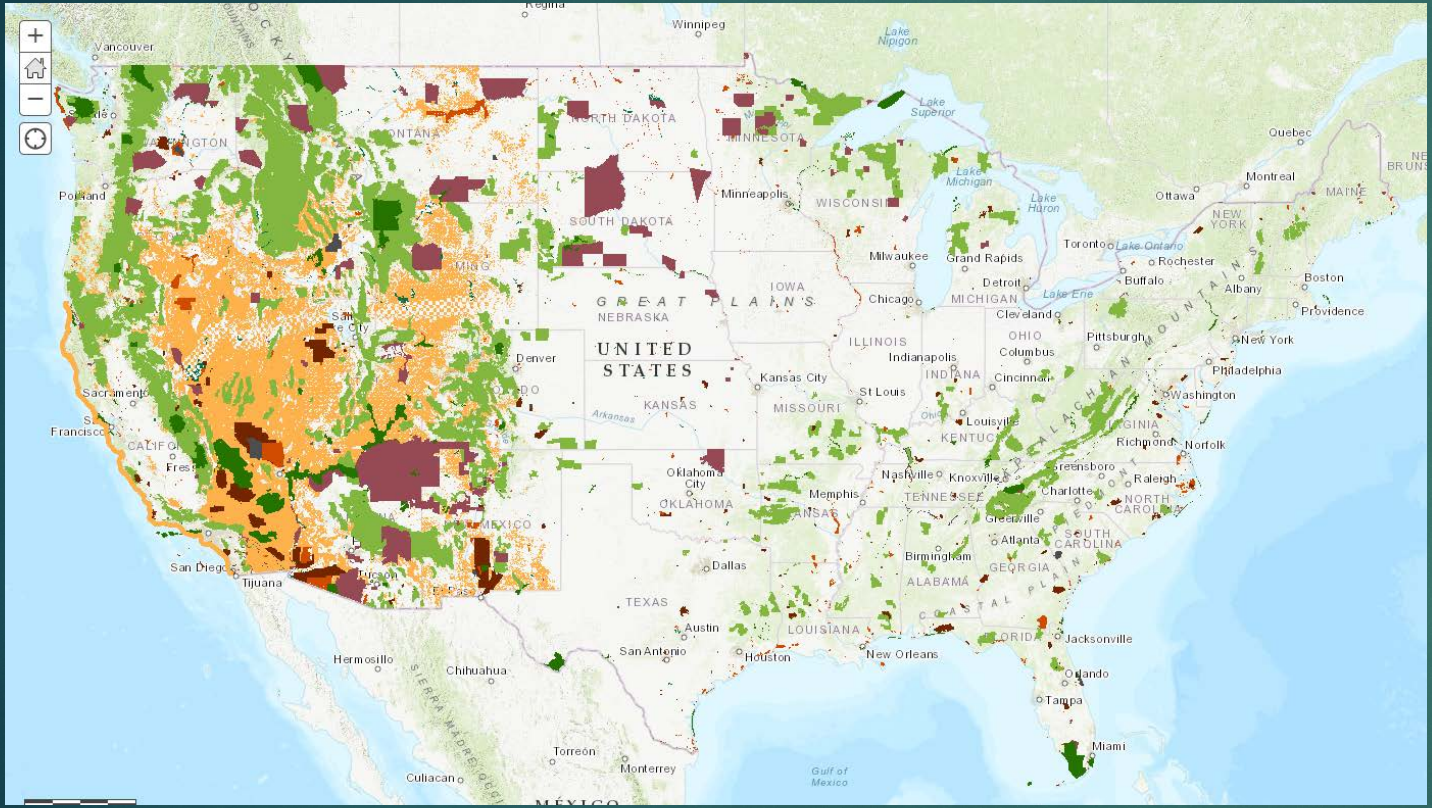
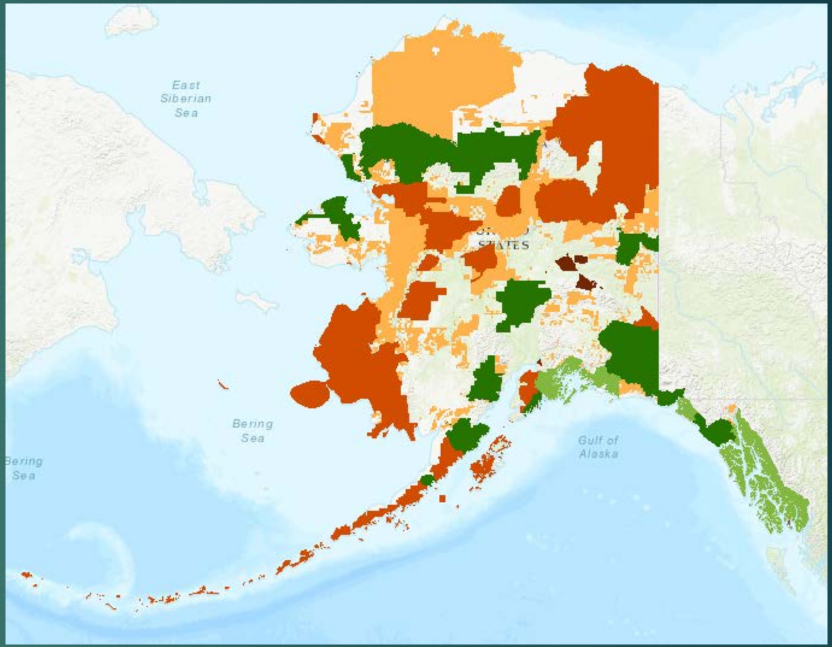
The value of lichen-based critical loads of atmospheric deposition to land managers

LINDA GEISER[1], PETER NELSON[2], MIKE BELL[3], LINDA PARDO[1], CHRIS CLARK[4], JASON LYNCH[4]

[1] USDA-FOREST SERVICE, [2] UNIVERSITY OF MAINE AT FT. KENT, [3] NATIONAL PARK SERVICE, [4] US EPA

Much of the US is federally managed





...So land manager decisions are important to the health and condition of natural resources

