Air Quality

Goal: The current air resource condition should be maintained to protect the Forest's ecosystems from on- and off-Forest pollution emission sources

Objective: Attain national and state ambient air quality standards Forest-wide.

Background: To address the monitoring question and maintain the goal of the air resource, the tasks outlined are evaluated annually and then analyzed in finer detail in the fifth year. In summary, the year 2013 is the time to; 1) report changes in ADEC and EPA regulations, guidance and site specific monitoring plans and reports, 2) summarize the information gathered over the previous five years (2008-2012) for lichen biomonitoring, 3) report results from other passive monitoring technology related to lichen biomonitoring, and 4) report nutrient nitrogen critical loads (CL) from Marine West Coast Forests that includes Southeast (SE) Alaska.

The Region 10 lichen biomonitoring plan (Dillman 2010) contains a schedule for revisits and sets priorities for lichen biomonitoring. This biomonitoring plan is used to budget for the resources required (personnel and financial) to help answer the Forest Plan air resource question. Most of the lichen biomonitoring conducted over the past five years has been in wilderness areas to address the air element of the Chief's 10 Year Wilderness Challenge for the Tongass National Forest (NF).

Passive air monitoring technology was deployed in Tracy Arm/Fords Terror Wilderness through a partnership with the National Park Service and the Alaska Regional Air Resource Management program. This work was done to be able to calibrate nitrogen and sulfur containing pollutants in the air with what is found in lichens. This work contributed to the refinement of nitrogen (N) CL for SE Alaska. A critical load is the level of atmospheric deposition below which no detrimental ecological effects occur over the long term, based on current scientific knowledge. The development of CLs for nutrient N in lichens was explored by a national team of air specialists using data from all over the United States including the lichen data from the Tongass National Forest. A publication was generated to be used by air and land managers of the potential for nitrogen damage to ecosystems in different ecoregions of the United States (Pardo et al. 2011). Alaska is included in the Marine West Coast Forests ecoregion that combines all of coastal Alaska and the Aleutian Islands south through northern California (CEC 1997). This critical load work can also be used for addressing the new forest planning rule for air.

Air Quality Monitoring Question: Is air quality being maintained?

To answer this monitoring question, both annually and every five years, several other factors must first be considered. Ultimately, we want to know how to protect resources from deleterious effects from air contaminants from on- and off-Forest emission sources.

Evaluation Criteria

Changes in air quality relative to state and federal Ambient Air Quality Standards. Ambient air quality standards are a measure for human health. Contaminant thresholds in lichens are used to assess ecosystem health.

Sampling/Reporting Period

Sampling Period: annual; reporting and evaluation period: 5 years

ADEC and EPA 2012

Monitoring Results

PM_{10} The City of Juneau was designated *non-attainment* for National Ambient Air Quality Standard (NAAQS) particulate matter PM_{10} in 1990. Efforts have been made over the years to minimize road dust through paving as well as educating the public to limit woodstove use and open burning during certain periods. Within the past few years, the Alaska Department of Environmental Conservation (ADEC) submitted a new maintenance plan to EPA. These efforts have allowed Juneau to be redesignated as a maintenance area with the US Environmental Protection Agency (EPA) in 2009. As of January 2013, the ADEC continues to wait for the EPA to designate Juneau's Mendenhall Valley with *attainment status* for PM_{10} (pers comm. ADEC).

$PM_{2.5}$ In 2006, the EPA strengthened its air quality standards for fine particulates or $PM_{2.5}$ to 35 g/m^3. As federal standards became stricter, the City of Juneau also tightened ordinances that originally dated from the 1980s and increased public education and compliance efforts. Data from 2006-2008 indicate that Juneau has met federal air quality standards for $PM_{2.5}$ (ADEC 2010). In 2012, Juneau was very close to exceeding the $PM_{2.5}$ health based standard of 24-hour 35 micrograms per cubic meter. However, Juneau is not on the national list of "non-attainment areas" for $PM_{2.5}$[1].

Evaluation of Results

In summary, the Mendenhall Valley area continues to be in maintenance status for PM_{10} and $PM_{2.5}$ National Ambient Air Quality Standards (NAAQS). The city has not received attainment status by the EPA for PM_{10}. Juneau has been very close to exceeding the $PM_{2.5}$ health based standard of twenty-four hour thirty five micrograms per cubic meter. However, Juneau is not on the national list of "non-attainment areas" for $PM_{2.5}$.

