

Using critical loads for risk assessments to inform management and policy in the United States

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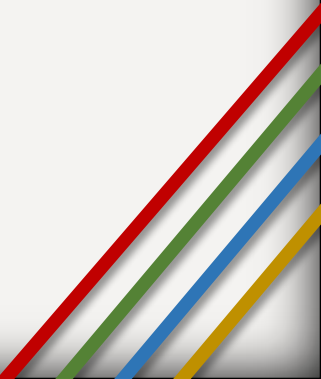
Robert Smith – US Forest Service

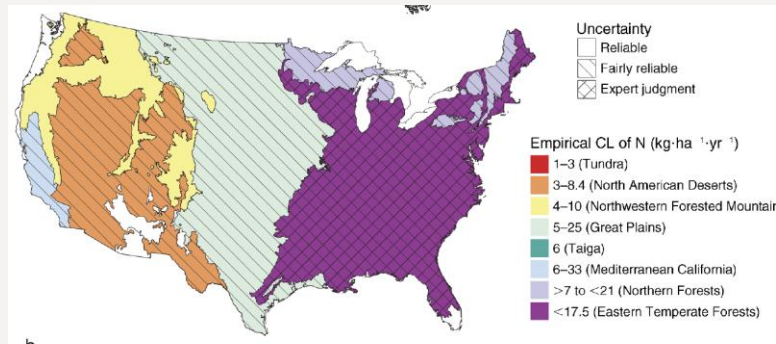
Nicholas Russell – US National Park Service



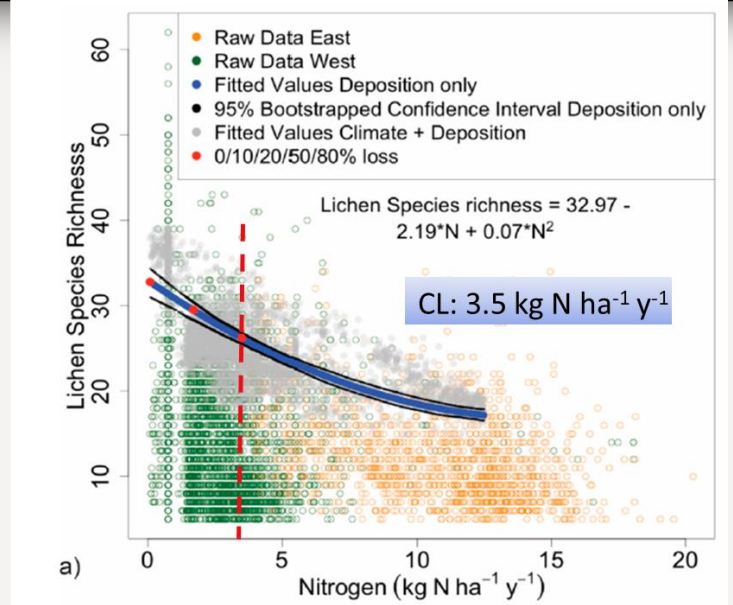
Critical Load uses by US federal agencies

- Setting national air quality standards.
- Understanding risk to ecosystems to use in management and planning.
- Determining impact of new/modified pollution sources near areas of interest.