Federal Land Management Goals

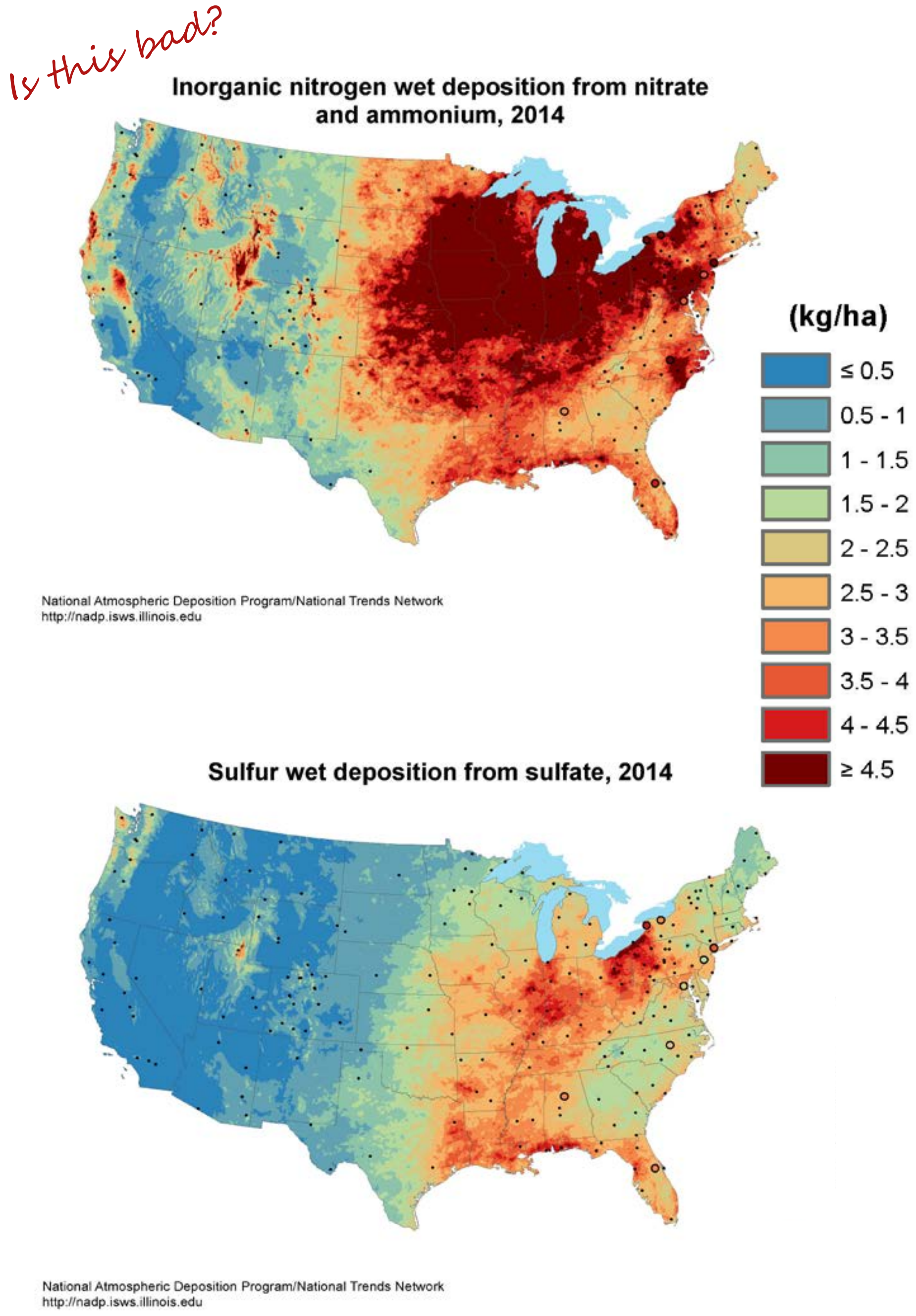
Federal laws (NFMA, NEPA, FLPMA, NPS Act, Wilderness Act) drive management objectives on federal lands.

The core requirements of these laws are reflected in the mission statements of the federal land management agencies, e.g.:

FS Mission: "To sustain the health, diversity, and productivity of the Nation's forests and grasslands to meet the needs of present and future generations."

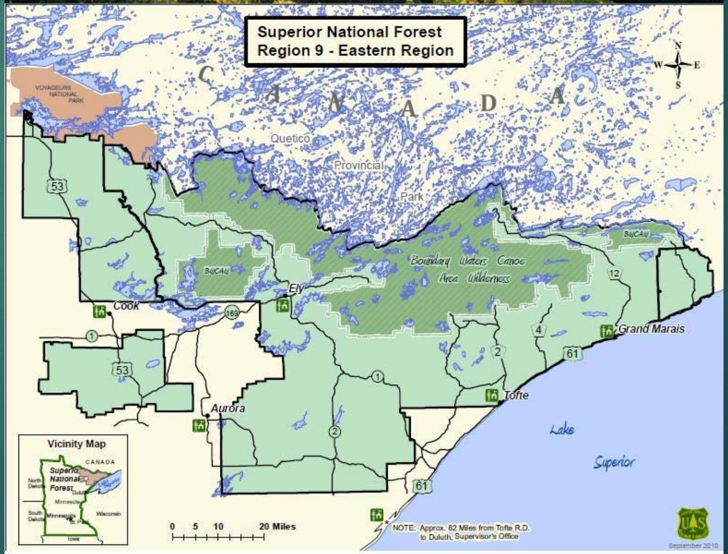
Mission-related questions about air pollution

- Is it reducing biodiversity? By how much and where?
- Is it reducing the viability of rare species? By how much and where?
- Is it reducing productivity and services provided by forests? How and where?