ADEC is producing a Limited Maintenance Plan (LMP) for the Mendenhall Valley area of Juneau. The LMP provides contingency plans should Juneau ever experience a PM_{10} problem in the future and allows for Juneau to be designated as attainment for PM_{10}.

Action Plan

The Forest Service should continue to keep abreast of ADEC and EPA particulate rulings for the Juneau area, as the watersheds in the urban area are part of the Tongass NF. The Mendenhall Glacier may be experiencing accelerated melting due to *black carbon* emitted from Juneau residents' woodstoves and fossil fuel combustions settling on the glacier over time. Black carbon, a main component of combustion generated soot, is a strong absorber of solar radiation and a major contributor to climate change. Black carbon particles deposited by snowfall over snow (or ice) darken the snow (or ice) and increase the amount of radiation absorbed by snow (or ice), which increases snow and ice melt rates. Collaborative

[1] http://dec.alaska.gov/air/anpms/comm/jun_pm.htm

research is recommended with the Juneau Icefield Research Program and others to determine if the black carbon pollution is a contributing factor in the glacier's retreat.

Contaminant Thresholds in Lichens for 2012

Monitoring Results

In 2012, seven lichen biomonitoring plots were revisited within two wilderness areas (table 1). Twenty lichen tissue samples were collected, processed and sent to the University of Minnesota Soil Analytical Lab for analysis of contaminants including N, S, Hg and other heavy metals. At the time of this report, results have not been received from the laboratory. Results will be entered into the USDA Forest Service National Lichens and Air Quality Database that is maintained by the Northwest Alliance for Computational Science & Engineering (NACSE) (USDA 2006). Results will be compared to the thresholds established for the Tongass NF in four target lichen species.

Air Quality Table 1. Locations of lichen biomonitoring plots revisited in 2012 within wilderness areas.

Plot Number	Location	Wilderness Area	First established
195	Gut Island mouth of river	Stikine-LeConte	1989
30	Shakes Slough past cabin	Stikine-LeConte	1989
494	Andrews Slough	Stikine-LeConte	2005
495	Flemmer Cabin at border	Stikine-LeConte	2005
547	Sawyer Island in Tracy Arm	Tracy Arm/Fords Terror	2009
505	West Tracy Arm north of Williams Cove	Tracy Arm/Fords Terror	2003
504	Salmon Creek in Holkam Bay	Tracy Arm/Fords Terror	2003

However, in late 2012 data were received from the University of Minnesota Soil Analytical Lab for the lichen tissue collected in 2011 (table 2). In 2011, wilderness areas were revisited for lichen biomonitoring work that supported the Chief's 10 Year Wilderness Stewardship Challenge. An additional plot in non-wilderness was established in Paradise Valley on the Juneau Icefield.

Air Quality Table 2. Results from 2011 lichen biomonitoring tissue analysis on Tongass National Forest. Contaminants in lichens were compared to past results and Tongass thresholds . “Na” indicates that contaminants level comparisons between years are “not applicable” since some of the 2011 data collected are from the first visit only. Those contaminants above threshold are indicated for each plot and lichen species. Alesar=*Alectoria sarmentosa*, Hypent=*Hypogymnia enteromorpha*, Hypdup=*Hypogymnia duplicata*, Hypapi=*Hypogymnia apinnata*, Plagla=*Platismatia glauca*.

