PROGRESS IN NATIONAL SCALE LICHEN CRITICAL LOADS

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National Atmospheric Deposition Program Fall 2016 Meeting

Santa Fe, NM

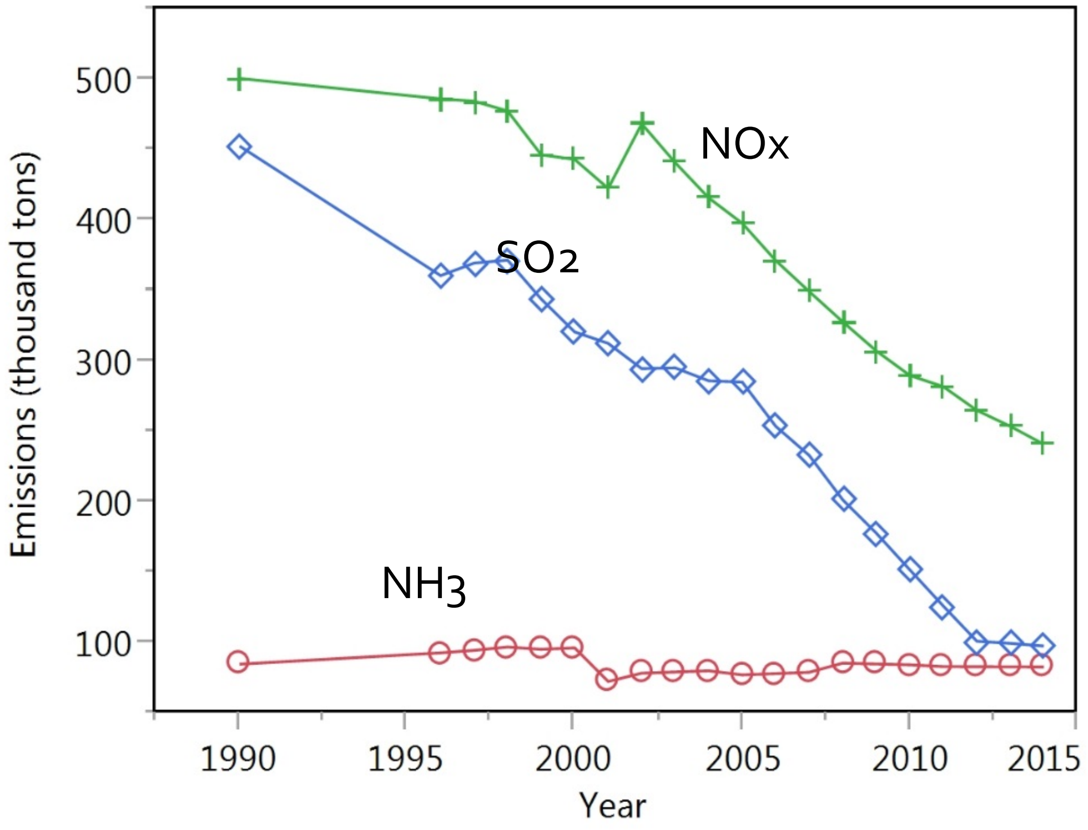
US Air Pollution: Some good news

EPA National **Emissions** Inventory 1990-2014 trends:

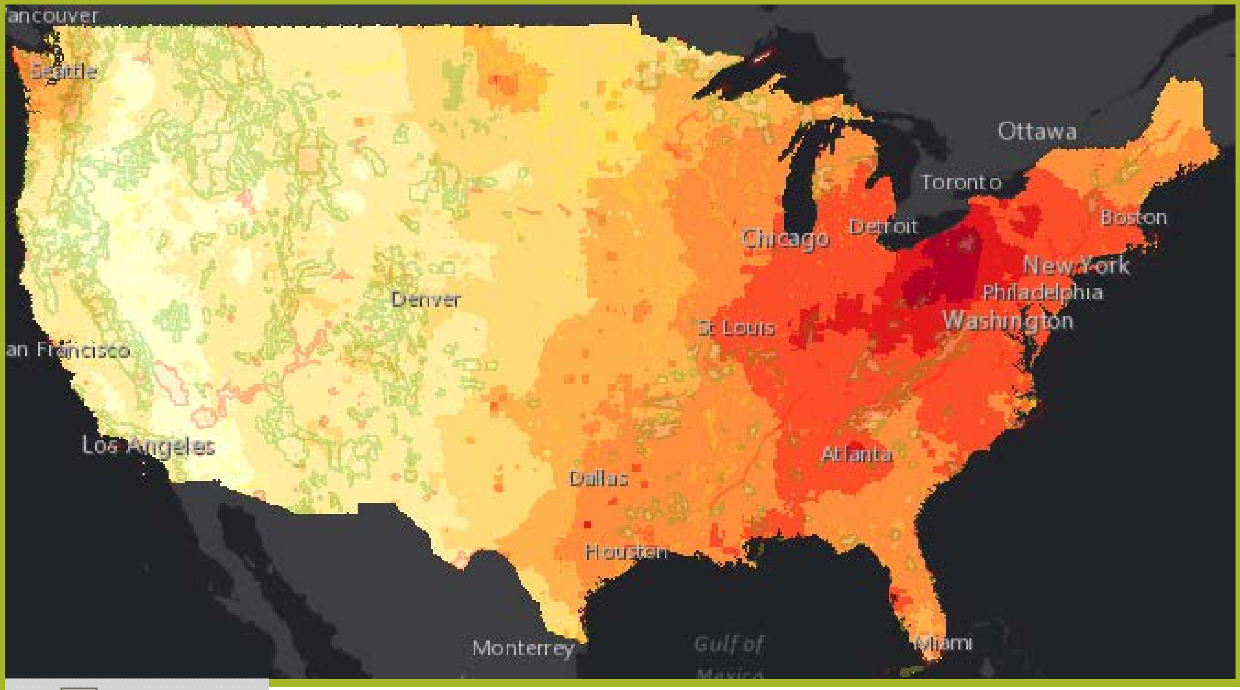
SO_2↓

NO_x↓

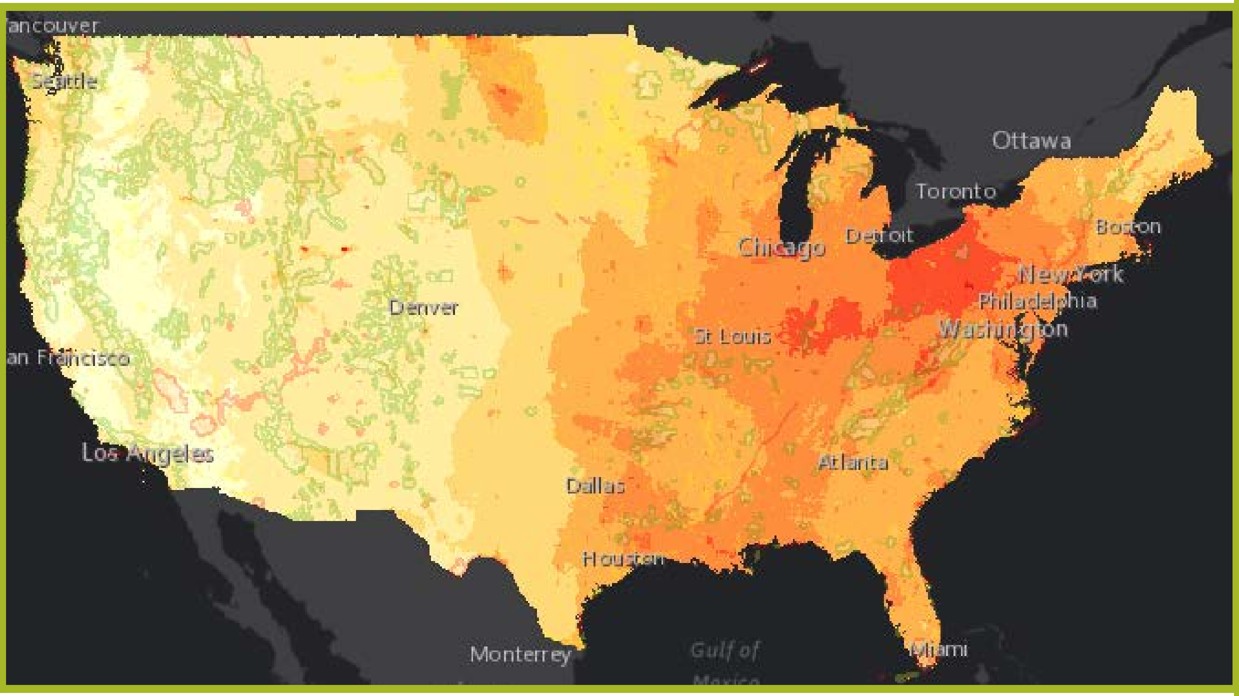
NH_3 ↔?



US Air Quality is Improving: S deposition



2000 TDEP S deposition (kg/ha)



2013 TDEP S deposition (kg/ha)

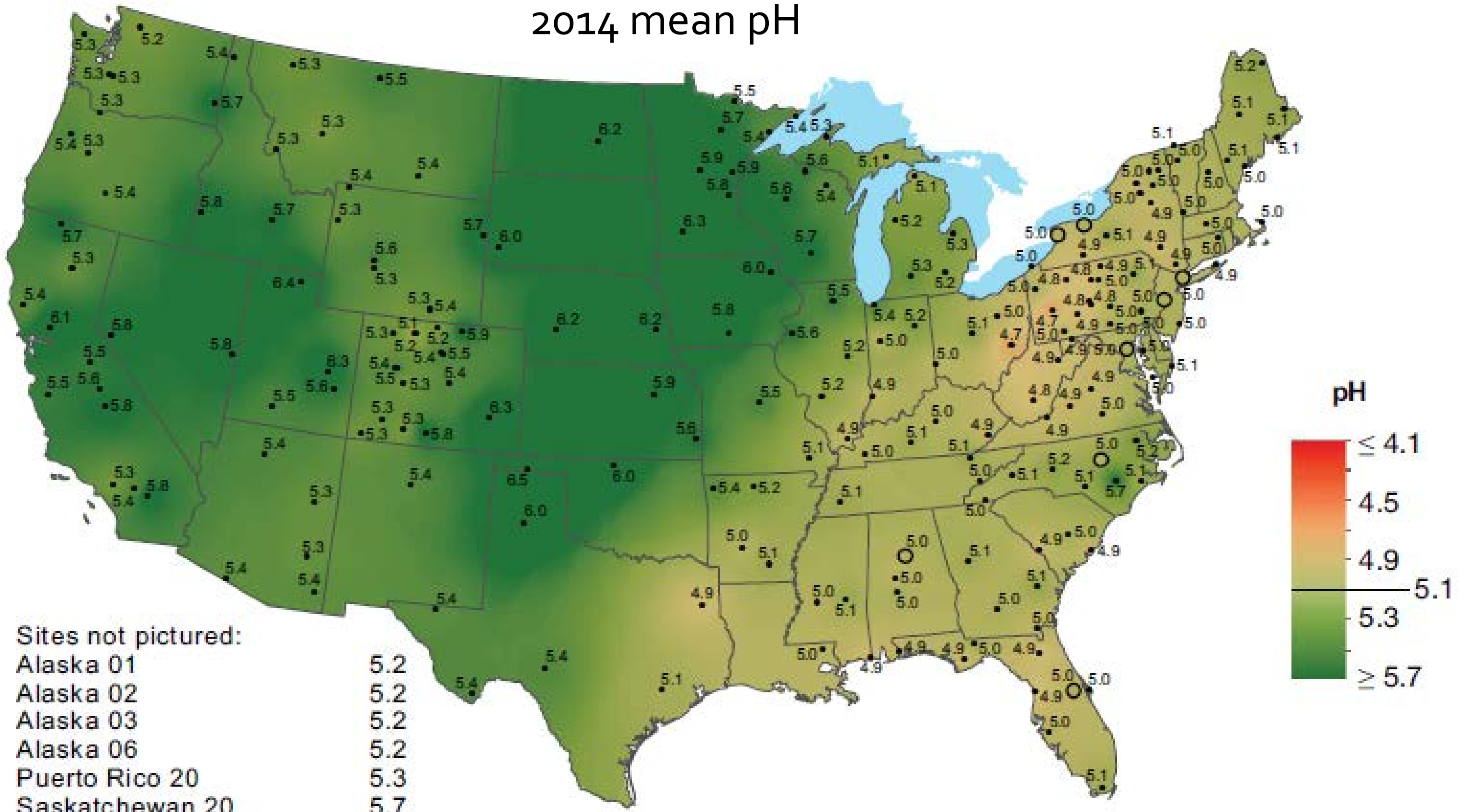
- 0 - 0.50
- 0.51 - 1.50
- 1.51 - 3.00
- 3.01 - 5.00
- 5.01 - 10.00
- 10.01 - 20.00
- 20.01 - 30.00
- > 30.00

Source: EPA Critical Loads Mapper Beta version: CMAQ Kg/ha with federal land boundaries

A similar pattern for acidified precipitation

- In the east an increasing number of sites now averaging >5.1) yet acidified precipitation still blankets the region
- From 2008-2010 nearly all sites received some acid deposition
- 2016 studies by Cleavitt et al and Knoepp et al discuss lag time in ecological recovery. Concerns that full recovery is not possible but continued improvement essential for optimizing recovery.

