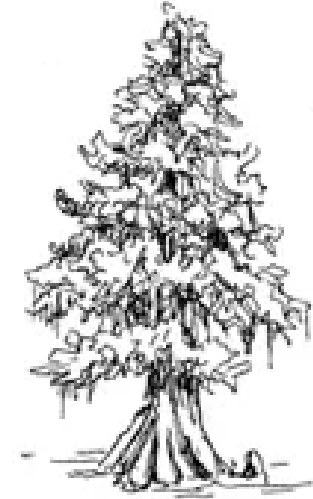
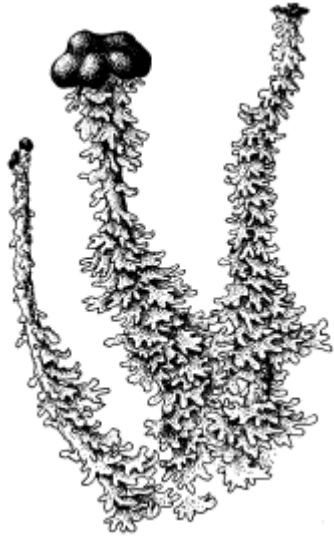


Lichen Biomonitoring in the USFS



2024

Amanda Hardman National FS Lichen Biomonitoring Coordinator
Linda Geiser National Air Resource Program Lead

Air Quality Monitoring and more



1970 Clean Air Act & 1977 amended

“prevent significant deterioration” of air quality in class 1 wilderness

1974 National Forest Management Act &
1976 Federal Land Management Policy Act

*Chief’s 10year Wilderness Stewardship Challenge

*Wilderness Character Monitoring

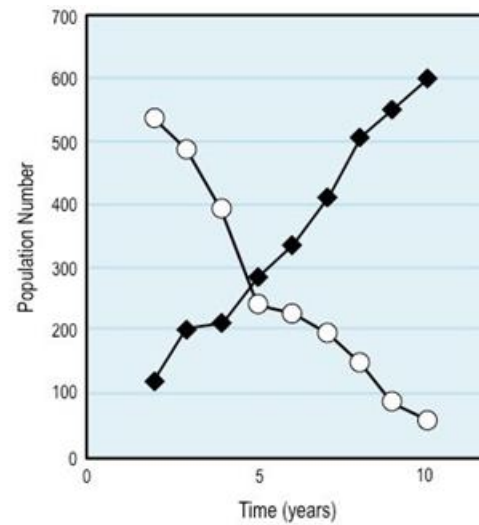
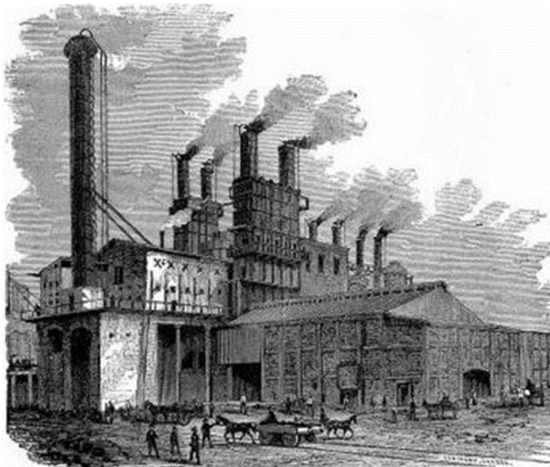
Agency Mission = sustain biodiversity

Forest and Project planning under NEPA (critical load exceedances)