Plot #	Location	Wilder-ness Area	New or revisit	First tissue collected	Compare to Tongass thresholds	Compare to first visit
515	Klakas Inlet muskeg	SPOW	revisit	2005	None elevated	same
516	Klakas Inlet beach	SPOW	revisit	2005	Alesar: magnesium	Continues to be elevated in Mg
568	Fisherman’s Cove	S. Etolin	new	2011	Alesar: cadmium	N/A
569	Fisherman’s Cove	S. Etolin	new	2011	None elevated	N/A
506	Lower Endicott River	Endicott River	revisit	2005	Lobore: zinc Alesar: zinc and near threshold for nitrogen (.52 ppm and threshold is .56 ppm)	Alesar new species with elevated zinc. Lobore still elevated with zinc but not calcium as in past. Alesar very near threshold in nitrogen. In past N was elevated in Hypent and Plagla. These species not collected in 2011 due to scarceness at plot.
507	Upper Endicott River	Endicott River	revisit	2005	Plagla: barium, potassium	In past Alesar was elevated in Ba and Ca, also in Hypent, S was elevated but not now. Nothing elevated in past with Plagla, now there are two contaminants Ba and P.
508	Upper Endicott River	Endicott River	revisit	2005	Plagla: boron, barium; Hypent: barium, beryllium, cobalt, silicon	Past Plagla was also elevated in Co, P, V and not B. In past, Hypent was elevated in S and K as well as those elevated now. Sulfur no longer elevated at this plot.
571	Sandborn Cove	Chuck River	new	2011	Plagla, Hypdup and Alesar : manganese	N/A

Plot #	Location	Wilder-ness Area	New or revisit	First tissue collected	Compare to Tongass thresholds	Compare to first visit
570	Endicott Arm	Tracy Arm / Fords Terror	New	2011	Plagla: barium	N/A
493	Chuck River estuary	Chuck River	Revisit	2004	Alesar: nitrogen, Plagla: phosphorus, very near threshold for potassium.	New elevated contaminant: N and P
492	Taylor Creek at beach	Chuck River	Revisit	2004	Alesar: phosphorus, potassium: Plagla: phosphorus, potassium	All are new contaminants elevated compared to the past.
491	Taylor Lake	Chuck River	Revisit-plot destroyed due to landslide	2004	Plagla: barium, cadmium	All are new contaminants elevated compared to the past
213 old 62	Harlequin Lake	Russell Fiords	Revisit	2005	Hypapi: barium, silicon, zinc	Past contaminants not presently elevated in Hypapi: Al, Cr, Li, Ti, and V. The Si is the same, and Ba and Zn are new
573	Knight Island	Russell Fiords	New	2011	Plagla: copper, potassium, silicon,	N/A
489	Red Bluff Bay	S. Baranof	Revisit	2004		same
490	Red Bluff Bay	S. Baranof	Revisit	2004		same
498	Malmsbury Lake	Kuiu	Revisit	2004		same
499	Malmsbury Lake	Kuiu	Revisit	2004		same
575	Salmon Lake	Karta	New	2011	none	N/A
159	Salmon Lake	Karta	New for	2011	Alesar:	N/A

Plot #	Location	Wilder-ness Area	New or revisit	First tissue collected	Compare to Tongass thresholds	Compare to first visit
			tissue, plot established in 1990		cadmium	
572	Paradise Valley	Juneau Icefield	new	2011	Hypent: aluminum, titanium	N/A

Evaluation of Results

Most of the lichen biomonitoring for the period of 2008 to 2012 was conducted in wilderness areas. Fifty one lichen biomonitoring plots were revisited during this period to collect tissue and lichen community data. Of those fifty one plots, twenty-five have lichens that are above threshold in one or more contaminants (table 3). Some of the contaminants are natural impacts due to windblown soils and geologic influences. Only a few are suspected to be impacted by anthropogenic fossil fuels or other factors.

2012 Revisit plots with new contaminants: No contaminants were above threshold from the first visit to Chuck River Wilderness in 2005, but are now exceeding thresholds for some contaminants (plots 491, 492, 493) (tables 1 and 3). The reasons for elevated nitrogen in the Chuck River wilderness could be due to increased marine traffic in Windham Bay. The other contaminants found above threshold (potassium and phosphorus) for two lichen species may also be due to fossil fuel combustion in the bay as a possible cause. Phosphorus and potassium are also emitted during wood burning. The lodge in the bay has not been working for years. Taylor Lake plot was obliterated in a landslide but tissue samples were collected at the lake edge and surrounding forest near the old plot location. The plot center was not reestablished due to time constraints, so no new lichen community information was collected. This plot contains *Platismatia glauca* elevated in cadmium and barium. No explanations for the increase above threshold are provided at this time.