2014 mean pH

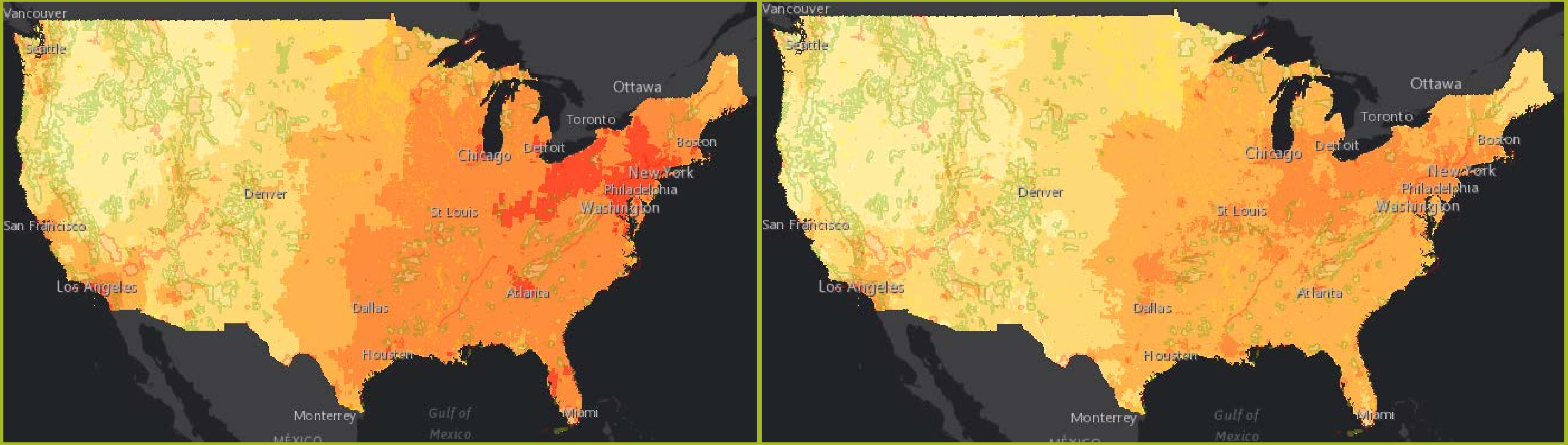


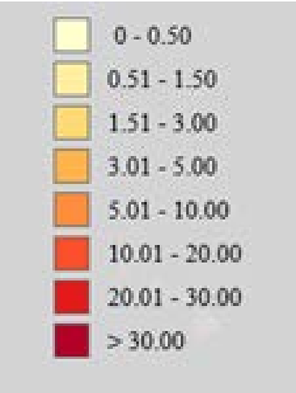
Sites not pictured:

Alaska 01	5.2
Alaska 02	5.2
Alaska 03	5.2
Alaska 06	5.2
Puerto Rico 20	5.3
Saskatchewan 20	5.7
Saskatchewan 21	5.5
British Columbia 22	4.6
British Columbia 23	5.3
British Columbia 24	5.3

Map source: NADP 2014 Annual Summary
See also Lehmann & Gay 2011. PPC13:278

US Air Quality is Improving: $N_{oxidized}$



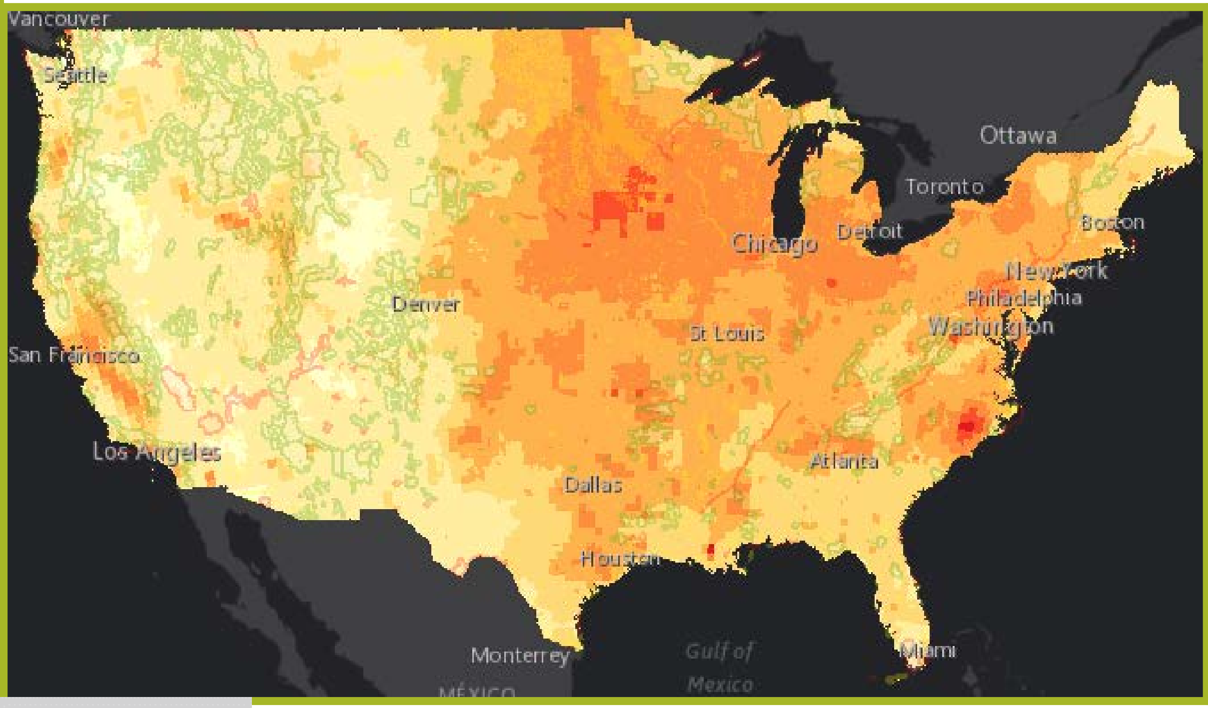


2000 TDEP Ox N Deposition kg/ha

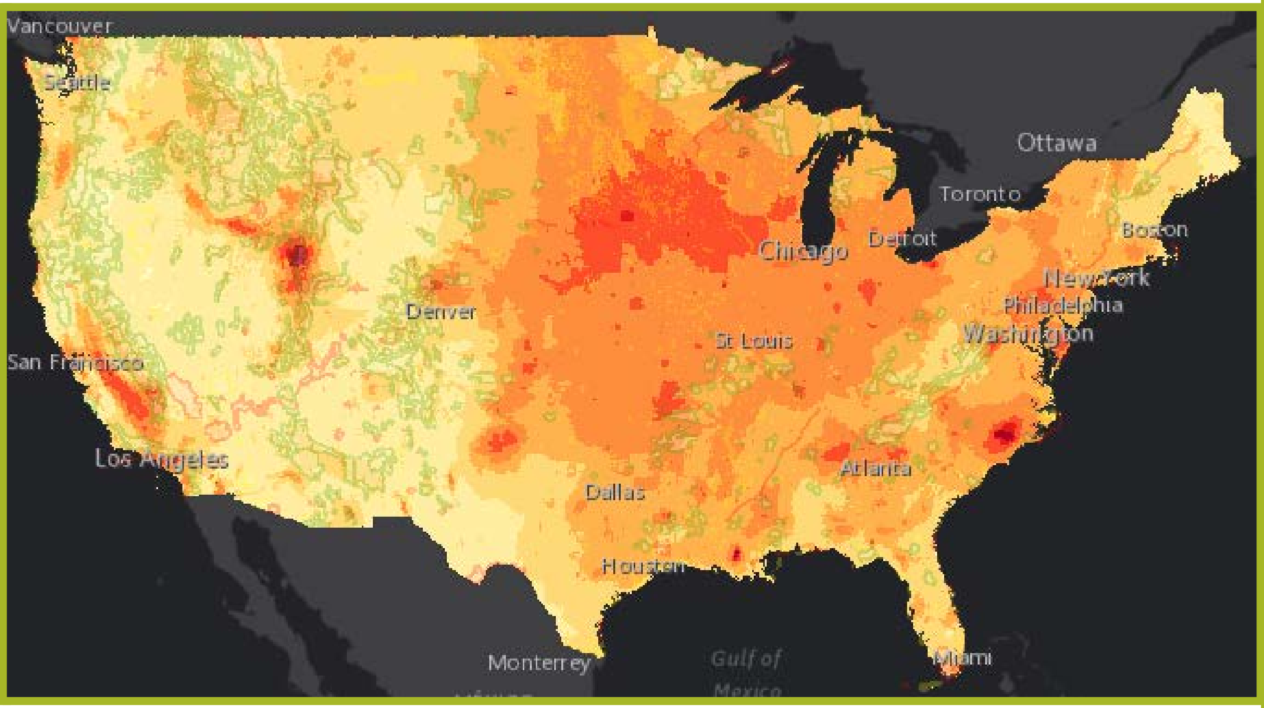
2013 TDEP Ox N Deposition kg/ha

Source: EPA Critical Loads Mapper Beta version: CMAQ Kg/ha with federal land boundaries

But deposition of reduced N is increasing



2000 TDEP Reduced N (kg/ha)



2013 TDEP Reduced N (kg/ha)

- 0 - 0.50
- 0.51 - 1.50
- 1.51 - 3.00
- 3.01 - 5.00
- 5.01 - 10.00
- 10.01 - 20.00
- 20.01 - 30.00
- > 30.00

Summary:
Localized nutrient n effects are a concern in the west
Blanket deposition of acidic and nutrient N still a concern in the east

Source: EPA Critical Loads Mapper Beta version: CMAQ Kg/ha with federal land boundaries