Climate Change



Early observations



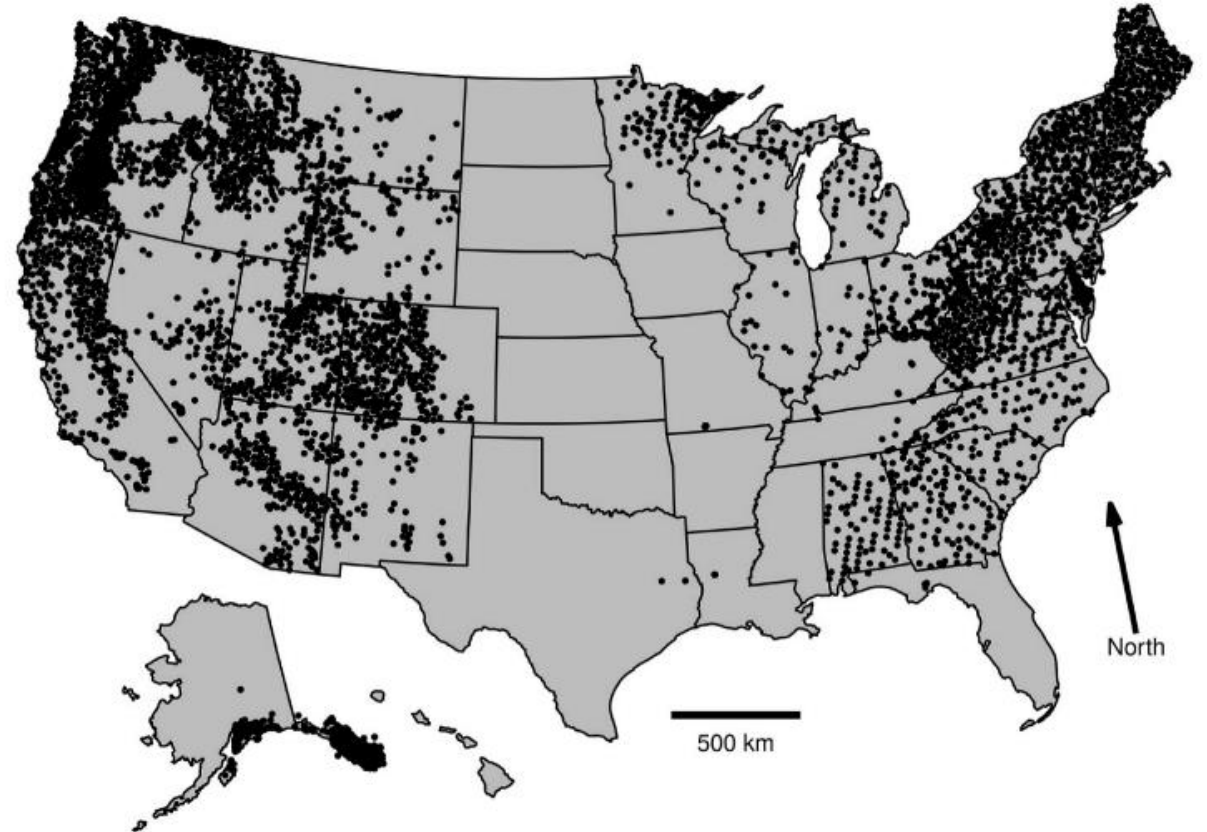
William Nylander
Early Lichenologist

Lichen Surveys Federal Land Nationwide

1973- 2023

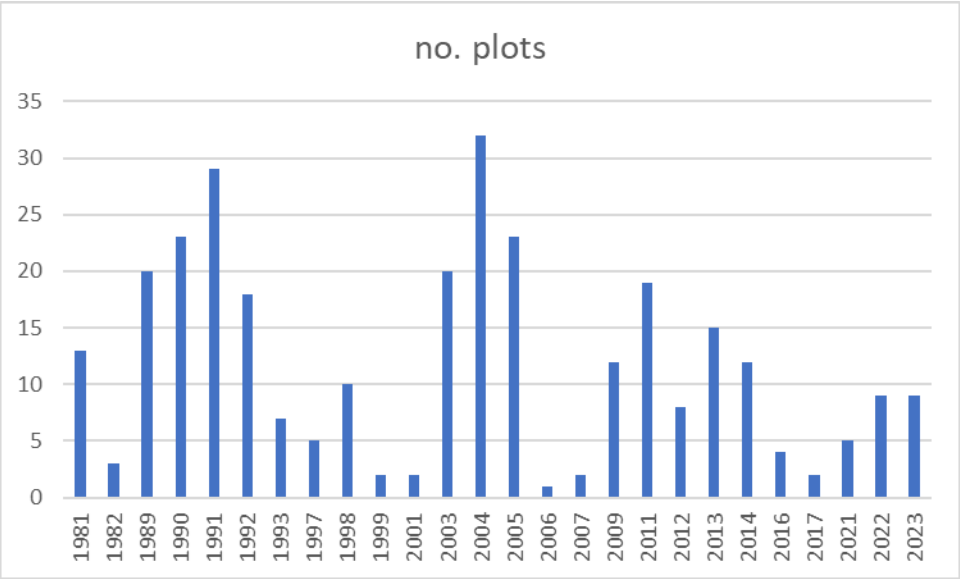
- 42 states
- **127 National Forests**
- **277 FS Wilderness areas**
- 9,000 baseline surveys, 4,000 with trends
 - NPS = 45
 - USFWS = 21
 - BLM = 327
- 200,000 species records
- 18,000 elemental analysis records

Efforts most notably accomplished by the Air Resource Management and FIA programs.

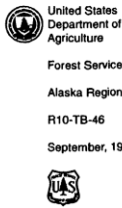


Alaska Biomonitoring

- **1989** First lichen biomonitoring installed Tongass
- **1993-1994** Chugach plots installed
- **2004** Chief's 10-year Wilderness Challenge



| Plots | | Chugach | Tongass |
|------------|-----|---------|---------|
| Baseline | 815 | 109 | 706 |
| Trends | 63 | 13 | 50 |
| Wilderness | 215 | 8 | 203 |



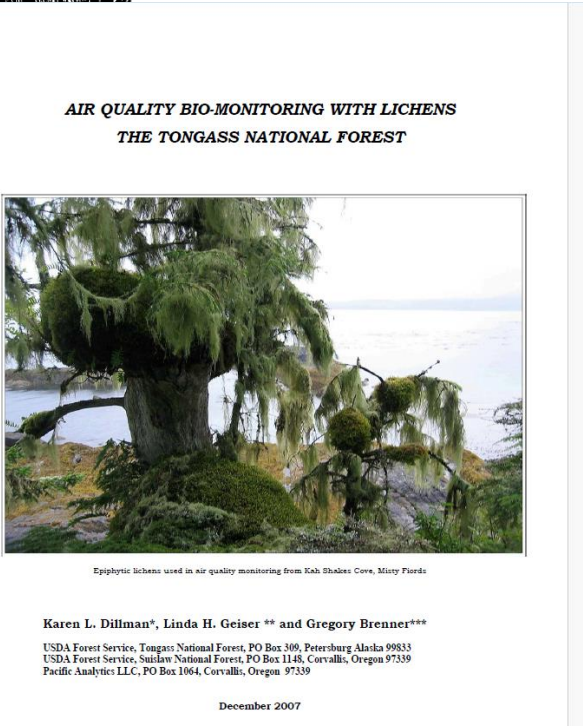
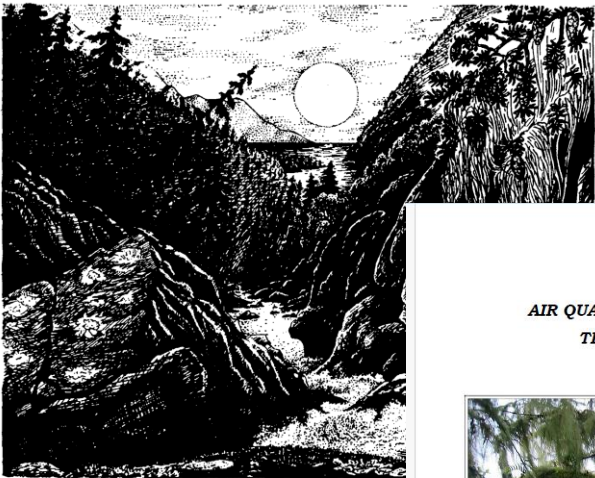
Air Quality Monitoring on the Tongass National Forest

Methods and Baselines Using Lichens

September 1994

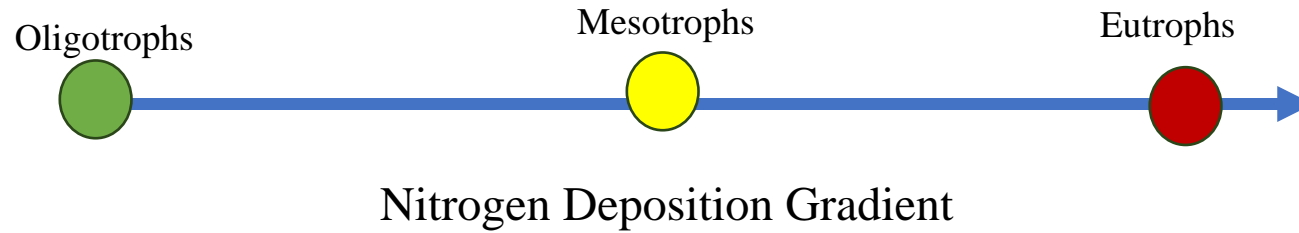
Linda H. Geiser, Chiska C. Derr, and Karen L. Dillman

USDA-Forest Service
Tongass National Forest/ Stikine Area
P.O. Box 309
Petersburg, Alaska 99833



Why Lichens?

- Sensitive absorb chemicals at proportions that reflect composition in the air through wet and dry deposition



- Inexpensive
- Common and diverse in most forested ecosystems
- Infrastructure, protocols, and baseline plots ~30 years

What else do lichens tell us:

- biodiversity
- Climate shifts



Sample Method 1: Elemental analysis

Measure pollution content in lichen tissues

1. Collect



2. Clean



3. Analyze



Sample Method 1: Elemental analysis

- Potential to measure SVOC, and persistent air pollutants (PFAS), and microplastics
- We track 27 elements: sulfur, nitrogen, lead, cadmium, chromium, lead, zinc and mercury



Periodic Table of the Elements

Period

| |
|---|
| 1 |
| 2 |
| 3 |
| 4 |
| 5 |
| 6 |
| 7 |

KEY

Atomic Mass → 12.011

Symbol → **C**

Atomic Number → **6**

Electron Configuration → 2-4

Selected Oxidation States

+4
+2
+4

Positive atomic masses are based on $^{12}\text{C} = 12.000$

Note: Mass numbers in parentheses are mass numbers of the most stable or common isotope.