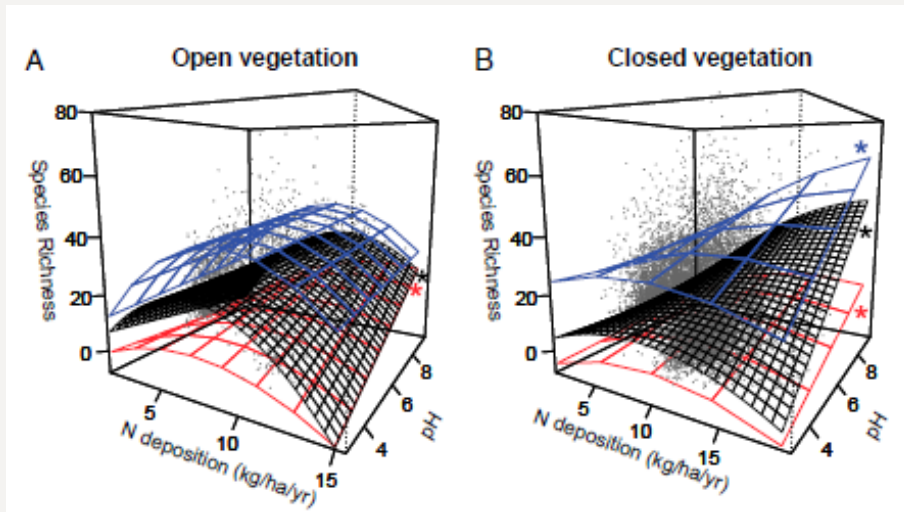




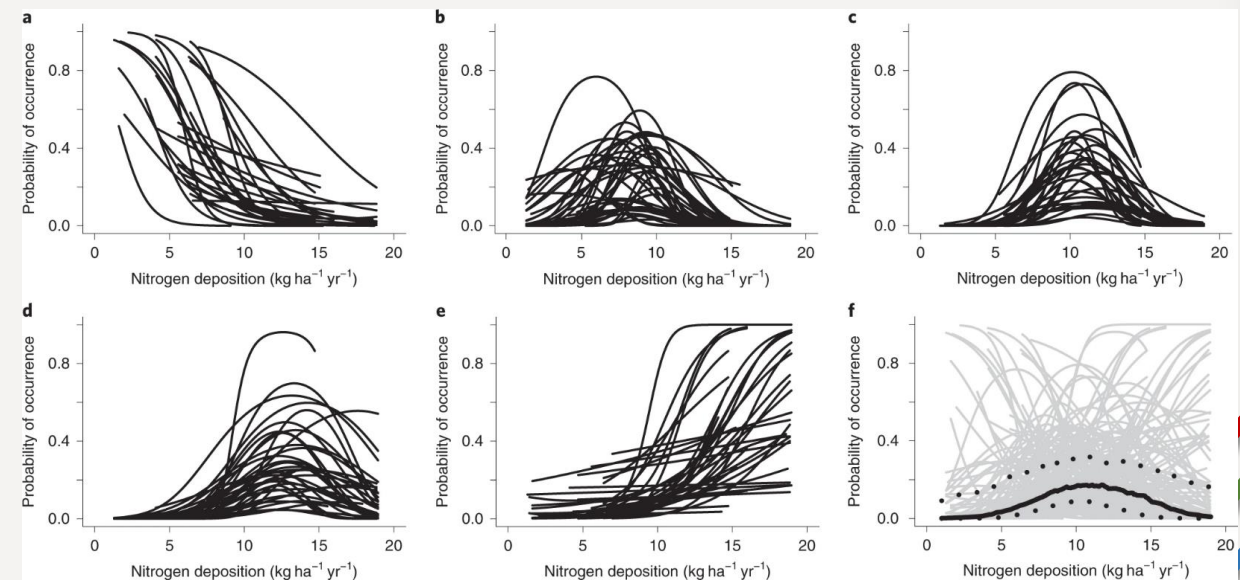
Single value for a set area



All data fitted to one curve



All data varies with other environmental variables

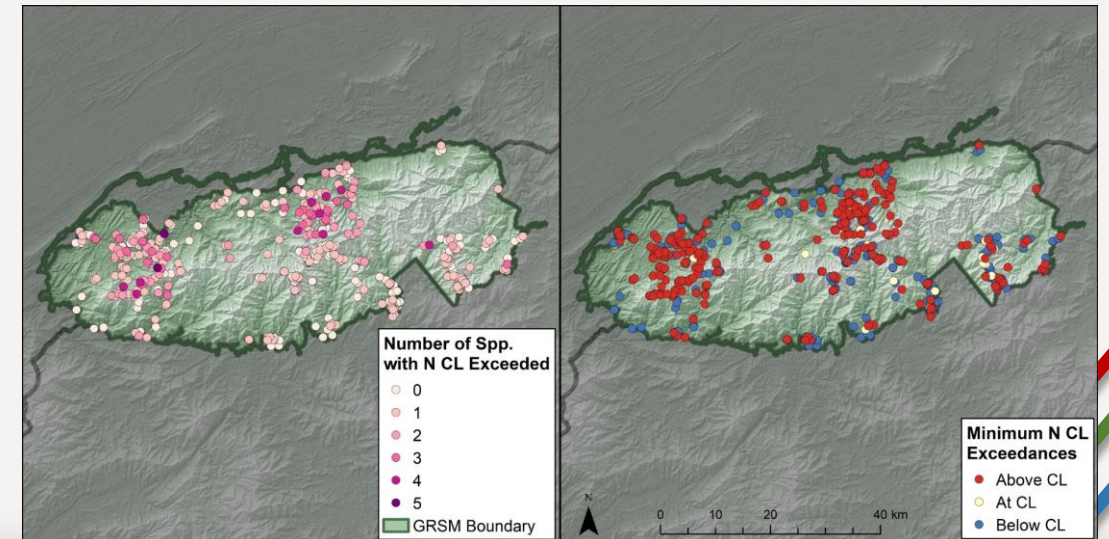
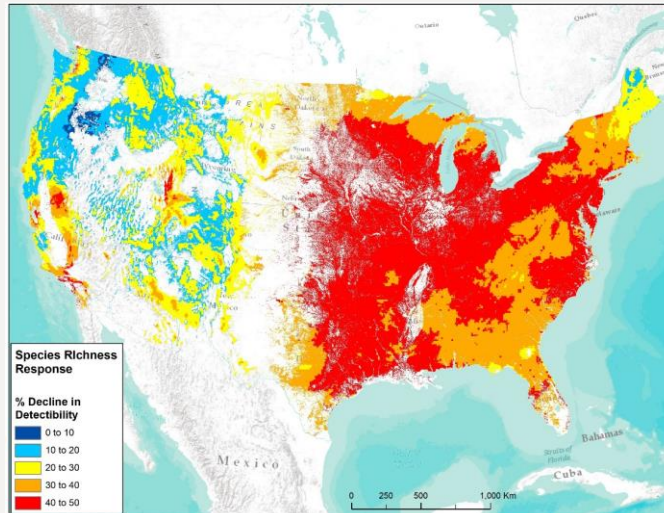
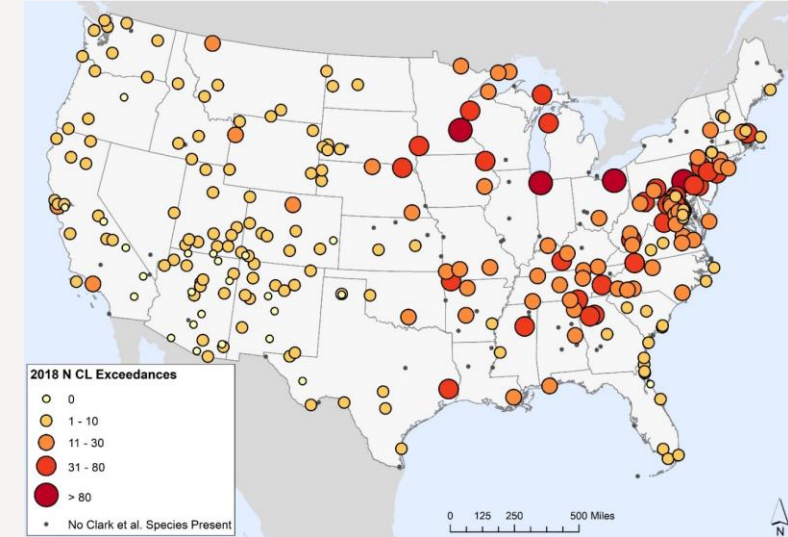
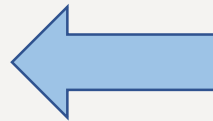
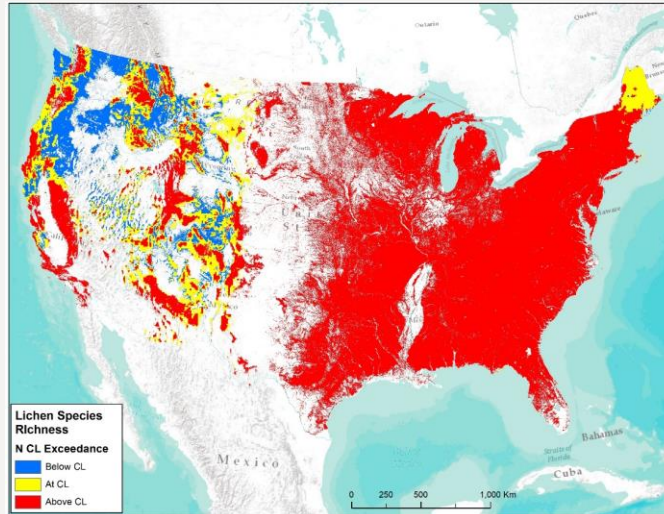


Species vary with N and other environmental variables

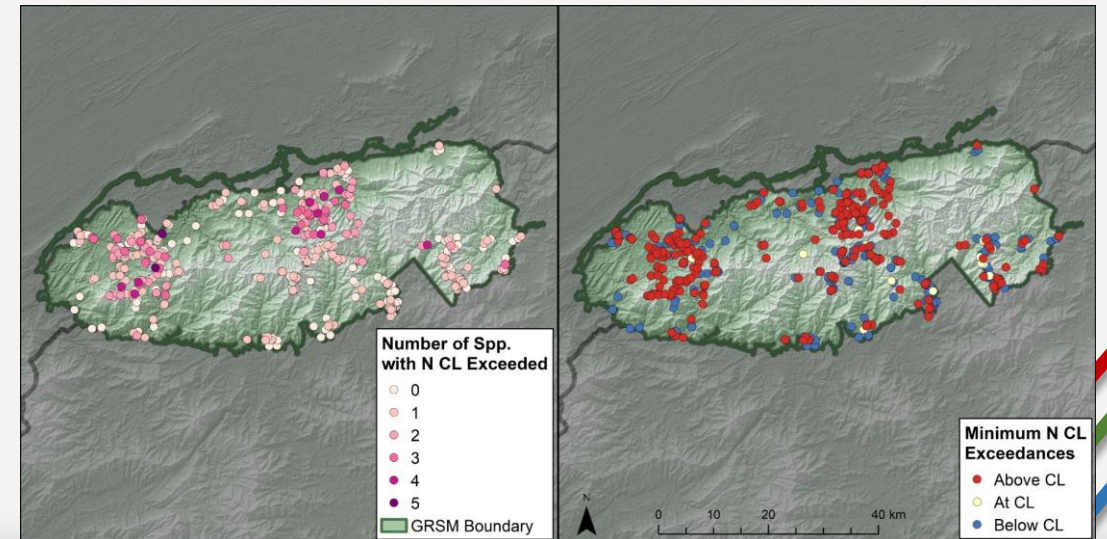
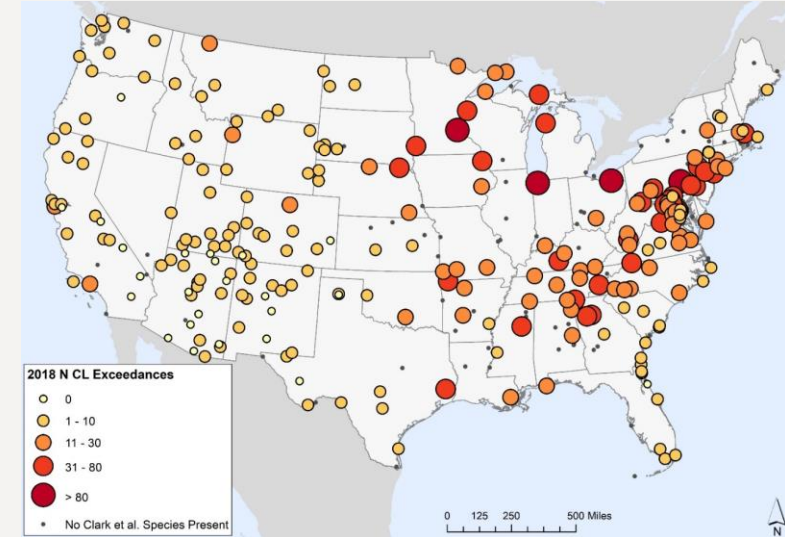
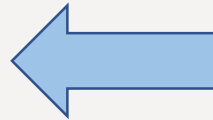
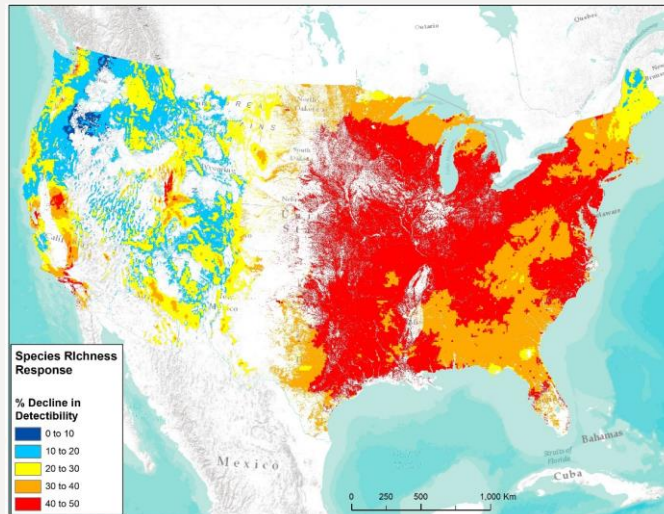
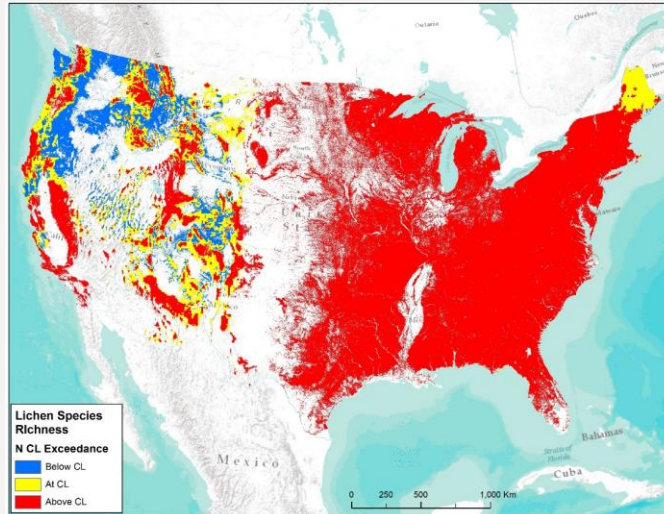
Evaluating Exceedances

- NADP Total Deposition Model
 - Measurement Model Fusion
 - Time series from 2000-2018
 - Total N and Total S
- Spatial location:
 - Above – Deposition is greater than 0.5 kg/ha/yr above CL
 - At – Deposition is +/-0.5 kg/ha/yr of CL
 - Below – Deposition is less than 0.5 kg/ha/yr below CL
- Grouped critical loads (Presence/Absence data)
 - Above - Deposition is greater than the CL
 - Below - Deposition is less than the CL