NADP: NH_4+ now dominates wet N deposition

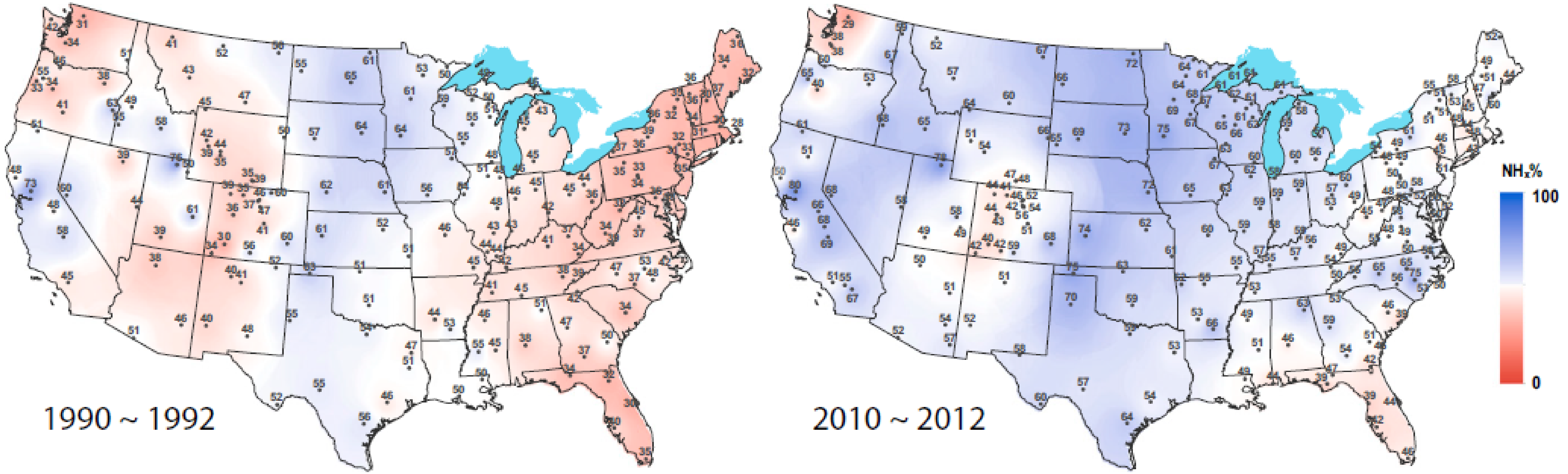
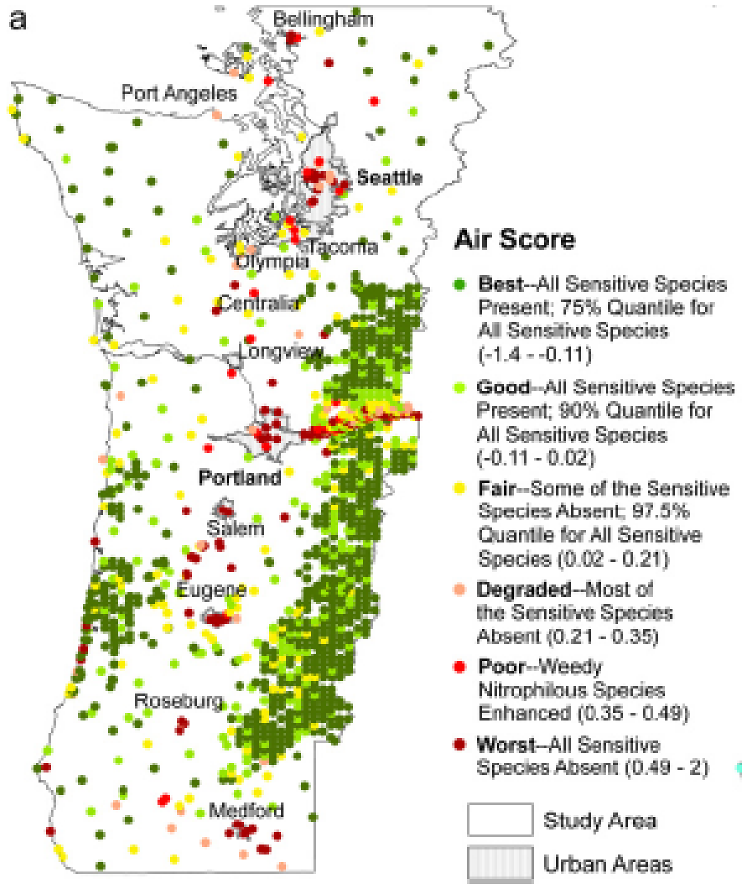


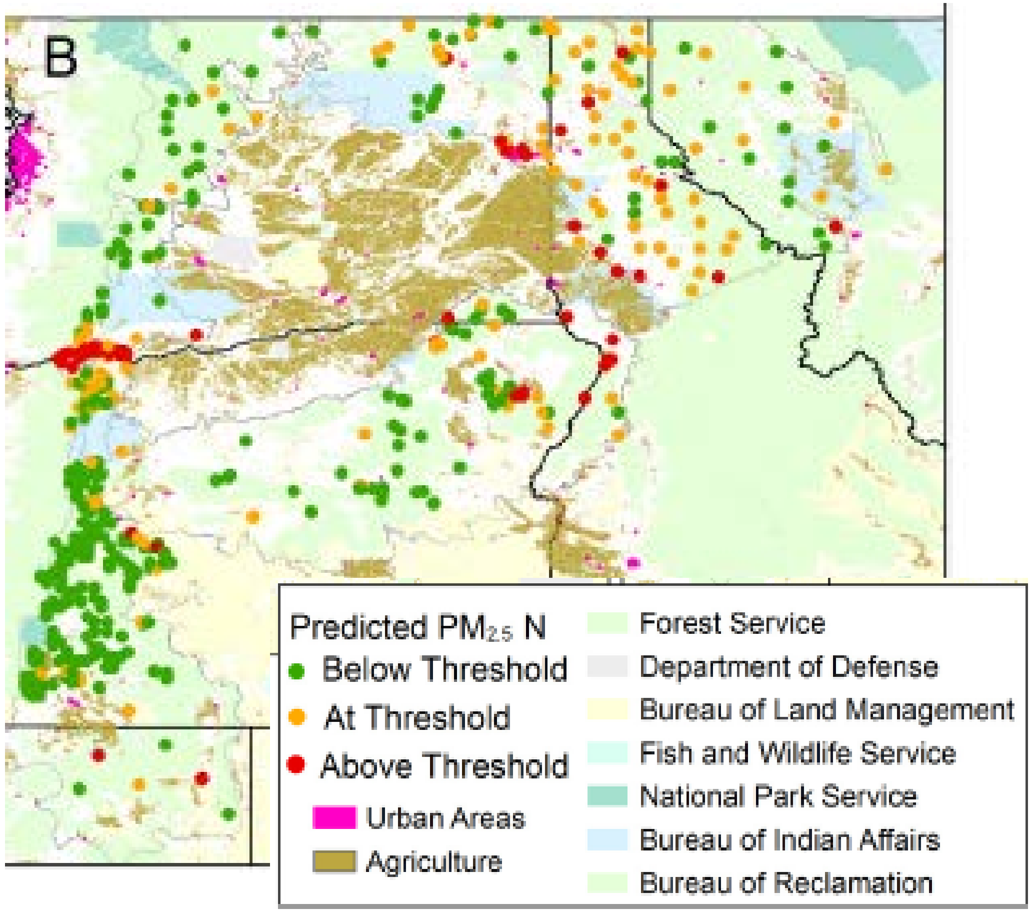
Fig. 1. Comparisons of the 3-y average NH_4^+ percentage of wet inorganic nitrogen deposition across the United States in 1990–1992 (*Left*) and 2010–2012 (*Right*). To help visualize spatial patterns, isopleths were produced by interpolating NH_4^+ mole percentages at individual monitoring sites using a cubic inverse-distance weighting of sites within 500 km of each observation station. The black dots on the map represent locations of sites with 3-y data available for each time period. The NH_4^+ percentage on a molar basis [(NH_4^+%) = (NH_4^+)/(NO_3^- + NH_4^+) × 100%] is noted at each site.

Source: Li et al. 2016. PNAS 201525736.

Lichen community composition indicates air quality

Can we quantify the relationship with N and S deposition and select CLs?





Ecosystem Services help explain the 'so what' of loss of air pollution ecosystem components

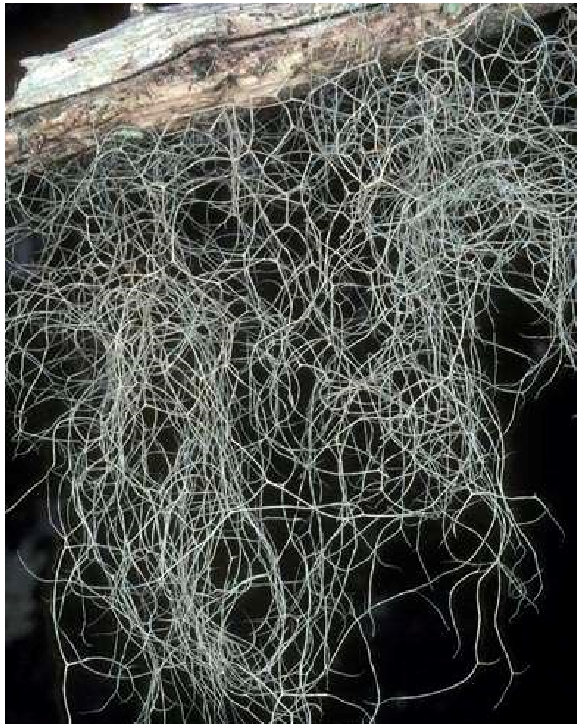
- Our new audiences need to understand the So What of Critical Loads—why is ecosystem health important, how does air pollution affect it—and particularly why we should care about some of the less well known taxa groups. For this reason we are also starting to talk about (and the President has ordered us to integrate into our work) the ecosystem services connected with CLs.

Today's Objectives: Understanding lichen CLs for acidifying and fertilizing air pollutants

- What they are and how they were calculated
- Why lichen CLs provide broad protections to forested ecosystems
- Why lichens in themselves are of value to people through their ecological roles, ecosystem services and direct human uses

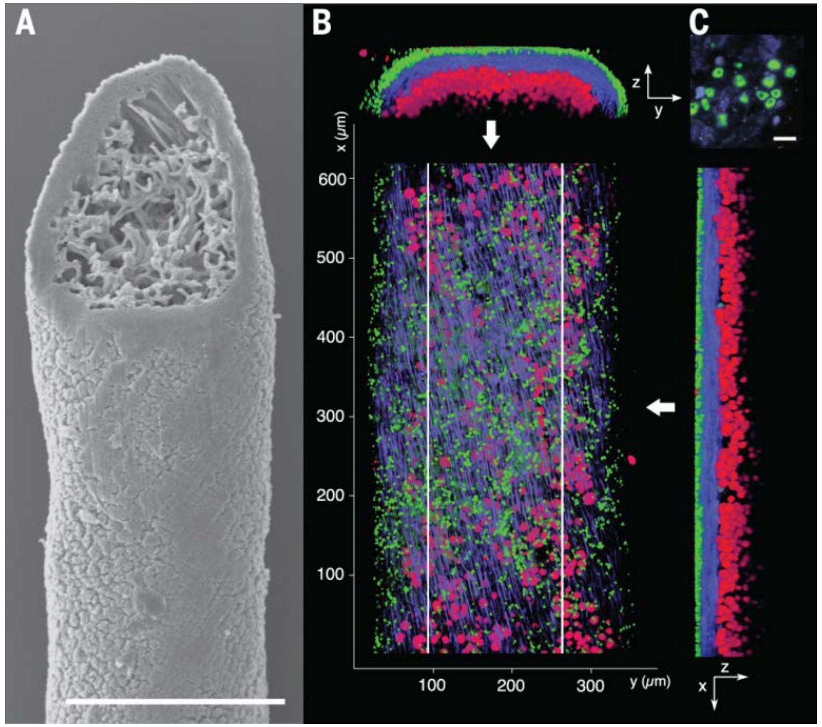
Lichens are multi-partite organisms

Consisting of fungi, algae or cyanobacteria.