18

| |
|----|
| He |
| 2 |

Group

| | |
|----|----|
| 1 | 2 |
| 3 | 4 |
| 5 | 6 |
| 7 | 8 |
| 9 | 10 |
| 11 | 12 |
| 13 | 14 |
| 15 | 16 |
| 17 | 18 |

Group

| | | | | | |
|-----|-----|-----|-----|-----|-----|
| 13 | 14 | 15 | 16 | 17 | 18 |
| B | C | N | O | F | Ne |
| 5 | 6 | 7 | 8 | 9 | 10 |
| Al | Si | P | S | Cl | Ar |
| 13 | 14 | 15 | 16 | 17 | 18 |
| K | Ca | Sc | Ti | V | Cr |
| 19 | 20 | 21 | 22 | 23 | 24 |
| Rb | Sr | Y | Zr | Nb | Mo |
| 37 | 38 | 39 | 40 | 41 | 42 |
| Cs | Ba | La | Hf | Ta | W |
| 55 | 56 | 57 | 72 | 73 | 74 |
| Fr | Ra | Ac | Rf | Db | Sg |
| 87 | 88 | 89 | 104 | 105 | 106 |
| 11 | 12 | 13 | 14 | 15 | 16 |
| Cu | Zn | Ga | Ge | As | Se |
| 29 | 30 | 31 | 32 | 33 | 34 |
| Ag | Cd | In | Sn | Sb | Te |
| 47 | 48 | 49 | 50 | 51 | 52 |
| Au | Hg | Tl | Pb | Bi | Po |
| 79 | 80 | 81 | 82 | 83 | 84 |
| Uun | Uuu | Uub | Uuq | | |
| 111 | 112 | 113 | 114 | | |

Group

| | | | | | |
|-----|-----|-----|-----|-----|-----|
| 13 | 14 | 15 | 16 | 17 | 18 |
| B | C | N | O | F | Ne |
| 5 | 6 | 7 | 8 | 9 | 10 |
| Al | Si | P | S | Cl | Ar |
| 13 | 14 | 15 | 16 | 17 | 18 |
| K | Ca | Sc | Ti | V | Cr |
| 19 | 20 | 21 | 22 | 23 | 24 |
| Rb | Sr | Y | Zr | Nb | Mo |
| 37 | 38 | 39 | 40 | 41 | 42 |
| Cs | Ba | La | Hf | Ta | W |
| 55 | 56 | 57 | 72 | 73 | 74 |
| Fr | Ra | Ac | Rf | Db | Sg |
| 87 | 88 | 89 | 104 | 105 | 106 |
| 11 | 12 | 13 | 14 | 15 | 16 |
| Cu | Zn | Ga | Ge | As | Se |
| 29 | 30 | 31 | 32 | 33 | 34 |
| Ag | Cd | In | Sn | Sb | Te |
| 47 | 48 | 49 | 50 | 51 | 52 |
| Au | Hg | Tl | Pb | Bi | Po |
| 79 | 80 | 81 | 82 | 83 | 84 |
| Uun | Uuu | Uub | Uuq | | |
| 111 | 112 | 113 | 114 | | |

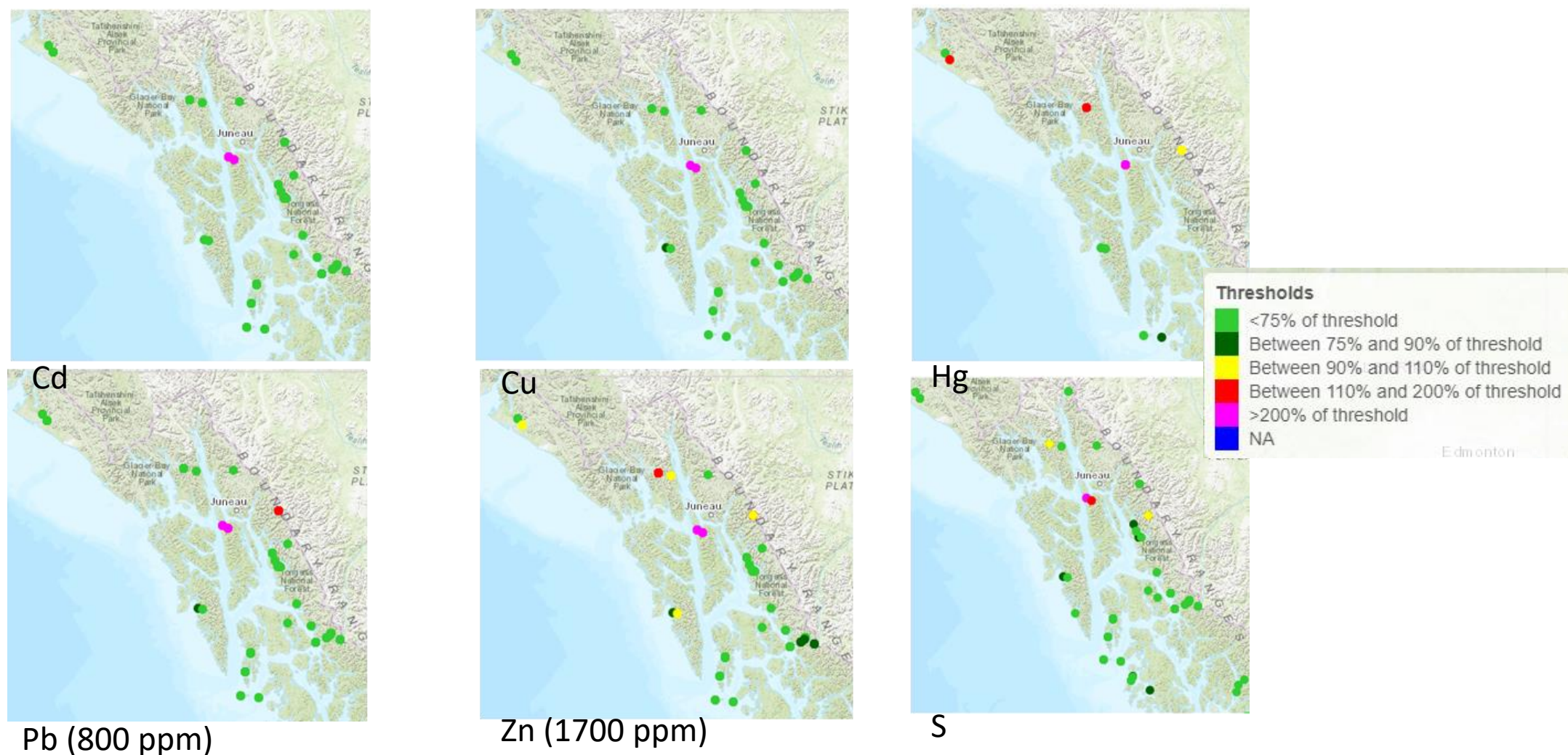
*The systematic names and symbols for elements of atomic numbers above 100 will be used until the approval of trivial names by IUPAC.

| | | | | | | | | | | | | | |
|----|----|----|----|----|----|----|----|----|----|-----|-----|-----|-----|
| Ce | Pr | Nd | Pm | Sm | Eu | Gd | Tb | Dy | Ho | Er | Tm | Yb | Lu |
| 58 | 59 | 60 | 61 | 62 | 63 | 64 | 65 | 66 | 67 | 68 | 69 | 70 | 71 |
| Th | Pa | U | Np | Pu | Am | Cm | Bk | Cf | Es | Fm | Md | No | Lr |
| 90 | 91 | 92 | 93 | 94 | 95 | 96 | 97 | 98 | 99 | 100 | 101 | 102 | 103 |

**Denotes the presence of (2-8-) for elements 72 and above

Green's Ck Mine The Tailings Disposal Facility Fugitive Dust Mitigation and Monitoring Plan

*Metal and sulfur levels in the lichen *Platismatia glauca* sampled near the tailings were more **than 200% above national thresholds**, and in some cases, orders of magnitude higher than thresholds (Cd 30x, Pb 100x, Zn 37x), warranting additional monitoring and monitoring sites to demonstrate effectiveness of best practices to be implemented.*