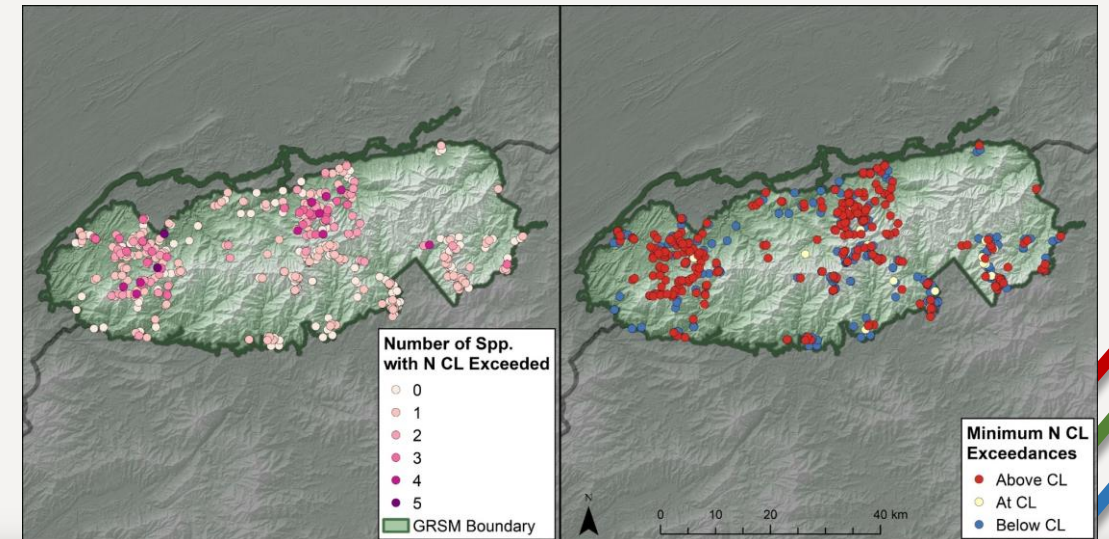
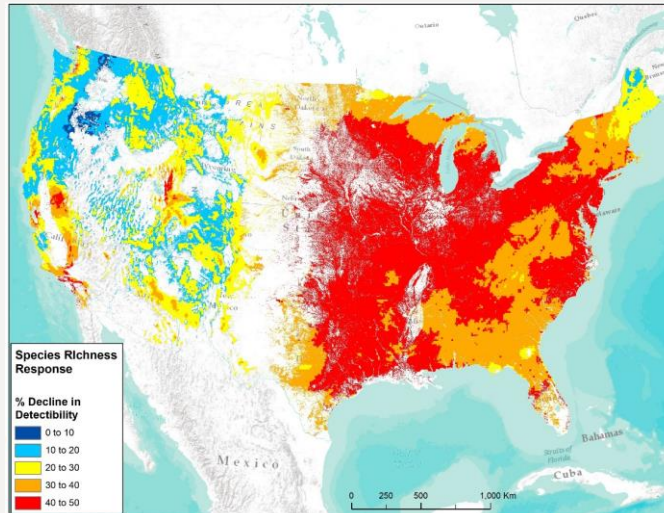
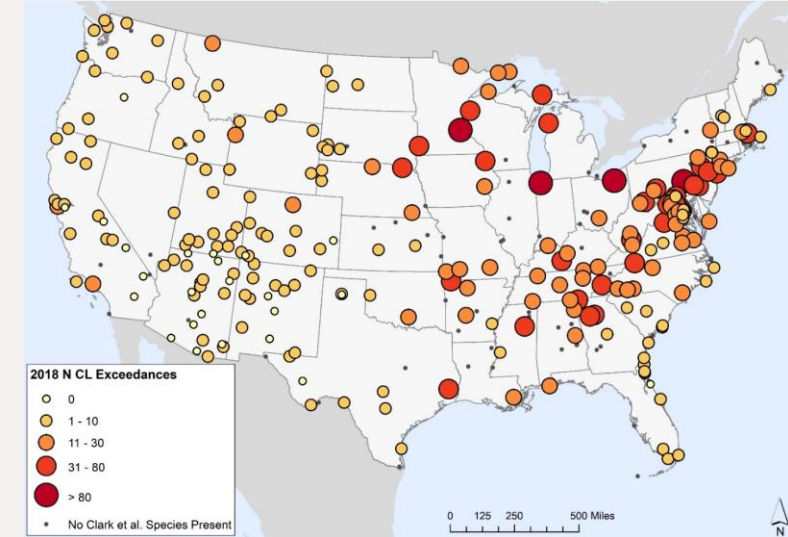
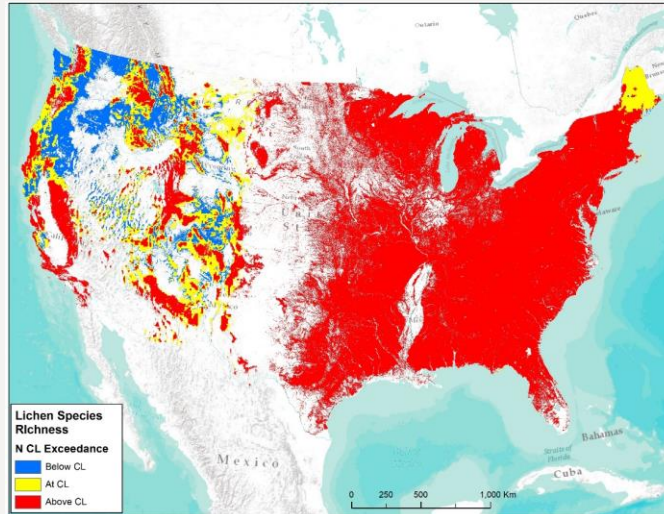
National Exceedance Maps



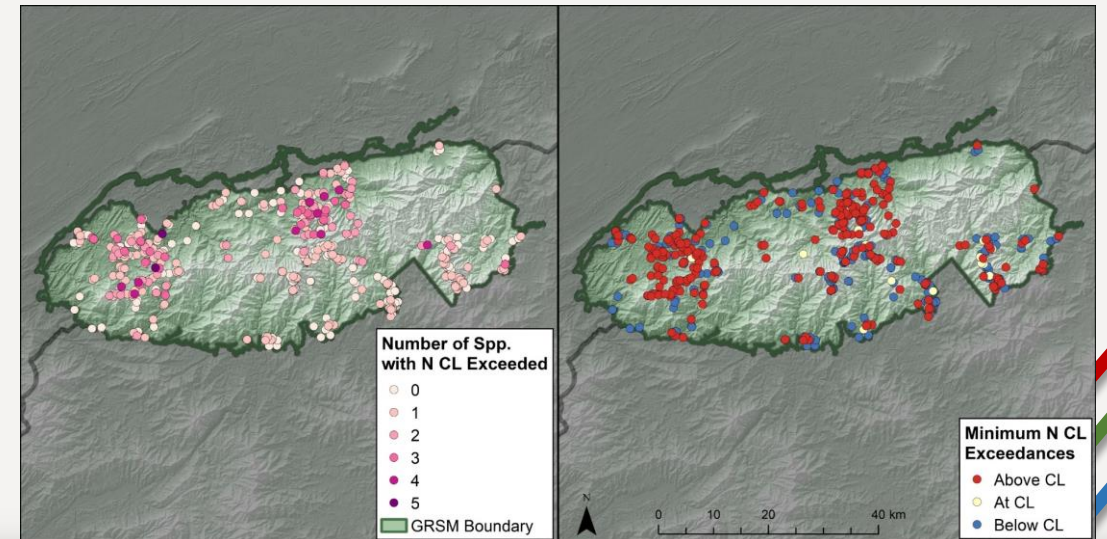
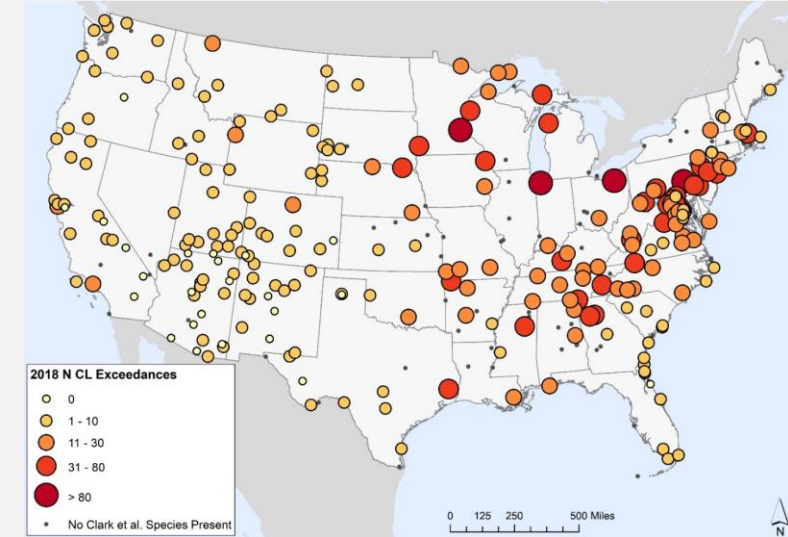
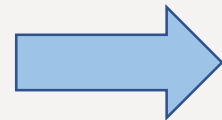
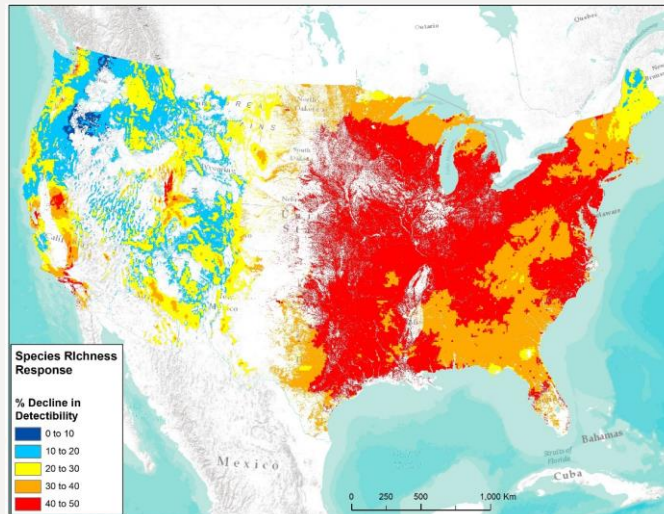
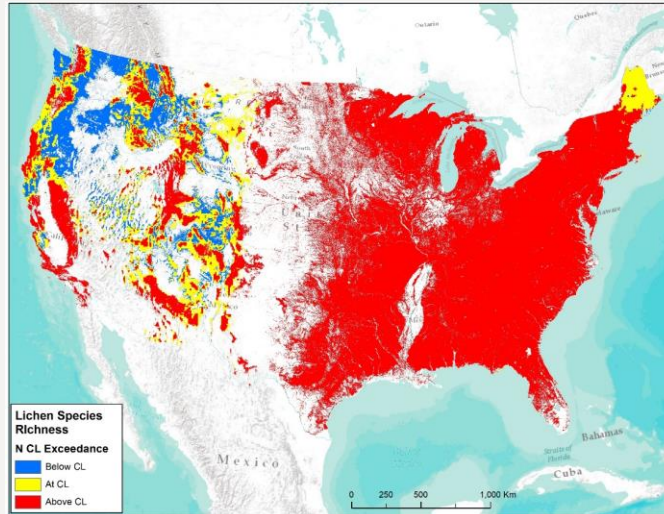
National Exceedance Maps