Bryoria pikei, horsehair lichen whole thallus

cross-section, light microscope



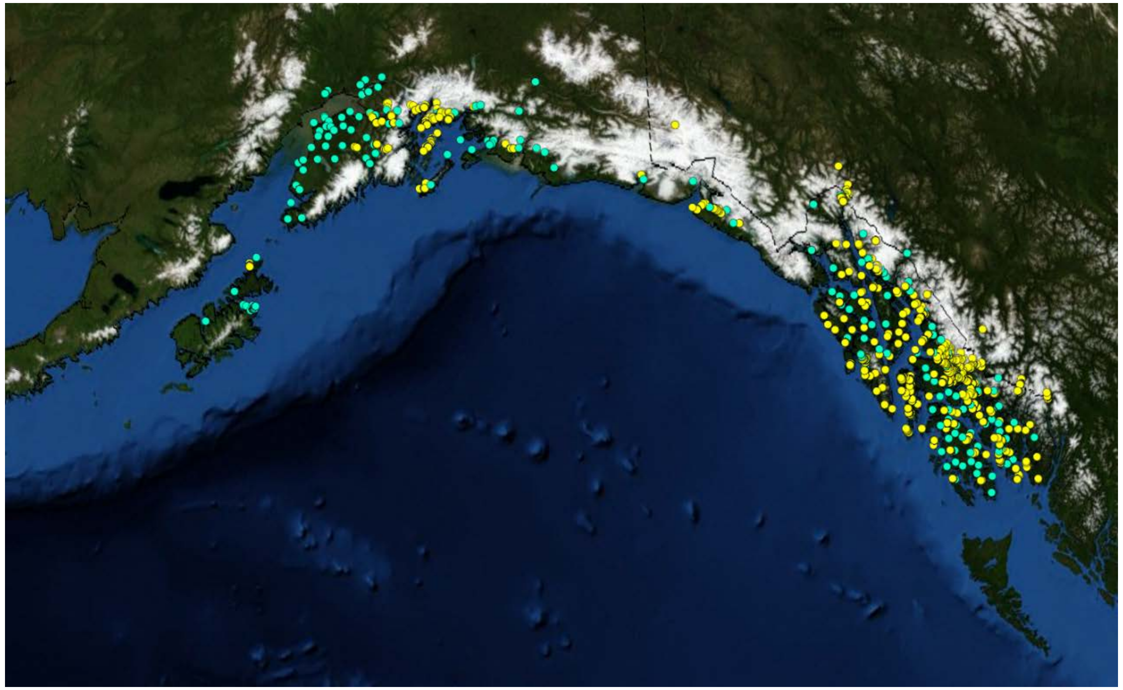
SEM

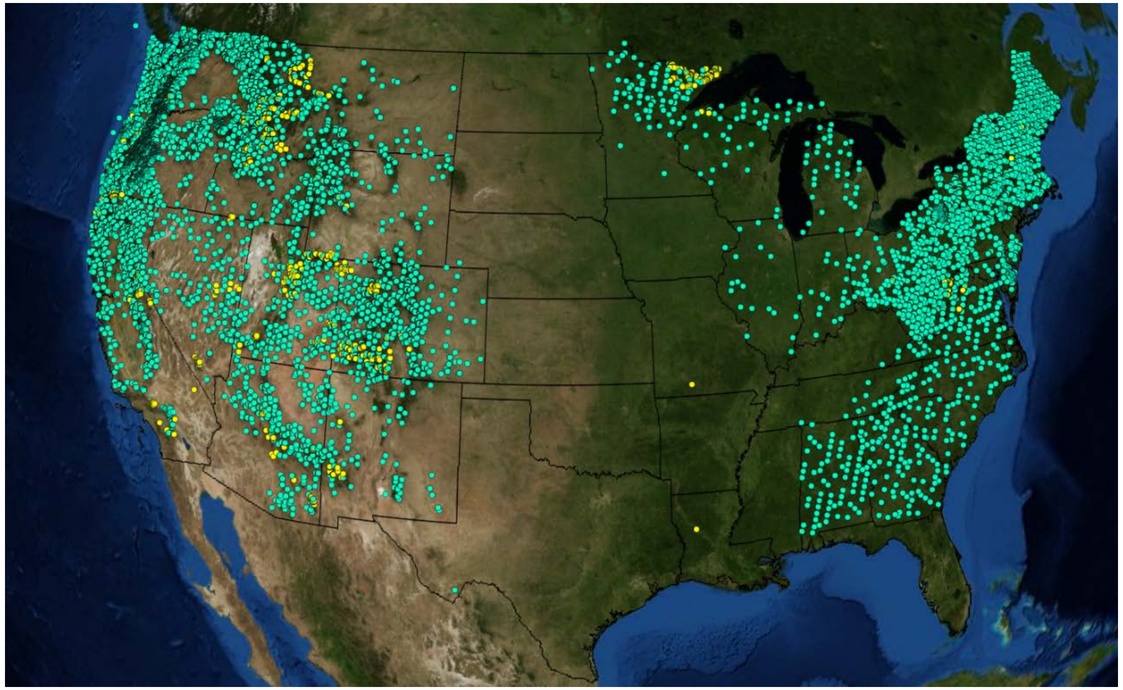
cyphobasidiales yeasts (green),
lecanoromycete (blue),
algal chlorophyll A (red)

Spribille *et al.*, *Science* 10.1126/science.aaf8287 (2016).

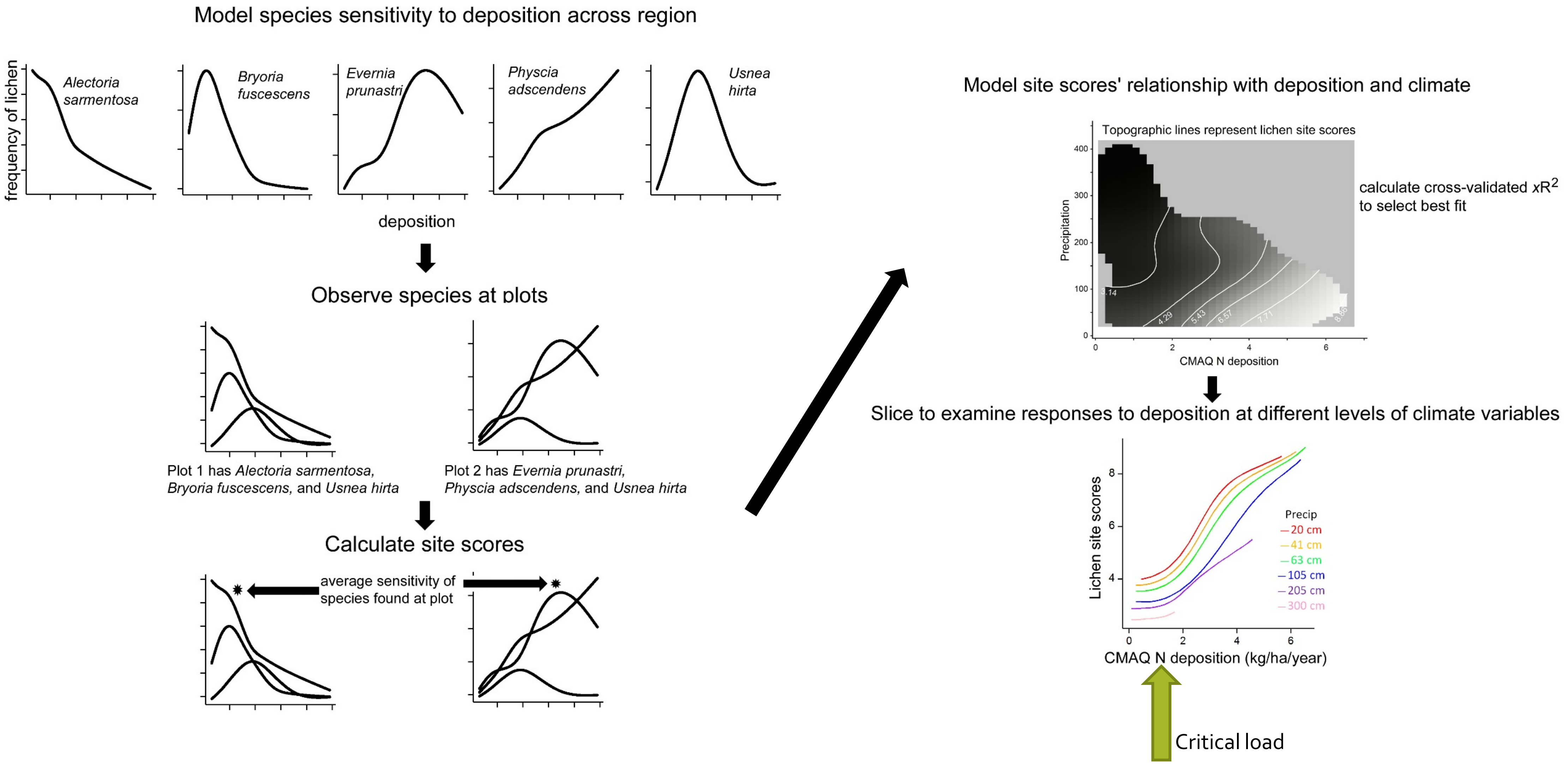
The US Forest Service has sponsored thousands of lichen surveys

- Largely following the Forest Inventory & Analysis/Forest Health Monitoring lichen communities protocol
- Purpose: track status and trends in air quality and climate