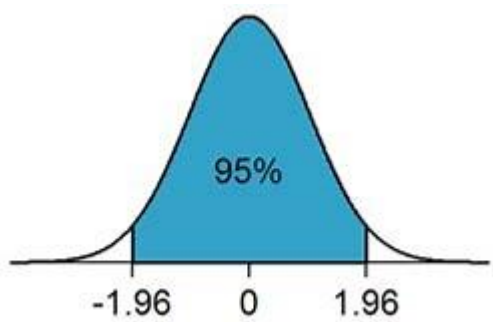


Sample Method 1: Elemental analysis

Determining National Thresholds



| | Cd ppm | Cr ppm | Cu ppm | Hg ppb | N % | Ni ppm | Pb ppm | S % | Zn ppm |
|---------------------------|--------|--------|--------|--------|-------------|--------|--------|-------|--------|
| <i>Platismatia glauca</i> | | | | | | | | | |
| Regional Threshold | 0.5 | 3 | 27.8 | n/a | 0.79 | 4.4 | 10 | 0.115 | 49.6 |
| Mean | | | | | | | | | |
| Round 1 (n= 14) | 0.2 | 1.3 | 8.6 | n/a | 0.61 | 1.8 | 5.6 | 0.072 | 32.6 |
| Round 2 (n= 4) | 0.2 | 1.4 | 3.6 | 144 | 0.84 | 1.3 | 3.8 | 0.074 | 31.9 |
| Standard deviation | | | | | | | | | |
| Round 1 (n= 14) | 0.1 | 0.4 | 5.8 | | 0.21 | 0.6 | 1.9 | 0.01 | 6 |
| Round 2 (n= 4) | | 0.6 | 1.3 | | 0.54 | 0.6 | 0.5 | 0.045 | 2.2 |
| Minimum | | | | | | | | | |
| Round 1 (n= 14) | 0.1 | 0.9 | 3.6 | | 0.25 | 0.9 | 3.6 | 0.06 | 26.7 |
| Round 2 (n= 4) | 0.2 | 0.6 | 2.9 | 144 | 0.5 | 0.6 | 3.5 | 0.037 | 29.6 |
| Maximum | | | | | | | | | |
| Round 1 (n= 14) | 0.6 | 1.9 | 19.8 | | 0.97 | 3.3 | 9.6 | 0.09 | 47.2 |
| Round 2 (n= 4) | 0.2 | 2.1 | 5.5 | 144 | 1.64 | 2.1 | 4.6 | 0.14 | 33.7 |



Sample Method 1: Elemental analysis

- Benefit: least amount of training
- Challenges: no climate change, high humidity, low biomass, can take up to a year for results

Periodic Table of the Elements

KEY

Atomic Mass \rightarrow 12.011
 Symbol \rightarrow C
 Atomic Number \rightarrow 6
 Electron Configuration \rightarrow 2-4

Selected Oxidation States: +4, +2, +4

Positive atomic masses are based on $^{12}\text{C} = 12.000$

Note: Mass numbers in parentheses are mass numbers of the most stable or common isotopes.

Group

1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18

1 H 2 He

3 Li 4 Be

5 Na 6 Mg

7 K 8 Ca 9 Sc 10 Ti 11 V 12 Cr 13 Mn 14 Fe 15 Co 16 Ni 17 Cu 18 Zn 19 Ga 20 Ge 21 As 22 Se 23 Br 24 Kr

25 Rb 26 Sr 27 Y 28 Zr 29 Nb 30 Mo 31 Tc 32 Ru 33 Rh 34 Pd 35 Ag 36 Cd 37 In 38 Sn 39 Sb 40 Te 41 I 42 Xe

43 Cs 44 Ba 45 La 46 Hf 47 Ta 48 W 49 Re 50 Os 51 Ir 52 Pt 53 Au 54 Hg 55 Tl 56 Pb 57 Bi 58 Po 59 At 60 Rn

61 Fr 62 Ra 63 Ac 64 Rf 65 Db 66 Sg 67 Bh 68 Hs 69 Mt 70 Uun 71 Uuu 72 Uub 73 Uuq

74 Ce 75 Pr 76 Nd 77 Pm 78 Sm 79 Eu 80 Gd 81 Tb 82 Dy 83 Ho 84 Er 85 Tm 86 Yb 87 Lu

88 Th 89 Pa 90 U 91 Np 92 Pu 93 Am 94 Cm 95 Bk 96 Cf 97 Es 98 Fm 99 Md 100 No 101 Lr

102 103 104 105 106 107 108 109 110 111 112 113 114 115 116 117 118

119 120

121 122 123 124 125 126 127 128 129 130 131 132 133 134 135 136 137 138

139 140 141 142 143 144 145 146 147 148 149 150 151 152 153 154 155 156

157 158 159 160 161 162 163 164 165 166 167 168 169 170 171 172 173 174

175 176 177 178 179 180 181 182 183 184 185 186 187 188 189 190 191 192

193 194 195 196 197 198 199 200 201 202 203 204 205 206 207 208 209 210

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337 338 339 340 341 342 343 344 345 346 347 348 349 350 351 352 353 354

355 356 357 358 359 360 361 362 363 364 365 366 367 368 369 370 371 372

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445 446 447 448 449 450 451 452 453 454 455 456 457 458 459 460 461 462

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625 626 627 628 629 630 631 632 633 634 635 636 637 638 639 640 641 642

643 644 645 646 647 648 649 650 651 652 653 654 655 656 657 658 659 660

661 662 663 664 665 666 667 668 669 670 671 672 673 674 675 676 677 678

679 680 681 682 683 684 685 686 687 688 689 690 691 692 693 694 695 696

697 698 699 700 701 702 703 704 705 706 707 708 709 710 711 712 713 714

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733 734 735 736 737 738 739 740 741 742 743 744 745 746 747 748 749 750

751 752 753 754 755 756 757 758 759 760 761 762 763 764 765 766 767 768

769 770 771 772 773 774 775 776 777 778 779 780 781 782 783 784 785 786

787 788 789 790 791 792 793 794 795 796 797 798 799 800 801 802 803 804

805 806 807 808 809 810 811 812 813 814 815 816 817 818 819 820 821 822

823 824 825 826 827 828 829 830 831 832 833 834 835 836 837 838 839 840

841 842 843 844 845 846 847 848 849 850 851 852 853 854 855 856 857 858

859 860 861 86

Sample Method 2:

Community analysis

- Can also detect climate change
- Relative proportion of sensitive vs. tolerant species indicates air quality
- Assessing community composition as a whole produces a robust Air Score

Oligotrophic (sensitive) species



Eutrophic (N tolerant) species



Acid rain



Sample Method 2

Community analysis

FIA “Lichen Indicator”