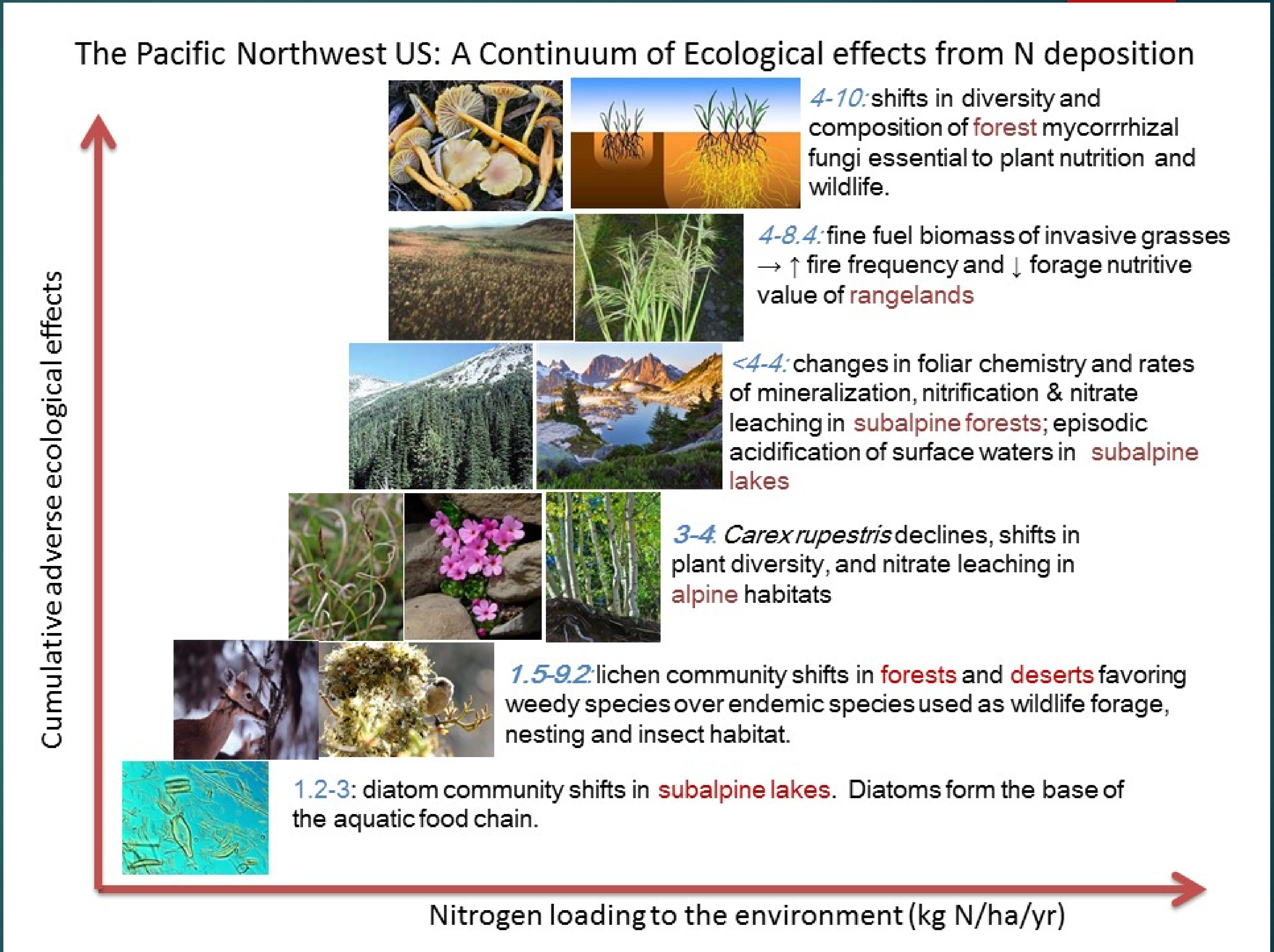
Superior NF case study: Objectives

- Here, we use lichens of the Superior National Forest, MN, to show how critical loads can be used to assess risks from atmospheric deposition to:
  - biological diversity
  - rare species viability
  - ecological functions and services, specifically
    - Wildlife forage and nesting materials: Forage lichens
    - Nutrient cycling: nitrogen-fixing Cyanolichens
    - Cover and forage for invertebrates: Matrix and Cyanolichens



Introduction

- Lichens, especially epiphytic macrolichens, are well known for their sensitivity to air pollution relative to other terrestrial biota
- As a corollary, lichen-based critical loads of atmospheric deposition may offer protection to the broader terrestrial flora.



Lichen ecosystem roles & services

- Lichens are less well known for their ecological roles. But, in fact, the roles they play are broadly exemplary of the many ecosystem functions and services provided by other forest and rangeland vegetation.
- Thus, lichen responses to air pollution can be used to illustrate the ecosystem risks, from a land manager's perspective, of exceeding terrestrial critical loads of atmospheric deposition.



Lichens provide cover, nesting materials and forage for mammals, birds, and invertebrates

Lichen ecosystem roles & services, cont.

Soil crusts improve water holding capacity and reduce erosion

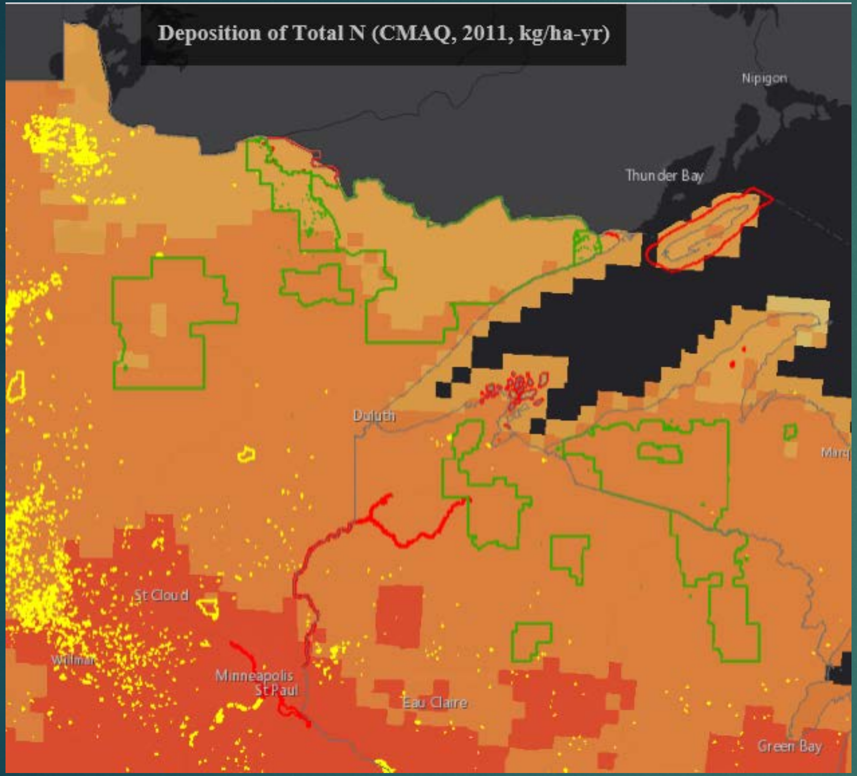
Nitrogen-fixing cyanolichens contribute substantial new N to old-growth forests in the PNW

Air quality indication

Pharmaceuticals, crafts

Traditional uses as dyes, medicines, fiber, and food

Superior National Forest: moderate N deposition, low S deposition



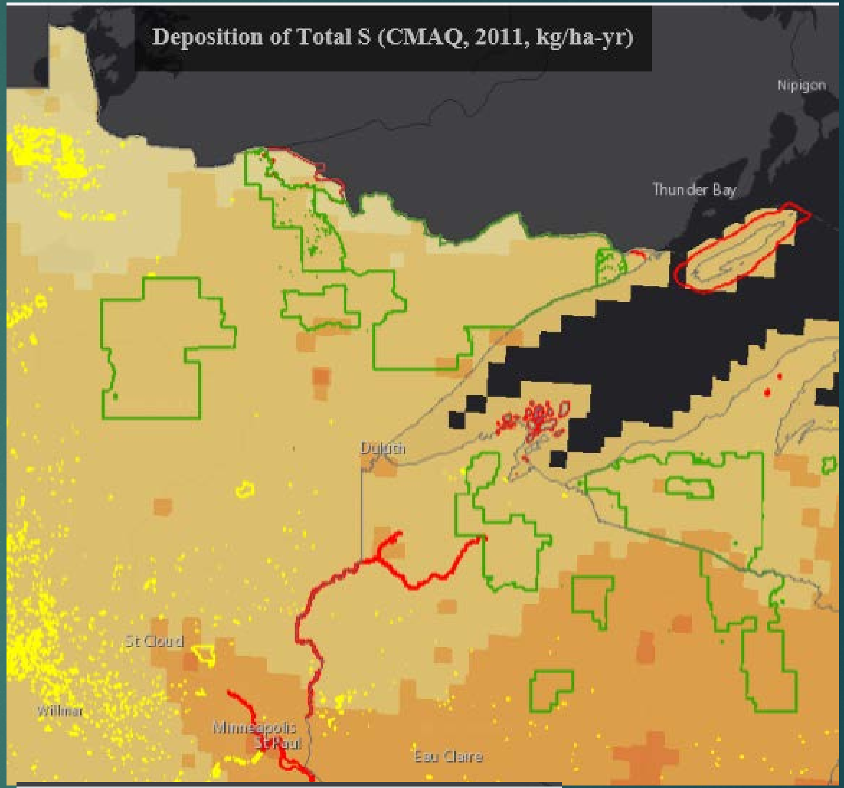
Deposition of Total N (CMAQ, 2011, kg/ha-yr)

- 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

CMAQ N Dep kg ha^{-1} yr^{-1}

75% =3.0 -5.0

25% = 5.0-10.0



Deposition of Total S (CMAQ, 2011, kg/ha-yr)