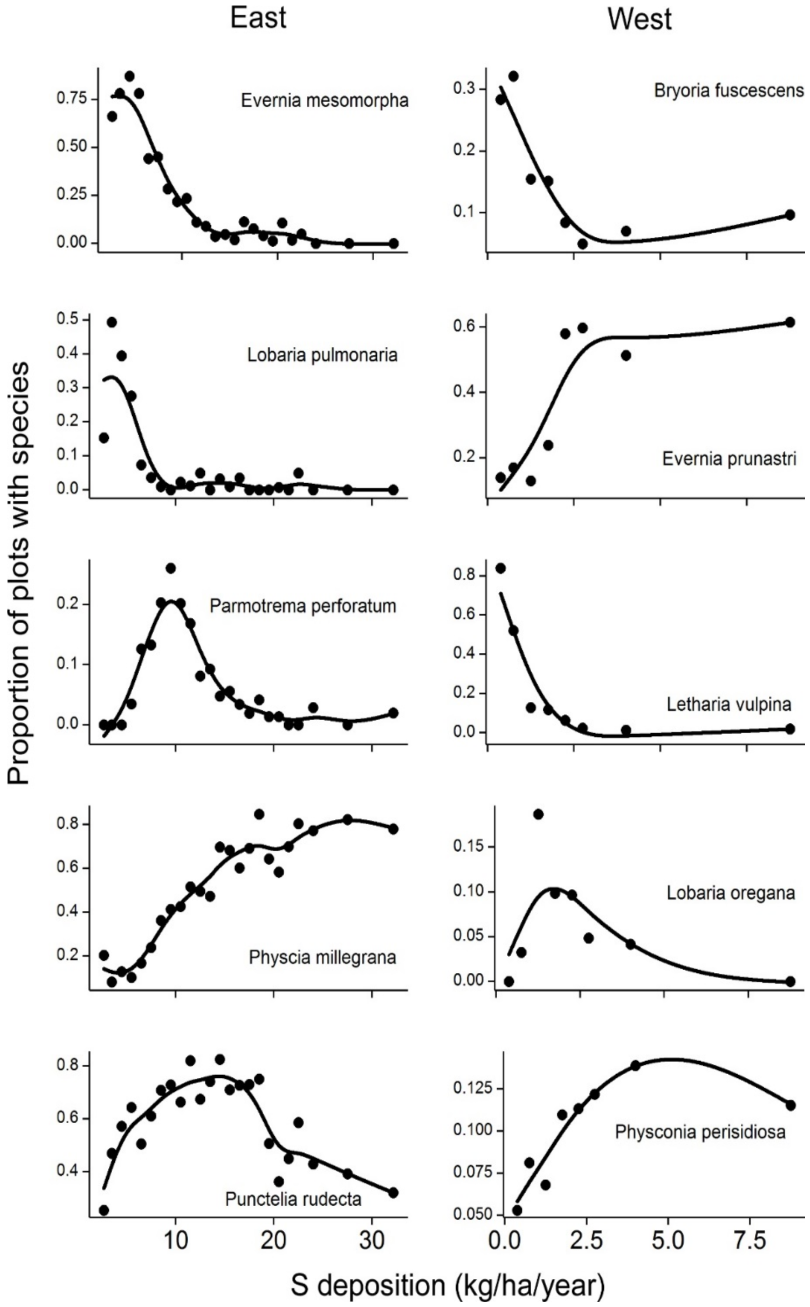


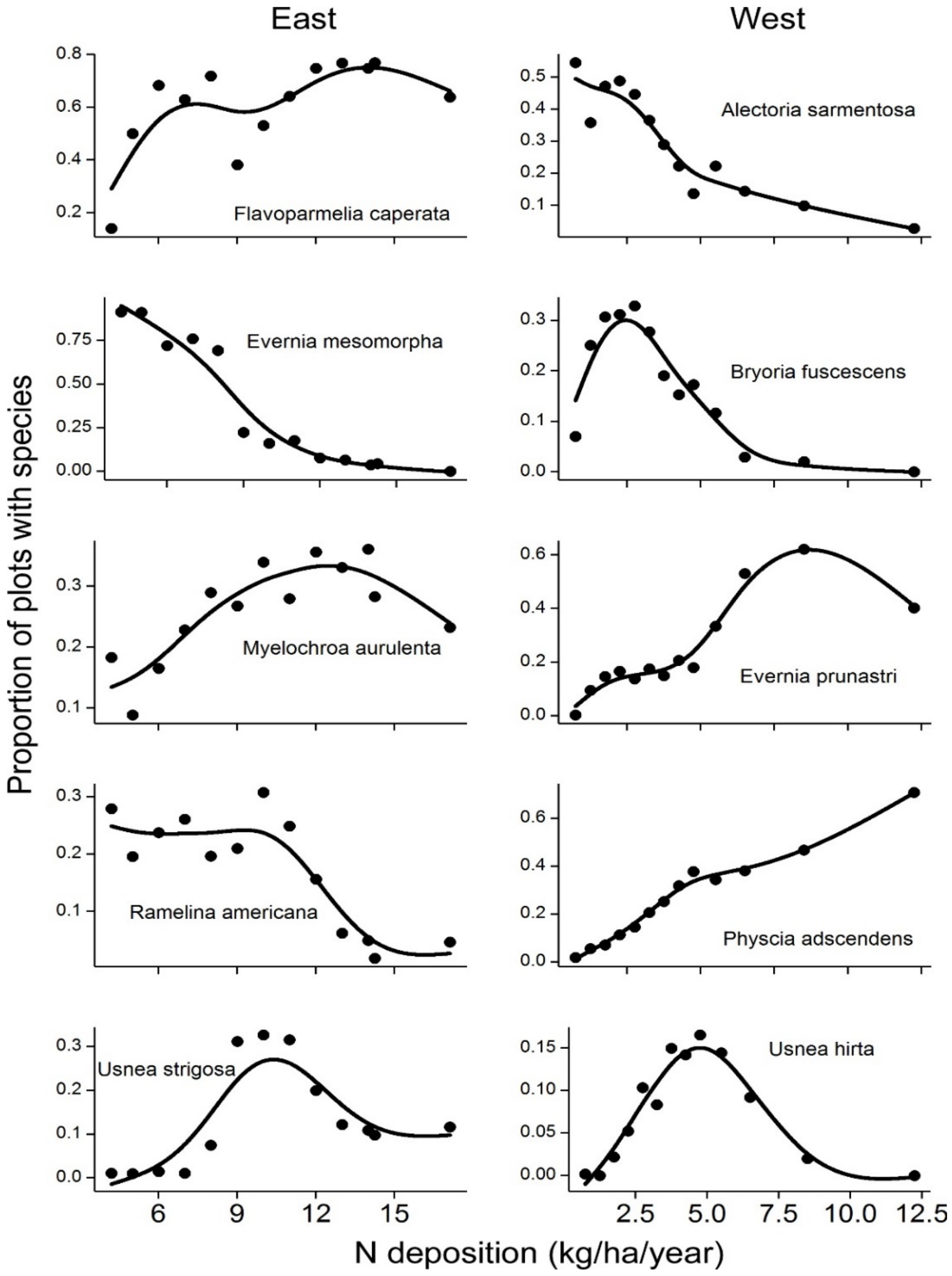


Calculating lichen critical loads: Overview



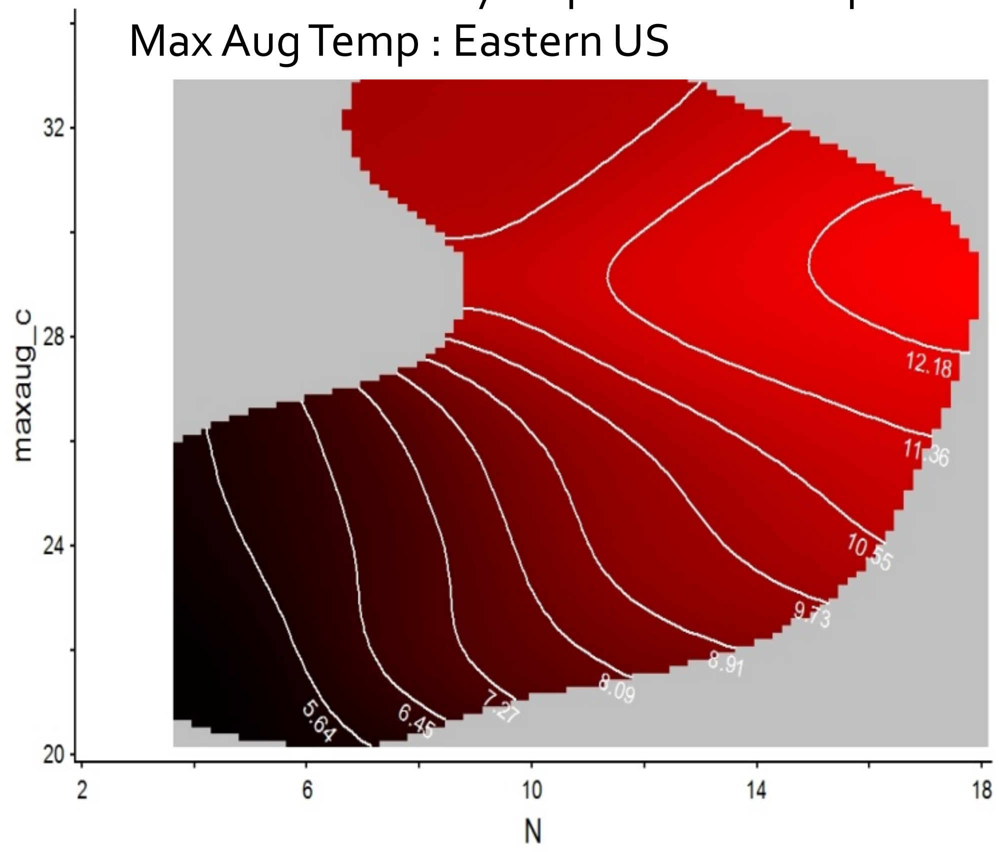
Species relationships to S and N deposition





Pollution and climate drive community composition at national scales

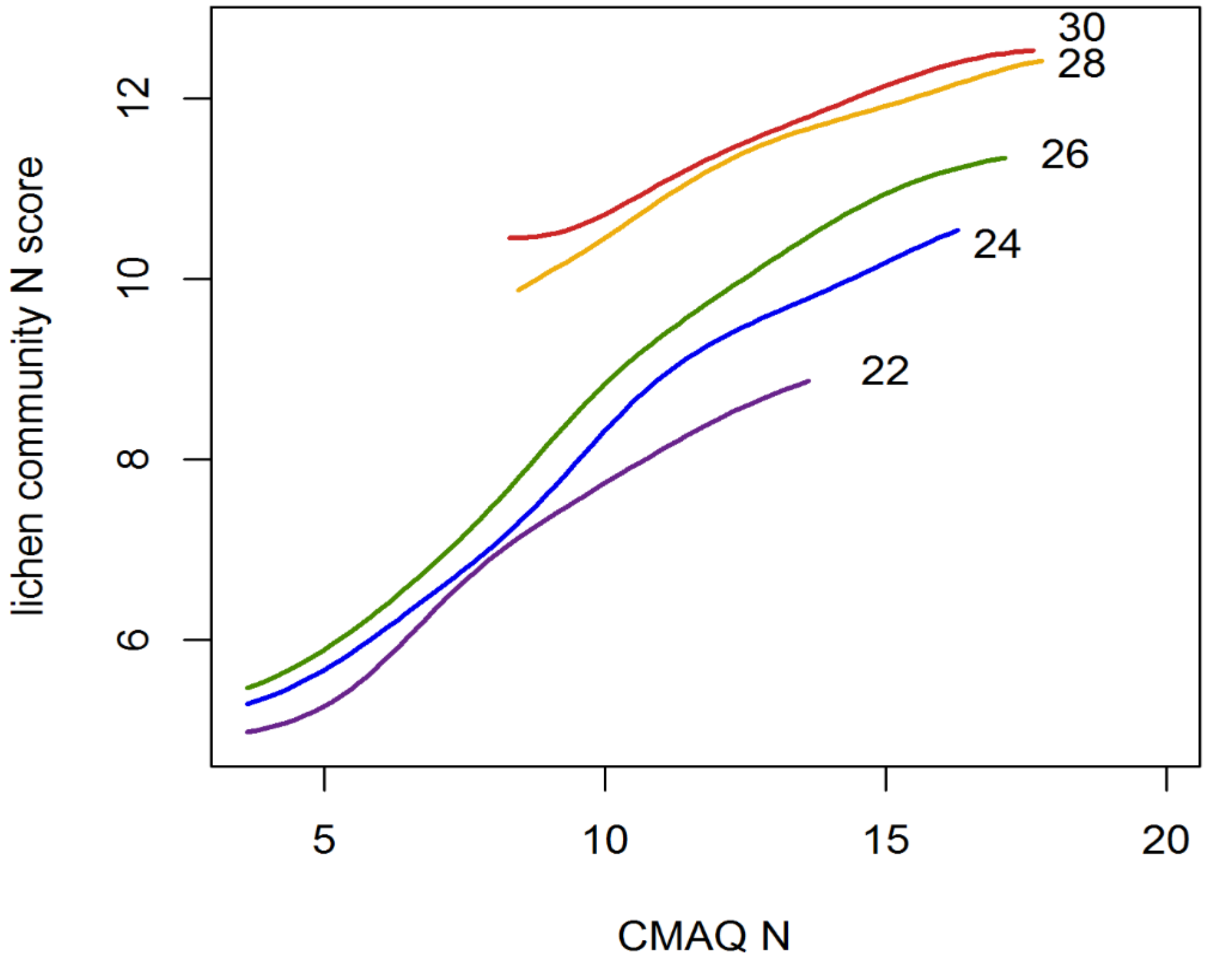
Lichen community response to N Dep and Max Aug Temp : Eastern US



- Lichen community N score = mean dep @peak frequency
- 1411 plots with abundance-weighted N scores
- 12 potential predictors: coast_km, maxaug_c, mindec_c, rh_ann, continen, precip_cam, raindays, pct_hwd, CMAQ S, CMAQ N, ecoregion (categorical)
- RANDOMIZATION TEST: xR2 = 0.7836= Fit to REAL DATA
- 0.0099= p = proportion of randomized runs with fit > or = observed fit

Predictor	Sensitivity
Nitrogen (CMAQ total N)	**0.4324**
Max mean Aug temp ° C	**0.3101**
Percent basal area in hardwoods	**0.0672**

Community models: Eastern US N Deposition



Lichen community N score = mean dep @peak frequency

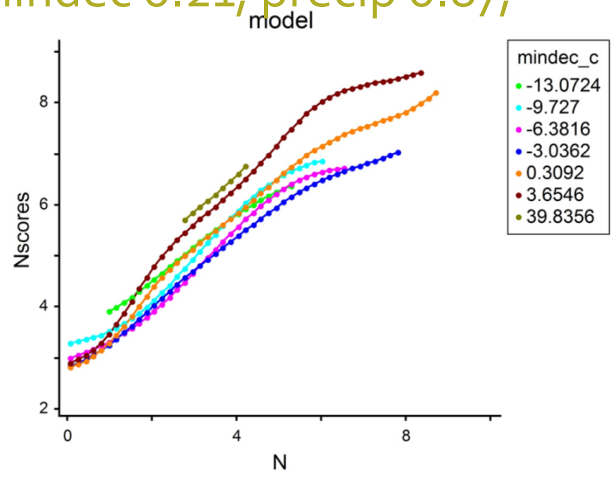
Low score: oligotrophs dominate
High score: eutrophs dominate

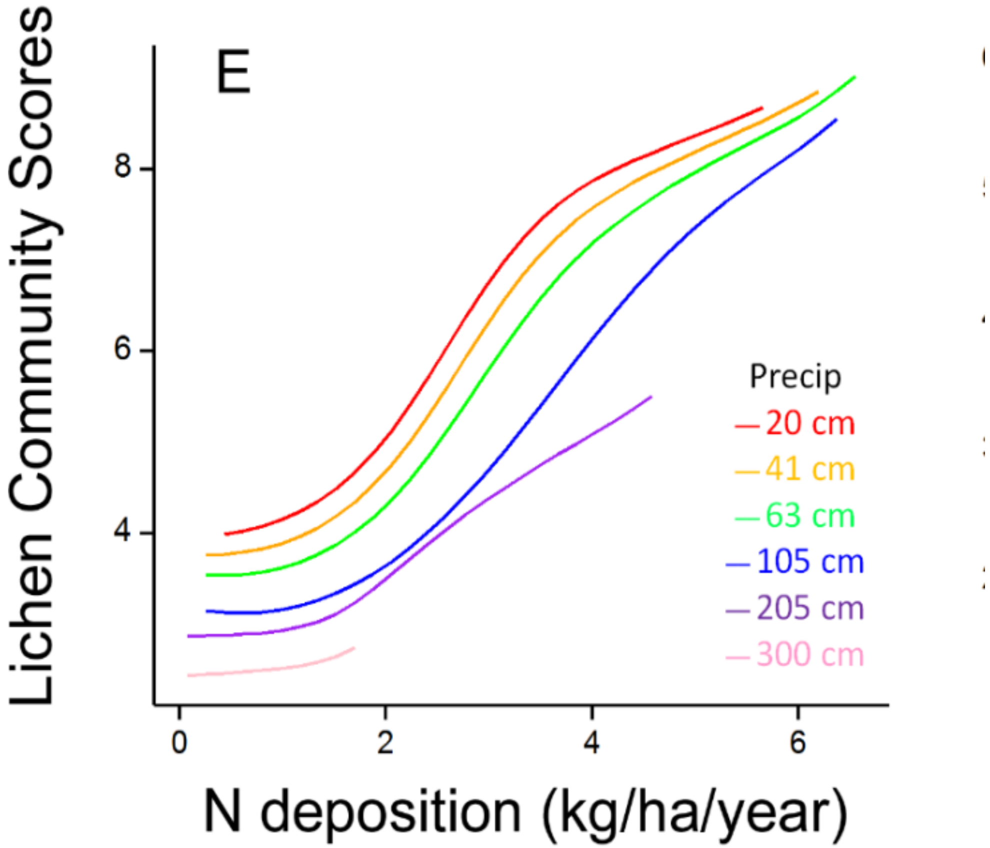
Lichen community scores increase with CMAQ N and August maximum temperatures °C (numbers)