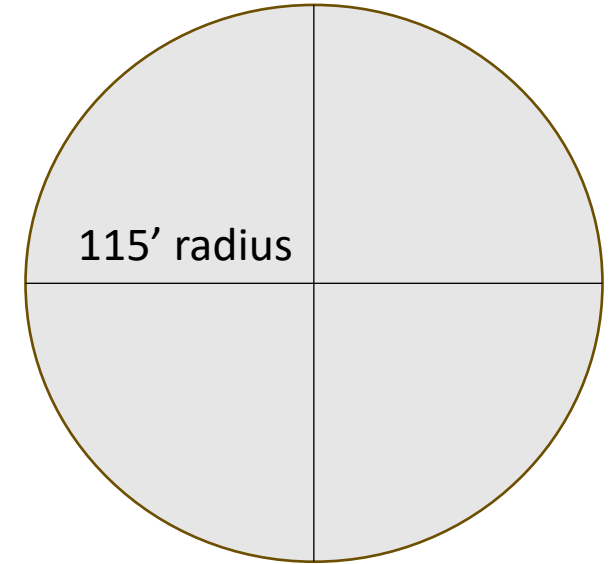
- ✓ 0.4 ha circular plots
- ✓ Time limited survey
- ✓ Epiphytic macrolichens
- ✓ Collect sample of each species
- ✓ Ocular estimates of abundance
- ✓ Quality assurance met through certification
- ✓ Revisits made every 10 years

1 = **Infrequent**

2 = **Uncommon**

3 = **Common**

4 = **Abundant**

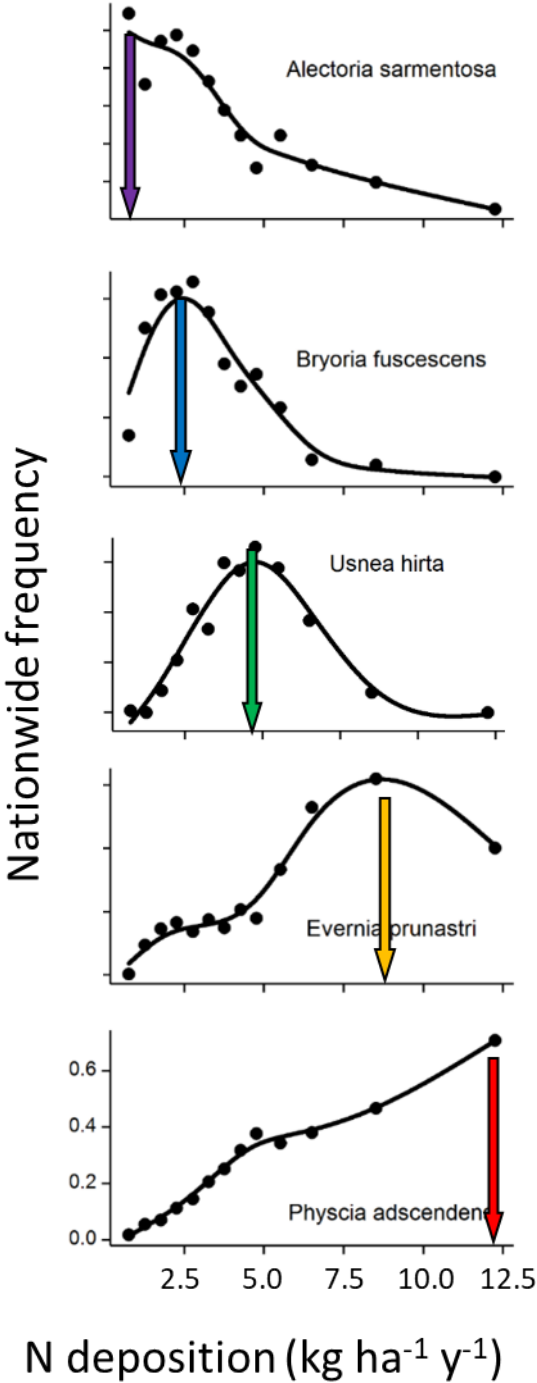


-
- ✓ Method requires some skill and training
 - ✓ An understanding of where species grow
 - ✓ Ability to see and collect the full diversity of lichen species
 - ✓ Physical fitness-endurance, backpacking
 - ✓ Navigation off
 - ✓ Tolerance for challenges of field work



Relating peak frequency of species to deposition

the deposition value at which each species reached its peak detection frequency

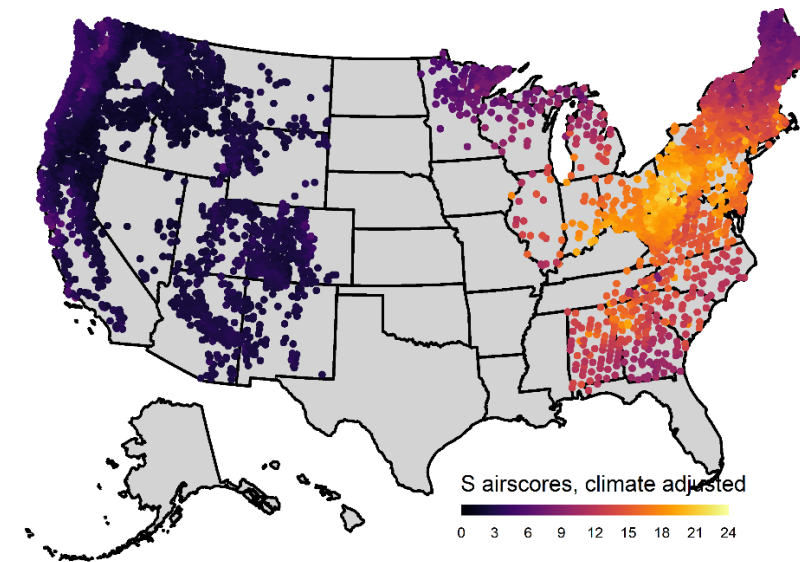
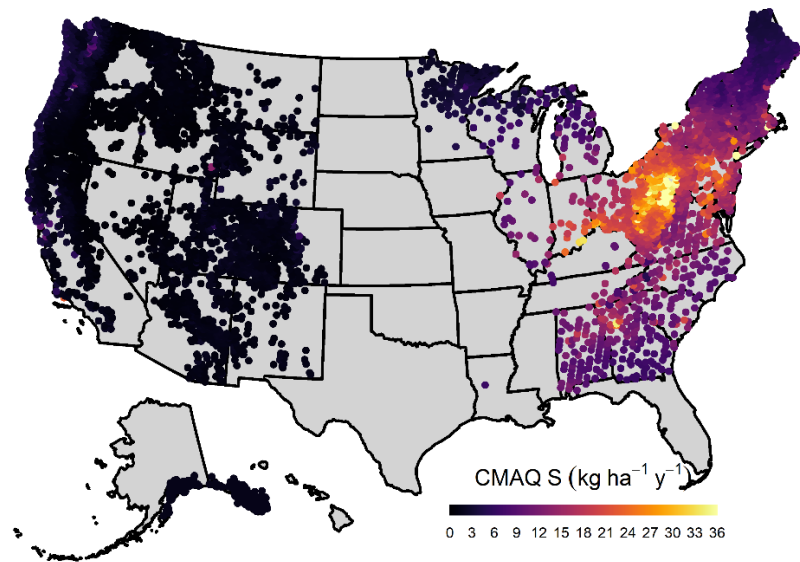
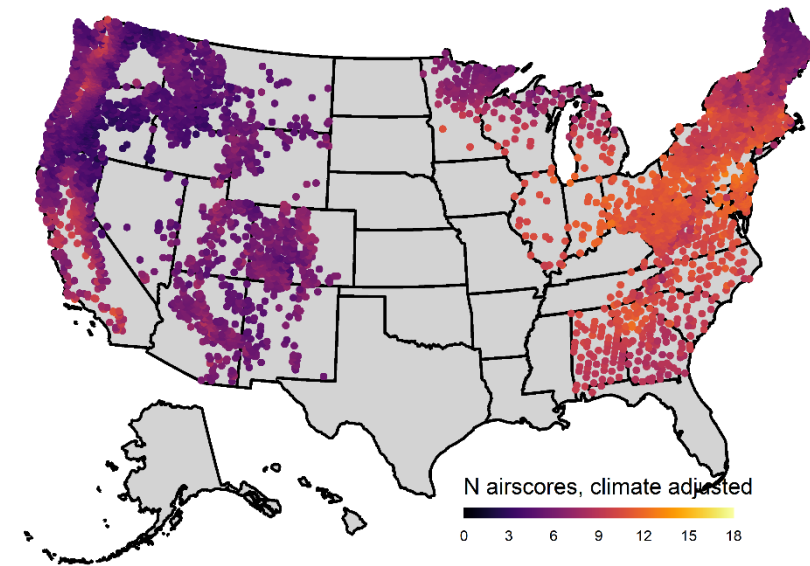
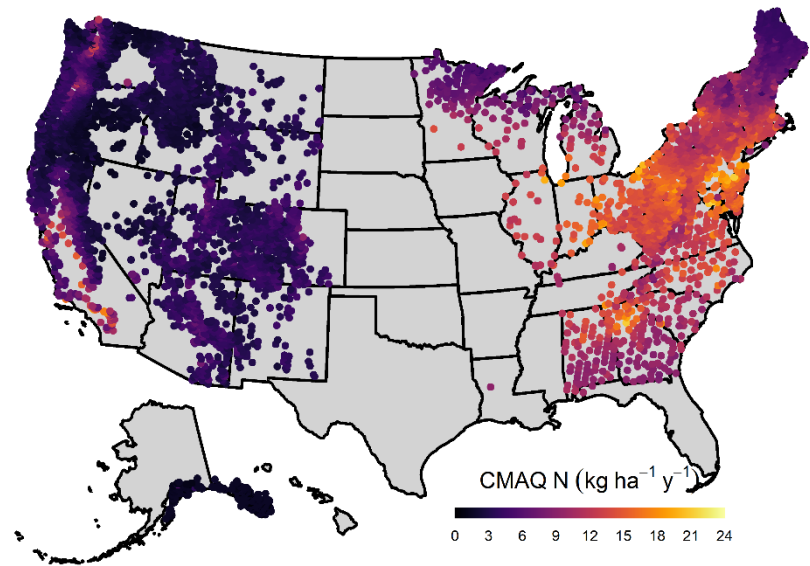