- 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

CMAQ S Dep kg ha^{-1} yr^{-1}

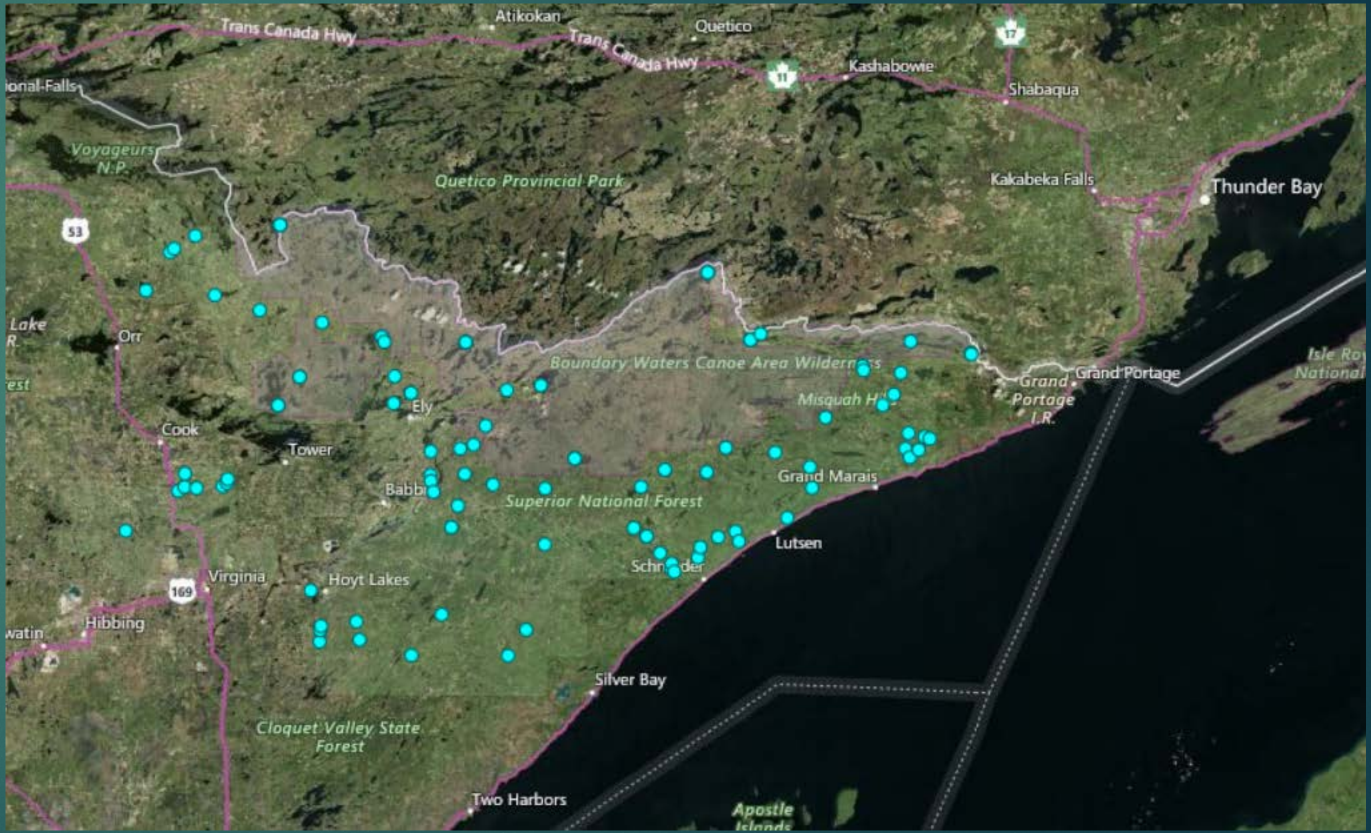
20% = 0.5-1.5

75% = 1.5-3.0

5% = 3.0-5.0

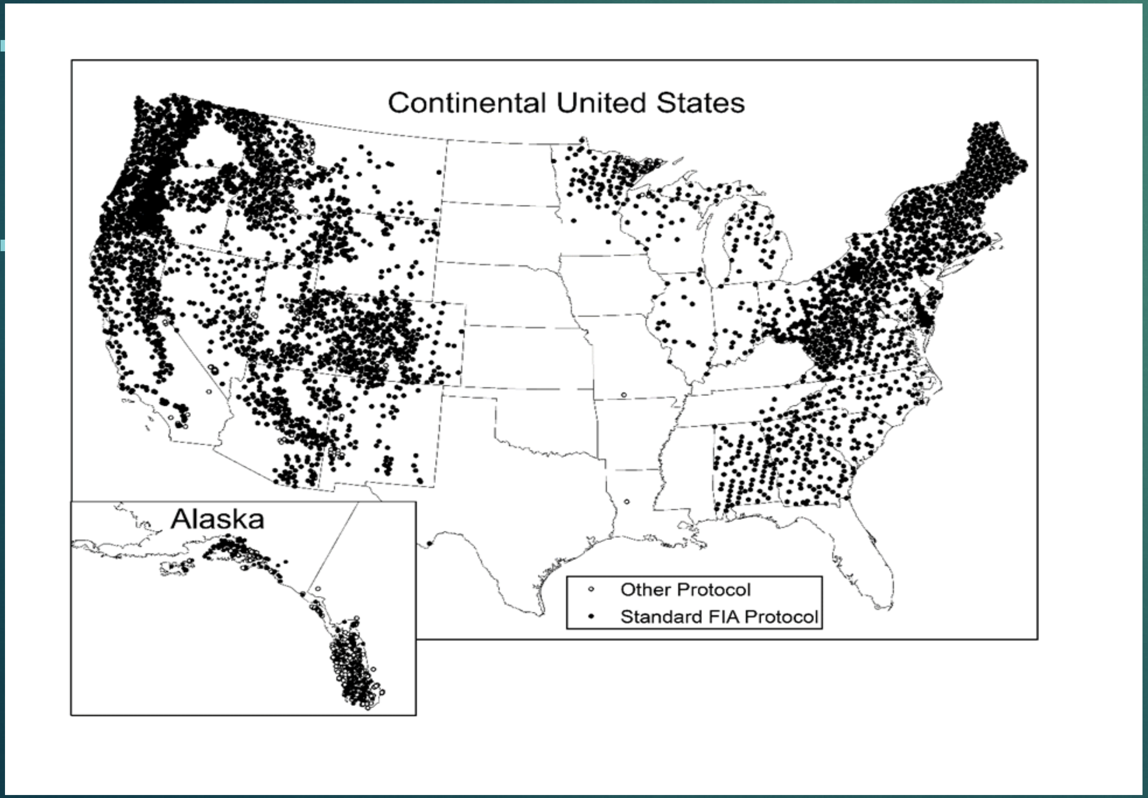
Data: Superior National Forest Lichen Survey Sites