2012 Revisit plots with other changes in contaminants: The plots with lichens elevated above threshold with heavy metals and others from the first monitoring cycle continue to be elevated to some degree (table 1). Endicott River wilderness contains three plots; two in the upper reaches of the river (plots 507, 508), and one near the mouth, about one mile upstream (plot 506). Zinc remains above threshold in the lower river plot while nitrogen reports just below threshold. Nitrogen was above threshold here in 2005 (Dillman et al. 2007). The elevated zinc could be related to geology in the area, as it was suspected that elevated calcium may be geology related from the 2005 sampling period. No elevated calcium was detected this time. More sampling is needed to detect a trend in nitrogen, as it could be from other natural sources or drifting from Lynn Canal boat traffic.

Harlequin Lake of Russell Fiords wilderness is still above threshold for some contaminants (barium, silicon and zinc). The past monitoring period (2005) did not report these elements as elevated, except for silicon (Dillman et al 2007). Others not detected in this monitoring period but were elevated in the past were mainly heavy metals such as titanium, nickel, lithium and aluminum.

The possible reasons for elevated contaminants in lichens is that all these plots are on the mainland near exposed glacial areas which contain windblown dusts from the coastal mountain areas. The variation in the contaminant species found in lichens across the monitoring periods help point to this hypothesis.

Air Quality Table 3. Summary of the past five years air biomonitoring plots and those contaminants exceeding thresholds in lichens on the Tongass National Forest.

Year	Plots revisited	New plots created	Plots with lichens above thresholds	Contaminants exceeding threshold
2008	Sitka area 107, 108, 239	139 Harbor Mountain-Sitka	All plots varying in contaminants	N, S, Al, Fe, Li, Mn, P, Ti, Pb, V, Co, Cr. Ni, Si
2009	Coronation and Warren wilderness areas 510, 513	Skagway area, Craig, Hyder, Misty Fiords 551, 546, 545, 550, 543, 544, 554, 549, 548, 547	551, 543, 549, 548, 547, 510, 513	N or S only, no heavy metals analyzed
2010	none	none	N/A	N/A
2011	Stikine River, Endicott River, Paradise Valley, Russell Fiords, S. Baranof, Kuiu, SPOW, Karta River, Chuck River (see table 2 for plot numbers)	568, 569 S. Etolin, 570 Chuck River, 571 Tracy Arm, 573 Russell Fiords, 575 Salmon Lake, and 572 Paradise Valley	516, 568, 506, 507, 508, 571, 570, 493, 572, 159, 492, 491, 213, and 573	N, Mn, Mg, Cd, Zn, B, K, Ba, Be, Co, Si (see table 2 for plots and elements)
2012	Stikine River, 195, 30, 494, 495, Tracy Arm/Fords Terror 504, 547, 505	none	Not yet analyzed	

2012 New plots: Some of the plots that were established during the 2011 period contain contaminants above threshold. Lichens from Karta River wilderness (plot 159) contain cadmium above threshold. There is an old silver mine near Karta Lake, but has not been operating for over thirty years. The geology of the area may be the cause of elevated Cd. Lichens from Paradise Valley on the Juneau Icefield are elevated in aluminum and titanium (plot 572). This could be due to being surrounded by glaciers and receiving windblown soils from many sources. Lichens from Knight Island in Yakutat Bay on the Russell Fiords wilderness are elevated above threshold for copper, potassium and silicon. This plot is exposed to the Hubbard and Malaspina Glaciers as well as the open Pacific Ocean. Cruise ships do travel by in the summer season, but it is unlikely that the contaminants are from those mobile sources as the bay is wide in this area and emissions are dispersed. Sandborn Canal in Endicott Arm and part of Chuck River wilderness is above thresholds in manganese in all three lichen species analyzed. Manganese is a naturally occurring substance that does not occur as a pure metal in the environment. It is released into the air when fossil fuels are burned. There is an old mine in the area. However, other nearby Tracy Arm wilderness plots are not elevated in this contaminant.

Air Quality Table 4. Summary Contaminant thresholds in lichens from the Tongass National Forest (from Dillman *et al*, 2007). Species of lichens are: *Alectoria sarmentosa* (Alesar), *Hypogymnia* species (Hypog), *Lobaria oregana* (Lobore) and *Platismatia glauca* (Plagla).