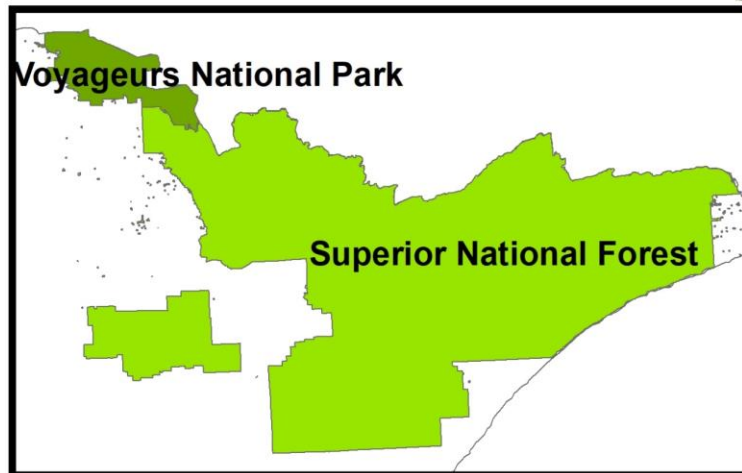
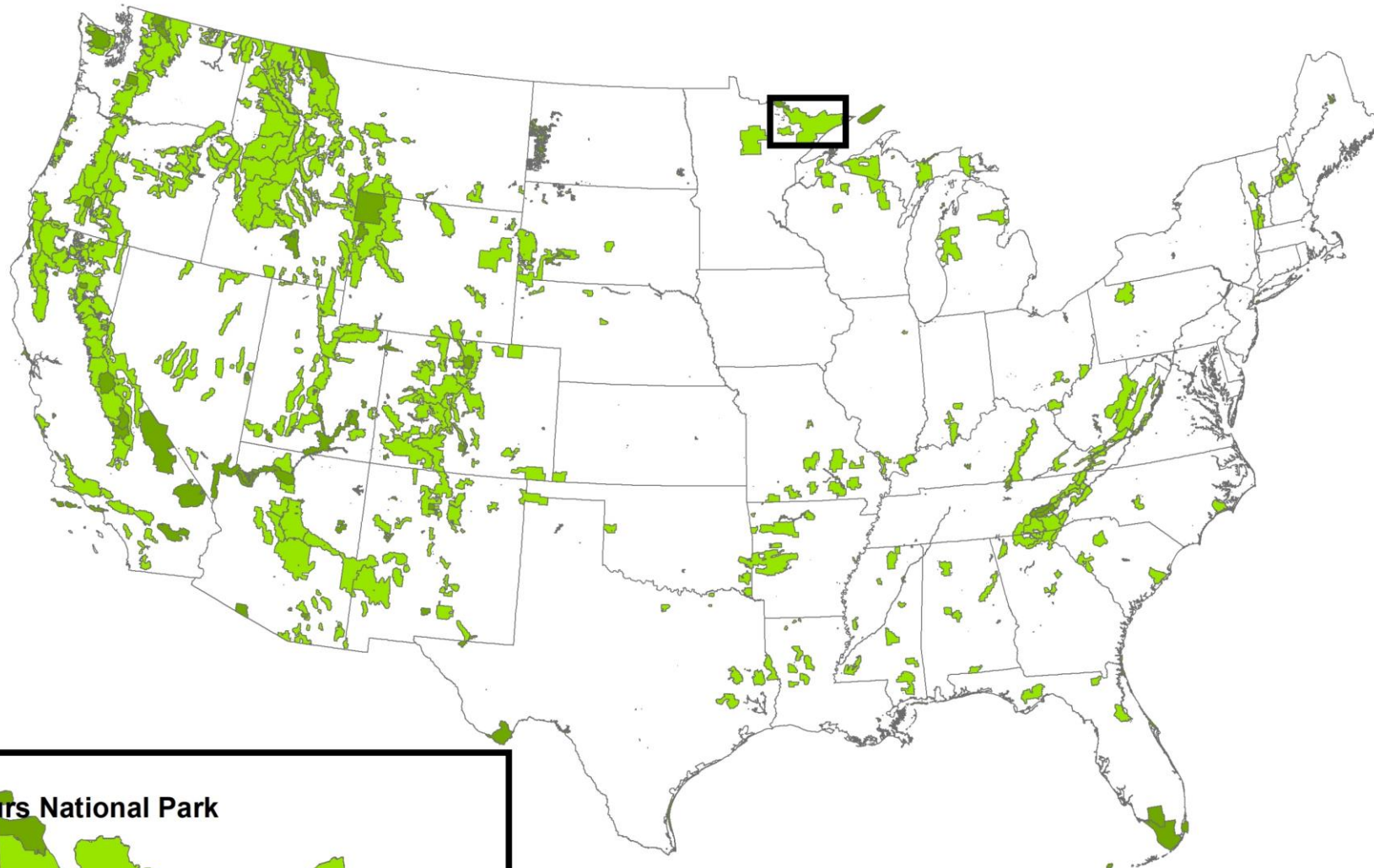


National Exceedance Maps



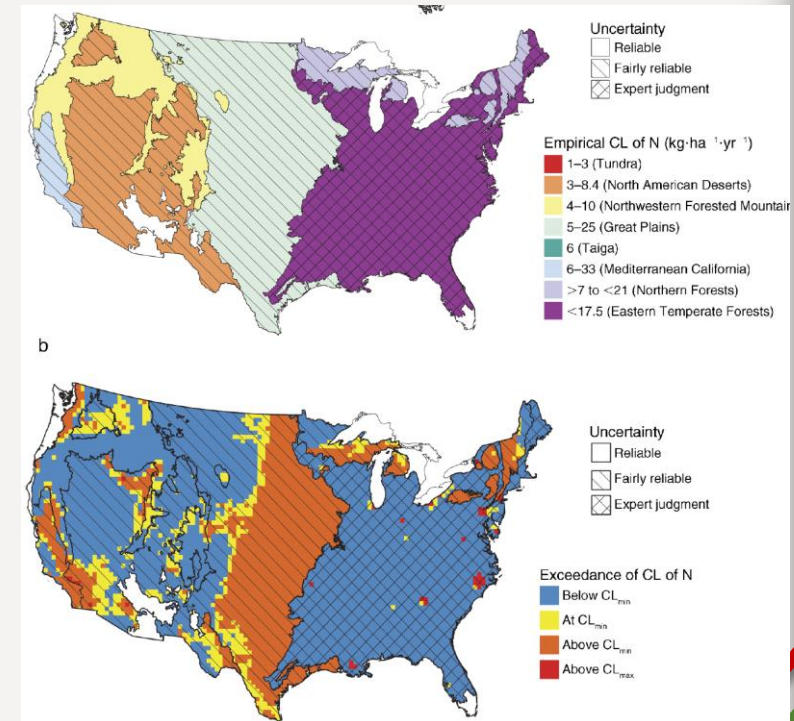
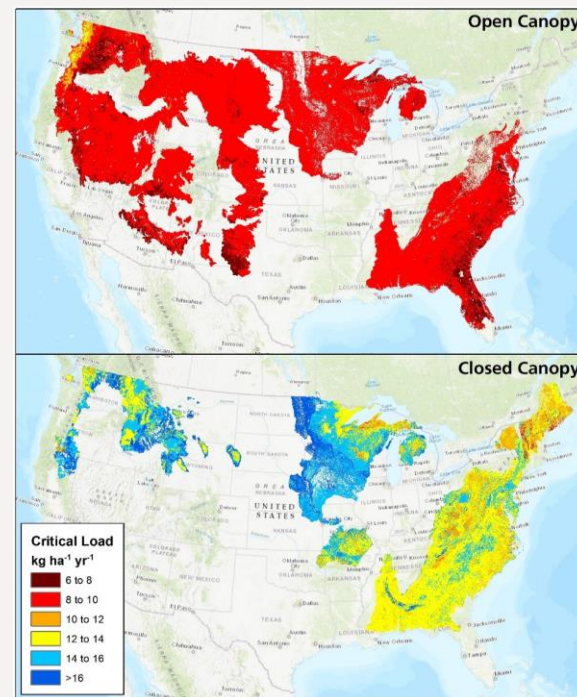
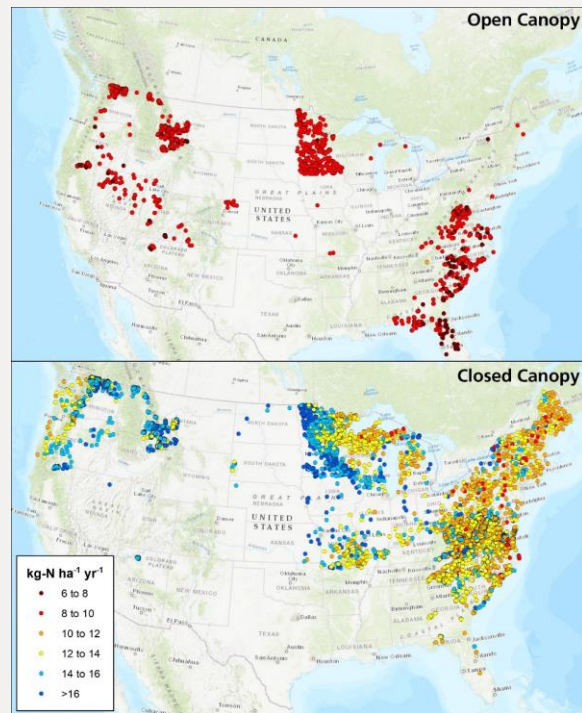
National Exceedance Maps