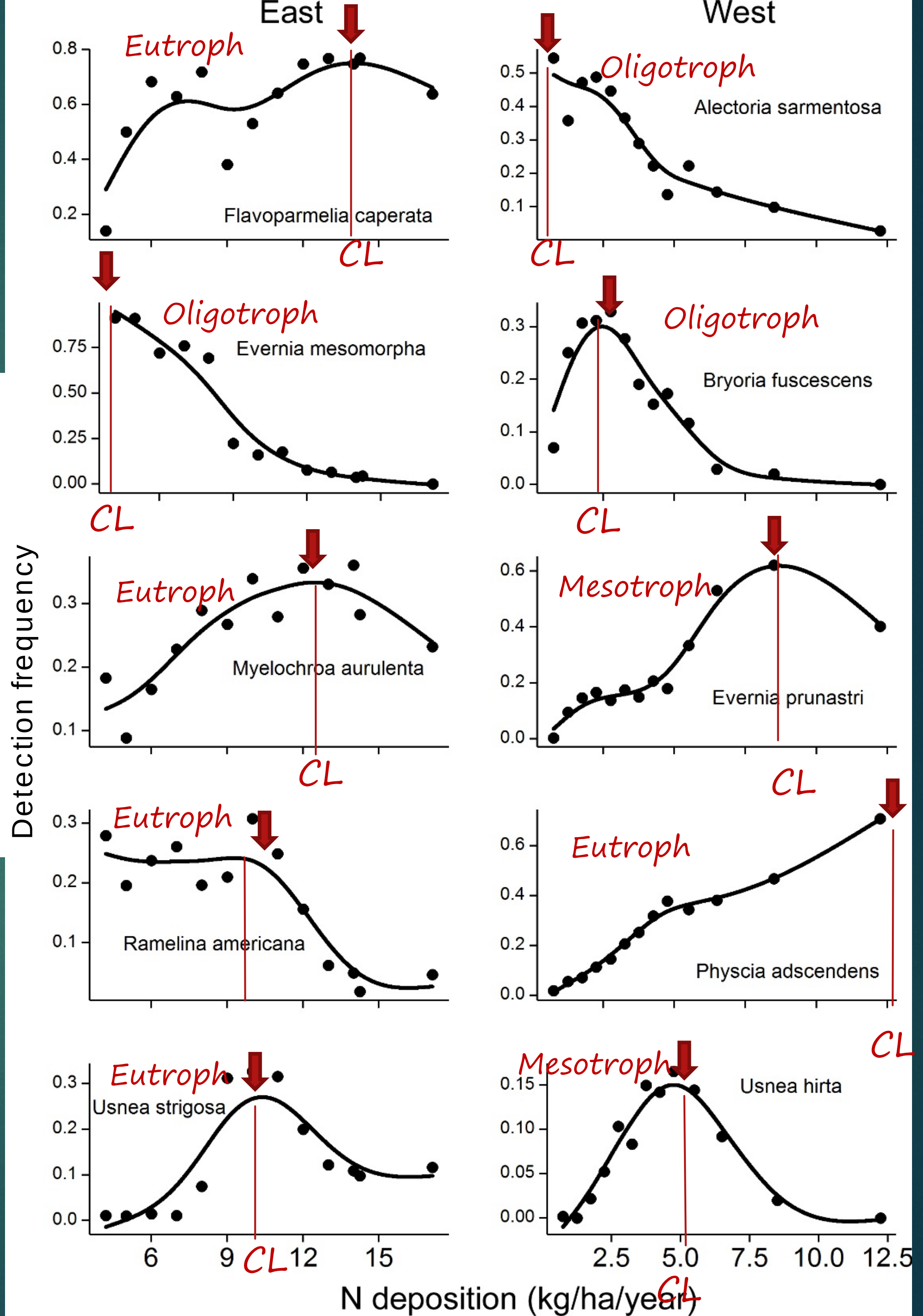
- Survey years 1994-2001
- 73 lichen surveys
- FIA lichen communities indicator protocol (9)l; Wetmore inventory protocol (64)
- 456 species found
- 154 Epiphytic macrolichens
- 129 Rated lichens (84%)
- Mean count of species per site 16 +/-7, min 1, max 34



Background: Lichen species critical loads

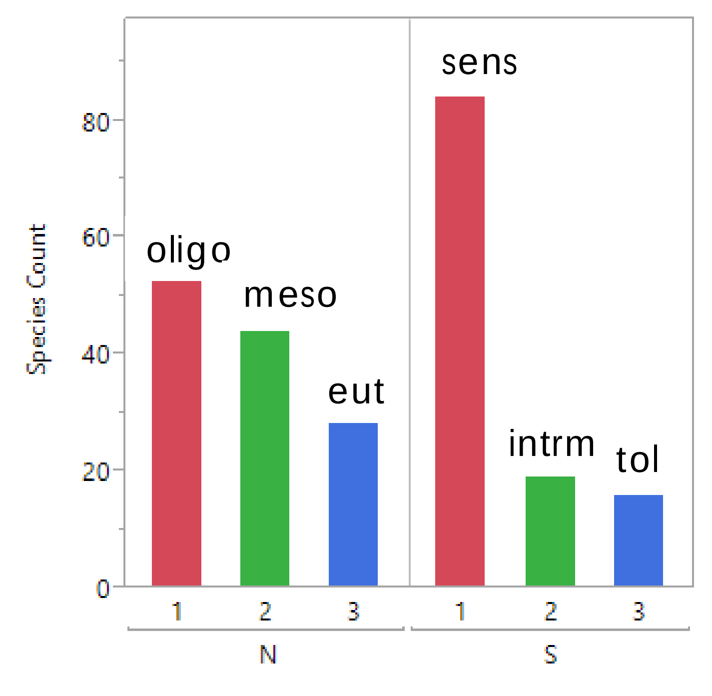
- **National data set: 8,885 lichen surveys**, mostly following the USFS FIA community indicator protocol.



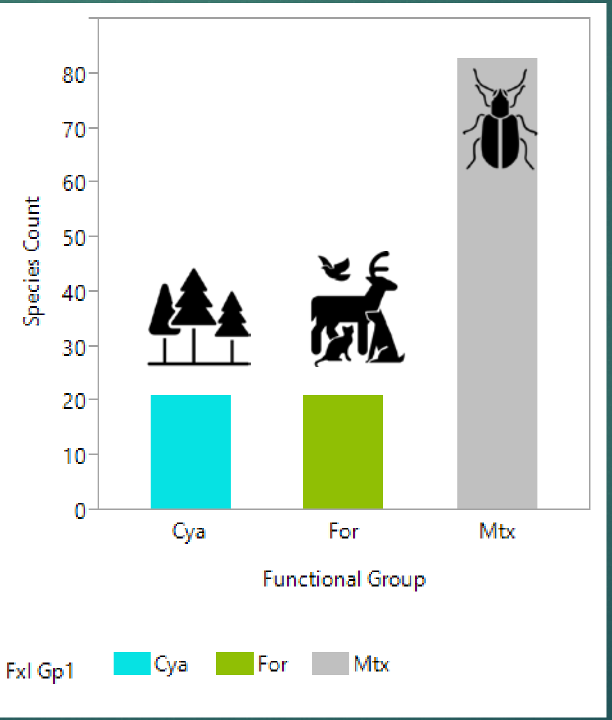


Lichens of Superior NF

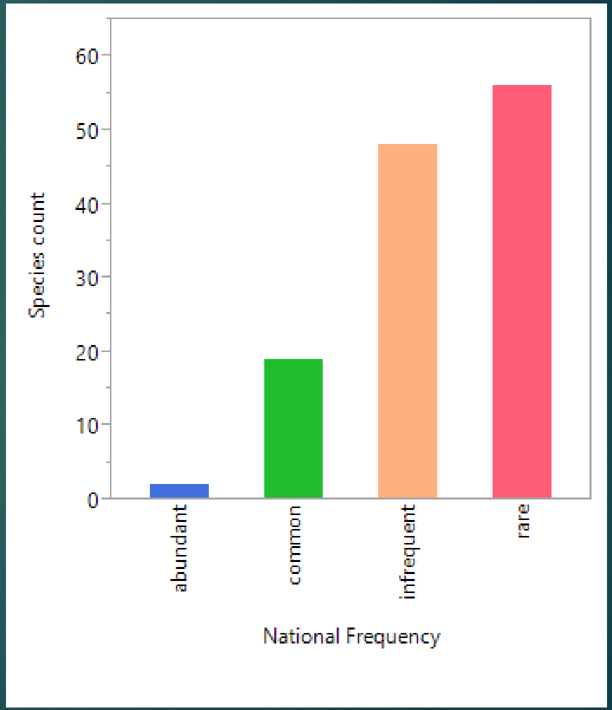
Most species (71%) are S-sensitive, many are N-sensitive oligotrophs (45%; baseline not known)