Species	**S**	**N**	**Al**	**B**	**Ba**	**Be**
Alesar	0.06	0.56	56.78	9.33	15.84	0.04
Hypog	0.09	0.88	1126.44	9.47	76.62	0.04
Lobore	0.13	NA	580.03	4.06	16.46	0.04
Plagla	0.08	0.80	1063.57	6.05	53.80	0.04
Species	**Ca**	**Cd**	**Co**	**Cr**	**Cu**	**Fe**
Alesar	9689.25	0.40	0.78	0.73	1.86	55.64
Hypog	24671.17	0.61	1.25	2.38	31.31	1990.78
Lobore	1158.10	0.55	0.83	1.51	10.18	1010.97
Plagla	4104.48	0.32	1.14	3.29	7.55	1773.56
Species	**K**	**Li**	**Mg**	**Mn**	**Mo**	**Na**
Alesar	2413.25	0.40	740.83	188.24	0.54	893.16
Hypog	3284.34	0.71	2127.70	860.85	0.54	929.13
Lobore	8001.57	0.59	735.79	168.00	0.54	394.30
Plagla	2523.88	0.60	1717.08	483.70	0.54	693.21
Species	**Ni**	**P**	**Pb**	**Rb**	**Si**	**Sr**
Alesar	0.96	913.75	5.00	53.00	134.75	33.56
Hypog	4.26	1597.23	10.13	53.00	563.82	61.26
Lobore	1.65	2532.49	3.52	53.00	681.18	6.30
Plagla	2.65	1115.00	3.52	53.00	635.83	28.91
Species	**Ti**	**V**	**Zn**			
Alesar	4.93	0.37	38.06			
Hypog	62.42	2.99	70.20			
Lobore	45.30	2.42	82.93			
Plagla	76.86	3.08	52.85			

Summary: It is unlikely that the sites with contaminants in lichens above thresholds will exceed the NAAQS for particulates during a twenty-four hour period for human health concerns. Lichens accumulate contaminants so they cannot be used to detect pollution for a short time period. However, with the development of critical loads and the calibration of the nutrient N in lichens, in the future we can use this lichen biomonitoring program to detect exceedances of nutrient and acidity CLs by collecting lichen samples for elemental analysis. The data can be used to track trends or map the spatial extent of the impacted areas. However, it is important to mention that lichens are passive monitors of ecosystem health. Monitoring air quality with lichens is relatively inexpensive and economically feasible. Lichens are potentially long lived, and can be collected for analysis during any time of the year. They accumulate pollutants throughout the year and can show signs of air pollution damage. Lichen communities in polluted locations will typically have low diversity, but possibly an abundance of pollution tolerant species. The lichens used for tissue analysis on the Tongass NF have a wide geographic range in the US, therefore, this allows for comparisons with other parts of the US and the world. The data presented here is what is accumulating over time in the lichens from both wet and dry deposition and from natural and anthropogenic sources. It is this accumulation that can damage lichen tissue over time, which is dependent upon the contaminants and the amount of rainfall that can help ameliorate the effects of the contaminants. Contaminant evidence above threshold in the lichens shows that certain locations are impacted by air pollution, natural or man-made, even in remote areas.

Action Plan

The air quality lichen biomonitoring work over the past five years has been supported by the wilderness program and the inventory and monitoring programs. The Chief’s 10 Year Wilderness Challenge is the main reason behind the wilderness focus of this work. The research has provided the Tongass NF insight into the threats to wilderness air quality, while at the same time boosting the scores of the wilderness areas for the Chief’s challenge. Additionally, this information can be used in the future to monitor trends in wilderness areas that are showing signs of human induced contaminants. Without these simple tools, land managers would be unable to report on the air resource condition or possible protection measures. These baseline values serve as just that, baseline conditions for continually changing atmospheric condition and climate. It is well documented that pollutants will continue to arrive on a daily basis to this region from across the Pacific Ocean. Local pollution sources will continue to change in intensity, depending on economics, population, and other factors. The elements of concern for lichens and other ecosystem processes are mainly nitrogen and sulfur, as they not only impact lichen communities but also impact ecosystem processes (Duarte et al. 2013).