Community response models: Western US N Deposition

Lichen community N score = mean dep @peak frequency of spp detected

3806 plots, 9 predictors,
xR2 =0.60 , mindec 0.21, precip 0.87, N 0.97



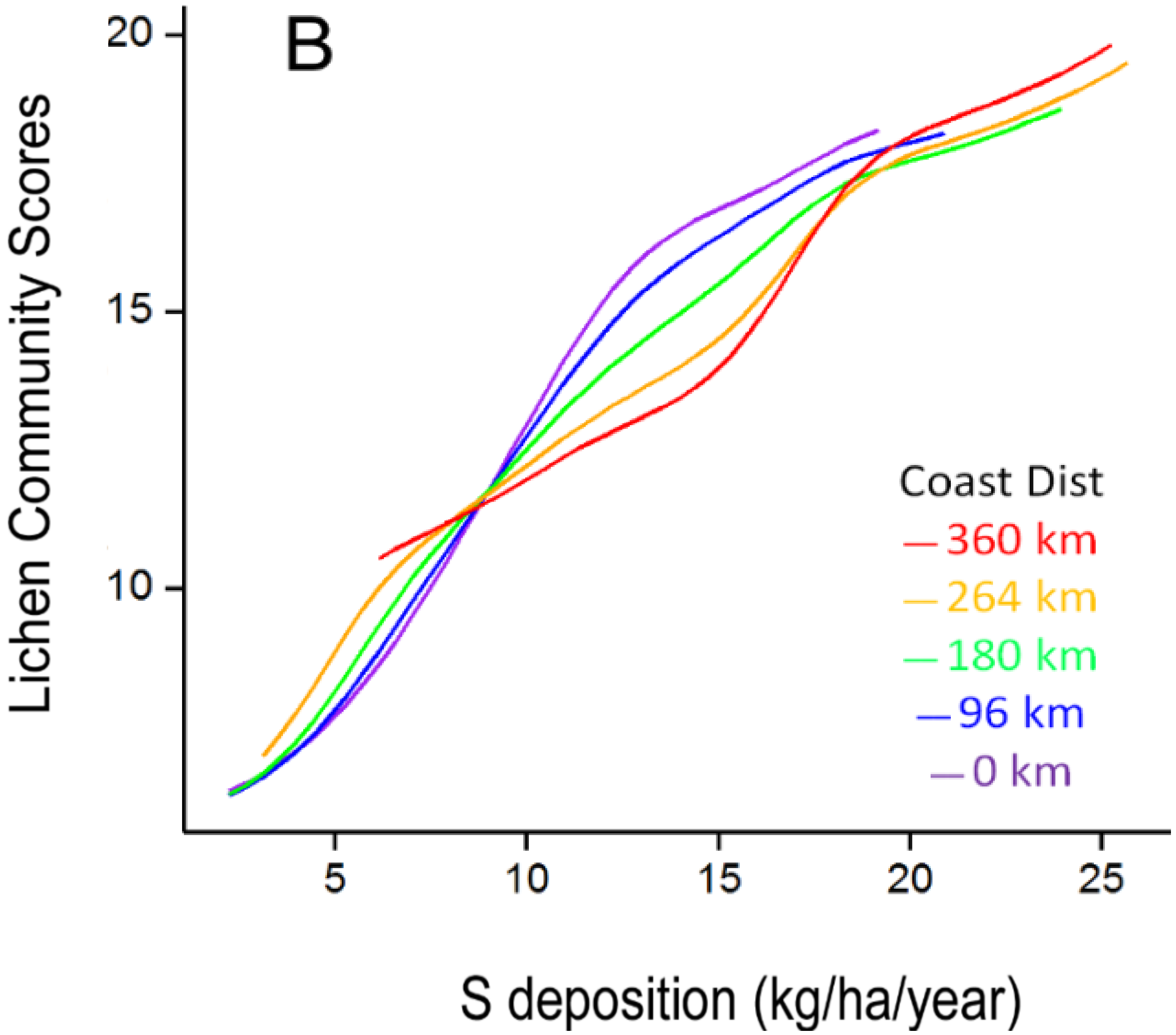


N scores are generally higher where there is low precip, and responses to cmaq n are slightly steeper where there is low precip. There is also a less strong but significant effect of December minimum temp:

Community models: Eastern US S Deposition

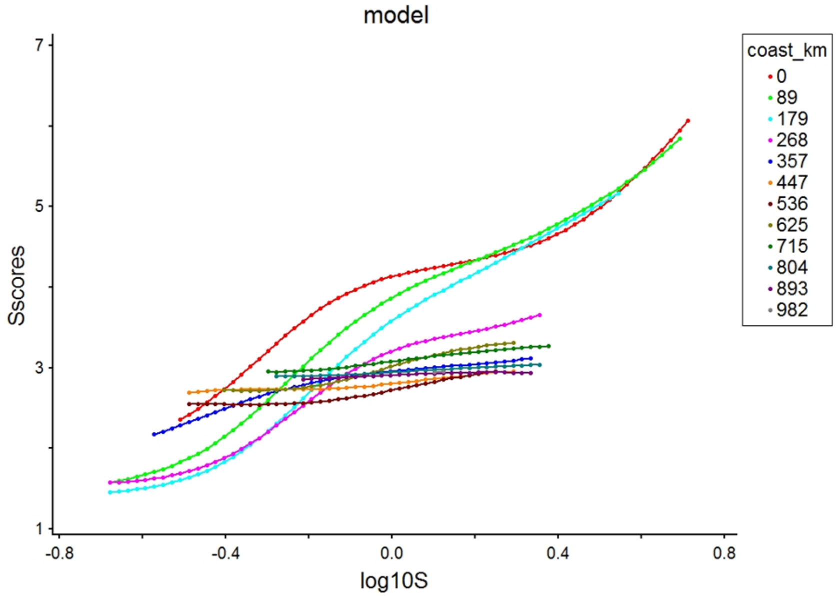
Best model has xR2 = 0.71, includes coast distance and CMAQ S (although the model without coast distance is ~R2 = .68)

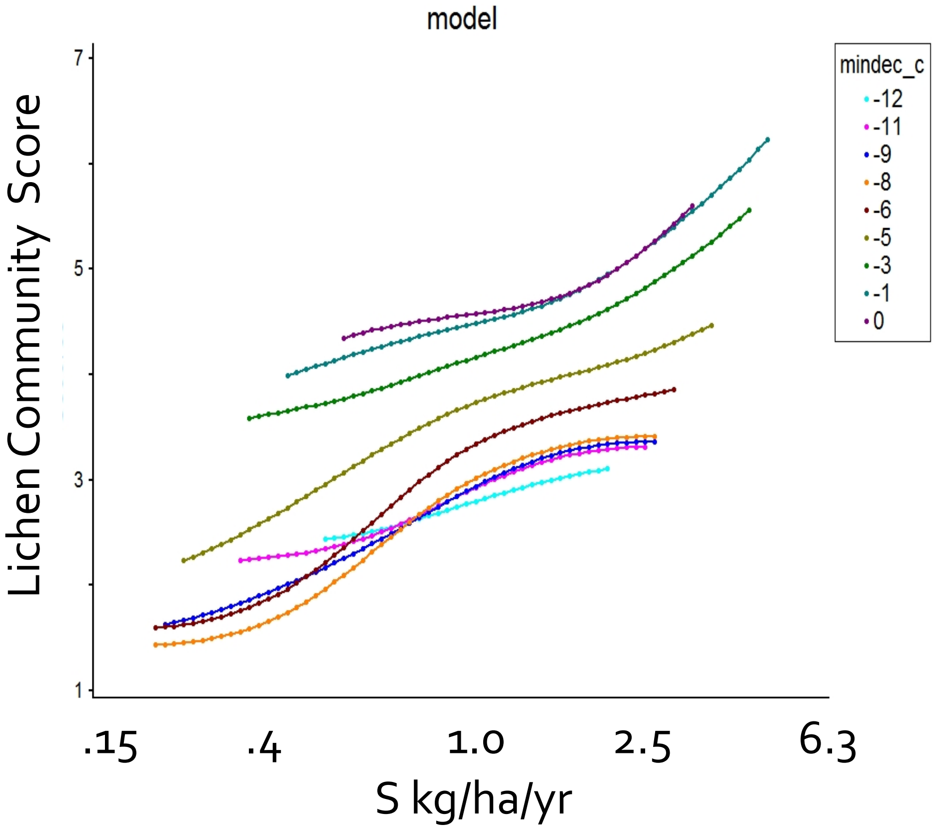
1416 plots, 13 predictors, S 1.17, coast 0.19