About 15% of species are cyanolichens and 15% are forage lichens



About 43% are rare nationally (detected on fewer than 1% of 8900 survey sites): 31% are rare on Superior NF

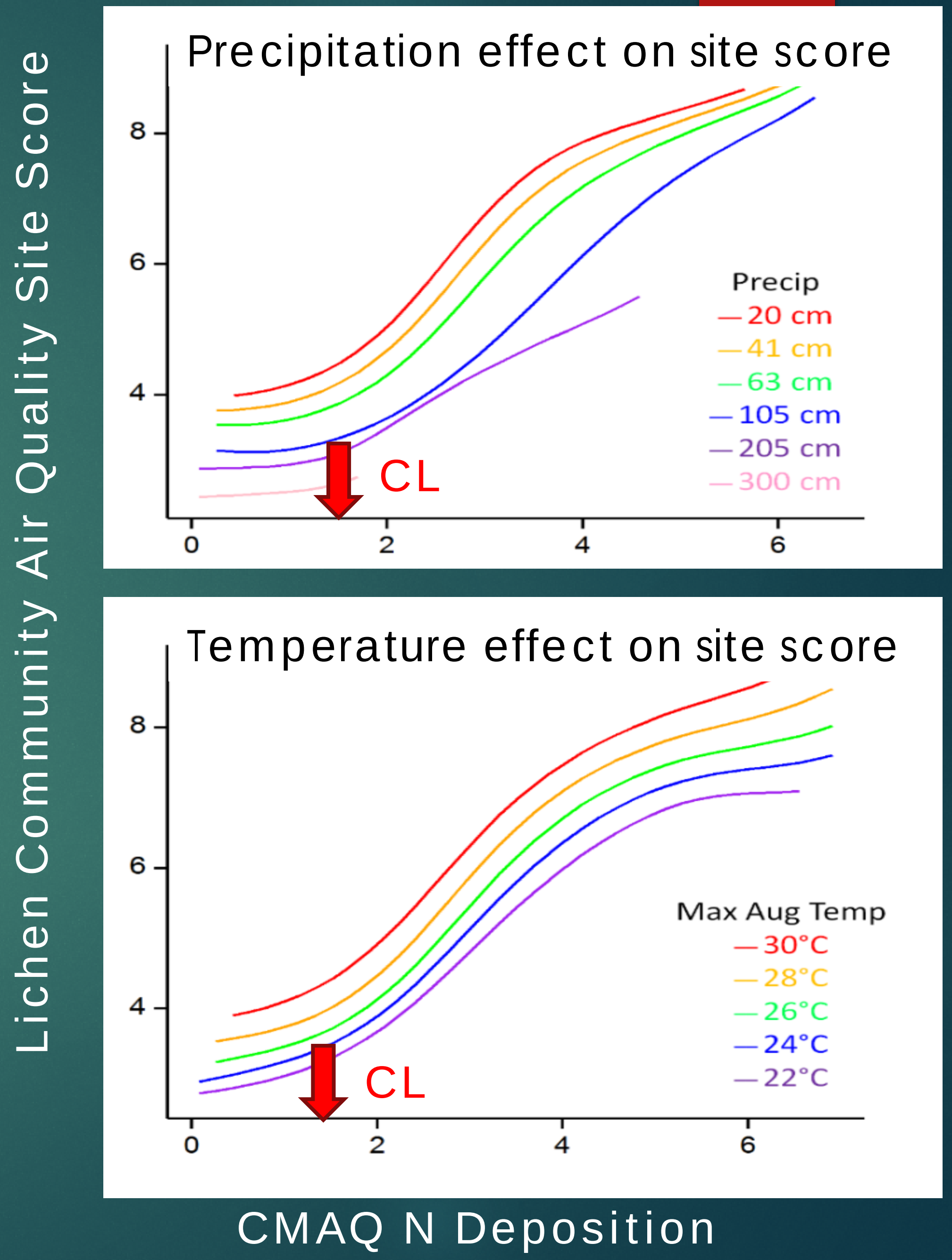


Background: One Critical Load

- Lichen community-based AQ site score = mean CL of the species detected at the site weighted by their abundance
- As deposition ↑, the proportion of air pollution tolerant species increases at the expense of more sensitive species; mean CL of species present increases
- Community composition shifts continuously with deposition
- Warmer, hotter climates mimic air pollution, but in a predictable way.
- Because the community composition critical load (inflection point) occurs at the same deposition across all climates, there need be just one CL for the whole country (~ 1.5 kg N ha^{-1} yr^{-1} and ~2.5 kg S ha^{-1} yr^{-1})

Purpose of this CL: Simple, fast, robust:

- *Protects vegetation in general*
- *Protects air pollution sensitive lichens*

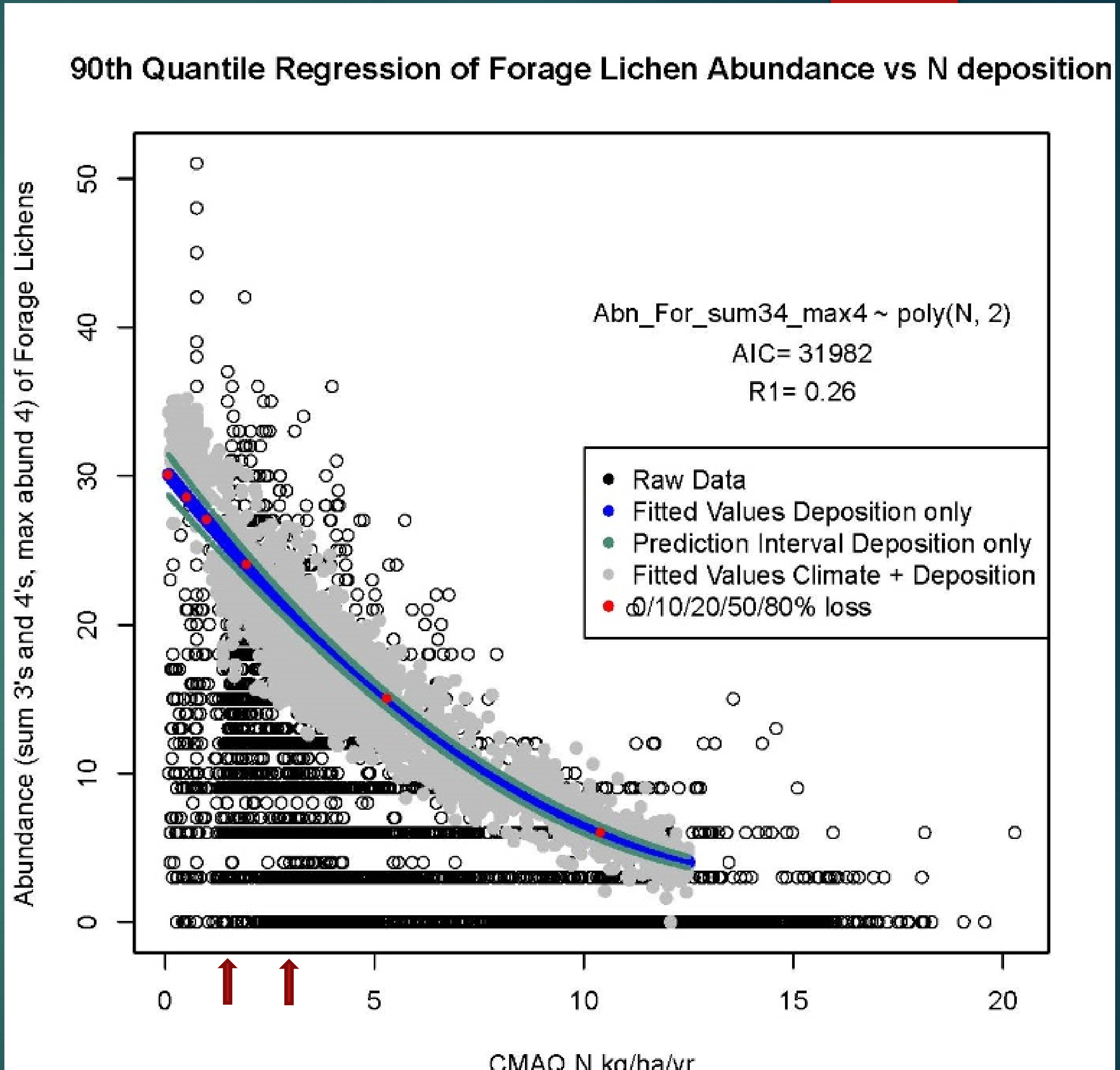


Background: Forage lichen diversity and abundance CLs

0%	5%	10%	LOSS 20%	50%	80%
0.1	0.5	1.0	Deposition 2.0	5.3	10.4

Purpose of this CL: Fast, simple, robust: Protects forage lichen diversity & abundance from air pollution in the US

…Conducted similar analyses for cyanolichens and total species richness for N & for S



CL= 1.0 –2.0 kg N ha^{-1} yr^{-1}

Superior NF: Exceedance of National CLs

Response Measure	Criteria	Poll	CL	Superior NF deposition	Area affected	Is this CL exceeded?	Estm ave decrease (%)
Community Composition	no shift in proportion of sensitive species	N	1.5	1.5-3.0	75%	Yes	10-20
				3.0-5.0	25%	Yes	20-50
		S	2.5	0.5-1.5	25%	No	
				1.5-3.0	75%	Maybe	
Species Richness	No more than 10-20% decrease	N	1.7-3.5	1.5-3.0	75%	No	
				3.0-5.0	25%	Yes	20-50
		S	2.9-6.0	0.5-1.5	25%	No	
				1.5-3.0	75%	No	
Forage lichen diversity and abundance	No more than 10-20% decrease	N	1.0-2.0	1.5-3.0	75%	No	
				3.0-5.0	25%	Yes	20-50
		S	1.4-2.6	0.5-1.5	25%	No	
				1.5-3.0	75%	No	
Cyanolichen diversity and abundance	No more than 10-20% decrease	N	0.7-1.3	1.5-3.0	75%	Yes	20-50
				3.0-5.0	25%	Yes	50-80
		S	1.2-2.3	0.5-1.5	25%	M	
				1.5-3.0	75%	Y	10-20

Conclusions

1. Throughout the Forest, accounting for climate, N deposition is likely reducing the

    a) frequency of N-sensitive spp by 10-50%

    b) diversity and abundance of cyanolichens 20-80%

2. In ~75% of the Forest, S deposition is likely reducing the diversity and abundance of forage lichens by 10-20%

3. In ~25% of the Forest N deposition is likely reducing species richness and forage lichen diversity and abundance by 20-50%

Some iconic widespread species

Common Lichens (12 spp) detected >45% of sites	**FxlGp**	**N CL**	**S CL**
Flavoparmelia caperata	Matrix	14.0	32.2
Punctelia rudecta	Matrix	11.1	14.4
Physcia aipolia	Matrix	8.6	**3.0**
Parmelia sulcata	Matrix	8.5	8.8
Hypogymnia physodes	Matrix	8.5	4.5
Usnea subfloridana	**Forage**	6.0	3.4
Heterodermia speciosa	Matrix	5.5	**2.7**
Vulpicida pinastri	Matrix	**4.6**	**1.4**
Parmelia squarrosa	Matrix	**4.2**	3.8
Evernia mesomorpha	**Forage**	**4.2**	3.4
Platismatia tuckermanii	Matrix	**4.2**	3.7
Lobaria pulmonaria	**Cyano**	**3.0**	**1.8**

Superior NF Common Lichens	NF Abun Pct	USAbun	FxlGp1	CL	-20	-50	-90	Predicted % decrease in frequency at 3-5 kg N	Risk from N dep	CL	-20	-50	-90	Predicted % decrease in frequency at 1.5-3 kg S	Risk from S dep
Flavoparmelia caperata	75.3	Common	Matrix	14.01				**0**	**none**	32.16				**0**	**none**
Parmelia squarrosa	70.1	Infrequent	Matrix	4.2	5.3	7	15.5	**0**	**none**	3.81	5.7	7.2		**0**	**none**
Hypogymnia physodes	61.0	Abundant	Matrix	8.5	10.9			**0**	**none**	4.48	6.6	8.6		**0**	**none**
Heterodermia speciosa	54.5	Infrequent	Matrix					**NA**	**?**	2.71	3.3	4.2	8.7	**<20**	**low**
Parmelia sulcata	54.5	Abundant	Matrix					**NA**	**?**	8.75				**0**	**none**
Heterodermia speciosa	54.5	Infrequent	Matrix	5.5	7	8.5		**0**	**none**					**NA**	**?**
Parmelia sulcata	54.5	Abundant	Matrix	8.47	11.4			**0**	**none**					**NA**	**?**
Punctelia rudecta	53.2	Common	Matrix	11.09				**0**	**none**	14.42	18.9	28.3		**0**	**none**
Evernia mesomorpha	51.9	Infrequent	**Forage**	4.2	6.3	8.4	11.9	**<20**	**low**	3.35	6	8	12.8	**0**	**none**
Lobaria pulmonaria	48.1	Infrequent	**Cyano**	3	9.6	10.9		**<20**	**low**	1.84	3			**<20**	**low**
Platismatia tuckermanii	40.3	Infrequent	Matrix	4.2	4.9	6	8.4	**0**	**none**	3.73	5.3	6.5	15.9	**0**	**none**
Usnea subfloridana	39.0	Infrequent	**Forage**	5.9	7.7	9.7		**0**	**none**	3.36	6.6			**0**	**none**
Physcia aipolia	32.5	Infrequent	Matrix	7.8	8.7	12.7		**0**	**none**					**NA**	**?**
Vulpicida pinastri	32.5	Infrequent	**Cyano**	4.58	5.6	6.7	8.2	**<20**	**low**	1.39	2.3	3	4	**20**	**low**
Physcia aipolia	32.5	Infrequent	Matrix	8.55	10.8			**0**	**none**					**NA**	**?**
Cladonia chlorophaea	29.9	Infrequent	Matrix	4.2	5.7	7.8	16.5	**<20**	**low**	3.27	6.1	8.6		**0**	**none**
Cladonia squamosa	29.9	Rare	Matrix	4.2	5.9	7	15	**<20**	**low**	2.53	4	6.7		**<20**	**low**
Tuckermannopsis americana	28.6	Infrequent	Matrix	4.2	6.1	7.8	10.6	**<20**	**low**	3.38	5.6	7.2	11.8	**0**	**none**
Melanelixia subaurifera	27.3	Infrequent	Matrix	8.4	10.6	12.1		**0**	**none**	3.5	6.3			**0**	**none**
Ramalina intermedia	26.0	Rare	**Forage**	5.2	6.6	7.7	9.4	**0**	**none**	2.71	3.2	4.1	5.9	**<20**	**low**
Phaeophyscia rubropulchra	26.0	Common	Matrix	13.57				**0**	**none**	18.33	30.1			**0**	**none**
Lobaria quercizans	24.7	Infrequent	**Cyano**	4.2	4.8	5.8	7.9	**20**	**low**	3.88	5.3	6.3	8.3	**0**	**none**
Bryoria furcellata	23.4	Infrequent	**Forage**	4.2	5	6.2	9	**<20**	**low**	0.38	2	2.6	8.8	**>50**	**high**
Usnea cavernosa	22.1	Rare	**Forage**	4.7	5.7	6.4	7.7	**<20**	**low**	1.77	2.4	3	3.8	**20**	**low**
Cetrelia olivetorum	22.1	Rare	Matrix	4.2	4.9	6	12.5	**20**	**low**	2.71	3.9	5.3	29.5	**<20**	**low**
Melanohalea septentrionalis	22.1	Infrequent	Matrix	4.2	5.2	6.8	9.5	**<20**	**low**	2.71	4.8	6.3	9.1	**<20**	**low**
Leptogium cyanescens	19.5	Infrequent	**Cyano**	4.2	4.9	6	17.1	**20**	**low**	2.4	3.3	3.7	4.6	**<20**	**low**