The proposed action plan with the lichen air biomonitoring program is that each wilderness should be visited at least twice for the life of this Forest Plan. This will help establish trends for future work in air pollution and climate change for the Alaska Region (R10) during the next few decades. At present, there are four wilderness areas that have one visit for both tissue and lichen community data together for a certain time period: Maurelle Islands, Coronation, Warren, Endicott River wilderness areas. The rest have at least two and a few more than two. Community surveys of epiphytic lichens for a plot are conducted to provide a reference condition and to detect community responses to threshold and critical load exceedances. The Endicott River, Coronation and Warren wilderness areas have two visits for tissue and one visit for lichen community analysis. Maurelle Islands have one visit with one complete set of data collected. These are the least accessible wilderness areas and the most expensive to travel to. The R10 Air Quality Lichen Biomonitoring plan can be consulted to determine schedules of remonitoring plots and the evaluation of contaminants above threshold. Once the calibration work being conducted by R6 air specialists is completed for nitrogen and acidity CLs with lichens, managers can detect exceedances of these contaminants in lichens. Exceedances in known CLs indicate some ecological effects are present due to air contaminant levels at a site and the ecosystem is not protected.

The lichen air databases are presently being updated and reformatted by Region 6 air specialists and uploaded into the National Lichens and Air Quality Database website (http://gis.nacse.org/lichenair/index.php). Future plans include an NRIS air module that will encompass all the lichen biomonitoring data across the United States. Having Tongass NF data in this national database will keep it safe, easy to update, and eventually facilitate that transfer once the NRIS module is ready.

Passive Monitoring Technology: SE Alaska Cruise ship emissions study

Background

The deposition and acidification associated with air pollutants effects 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. In SE Alaska, the Pacific Northwest and other temperate areas, with comparatively low rates of anthropogenic nitrogen deposition, sensitive lichen species are used as important sentinels of ecosystem change (Geiser 2004, Geiser and Neitlich 2007, Otnyukova and Sekretenko 2008, Sutton et al. 2009, Wolseley et al. 2009). In polluted areas, lichen biodiversity and community composition shifts as sensitive species are replaced by previously nitrogen limited, pollution-tolerant species.

The results presented here represents a collaboration of researchers and managers of the National Park Service Air Resources Division, Tongass National Forest, R10 Air Resource Management Program, Municipality of Skagway (MOS), and the National Parks of Southeast Alaska which include Glacier Bay, Klondike Goldrush, and Sitka. The interest and resources of these agencies 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 lichens due to air pollution. Marine transportation emissions are currently the dominant local pollution sources at all sites, but an increase in trans-Pacific emissions and their potential transport to Southeast Alaska during spring, monsoon driven outflows (Lin et al. 2012) is also of concern.

Monitoring sites in the three national parks, the City of Skagway, and on Sawyer Island in Tracy Arm/Fords Terror wilderness were established to host several different passive sensors. They were co-located with air quality lichen biomonitoring plots. The site locations were primarily selected for access in specific areas of interest to demonstrate impacts from marine transportation emission sources.

Open site (bulk deposition) and canopy through-fall resin tube samplers were installed in all sites including Sawyer Island on the Tongass NF 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. Results were compared to clean site ranges and thresholds established by the Tongass NF for nitrogen, sulfur, and metals (Dillman et al. 2007). Community surveys of epiphytic lichens were conducted as a reference condition for future change detection analysis.

Resin tube deposition samplers measure *bulk deposition* (defined as wet deposition plus inadvertent dry deposition to continually open samplers), and 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 of 2008 and 2009.

Passive samplers to measure *ambient concentrations* were installed in all the national parks and around the City of Skagway, but not on the Tongass NF. These samplers captured *nitrogen oxide(s), nitric acid, ammonia,* and *sulfur dioxide gases*. The Tongass NF did not install these passive samplers due to the cost of installation and maintenance. Therefore the results for ambient concentrations study will not be reported here.

Monitoring Results

The resin tubes from the throughfall samplers for both years were analyzed at the USDA Forest Service Pacific Southwest Research Station in Riverside California. Lichens were analyzed at the University of Minnesota Soil Analytical Lab Soil. Resin tube analysis results show that ammonium was slightly higher in throughfall than in bulk deposition (open sites) in most instances. This suggests that ammonium accumulates in the canopy and that a significant fraction is then washed out during rain events. Sulfate levels were much higher at throughfall collectors than at open sites. Many studies have shown that sulfate deposited on canopies during fog events or as dry deposition is effectively washed from the canopy as throughfall, while thirty to forty percent 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 study cited below from Washington, up to 90 percent of atmospheric nitrate can be retained in the canopy.