Ecosystem Component	Type	Name	Superior National Forest (kg/ha/yr)		Forest Unit	Superior National Forest (kg/ha/yr)
Deposition	Model	Min Dep	4.3			
	Model	Max Dep	7.7			
Alpine	Area	Alpine Vegetation Change Critical Load	-			
	Area	Alpine Soil Leaching Critical Load	-			
Herb	Plot	Herb. Spp. Richness (Open Plot Min)	-			
	Model	Herb. Spp. Richness (Open Surface Min)	8.0			
	Model	Herb. Spp. Richness (Open Surface 10% decline)	10.4			
	Plot	Herb. Spp. Richness (Closed Plot Min)	-			
	Model	Herb. Spp. Richness (Closed Surface Min)	12.2			
	Model	Herb. Spp. Richness (Closed Surface 10% decline)	16.4			
	Area	Pardo Herb. Plants Min.	7.0			
	Area	Pardo Herb. Plants Max.	21.0			
	Plot	Herb. Spp. Min.	1.3			
	Plot	Herb. Spp. 10th	5.6			
	Plot	Herb. Spp. Med	8.9			
	Plot	Herb. Spp. Max	18.9			
Forest	Area	Forest Min.	3.0			
	Area	Forest Max.	26.0			
	Plot	Tree spp. growth min	2.6			
	Plot	Tree spp. growth median	6.9			
	Plot	Tree spp. growth max	20.1			
	Plot	Tree spp. survival min	3.6			
	Plot	Tree spp. survival median	6.1			
	Plot	Tree spp. survival max	12.0			
Lichen	Area	Lichen Min.	4.0			
	Area	Lichen Max.	6.0			
	Model	Lichen Species Richness Critical Load	3.5			
	Model	Lichen Species Richness Critical Load 30%	5.5			
	Model	N-sensitive Lichen Critical Load	3.1			
	Model	N-sensitive Lichen 30% decline	4.7			
	Model	Forage Lichen Critical Load	1.9			
	Model	Forage Lichen Critical Load 30%	2.8			
	Model	Cyanolichen Critical Load	1.3			
	Model	Cyanolichen Critical Load 30%	1.9			
Soil	Area	Mycorr. Fungi Min.	5.0			
	Area	Mycorr. Fungi Max.	7.0			
	Area	Nitrate Leaching Min.	8.0			
	Area	Nitrate Leaching Max.	8.0			
Aquatic	Plot	Baron Aquatic Eutrophication (East) Min	2.5			
	Plot	Baron Aquatic Eutrophication (East) Max	6.0			
					Forest Unit	Superior National Forest (kg/ha/yr)
					Min. Total N Dep.	4.3
					Max. Total N Dep.	7.7
					Alpine Min.	NA
					Alpine Max.	NA
					Herb. Spp. Rich Min.	8.0
					Herb. Spp. Rich Max	10.4
					Herb Spp. 10th per Herb Spp. Median	5.6
						8.9
					Tree Growth Min.	2.6
					Tree Growth Med.	6.9
					Tree Survival Min.	3.6
					Tree Survival Med.	6.1
					Lichen Min.	3.1
					Lichen Max.	4.7
					Mycorr. Fungi Min.	5.0
					Mycorr. Fungi Max.	7.0
					Nitrate Leaching Min.	8.0
					Nitrate Leaching Max.	8.0
					Aquatic Min	2.5
					Aquatic Max	6.0

CL Decision Tree – Herbaceous Richness



Ecosystem Component	Type	Name	Superior National Forest (kg/ha/yr)	Forest Unit	Superior National Forest (kg/ha/yr)
Deposition	Model	Min Dep	4.3	Min. Total N Dep.	4.3
	Model	Max Dep	7.7		
Alpine	Area	Alpine Vegetation Change Critical Load	-	Max. Total N Dep.	7.7
	Area	Alpine Soil Leaching Critical Load	-		
Herb	Plot	Herb. Spp. Richness (Open Plot Min)	-	Alpine Min.	NA
	Model	Herb. Spp. Richness (Open Surface Min)	8.0	Alpine Max.	NA
	Model	Herb. Spp. Richness (Open Surface 10% decline)	10.4		
	Plot	Herb. Spp. Richness (Closed Plot Min)	-	Herb. Spp. Rich Min.	8.0
	Model	Herb. Spp. Richness (Closed Surface Min)	12.2	Herb. Spp. Rich Max	10.4
	Model	Herb. Spp. Richness (Closed Surface 10% decline)	16.4	Herb Spp. 10th per	5.6
	Area	Pardo Herb. Plants Min.	7.0	Herb Spp. Median	8.9
	Area	Pardo Herb. Plants Max.	21.0	Tree Growth Min.	2.6
	Plot	Herb. Spp. Min.	1.3	Tree Growth Med.	6.9
	Plot	Herb. Spp. 10th	5.6	Tree Survival Min.	3.6
	Plot	Herb. Spp. Med	8.9	Tree Survival Med.	6.1
	Plot	Herb. Spp. Max	18.9	Lichen Min.	3.1
Forest	Area	Forest Min.	3.0	Lichen Max.	4.7
	Area	Forest Max.	26.0	Mycorr. Fungi Min.	5.0
	Plot	Tree spp. growth min	2.6	Mycorr. Fungi Max.	7.0
	Plot	Tree spp. growth median	6.9	Nitrate Leaching Min.	8.0
	Plot	Tree spp. growth max	20.1	Nitrate Leaching Max.	8.0
	Plot	Tree spp. survival min	3.6	Aquatic Min	2.5
	Plot	Tree spp. survival median	6.1	Aquatic Max	6.0
	Plot	Tree spp. survival max	12.0		
Lichen	Area	Lichen Min.	4.0		
	Area	Lichen Max.	6.0		
	Model	Lichen Species Richness Critical Load	3.5		
	Model	Lichen Species Richness Critical Load 30%	5.5		
	Model	N-sensitive Lichen Critical Load	3.1		
	Model	N-sensitive Lichen 30% decline	4.7		
	Model	Forage Lichen Critical Load	1.9		
	Model	Forage Lichen Critical Load 30%	2.8		
	Model	Cyanolichen Critical Load	1.3		
	Model	Cyanolichen Critical Load 30%	1.9		
Soil	Area	Mycorr. Fungi Min.	5.0		
	Area	Mycorr. Fungi Max.	7.0		
	Area	Nitrate Leaching Min.	8.0		
	Area	Nitrate Leaching Max.	8.0		
Aquatic	Plot	Baron Aquatic Eutrophication (East) Min	2.5		
	Plot	Baron Aquatic Eutrophication (East) Max	6.0		

Species	Response	Max of N	CL
Gymnocarpium dryopteris	decrease	1.3	
Matteuccia struthiopteris	decrease	1.3	
Carex disperma	decrease	1.6	
Cinna latifolia	decrease	1.6	
Juncus effusus	decrease	2.3	
Cirsium arvense	hump	3.2	
Carex brunnescens	decrease	3.4	
Goodyera pubescens	decrease	4.1	
Fragaria vesca	hump	4.4	
Mitella nuda	hump	5.6	
Trientalis borealis	hump	6.0	
Fragaria virginiana	hump	6.9	
Bromus ciliatus	hump	7.0	
Clintonia borealis	hump	7.0	
Dryopteris carthusiana	hump	7.3	

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1

Species	Response	CL of N	Plot count	Below CL	At CL	Above CL
Doellingeria umbellata	decrease	1.3	2	0	0	2
Gymnocarpium dryopteris	decrease	1.3	20	0	0	18
Matteuccia struthiopteris	decrease	1.3	1	0	0	1
Carex disperma	decrease	1.6	15	0	0	15
Cinna latifolia	decrease	1.6	21	0	0	20
Juncus effusus	decrease	2.3	1	0	0	1
Cirsium arvense	hump	3.2	2	0	0	2
Carex brunnescens	decrease	3.4	7	0	0	7
Goodyera pubescens	decrease	4.1	1	0	0	1
Fragaria vesca	hump	4.4	16	1	6	9
Mitella nuda	hump	5.6	27	21	6	0
Trientalis borealis	hump	6.0	79	78	1	0
Fragaria virginiana	hump	6.9	16	16	0	0
Bromus ciliatus	hump	7.0	13	13	0	0
Clintonia borealis	hump	7.0	44	44	0	0