Community models:
Western US
S Deposition

4413 plots, 10 predictors, xR2= 0.58
Coast 0.22, mindec 0.5, log10S 0.40

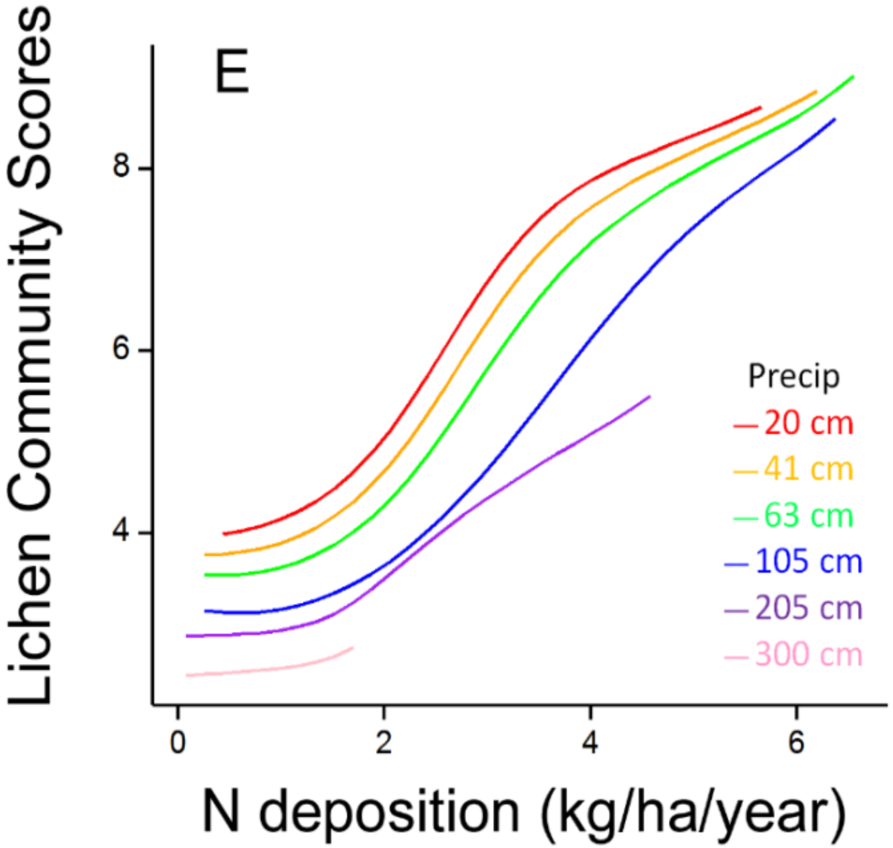




Warmer places have higher lichen S scores regardless of CMAQ S

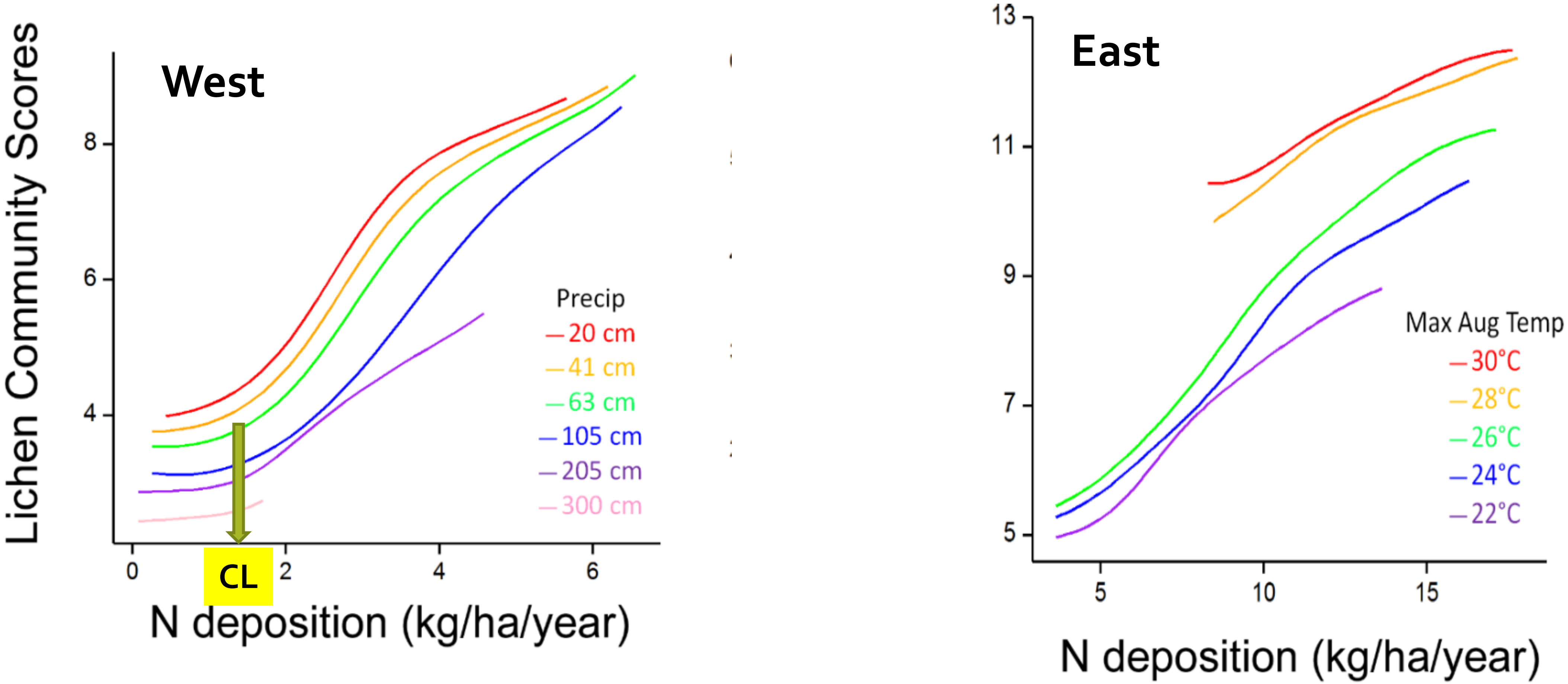
At places more than ~300 km from the coast, there's basically no relationship between S and lichen S scores. But at places closer than 300 km to the coast, there's a fairly strong positive relationship.

Reducing air pollution enhances climate resiliency of lichens and vice versa

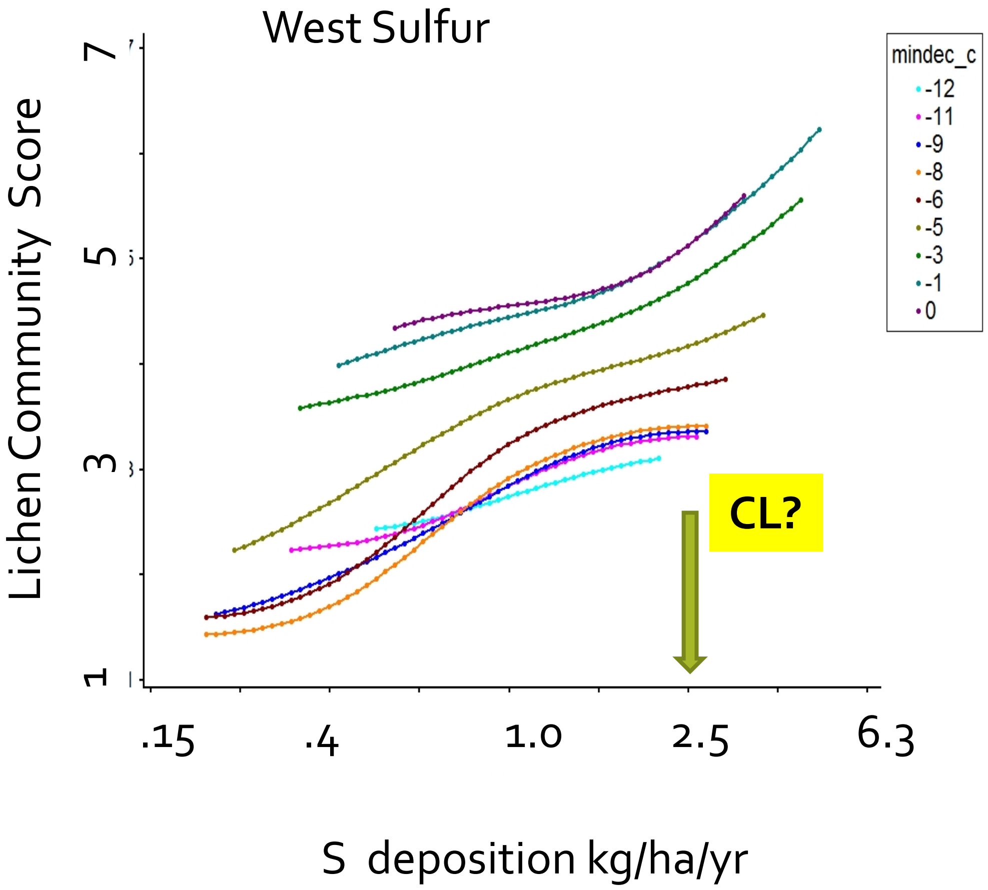


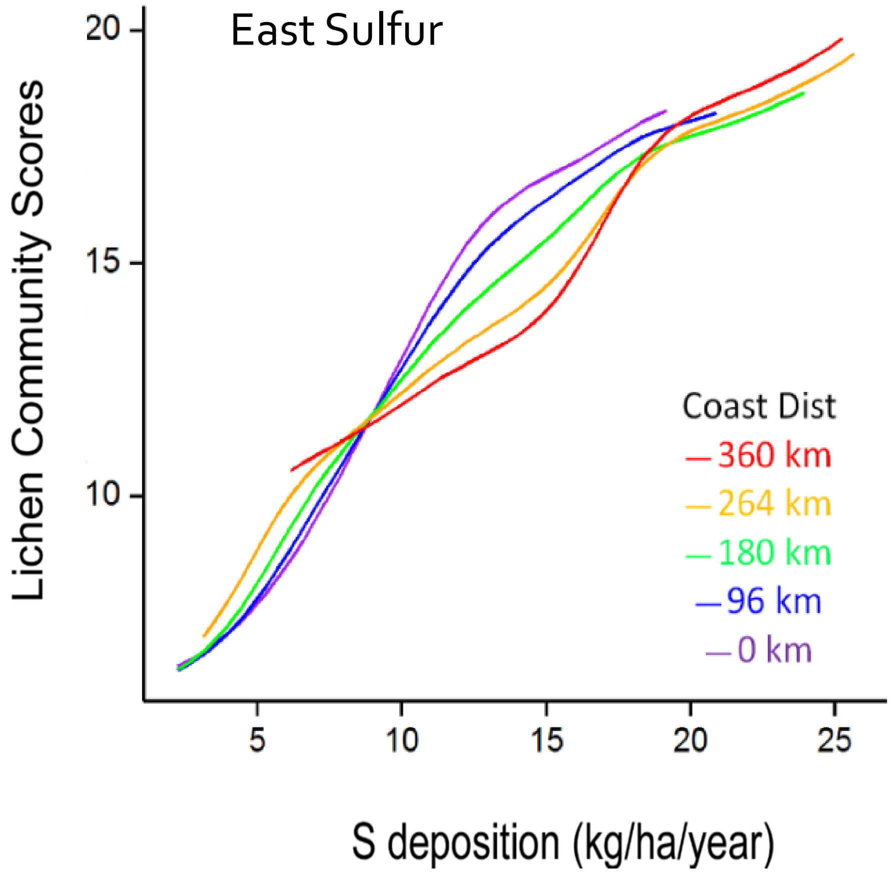
- Good air quality creates climate resilience and cool, moist climates mitigate air pollution effects

A single national lichen critical load for N of 1.5 kg N ha^{-1} yr^{-1}



A single national lichen critical load for S of 2.5 kg N ha^{-1} yr^{-1}?





Model	# plots	xR^2	p	Selected Predictors	Sensitivity
East N	1411	0.784	0.01	CMAQ N	0.430
				Maxaug_c	0.312
				Pct_hwd	0.067
West N	2946	0.626	0.01	CMAQ N	1.4794
				Precip_c	0.7707
				Maxaug_c	0.2057
East S	1416	0.723	0.01	CMAQ S	1.1430
				Coast_km	0.1912
West S	3757	0.581	0.01	$\log_{10}$(CMAQ S)	0.6474
				Maxaug_c	0.3226

Lichens benefit people and nature

Pharmaceutical Uses
- Antibacterial
- Antioxidant
- Anticancer
- Antiviral
- Antifungal
- Analgesic
- Anti-inflammatory
- Antipyretic
- Hepatoxic

Environmental Monitoring
- Sulfur dioxide
- Acidic and nutrient N deposition
- Toxic metals
- Semi-volatile organic pollutants
- Radio-isotopes
- Climate
- Biodiversity& Habitat Condition

Traditional Human Uses
- Medicine
- Food
- Fiber and textiles
- Dyes
- Decorations

Mammal Uses
- Preferred year round forage
- Winter survival food
- Nesting materials
- Eats birds or rodents that rely on lichens

Bird Uses
- Nest construction and decoration
- Nest lining
- Forages among lichens for prey
- Breeding habit lichen-dominated
- Uses lichen colors as camoflauge
- Hides food caches in or with lichens
- Eats mammals reliant on lichens
- Cultivates lichens

Invertebrate Uses
- Cover
- Food
- Camoflauge
- Forages among lichens for prey

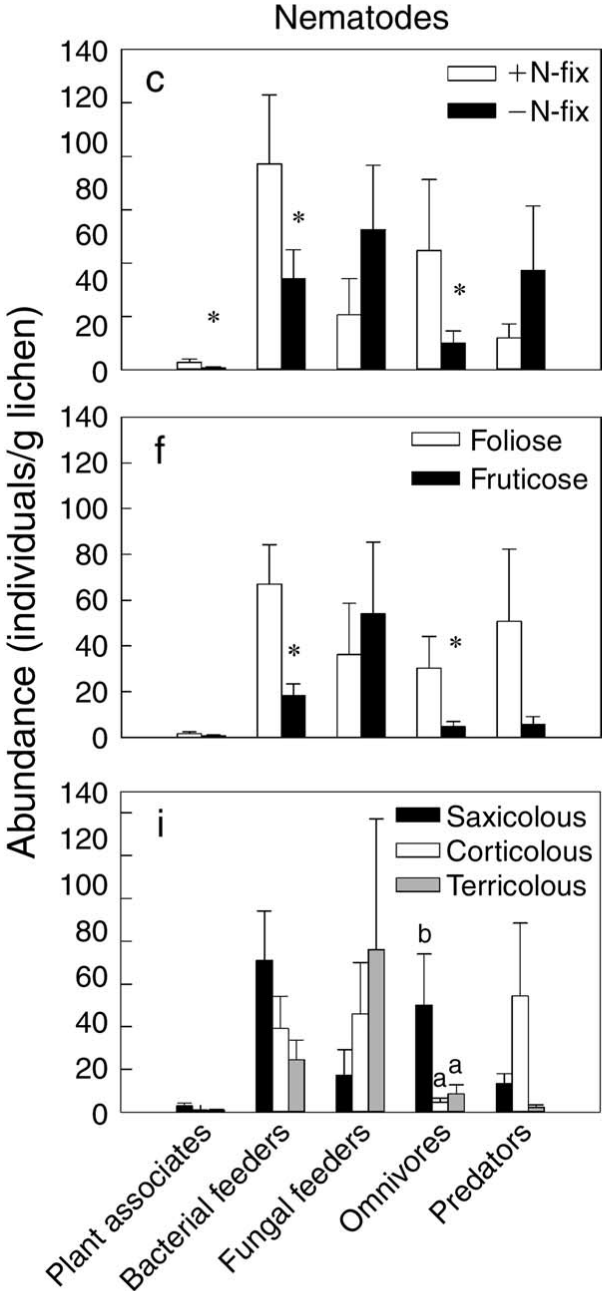
Biogeochemical Roles
- Nitrogen fixation
- Mineral release
- Moderate humidity
- Pioneer vegetation, soil building