Lichen-based critical loads for deposition of nitrogen and sulfur in US forests ☆

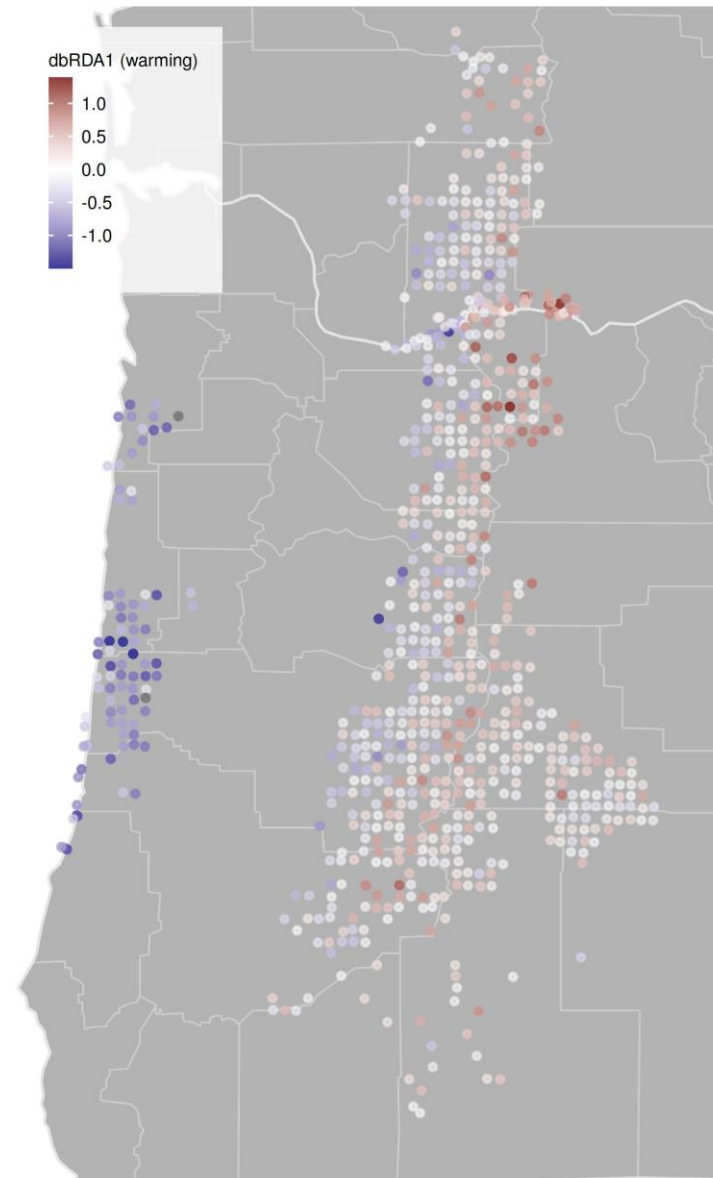
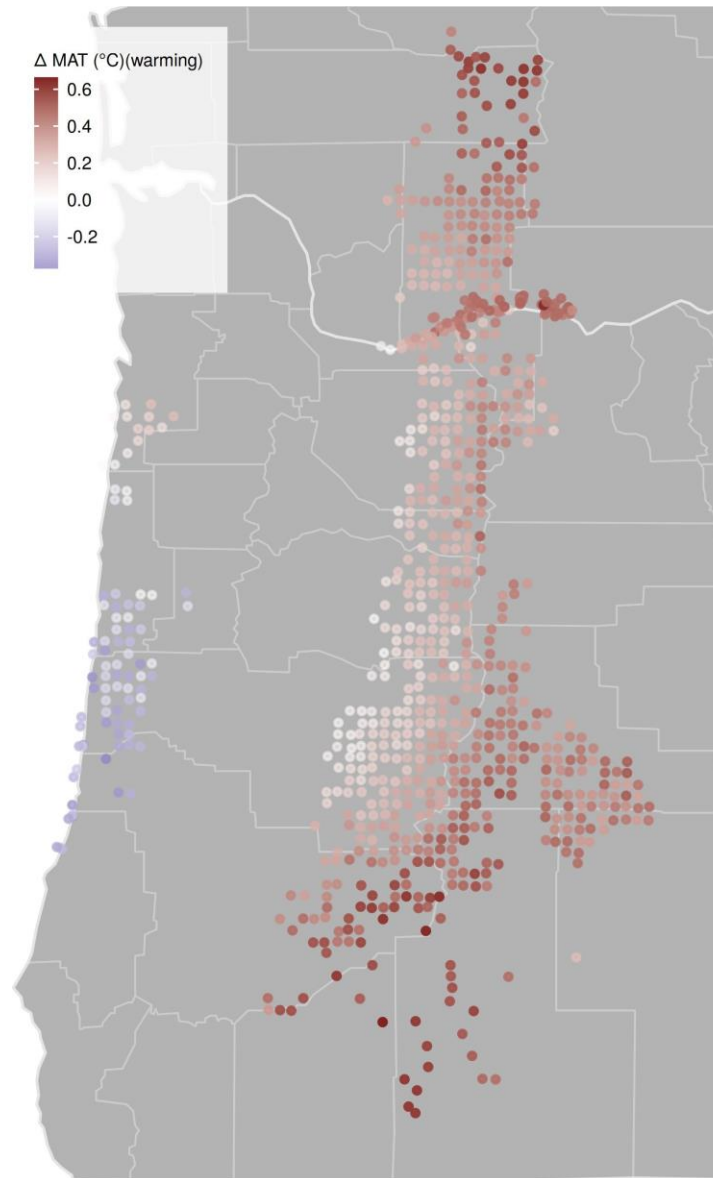
Linda H. Geiser^a, Heather Root^b, Robert J. Smith^a, Sarah E. Iovan^c, Larry St Clair^d, Karen L. Dillman^a