Species	Response	CL of N	Plot count	Below CL	At CL	Above CL
Doellingeria umbellata	decrease	1.3	2	0	0	2
Gymnocarpium dryopteris	decrease	1.3	20	0	0	18
Matteuccia struthiopteris	decrease	1.3	1	0	0	1
Carex disperma	decrease	1.6	15	0	0	15
Cinna latifolia	decrease	1.6	21	0	0	20
Juncus effusus	decrease	2.3	1	0	0	1
Cirsium arvense	hump	3.2	2	0	0	2
Carex brunnescens	decrease	3.4	7	0	0	7
Goodyera pubescens	decrease	4.1	1	0	0	1
Fragaria vesca	hump	4.4	16	1	6	9
Mitella nuda	hump	5.6	27	21	6	0
Trientalis borealis	hump	6.0	79	78	1	0
Fragaria virginiana	hump	6.9	16	16	0	0
Bromus ciliatus	hump	7.0	13	13	0	0
Clintonia borealis	hump	7.0	44	44	0	0

Herb

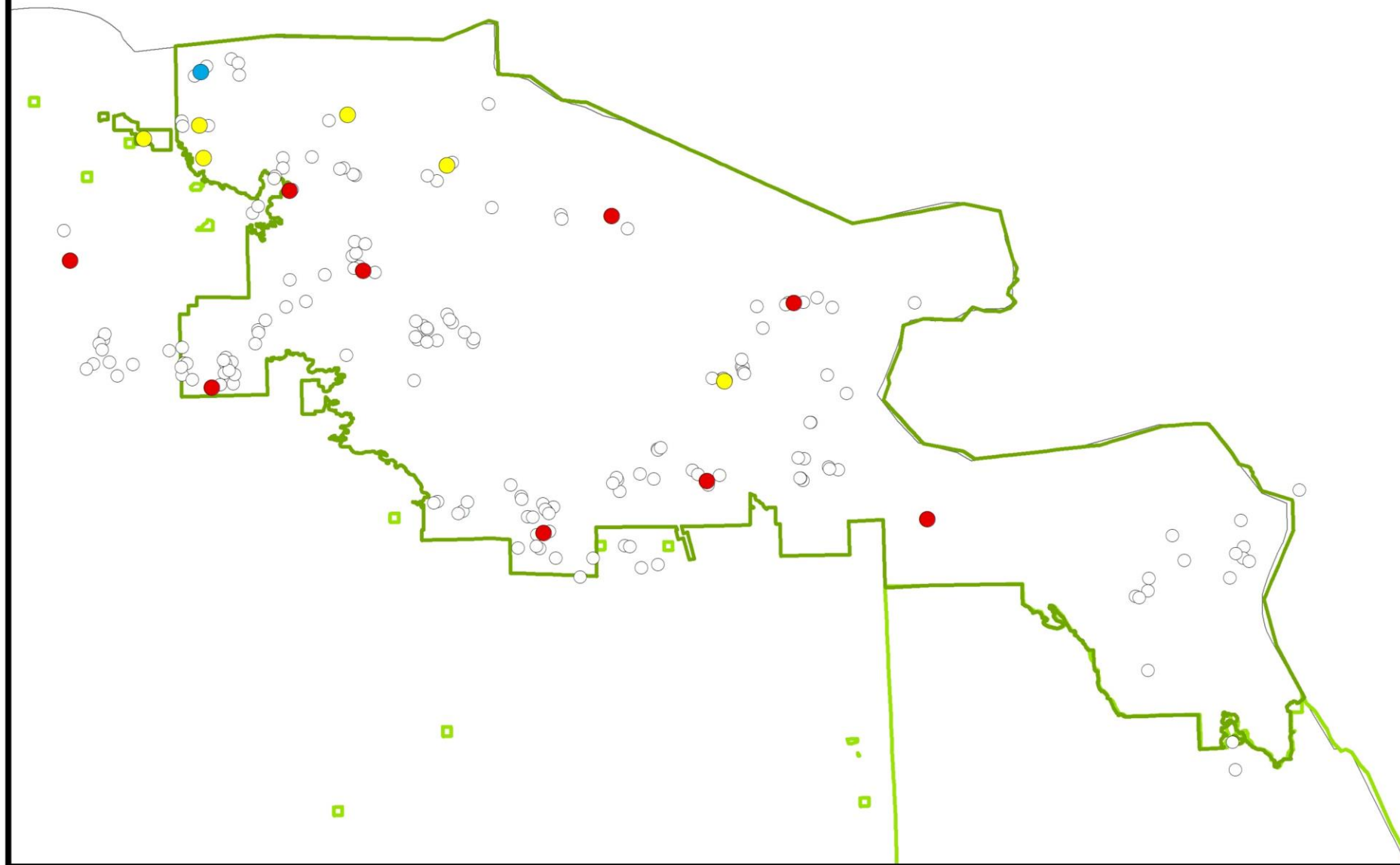
Plot	Herb. Spp. Richness (Open Plot Mi
Model	Herb. Spp. Richness (Open Surface
Model	Herb. Spp. Richness (Open Surface
Plot	Herb. Spp. Richness (Closed Plot M
Model	Herb. Spp. Richness (Closed Surface
Model	Herb. Spp. Richness (Closed Surface
Area	Pardo Herb. Plants Min.
Area	Pardo Herb. Plants Max.
Plot	Herb. Spp. Min.
Plot	Herb. Spp. 10th
Plot	Herb. Spp. Med
Plot	Herb. Spp. Max

Osmunda cinnamomea	hump	14.4
Agrostis stolonifera	increase	14.7
Allium stellatum	increase	14.7
Trifolium pratense	increase	14.7
Cypripedium acaule	increase	15.3
Schizachne purpurascens	increase	15.3
Solidago gigantea	increase	15.3
Trillium cernuum	increase	15.3
Ranunculus hispidus	increase	16.0
Solidago canadensis	hump	17.6
Agrostis perennans	increase	18.8
Asarum canadense	increase	18.8
Impatiens capensis	increase	18.9
Polygonatum biflorum	increase	18.9
Polygonum virginianum	increase	18.9
Urtica dioica	increase	18.9