Common lichens

Only 1 of the forest's 27 most common lichens may be sensitive to current levels of S deposition on most of the forest:

- *Forage lichen Bryoria furcellata*

Some iconic rare species

Lichen	NF Abun	US Abun	FxlGp	N CL	S CL
Cetrelia olivetorum	Abun	Rare	Matrix	**4.2**	**2.7**
Usnea cavernosa	Abun	Rare	**Forage**	**4.7**	**1.8**
Ramalina intermedia	Abun	Rare	**Forage**	5.27	**2.7**
Collema nigrescens	Rare	Rare	**Cyano**	10.0	5.5
Bryoria nadvornikiana	Rare	Rare	**Forage**	**2.8**	**1.2**
Fuscopannaria praetermissa	Rare	Rare	**Cyano**	**0.8**	**1.6**
Leptogium burnetiae	Rare	Rare	**Cyano**	**0.8**	5.3

*Forest N dep: **1.5-5** kg $ha^{-1}yr^{-1}$*
*Forest S dep: **0.5-3** kg $ha^{-1}yr^{-1}$*

Rare Lichen of Superior NF	US Abun	FxlGp	CL	-20	-50	-90	Predicted % Decrease in frequency at 3-5 kg N	Risk from N dep	CL	-20	-50	-90	Predicted % Decrease in frequency at 1.5-3 kg S	Risk from S dep
Bryoria nadvornikiana	Rare	Forage	2.82	3.9	6.5	7.9	20	low	1	2.3	2.6	3.5	50	high
Cladonia coccifera	Rare	Matrix	0.75	1	1.3	2	90	very high	1	2.4	3.1	8.8	20	low
Cladonia sulphurina	Infrequent	Matrix	0.75	1.1	1.7	8.3	50	high	2	3.2	3.7	4.5	<20	low
Collema nigrescens	Rare	Cyano	9.95				0	none	5	7.3	8.6		0	none
Fuscopannaria praetermissa	Rare	Cyano	0.75	1.2	1.9	12.1	50	high	2	2.5	2.9	3.7	50	high
Heterodermia hypoleuca	Rare	Matrix	11.22	12.9	14	16.2	0	none	12	14	16	20.5	0	none
Lathagrium fuscovirens	Rare	Cyano	6.3	7.4	8.2	10	0	none	1	2.3	2.6	3.6	90	very high
Leptogium burnetiae	Rare	Cyano	0.75	1.1	1.6	2.4	90	very high	5	6.7	7.6	8.7	0	none
Montanelia tominii	Rare	Matrix	6.04	7.2	7.8	9	0	none	5	6.7	7.7	8.7	0	none
Phaeophyscia endococcina	Rare	Matrix	5.51	6.7	10.5	12.2	20	low	2	2.5	3.1	3.9	20	low
Phaeophyscia hirsuta	Infrequent	Matrix	4.33	5.4	6.3		0-20	low	1	2.7	6	8.3	20	low
Phaeophyscia sciastra	Rare	Matrix	6.25	7.3	8	8.9	0	none	1	2.1	2.5	3.4	50	high
Physcia americana	Infrequent	Matrix	11.8				0	none	14	17	20		0	none
Physcia caesia	Infrequent	Matrix	6.01	7.3	8.3	10.7	0	none	1	2.2	2.7	3.6	50	high
Physcia millegrana	Common	Matrix	15.63				0	none	28				0	none
Physconia muscigena	Rare	Matrix	4.71	5.7	6.5	12	0-20	low	1	2	2.8	3.7	50	high
Placidium arboreum	Rare	Matrix	5.56	6.3	7	12.3	0	none	1	2.4	2.4	8.8	50	high
Protopannaria pezizoides	Rare	Cyano	0.75	1	1.4	6	50	high	1	2	2.6	3.5	90	very high
Ramalina farinacea	Common	Forage	8.36	10.9			0	none	9				0	none
Rusavskia sorediata	Rare	Matrix	4.98	6.2	7	8.5	0-20	low	1	2.4	2.7	3.6	50	high
Sticta fuliginosa	Infrequent	Cyano	7.95	10	11.4		0	none	3	3.8	5.2		<20	low
Tuckermannopsis sepincola	Rare	Matrix	0.75	1.2	1.9	6	50	high	5	6.9	11	13.7	0	none
Usnea trichodea	Rare	Forage	4.2	4.9	5.9	7.6	20	low	4	5.6	6.5	8.1	0	none
Xanthomendoza fallax	Common	Matrix	12.25				0	none	3	3.3	4.2	6.4	<20	low

Rare lichens

S and N air pollutants may be exacerbating the risk of extirpation for >50% of the Forest's rare spp.

Very high risk (5 spp)

Cladonia coccifera

Lathagrium fuscovirens

Leptogium burnetiae

Fuscopannaria praetermissa

Protopannaria pezioides

High risk 9 spp

Low risk 6 spp

Not at risk 9 spp

Conclusions

1. Managers are required to sustain the health, diversity and productivity of federal lands
2. A single robust national lichen CLs account for climate effects and provide broad protection for vegetation and sensitive lichens.
3. Other robust national CLs protect lichen species richness and forage and cyanolichen diversity and abundance. Risk (0,5,10,20,50 and 80% decreases) can be quickly assessed from current deposition derived from the CL Mapper.
4. In Superior National Forest, current N deposition levels are moderate and S deposition is low. Risk for reductions in the detection frequency (0, 20, 50, 80%) of 119 lichens can be estimated from deposition based on individual response curves.
5. Deposition may be exacerbating extirpation risks for >50% of the Forest's rare spp.
6. Lichen CLs allow rapid assessments of CL exceedances and risks-- quantifiable at community, functional group, and species levels.