Mapping site scores

Lichen climate-
adjusted
'airscores' track
deposition at
monitoring sites



Climate changes mirrored by compositional shifts



Available Resources

- Many publications
- New Website is Forthcoming
- New tools to improve databasing



Lichen communities and species indicate climate thresholds in southeast and south-central Alaska, USA

Heather T. Root^{1,3}, Bruce McCune¹ and Sarah Jovan²

¹ Department of Botany and Plant Pathology, Oregon State University, 2082 Cordley Hall, Corvallis, OR, 97331, U.S.A.;



Environmental Pollution


Volume 291, 15 December 2021, 118187




Recommended articles

Loading...

Lichen-based critical loads for deposition of nitrogen and sulfur in US forests ☆

Linda H. Geiser^a, Heather Root^b, Robert J. Smith^a  , Sarah E. Jovan^c,
Larry St Clair^d, Karen L. Dillman^a

Lichen bioindicators of nitrogen and sulfur deposition in dry forests of Utah and New Mexico, USA

Heather T. Root^a  , Sarah Jovan^b, Mark Fenn^c, Michael Amacher^d, Josh Hall^e,
John D. Shaw^f

Wilderness Stewardship

← → ↻ lichenlab.shinyapps.io/shinyapp/

Lichen Data Query and Mapping Tool

Data:

☐ Elemental

☒ Lichen

☐ Plot

National Forest

Wilderness

Select the Round Years

☒ Show Data Table

Wilderness Stewardship Lichen Report:
<https://ecol.shinyapps.io/wildstew/>

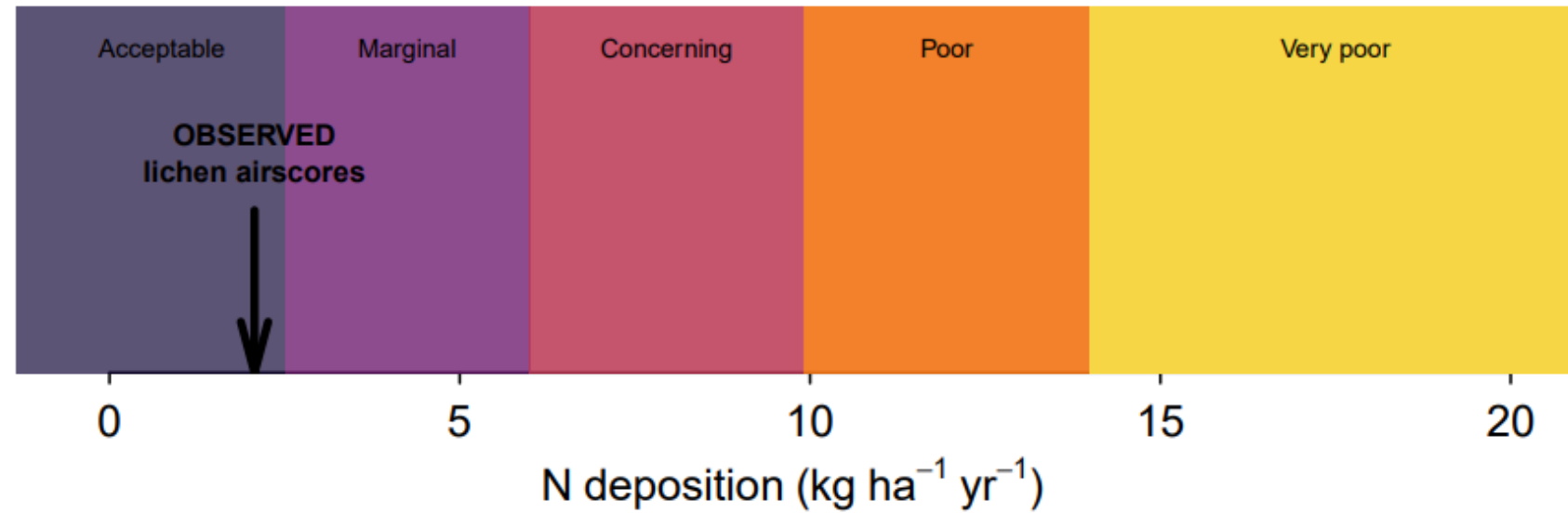
Wilderness Air Quality Values for Mount Hood Wilderness