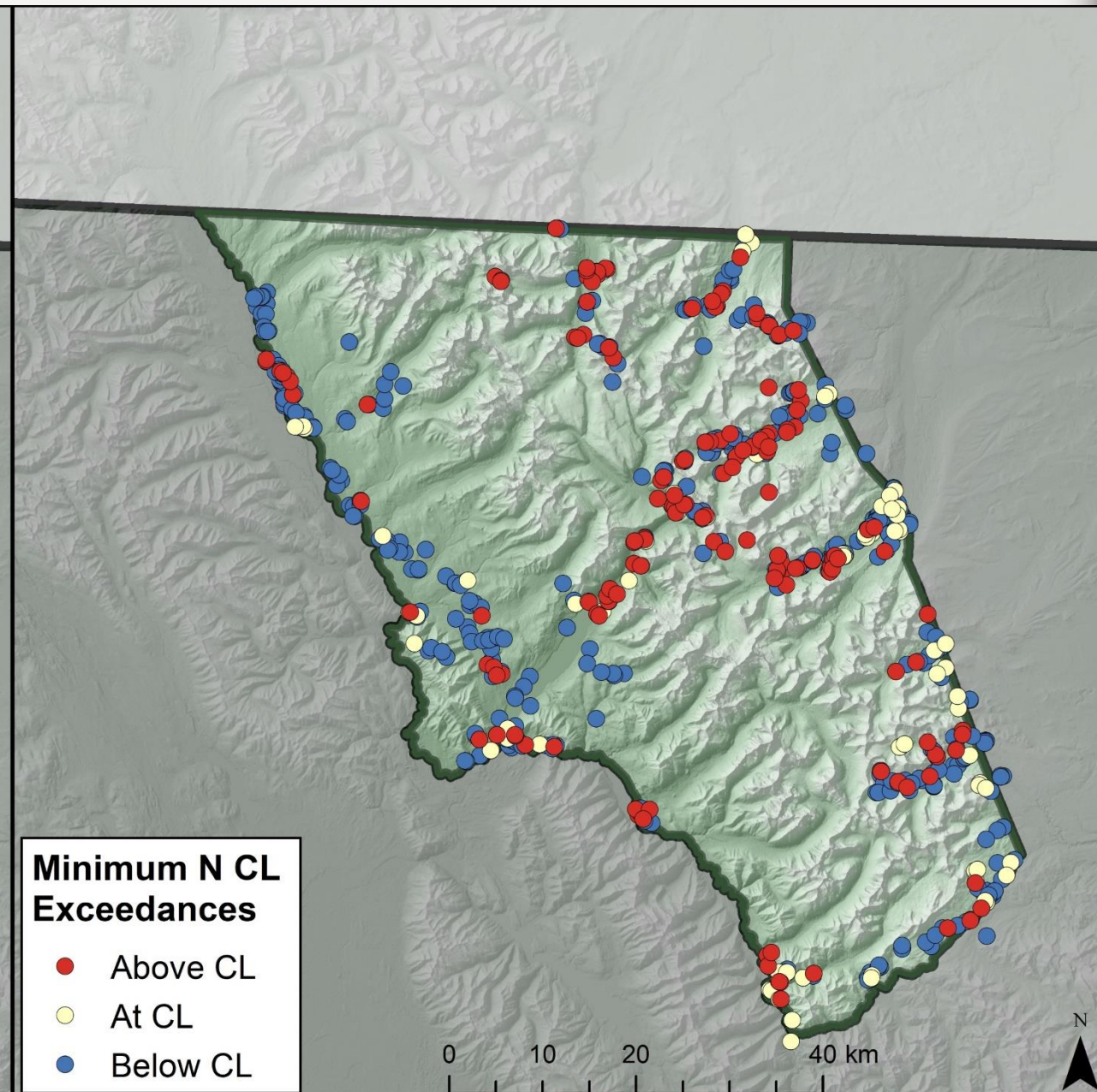
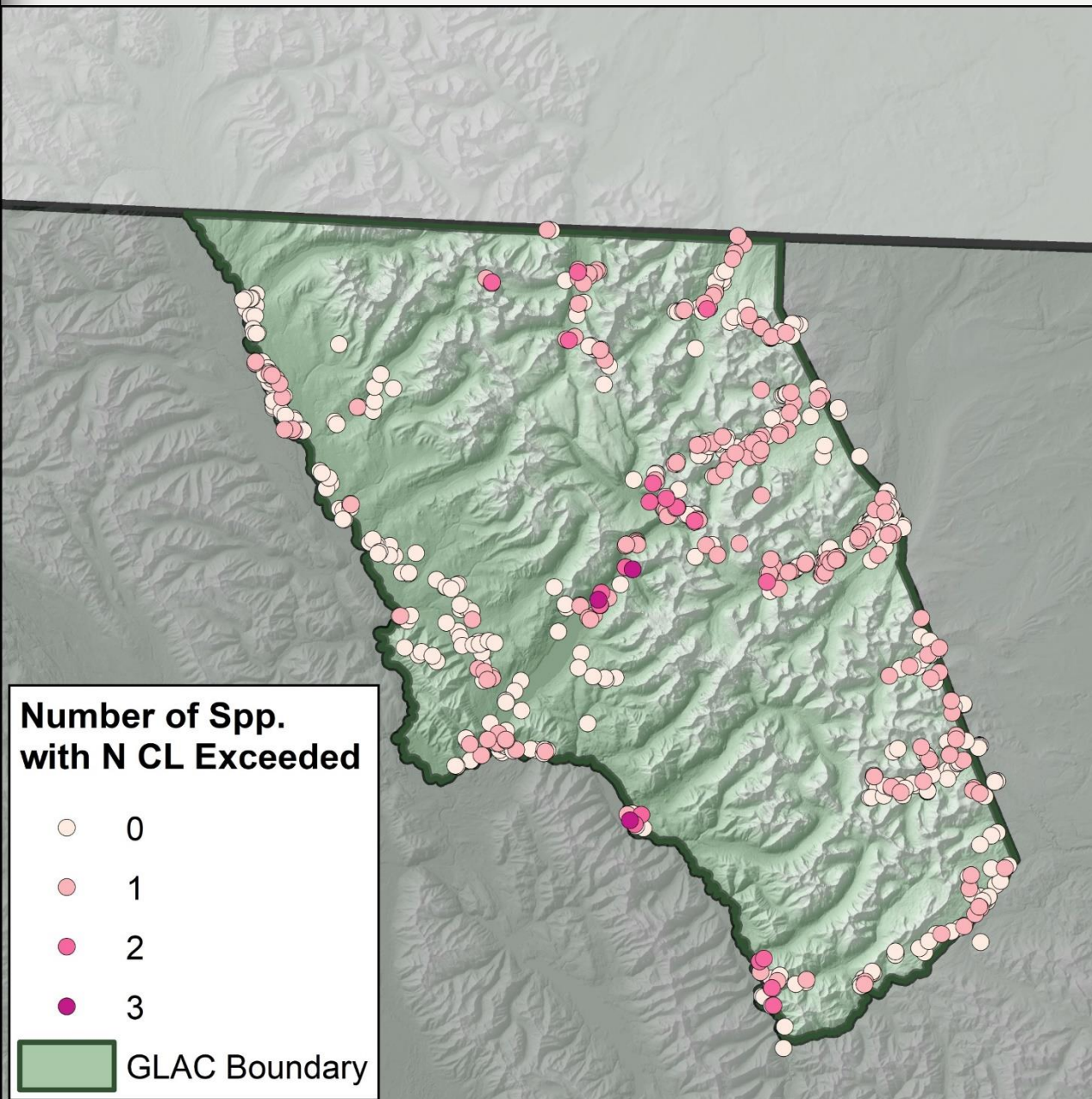
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Osmunda cinnamomea	hump	14.4	10	10	0	0
Agrostis stolonifera	increase	14.7	3	3	0	0
Allium stellatum	increase	14.7	1	1	0	0
Trifolium pratense	increase	14.7	2	2	0	0
Cypripedium acaule	increase	15.3	7	7	0	0
Schizachne purpurascens	increase	15.3	23	23	0	0
Solidago gigantea	increase	15.3	3	3	0	0
Trillium cernuum	increase	15.3	8	8	0	0
Ranunculus hispidus	increase	16.0	1	1	0	0
Solidago canadensis	hump	17.6	6	6	0	0
Agrostis perennans	increase	18.8	1	1	0	0
Asarum canadense	increase	18.8	6	6	0	0
Impatiens capensis	increase	18.9	8	8	0	0
Polygonatum biflorum	increase	18.9	2	2	0	0
Polygonum virginianum	increase	18.9	4	4	0	0
Urtica dioica	increase	18.9	2	2	0	0

Fragaria vesca

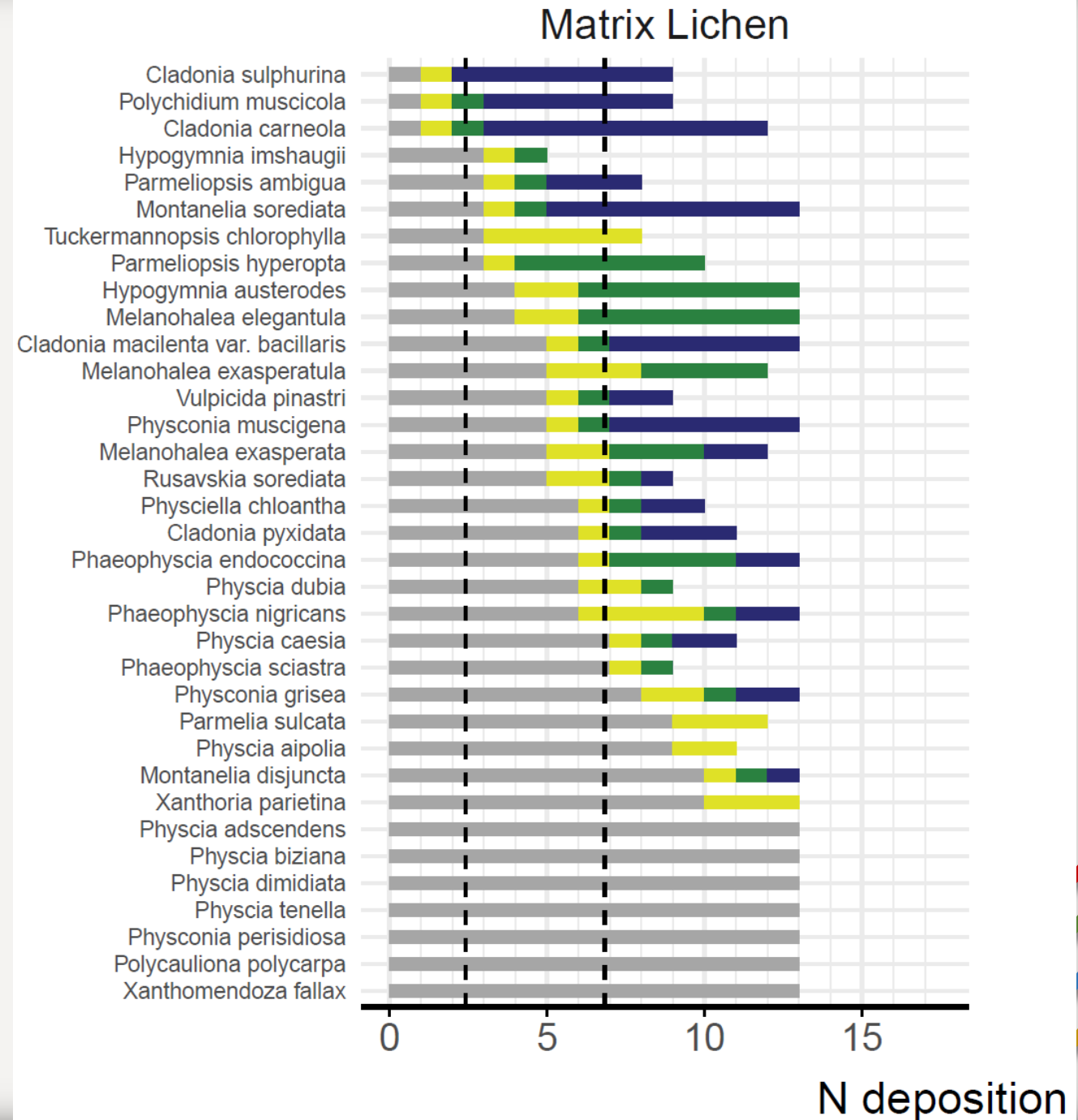


*Glacier National Park



Responses based on species list

- Categorize response in multiple thresholds
- Allows for visual comparison of response curves.

