEAN parks. Cameras recorded episodes of haze from cruise ship emissions in GLBA during summer of 2004. Ships were observed in the camera view on 97 of the 154 days during the monitoring season. Of the total number of observations during the study, 18% (2,185 of 12,140 daylight images) included visible vessel exhaust. Ground-based and elevated layered haze were also documented by the cameras (ARS 2005).

Cruise ship and related activities also commonly contribute to haze in KLGO. Visible haze accumulates in the morning on most days from May to September, beginning at the Skagway harbor and spreading up and down the Skagway River valley adjacent to KLGO (Geiser et al. 2010). New pollutant emissions standards required of cruise ships are expected to significantly reduce seasonal emissions of SO₂, N oxides, PM_{2.5}, and PM₁₀, yielding improvements in visibility across southeast Alaska and the SEAN parks (Mölders et al. 2013).

Toxic Airborne Contaminants

Airborne toxic pollutants are deposited into SEAN ecosystems from local, regional, and global sources, including industry, power production, mining activities, and agriculture. Locally, Pb-Zn ore was transported through, and shipped out of, the port of Skagway beginning in the 1960s and continuing through 1993. A considerable amount of dust was generated by transport activities, leading to high concentrations of heavy metals in the environment around Skagway, including the KLGO Skagway Historic District (Furbish et al. 2000). Furbish et al. (2000) found that lichens collected near the port of Skagway in 1999 had significantly elevated levels of Cd, chromium, copper, Pb, Ni, and Zn compared to lichens collected from the Tongass National Forest at sites considered to represent pristine, baseline conditions. More recently in 2008-2009, Schirokauer et al. (2014) found levels of Pb, Zn, and vanadium (a by-product of diesel combustion) elevated above background levels (i.e., levels found in Tongass National Forest) in lichens near the Skagway ship docks. From 1999 to 2008-2009, concentrations of some metals had decreased around Skagway and the KLGO Skagway Historic District. Aluminum, which had exceeded background thresholds in 1999, had declined to levels well below thresholds by 2008-2009; Cd and chromium also dropped below the thresholds; Ni declined, but remained above thresholds at several sites. Lead levels remained high near Skagway and at other sites in KLGO, up to 150 times higher than background levels; Zn also declined, but remained above thresholds near the Skagway docks and other sites around Skagway, including Glacier Gorge in KLGO (Schirokauer et al. 2014).

Mercury can be emitted by power plants and incinerators, as well as by natural sources; sources may be local, regional, or global. Mercury is a metal of particular concern because it can bioaccumulate and have detrimental neurological effects, as well as other effects, on humans, fish, and other organisms. Lichens can be used as passive monitors of Hg deposition, although no effects thresholds,

or background levels of Hg, are available for lichens. Lichens were sampled in 2008 and 2009 in the SEAN and levels of Hg were above detection limits at all sites. They were approximately an order of magnitude higher than levels detected in arctic national parks, similar to those found in Oregon and Washington (Schirokauer et al. 2014). Mercury in wet deposition was monitored in GLBA at Bartlett Cove from 2010 to 2013 as part of the Mercury Deposition Network of NADP; funding for the site was subsequently discontinued. Fish have been analyzed for Hg in other part of Alaska. Landers et al. (2008) analyzed fish from lakes in Noatak National Preserve, Gates of the Arctic National Park and Preserve, and Denali NP as part of the Western Airborne Contaminants Assessment Project (WACAP; Landers et al. 2008), and Hg levels in some of those fish exceeded human or wildlife health thresholds.

Dolly Varden (*Salmo malma malma*) were sampled by Eagles-Smith et al. (2014) from two lakes and one stream in GLBA. Concentrations of Hg (90 ng/g ww) were somewhat higher than the mean across all fish and lakes sampled in the study (78 ng/g ww). There was considerable variation among the study lakes, suggesting the importance of local factors in regulating fish Hg concentrations. These results for Dolly Varden in GLBA were similar to results obtained for this species elsewhere in Alaska (Jewett and Duffy 2007).

During the summer of 2007, Nagorski et al. (2011) sampled stream water, sediments, and aquatic biota in 19 streams in and near national park units in SEAN. Sampled watersheds included the Indian River in SITK, the Taiya and Skagway rivers in KLGO, and 16 watersheds in and near GLBA. The highest concentrations of total Hg in stream water were found in streams that were old (not recently glaciated) and draining landscapes having peat lands. The concentration of Hg in water was associated with the stream dissolved organic carbon concentration. The Hg concentrations increased with the time since glaciation. The levels of Hg in sampled fish were within health criteria values for protection of piscivorous birds and mammals.

WACAP sampled lichens and conifer needles at four sites in GLBA for semivolatile organic compounds (SOCs), including current-use and historic-use pesticides, combustion by-products, and industrial compounds. The dominant SOCs found in lichens were PAHs (combustion by-products), endosulfans (current-use pesticides), and HCB and α -HCH (historic-use pesticides). The dominant SOCs detected in conifer needles were PAHs, γ -HCH (a current-use pesticide), and HCB and α -HCH. PAHs appeared to come from local sources, while pesticides were similar in concentrations to those found in other areas of Alaska, suggesting more regional or global sources.

Simonich et al. (2012) reported concentrations of airborne SOCs in salmonid fish in five national parks, including WRST. Contaminant concentrations in fish at the two study lakes in WRST (Copper and Tanada Lakes) were comparable to those in the Alaska parks sampled as part of WACAP.

Of the 77 persistent organic pollutants analyzed in juvenile coho salmon (*Oncorhynchus kisutch*) samples collected by Nagorski et al. (2011) in and near SEAN, most were below quantitative limits. However, some that had been banned in the United States for over three decades were present, albeit at levels below environmental and human health criteria.

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