The results also show that 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. 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 (Mark Fenn, unpublished data) and in the Wind River Experimental Forest in the Gifford Pinchot National Forest in south central Washington (Klopatek et al. 2006).

The wet deposition values for total inorganic N detected in 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/year 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 three to twenty-five times lower than the reported wet deposition value of 1.6 kg N/ha/year (Fenn et al. 2003b). For both NO_3^- and NH_4^+, higher rates of deposition were reported for 2008 compared to 2009. 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 eleven percent. However, the differences in N deposition between the two years are more likely due to differences in the amount, timing and intensity of precipitation. There was more precipitation in 2008 than 2009. The higher volume of precipitation in 2008 explains some of the difference in wet deposition between the two years. Summer time precipitation is the driving co-variable for wet deposition, especially in Southeast Alaska's wet maritime climate.

The lichen plots established at the sites where throughfall samplers were deployed contained lichen tissue well below Tongass NF threshold values and several elements are below the detection limits of the methods applied. However, a few exceptions stand out. For example, potassium (K) was slightly over threshold as several locations across all SE Alaska sites, 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 Klondike Goldrush in 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 Glacier Bay and in Klondike Goldrush at Lower Dewey and Dyea. Si is abundant as silica (in quartz) and a variety of metallic ores. On the Tongass NF elevated Si levels are associated with mine tailings 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.

Nitrogen (N) levels at Lower Dewey in Skagway 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 Skagway area. Data from the Tongass NF 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).

Sulfur levels (S) were above threshold concentration in lichens during both the 1999 and the 2009 samplings with little change at Lower Dewey and Sturgill’s in Skagway. The relatively high levels of wet deposition in the throughfall samplers at Lower Dewey described above corroborate the signal in lichen. Sulfur levels associated with adverse effects to sensitive plants (Glavich and Geiser 2008) were primarily observed in lichens within 2 km of Skagway at Lower Dewey and Icy Junction.

Although most other SE Alaska lichen samples are below Tongass NF 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 SE Alaska 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 Tongass plots that displayed elevated S levels were from sites with local anthropogenic influence (Dillman et al. 2007).

The Sawyer Island site in Tracy Arm had the highest lichen tissue levels exceeding N and S thresholds. In addition throughfall nitrates and ammonia as well as throughfall and bulk deposition of sulfates was also enhanced at this site. Although bird activity is high in the area and fertilization of the lichens with bird droppings may be contributing to the effect, the fact that phosphate levels in the bulk and throughfall deposition were within same range as other sites and the relatively high sulfate deposition indicate that bird droppings may not be the sole explanation for the observed enhancements and responses to sulfur and nitrogen. Cruise ships turn around and linger in front of Sawyer Island.

Evaluation of Results

This study suggests that acidic deposition from local sources of nitrogen and sulfur oxides is likely to be more important than local or long distance transport of nutrient nitrogen as ammonium nitrates and sulfates. This is especially true in areas with frequent inversions and docking ports where ships are continuously running their generators (Sitka, Skagway, Ketchikan and Juneau).

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). Significant reductions in sulfur emissions in the United States 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 Environmental Protection Agency 2009). Monitoring the effectiveness of these new regulations is another motivation for repeating sulfur pollution assessments. Using lichens as bio-indicators of heavy sulfur loads is one way to indicate if S is a problem in remote areas where fossil fuels are emitted.

Action Plan

The primary pollutants detected through passive atmospheric and lichen biomonitoring 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 most dense population centers, human health impacts are a potential concern. Lead, nickel and vanadium were significantly enhanced in the KLGO/Skagway area. Although SO_2 and NO_x were elevated at KLGO/Skagway, they were 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 Tongass NF thresholds were exceeded (KLGO/Skagway and SITK). Lichen community changes should be assessed after the plots are read again in 2018 and 2019. Possibly additional lichen plots in the area on National Forest Lands could be included in this research in the future.