Report prepared: 22 February 2021

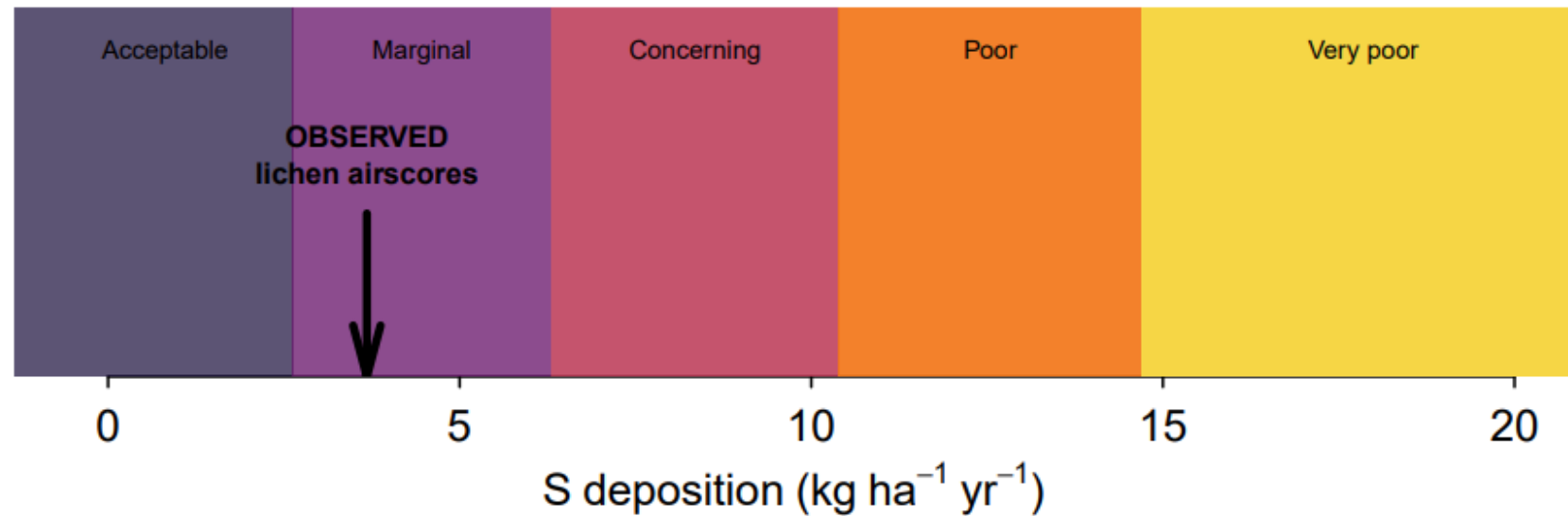
Contents

| | |
|---|----------|
| 1 Overview | 2 |
| 1.1 Motivation | 2 |
| 1.2 Sensitive receptors | 2 |
| 1.3 Sensitive receptor indicators | 2 |
| 1.3.1 Indicator: Air scores | 2 |
| 1.3.2 Indicator: Critical loads exceedances | 2 |
| 1.4 Conservation status | 2 |
| 1.5 Critical loads we used | 3 |
| 1.6 Why monitor lichens? Ecological functions | 3 |
| 2 Summary for Mount Hood Wilderness | 4 |
| 2.1 Nitrogen snapshot | 4 |
| 2.2 Sulfur snapshot | 4 |
| 2.3 Significant trends | 5 |
| 2.4 Area map | 6 |
| 3 Site scores | 7 |
| 3.1 Nitrogen | 7 |
| 3.1.1 N: mean deposition | 7 |
| 3.1.2 N: percentiles | 7 |
| 3.2 Sulfur | 7 |
| 3.2.1 S: mean deposition | 7 |
| 3.2.2 S: percentiles | 7 |
| 4 Critical loads exceedances | 8 |
| 4.1 Nitrogen | 8 |
| 4.1.1 N exceedance: raw lichen airtcores | 8 |
| 4.1.2 N exceedance: climate-adjusted lichen airtcores | 8 |
| 4.2 Sulfur | 8 |
| 4.2.1 S exceedance: raw lichen airtcores | 8 |
| 4.2.2 S exceedance: climate-adjusted lichen airtcores | 8 |
| 5 Lichen species observed | 9 |
| 5.1 Sampling completeness | 9 |
| 5.2 Rare and pollution-sensitive species | 9 |
| 5.3 Species list | 9 |

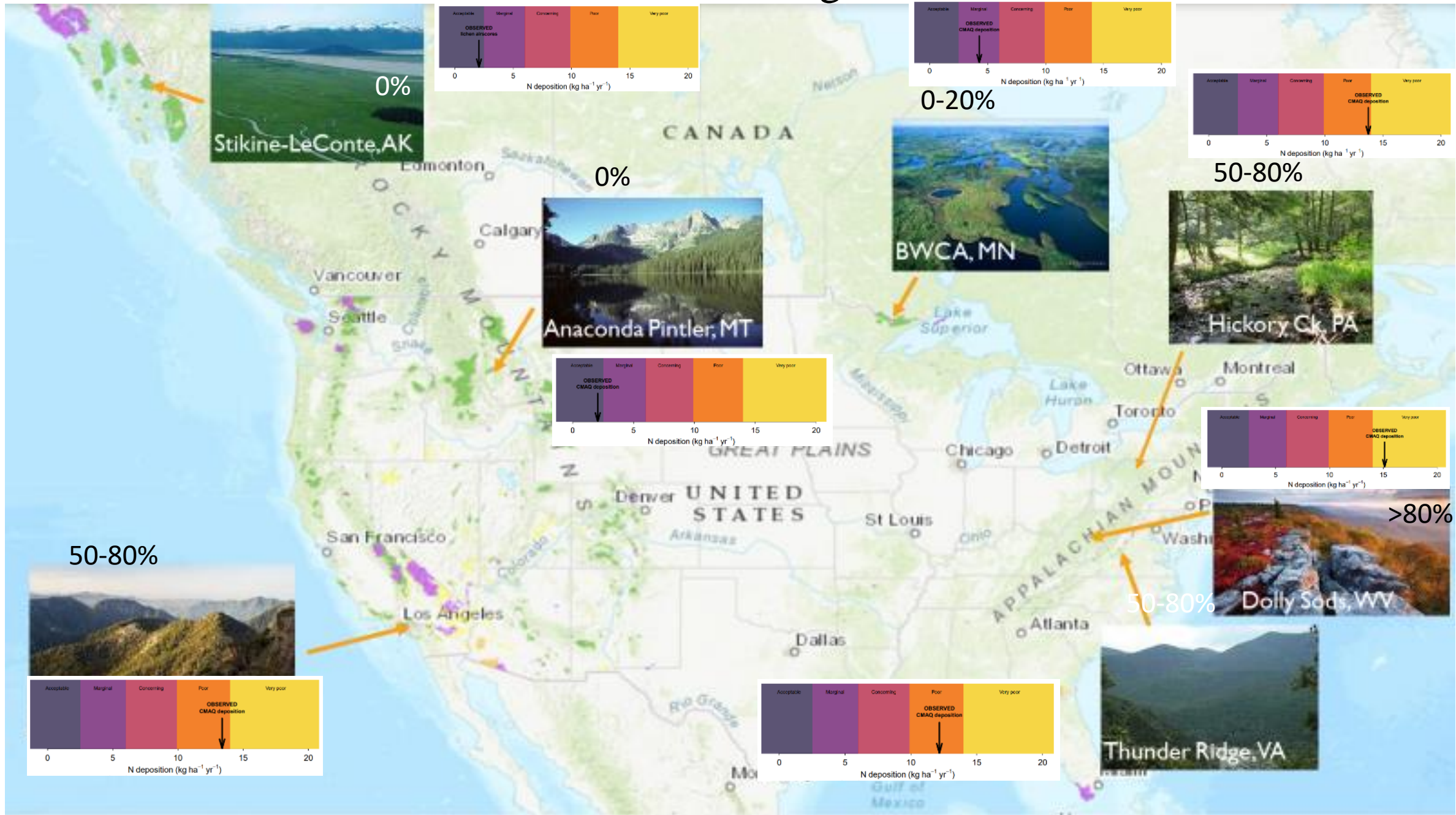
2.1 Nitrogen snapshot



2.2 Sulfur snapshot



Risk lichen richness decline with increasing



Challenges

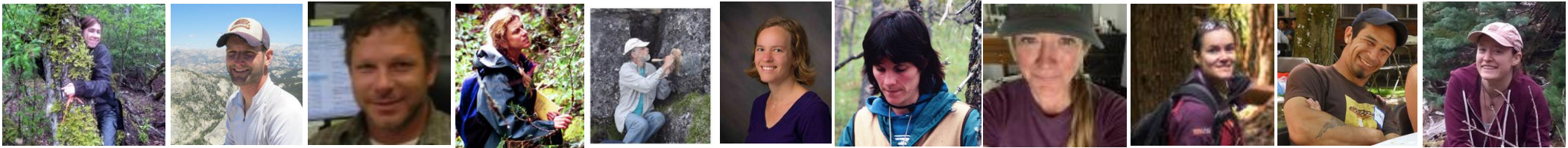


- Budget Modernization
- Increased catastrophic fire
- Limited funding
- Data and Lab can be slow



Benefits

- Lichens don't lie
- Many tools have been developed for analyzing Forest Health
- Proven repeatable protocols
- Baseline and trends data going back 33 years
- Much less expensive for making initial detections



*Thank you to Linda Geiser, Bruce McCune, Sarah Jovan, Karen Dillman, Doug Glavich, Heather Root, Rob Smith, Rick Graw **and many, many more** people who have been a part of this program's history, especially all the Forest Service staff, wilderness program managers, partners, volunteers, and contractors that have contributed over the years!*