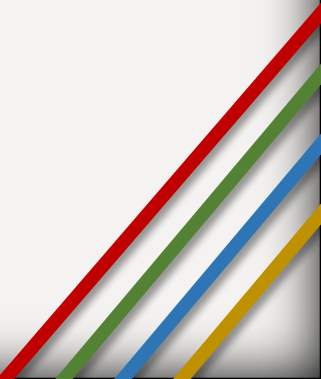


Multi-area evaluation

Forest Unit	Min. Total N Dep.	Max. Total N Dep.	Alpine Min.	Alpine Max.	Aquatic Min	Aquatic Max	Herb. Spp. Rich Min.	Herb. Spp. Rich Max	Forest Min.	Forest Max.	Lichen Min.	Lichen Max.	Mycorr. Fungi Min.	Mycorr. Fungi Max.	Nitrate Leaching Min.	Nitrate Leaching Max.	Tree Growth Min.	Tree Growth Med.	Tree Survival Min.	Tree Survival Med.
Allegheny National Forest	7.8	9.3	NA	NA	2.5	6.0	10.0	14.8	3.0	26.0	3.1	4.7	5.0	7.0	8.0	8.0	2.6	12.6	4.2	6.8
Angeles National Forest	5.5	13.4	NA	NA	3.0	4.1	3.0	8.4	17.0	39.0	3.1	4.7	7.8	9.2	10.0	17.0	0.0	0.0	3.0	3.0
Angelina National Forest	6.9	10.9	NA	NA	NA	NA	17.5	17.5	3.0	8.0	3.1	4.7	5.0	12.0	8.0	8.0	10.1	12.3	3.6	5.5
Apache National Forest	3.2	6.7	NA	NA	3.0	4.1	7.7	9.8	NA	NA	3.1	4.7	NA	NA	NA	NA	1.4	6.3	1.7	3.1
Apalachicola National Forest	5.2	7.3	NA	NA	2.5	6.0	8.1	9.7	3.0	8.0	3.1	4.7	5.0	12.0	8.0	8.0	10.4	12.3	3.6	5.6
Arapaho National Forest	2.4	6.1	3.0	10.0	3.0	4.1	4.0	10.0	4.0	17.0	3.1	4.7	5.0	10.0	4.0	17.0	1.4	6.3	2.0	4.2
Ashley National Forest	2.1	8.3	3.0	10.0	3.0	4.1	7.5	9.8	4.0	17.0	3.1	4.7	5.0	10.0	4.0	17.0	1.4	6.3	1.7	3.1
Beaverhead National Forest	1.9	6.1	3.0	10.0	3.0	4.1	7.8	9.8	4.0	17.0	3.1	4.7	5.0	10.0	4.0	17.0	1.4	6.3	2.0	4.2
Bienville National Forest	6.9	9.5	NA	NA	NA	NA	8.2	10.3	3.0	8.0	3.1	4.7	5.0	12.0	8.0	8.0	10.1	12.3	3.6	5.6
Bighorn National Forest	2.8	6.5	3.0	10.0	3.0	4.1	7.2	9.5	4.0	17.0	3.1	4.7	5.0	10.0	4.0	17.0	1.4	6.3	2.0	4.2
Bitterroot National Forest	2.1	5.9	3.0	10.0	3.0	4.1	7.4	9.7	4.0	17.0	3.1	4.7	5.0	10.0	4.0	17.0	1.4	6.3	2.0	5.0
Black Hills National Forest	4.4	6.7	NA	NA	3.0	4.1	7.0	9.2	4.0	17.0	3.1	4.7	5.0	10.0	4.0	17.0	6.9	11.1	3.6	5.1
Black Kettle National Grassland	7.0	7.7	NA	NA	NA	NA	5.0	25.0	NA	NA	3.1	4.7	12.0	12.0	10.0	25.0	0.0	0.0	3.6	13.5
Boise National Forest	2.4	5.8	3.0	10.0	3.0	4.1	12.7	16.8	4.0	17.0	3.1	4.7	5.0	10.0	4.0	17.0	1.4	6.3	2.0	5.0
Bridger National Forest	2.4	7.2	3.0	10.0	3.0	4.1	7.7	10.1	4.0	17.0	3.1	4.7	5.0	10.0	4.0	17.0	1.4	6.3	2.0	4.2
Buffalo Gap National Grassland	4.3	5.6	NA	NA	3.0	4.1	7.1	9.3	NA	NA	3.1	4.7	12.0	12.0	10.0	25.0	NA	NA	NA	NA
Butte Valley National Grassland	1.7	1.9	NA	NA	3.0	4.1	7.9	10.2	4.0	17.0	3.1	4.7	5.0	10.0	4.0	17.0	NA	NA	NA	NA
Cache National Forest	4.6	15.4	3.0	10.0	3.0	4.1	7.8	10.2	4.0	17.0	3.1	4.7	5.0	10.0	4.0	17.0	1.4	6.3	1.7	3.0
Caddo National Grassland	9.4	9.9	NA	NA	2.5	6.0	5.0	17.5	3.0	8.0	3.1	4.7	5.0	12.0	8.0	8.0	NA	NA	NA	NA
Caribou National Forest	3.4	8.1	3.0	10.0	3.0	4.1	7.4	9.7	4.0	17.0	3.1	4.7	5.0	10.0	4.0	17.0	1.4	6.3	1.7	3.1
Carson National Forest	2.4	6.9	3.0	10.0	3.0	4.1	8.0	10.3	4.0	17.0	3.1	4.7	5.0	10.0	4.0	17.0	1.4	6.3	1.7	3.1
Cedar River National Grassland	5.5	6.5	NA	NA	NA	NA	8.0	10.4	NA	NA	3.1	4.7	12.0	12.0	10.0	25.0	NA	NA	NA	NA
Challis National Forest	1.8	5.7	3.0	10.0	3.0	4.1	7.7	10.1	4.0	17.0	3.1	4.7	5.0	10.0	4.0	17.0	1.4	6.3	1.7	3.1
Chattahoochee National Forest	5.8	11.1	NA	NA	2.5	6.0	8.1	10.3	3.0	8.0	3.1	4.7	5.0	12.0	8.0	8.0	3.1	13.2	3.6	6.4
Chequamegon National Forest	7.5	10.2	NA	NA	2.5	6.0	7.6	9.9	3.0	8.0	3.1	4.7	5.0	7.0	8.0	8.0	2.6	5.2	3.6	6.1
Cherokee National Forest	5.3	9.4	NA	NA	2.5	6.0	7.8	10.0	3.0	8.0	3.1	4.7	5.0	12.0	8.0	8.0	2.6	14.0	3.6	6.5
Chippewa National Forest	4.9	7.8	NA	NA	2.5	6.0	8.0	10.7	3.0	26.0	3.1	4.7	5.0	7.0	8.0	8.0	2.6	5.2	3.6	6.1
Cibola National Forest	2.5	6.1	NA	NA	3.0	4.1	7.3	9.5	NA	NA	3.1	4.7	12.0	12.0	10.0	25.0	1.4	6.3	1.7	3.1
Cimarron National Grassland	7.7	10.0	NA	NA	NA	NA	7.8	10.0	NA	NA	3.1	4.7	12.0	12.0	10.0	25.0	NA	NA	NA	NA
Clearwater National Forest	3.6	6.3	3.0	10.0	3.0	4.1	7.5	9.7	4.0	17.0	3.1	4.7	5.0	10.0	4.0	17.0	1.4	3.7	2.0	6.8
Cleveland National Forest	4.2	11.5	NA	NA	3.0	4.1	6.0	33.0	17.0	39.0	3.1	4.7	7.8	9.2	10.0	17.0	NA	NA	NA	NA
Coconino National Forest	2.4	6.8	3.0	10.0	3.0	4.1	6.7	8.8	NA	NA	3.1	4.7	NA	NA	NA	NA	1.4	6.3	1.7	3.0
Coeur D Alene National Forest	3.6	5.9	3.0	10.0	3.0	4.1	7.8	10.1	4.0	17.0	3.1	4.7	5.0	10.0	4.0	17.0	1.4	6.0	2.0	6.3
Colville National Forest	1.4	4.4	NA	NA	3.0	4.1	7.5	9.7	4.0	17.0	3.1	4.7	5.0	10.0	4.0	17.0	1.4	6.0	2.0	5.8
Comanche National Grassland	4.4	7.5	NA	NA	3.0	4.1	7.9	10.1	NA	NA	3.1	4.7	12.0	12.0	10.0	25.0	NA	NA	NA	NA
Conecuh National Forest	6.7	7.3	NA	NA	NA	NA	8.1	10.1	3.0	8.0	3.1	4.7	5.0	12.0	8.0	8.0	10.4	12.3	4.5	5.6
Coronado National Forest	3.2	7.4	NA	NA	3.0	4.1	3.0	8.4	NA	NA	3.1	4.7	NA	NA	NA	NA	1.4	6.3	2.0	3.6
Croatian National Forest	6.1	10.1	NA	NA	2.5	6.0	7.6	9.6	3.0	8.0	3.1	4.7	5.0	12.0	8.0	8.0	10.4	12.3	4.5	5.8
Crooked River National Grassland	1.0	1.5	NA	NA	NA	NA	7.2	9.4	4.0	17.0	3.1	4.7	5.0	10.0	4.0	17.0	4.8	4.8	0.0	0.0
Curlew National Grassland	4.0	5.1	NA	NA	3.0	4.1	7.1	9.4	NA	NA	3.1	4.7	NA	NA	NA	NA	NA	NA	NA	NA
Custer National Forest	2.5	7.2	3.0	10.0	3.0	4.1	7.9	10.3	4.0	17.0	3.1	4.7	5.0	10.0	4.0	17.0	1.4	11.1	1.7	4.2

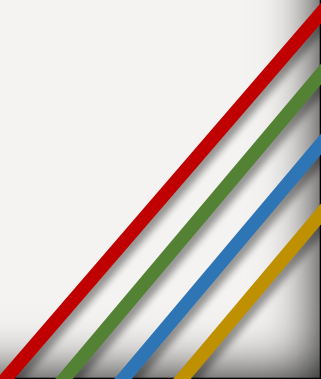
Uses and Next Steps

- Helps identify what data is available within an area of interest.
- Helps communicate what additional data can be collected within an area to better inform risk from air pollution.
- Adaptable to add new information into the hierarchy.



Uses and Next Steps

- When working with managers and policy makers summarizing the extensive data into workable units.
- Having a hierarchical structure allows those with interest to get species and location specific information.
- Exceedance maps allows for prioritization of active management and identify risk of new pollutants.



Uses and Next Steps

- Add new critical load data and fitting it in to summaries.
- Add critical load uncertainty estimates to outputs.