The results from this passive monitoring project will allow air specialists to calibrate lichen elemental content to deposition of nitrogen and sulfur for the Alaska Region. This will help determine if the goal of air resource protection is being accomplished by then using lichen biomonitoring as the tool to determine exceedances in CLs for nitrogen and sulfur.

Nitrogen Critical Loads

Background

In order to answer the air question in the Forest Plan, it is necessary to determine how much pollution is entering into the ecosystem from the air in known problem areas (i.e. deposition study mentioned above), and what a certain level of a contaminant means to sensitive indicators (i.e. biomonitoring with lichens). To help answer this question, CLs were developed for nitrogen as a contaminant of concern. A CL is the level of atmospheric deposition below which no detrimental ecological effects occur over the long term, based on current scientific knowledge. Managers can use CLs as a tool to help with the new forest planning rule for air that includes CLs and to set resource protection goals and policy.

The air quality lichen biomonitoring data from the Tongass NF has helped develop critical loads for nitrogen within the Marine West Coast Forest ecoregion that includes SE Alaska (Pardo et al. 2011). The ecoregions are based on the Commission for Environmental Cooperation (CEC) for North America Level I map of ecoregions for North America (CEC 1997). The lichen air plots from the Tongass NF and Region 6 were run in a model developed by Geiser and Neitlich (2007) to determine air quality scores for the lichen air plots and develop the nitrogen CL for the ecoregion. Critical loads are the best tool available to determine if the forest ecosystems are protected from on- and off -forest emissions. Elements in lichens can be used to determine if a CL has been exceeded.

Monitoring Results

Lichen community data from the Tongass NF and Forest Inventory and Analysis (FIA) support that lichen species overlap with western Oregon and Washington (Region 6) is sufficient to apply nutrient N critical loads to Region 10 until Forest Service region-specific critical loads can be established (Pardo 2011). Based on existing literature (Geiser et al. 2010) and a recent study to calibrate dry weight lichen nitrogen concentrations with nitrogen deposition in Alaska, Oregon, Washington and California (Root et al. 2013), a conservative nutrient nitrogen (N) CL for the Tongass would be between 2.7 and 4 kg/ha/yr.

Geiser and Neitlich (2007) used a non-metric multidimensional scaling ordination technique to separate climate from pollution effects on lichen communities and scored air quality at each of the lichen survey sites in Region 6. The calculated Tongass NF scores are based on lichen community composition on the Tongass NF using the Region 6 gradient model for nutrient N deposition. Scores over 0.21 exceed the threshold for clean sites. Those between 0.1 and 2.1 are approaching CLs. Some of the high scoring sites are not high because of air pollution but because the sites are along the beach fringe and are nutrient enriched from organic N in sea water spray and the presence of hardwoods in the community. Others are nutrient enriched because they are in mainland valley floors that receive a lot of glacial dust (e.g. Stikine River valley). Since those are not anthropogenic nutrient N sources, these are not considered impacted. Future work will involve the lichen community response to acidity (S). The acidity community response will be clearer as there are no natural sources of it and the impact is always to decrease biodiversity. As of 2010 there were two lichen monitoring sites that exceeded this N critical load that are attributed to anthropogenic sources: the forested area of Mt. Roberts facing the cruise ship docking area below the tram in Juneau, and the forested slope above the cruise ship dock in Skagway.

Action Plan

The lichen biomonitoring work documents that some places are impacted by emissions as evidenced from the lichen community responses and tissue analysis. Nitrogen concentrations in lichens can shift across a large gradient depending on the emissions sources. Lichens that are sensitive to high concentrations of nitrogen play important ecological roles as forage, nesting material, habitat for mollusks and invertebrates, and contribute to N_2 fixation, nutrient cycling and moderation of humidity (McCune and Geiser 2009). Shifts in lichen community composition in our old growth forests where lichen biomass is one of the highest, can have broader effects on forest ecosystems and food webs.

The lichen community monitoring and tissue analysis could be useful tools to track loading of N and S on Forest air resources in the future. As more research is done in this area of lichen and air pollution, the Tongass NF may consider these tools for monitoring air quality and climate change. Researchers are presently developing a model to score air plots along a climate gradient. This will help managers track changes in scores which reflect real shifts in lichen community composition and diversity due to changes in climate.

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