Birds, many threatened, use lichens as nesting materials

Akekee **	Golden-crowned Kinglet	Philadelphia vireo *
American Golden-Plover *	Gray Jay	Pine grosbeak *
American redstart *	Gray-crowned Rosy-Finch	Pine siskin *
Anianiau **	Greater Akialoa[E]	Pygmy Nuthatch *
Anna's Hummingbird	Harris's Sparrow **	Red Crossbill
Baird's Sandpiper*	Hutton's Vireo *	Ruby-crowned Kinglet
Barred Owl	Lesser Akialoa[E]	Red Phalarope *
Bay-breasted Warbler *	Kauai Elepaio **	Ruby-throated Hummingbird
Bicknell's Thrush **	Lanai Hookbill[E]	Ruddy Turnstone *
Blackburnian Warbler *	Lawrence's Goldfinch **	Rufous Hummingbird **
Black-chinned Hummingbird*	Lesser Goldfinch	Rusty Blackbird *
Blackpoll Warbler *	Lincoln's sparrow *	Semi-palmated Plover *
Black-whiskered vireo *	Lucifer Hummingbird **	Surfbird *
Blue-gray Gnatcatcher	Magnificent Hummingbird *	Swallow-tailed Kite *
Blue-headed Vireo	Magnolia Warbler	Tropical Parula *
Bristle-thighed Curlew **	Marbled Godwit **	Upland Sandpiper *
Broad-tailed Hummingbird *	Marbled Murrelet **	Varied Thrush *
Buff-breasted Flycatcher *	Maui Alauahio **	Virginia's Warbler **
Bushtit *	Maui Parrotbill **	Warbling Vireo*
Canada Goose	Mountain Chickadee*	Whimbrel *
Cassin's Vireo *	Mountain Plover **	White-crowned Sparrow
Cerulean Warbler**	Olive Warbler *	White-eyed Vireo
Costa's Hummingbird *	Northern Parvula	White-winged Crossbill
Cuban Emerald	Oahu Alauahio **	Wrentit **
Eastern Wood-Pewee *	Oahu Elepaio **	Xantus's Hummingbird **
Evening Grosbeak	Olive Warbler *	Yellow Warbler
Golden Cheeked Warbler **	Orange-crowned Warbler *	Yellow-rumped Warbler
Golden-Crowned Kinglet	Pacific Golden-Plover *	Yellow-throated Vireo *
Hawaii Elepaio **	Pacific-slope Flycatcher *	
Iceland Gull *	Red-eyed vireo	
Ivory Gull **	Red-necked Phalarope *	
Kakawahie **	Rose-throated Becard *	

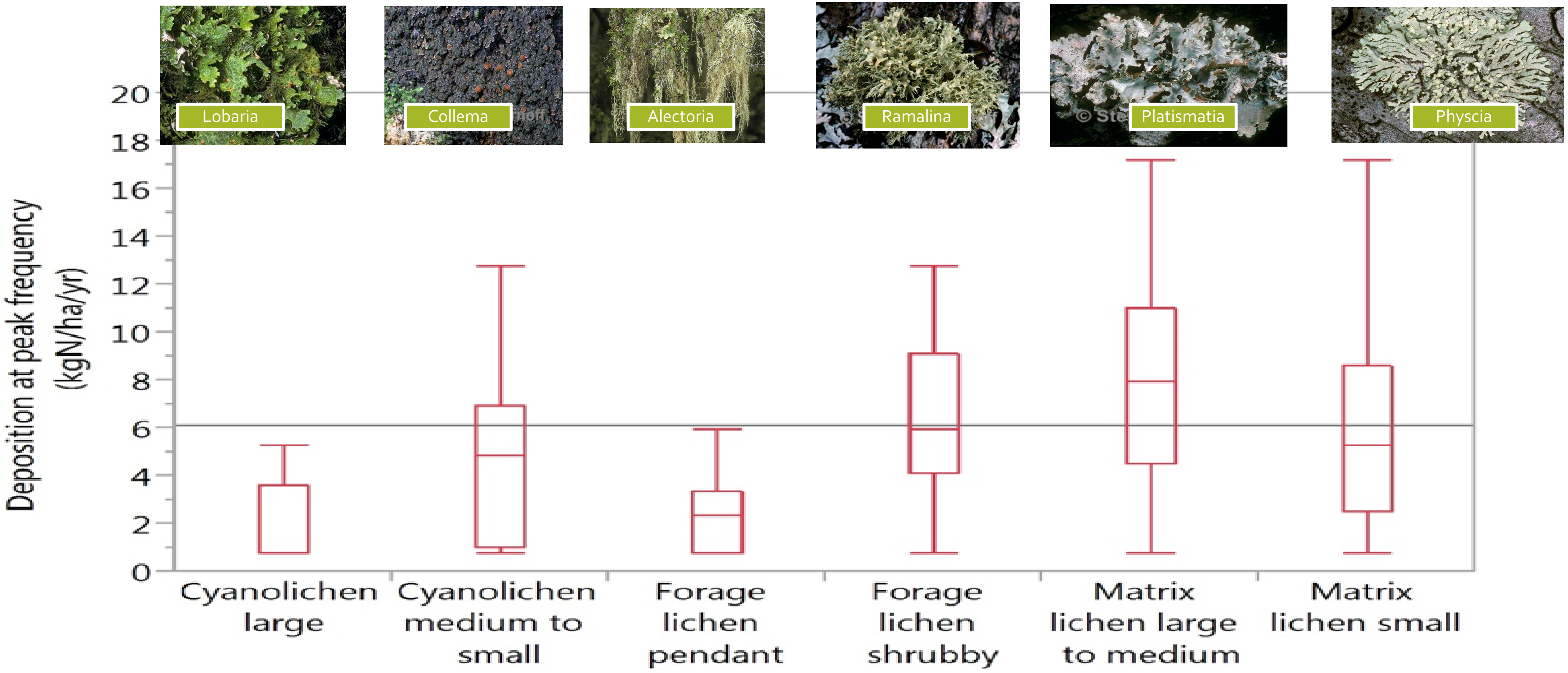
Common Names
bristletails, jumping bristletails
beetles
flies
webspinners
true bugs
wasps, bees and ants
termites
butterflies and moths
mantids
net-winged insects
grasshoppers, crickets and locusts
walking sticks, ghost insects and leaf insects
barklice
cryptogstigmitid mites (oribatid mites, beetle mites, moss mites) and prostigmatid mites, including gall mites
spiders
tubificids, pot worms and ice worms
land snails and slugs
round worms
rotifers
water bears, moss piglets

Diverse invertebrate communities are associated with plentiful lichen cover



Source: Bokhorst et al. 2015. Ecology 96:2394-2407.

Ecologically valuable lichens tend to be the most pollution and climate sensitive



Lichen functional groups a means for conceptualizing pollution's ecological effects

Fxnl gp	Median sensitivity rating of spp in gp	No. rated species W	No. rated species E	General ecological roles	Assigned genera
Large cyano-lichens	S&N: Sensitive	26	7	Primary nitrogen-fixing epiphytes acheiving high biomass in moist, temperate, old-growth forests, contributing significant amounts of new nitrogen to the forest floor. Nutrient-rich food for molluscs and other invertebrates; habitat and cover for invertebrates.	Anomolobaria, Dendriscosticta, Lobaria, Nephroma, Pseudocyphellaria, Sticta
Small to medium cyano-lichens	S: Sensitive in W, intermediate in E; N: Intermediate	35	9	Nitrogen-fixing lichens but typically low biomass due to small size and low abundance. Habitat and nutrient rich food for invertebrates.	Collema, Dendriscocaulon, Enchylium, Erioderma, Fuscopannaria, Lathagrium, Leioderma, Leptogium, Leptochidium, Pannaria, Scytinium, Vahliella
Pendant forage lichens	S&N: Sensitive	29	9	Critical winter forage for ungulates in areas with deep snow; primary winter forage for flying squirrels, voles, other rodents. Nesting materials for rodents and birds. Habitat and food for invertebrates.	Alectoria, Bryocaulon, Bryoria, Nodobryoria, pendant Ramalina and Usnea
Shrubby forage lichens	S: Sensitive in W, intermediate in E; N: Intermediate	32	17	Winter forage for flying squirrels, voles, other rodents. Nesting materials for birds. Habitat and food for invertebrates.	Bunodophorun,Evernia, Letharia, Pseudevernia, Sphaerophorus, Teleoschistes, shrubby Ramalina and Usnea
Medium to large matrix lichens	S&N: Sensitive in W, tolerant in E	90	82	Nesting materials for birds; habitat, cover and food for invertebrates.	Ahtiana, Canoparmelia, Cetrelia, Crespoa, Esslingeriana, Flavoparmelia, Flavopunctelia, Heterodermia, Hypogymnia, Hypotrachyna, Imshaugia, Melanelixia, Melanohalea, Menegazzia, Montanelia, Myelochroa, Niebla, Parmelia, Parmelina, Parmotrema, Physcia, Physconia, Platismatia, Punctelia, Teloschistes, Tuckermanella, Tuckermannopsis, Usnocetraria, Vulpicida
Small matrix lichens	S&N: Sensitive in W, intermediate to tolerant in E	56	40	Exposed habitat and food for invertebrates	Anaptychia, Bulbothrix, Candelaria, Cavernularia, Cladonia, Coccocarpia, Crespoa, Hyperphyscia, Kaernefeltia, Loxosporopsis, Parmeliella, Parmeliopsis, Phaeophyscia, Physciella, Placidium, Polycaulon, Polychidium, Pyxine, Rusavskia, Xanthomendoza, Xanthoria

Ecosystem services supported by lichens

- Wood
- Pollination
- Recreation & Hunting
- Aesthetic
- Habitat
- Biodiversity
- Stewardship
- Soil formation
- Control flooding
- Store carbon
- Food, forage & medicines
- Clean air
- Photosynthesis

Improvements in critical load science are paving the way for critical load uses

- Critical loads are a rapidly evolving science and these days our minds are turning to how we, the federal land managers can utilize them to protect resources and or protect or improve air quality.
- In the US Forest Service we do/could potentially use them for
  - **Forest planning.** Assessing and mitigating CL exceedances.
  - **Clean Air Act: New Source Review/Prevention of Significant Deterioration** permit reviews
  - **Federal Land Managers Air Quality Guide (FLAG)** revision to incorporate CLs
  - **National Environmental Policy Act (NEPA)** environmental impact analyses for Oil, Gas, and Coal development (NOx, VOCs, O3, AQRVs)
  - **Inform EPA's integrated science assessment for NOx and Sox secondary standards**
  - **Protect biodiversity** (agency mission, T&E, SSSP)

Conclusions

- Emissions, concentrations and deposition of S and N containing pollutants are largely decreasing in the US; yet widespread (east) and localized (west) concerns remain
- We propose single, lichen-community based, national critical loads for sulfur and nitrogen that allow lichen community composition at the CL to vary with climate
- Lichen critical loads are close to natural background deposition ranges (1.5-2 kg N; 2.5 kg S)
- Improving air quality enhances the climate resilience of lichen communities and vice versa
- Air pollution and climate sensitive lichens play important ecological roles and many mammals, birds, and invertebrates depend on them.
- Lichen ecosystem services include pharmaceutical, traditional medicinal, and monitoring uses; nutrient cycling; forage for protected species; nesting and hunting ground for bird-based pollination and insect pest control; forage for ungulates; mycorrhizal dispersal and tree growth
- Because epiphytic lichens are highly sensitive to air pollution, critical loads protective of lichens offer broad protection to other terrestrial ecosystem components of forests

Acknowledgements

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Thank you for listening!